ESAP CHAPTER 2

History and Impact of Agricultural Knowledge, Science and Technology (AKST) in East and South Asia and the Pacific (ESAP)

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Key Messages

1. Modern AKST has increased crop, livestock and fishery production over the last 50 years more rapidly than the population increased, improving food availability in the region. The increase has not, however, translated into complete availability, accessibility and affordability of food. Food insecurity, poverty and malnutrition remain widespread in some Southeast Asia countries.

2. AKST has improved availability of staple cereals and meat, but micronutrient deficiencies persist. Per capita consumption of cereals has increased in most countries in ESAP. Meat consumption has increased during the 1990s, particularly in China. However, underweight children are still prevalent, as are deficiencies in vitamin A and iron.

3. New irrigation AKST and expanded irrigated areas and inputs (chemical fertilizers, pesticides and herbicides), have made it profitable to grow high-yield varieties. However, increasing withdrawal of water for irrigation has intensified water scarcity in many areas. Irrigation was important in the Green Revolution in the 1960s through the 1980s. However, increasing water withdrawal has decreased discharge of many rivers, affecting aquatic, wetland and estuary ecosystems. The rapid decline in groundwater tables has reduced the resources available and increased costs of accessing water.

3. Inadequate attention has been paid to rainfed production and technology, despite its great importance in area, production and support of the rural poor. The paucity of rainfed technology has partly been from decisions by authorities to concentrate research and extension on irrigated areas because of the perception these areas are likely to yield greater return. For most crops current drought-resistant varieties are associated with low yield.

4. Grazing livestock production systems have generally shifted to mixed farming and intensive commercial production systems in most ESAP countries. The changes in livestock production systems have been related to increased urbanization, improved income and changes in dietary preference. In ESAP, the greatest growth has been in swine production and poultry production, which both depend heavily on commercially processed and traded feed and feed concentrates. Small-scale farmers have increasingly been marginalized.

5. Native forest cover continues to decline across the region as land is converted to agriculture and commercial logging. Although only 5% of the world's forests are in Southeast Asia, this region has had nearly 25% of global forest loss in the last decade. The greatest forest declines have been in the small island states, such as Micronesia, which lost half their forest cover. Increasing population pressure and illegal logging are the dominant drivers in Southeast Asia, East Asia and South Asia, driven mostly by China, a world leader in plantation forestry. Most plantation systems, except in Japan, are less than 15 years old.

6. AKST has enabled innovations in aquaculture, diversified the culture system, accelerated its productivity and improved its sustainability. The supply of aquaculture products to domestic and export markets, with valuable protein and other nutrients, has increased. AKST in aquaculture offset the stagnation and decreased productivity of marine and inland fisheries. Diversified aquaculture technology—pond, pen, cage, raft and raceway culture, monoculture, polyculture and integrated aqua-agriculture—have developed to suit the region’s diverse aquatic environment.

7. Transgenic cultivars of some crops are increasingly grown in some countries, but not in others because of concerns of human and environmental safety and restrictions of export markets. Cotton, maize and wheat are the important crops. The most widespread use of transgenics is in China and India. The target characteristics are herbicide and insect resistance; research is seeking wider improvement, to stress resistance and nutritive quality.

8. Traditional knowledge and indigenous practices as part of AKST contribute to the welfare of many local communities in ESAP. However, many countries have had an evident trend of loss in traditional knowledge in agriculture because of historical neglect; fast demographic, economic, political and cultural changes; and the aggressive expansion of modern agriculture. Nongovernmental organizations (NGOs) and local communities have been active in using and developing traditional knowledge systems.

9. The funding of AKST in most ESAP countries remains inadequate, despite clear evidence linking productivity improvement to investment in agricultural research and development. The public sector continues to fund the bulk of agricultural research and development in many ESAP countries because of the “public good” character of many technologies that it generates. Private investment is largely concentrated on technology that can provide privileges to property rights, relevant to only a small portion of the needs of small-scale farmers. This observation has been prevalent in many developing countries, where limited and fluctuating funding has led to institutional instability.

10. Modern AKST, especially the intensive use of chemical fertilizer and pesticides, has had considerable adverse effect on sustaining soil, water, biodiversity and the ecology.

Productivity in many food crops has increased. However, soils and water have deteriorated in many instances and some offsite effects have been observed. Technologies for improving soil fertility and water management are available but have not been widely adopted. Biodiversity conservation has not been fully integrated in major agricultural production systems.

11. The benefits of AKST have been inequitably distributed to the farmer community, particularly to women. Women's control over key economic resources, including land ownership, remains weak, despite women contributing the most time to agricultural production. Accrual of benefits by women has been limited by unequal access to education, information and capacity-building programs. Neither unpaid nor paid contributions to agricultural production by women and children have been fully recognized. Small-scale and group programs and special training, including in marketing and management, have helped some women benefit from AKST.

2.1 Agriculture and AKST in ESAP

In ESAP, the past half century witnessed a rapid population increase, from around 1.6 billion in 1960 to 3.4 billion in 2004. At the same time, remarkable economic growth took place in most countries, leading to significant increase in income and to demand for more and better food and other agricultural products. During this period, AKST experienced unprecedented progress, which has been the foundation underlying the growth of agricultural production. Despite the encouraging achievement, it was also evident in many ESAP countries that the benefits of economic development and the increased food supply were not equally distributed. Meanwhile, the exploitation of natural resources and intensive use of modern inputs caused serious environmental degradation, which undermined the sustainability of agricultural development.

Agriculture is traditionally important in the national economy in most countries in the region. However, the share of agriculture in the gross domestic product (GDP) has declined since World War II, especially in the last three decades. As of 2005, ESAP produced more than 80% of the world's rice, vegetables, jute, sweet potato and coconut. It provided more than half of the world's tea, tobacco and peanuts, while accounting for more than 25% of the wheat, maize, white potato, cassava, millet, melon and sugarcane. The region is also home to 30% of the world's livestock species. With the exception of the industrial countries in the region, most of the agriculture is in smallholdings and diversified farming. Small farm size has limited the potential of employment and income from agriculture. Rural-to-urban migration, multiple occupations of the laborers and diversification of the rural economy have been evident in many countries.

Except in a few countries, the absolute size of the agricultural labor force has still been rising. Agricultural employment has been especially important for the livelihood of the poor. Agriculture has served as an employment buffer and safety net in the face of large economic shocks, such as the Asian financial crisis in 1997 and 1998.

During the last two to three decades, remarkable progress in rural economic development has taken place in many countries, particularly China and India. AKST has played an important role. The significant improvement in crop yields enabled a large increase in food production. The amount of rural population living under poverty has reduced substantially, although reduction rates vary greatly. However, evidence from India suggests that the augmentation of total food production has not always benefited the poor in increasing income and improving food security.

Population growth and economic development have generated greater demand for food. An increasing population combined with limited arable land means little agricultural area per capita—an average of 0.2 ha each person—in the developing countries in the region (FAO, 2006a). With most people on less than half of the total land, pressure on land, water, flora and fauna has been increasingly severe. Intensification of production with the support of modern AKST in almost all crop farming, animal husbandry, fishery and forestry has been evident in most ESAP countries.

Modern AKST, particularly that associated with the Green Revolution, has been developed to increase the quantity of agricultural products and enhance their resilience to physical stress. However, the effects of AKST have varied from positive to negative, depending on the wealth and farm size of the groups involved. Some aspects of AKST are applicable mainly to large and commercial farms; others are more suitable for small and subsistence farmers. Natural endowments, socioeconomics, culture and tradition all influence AKST innovation and adoption.

ESAP countries face new challenges for agricultural production. In many areas absolutely no more land is available for cultivation. Many areas, particularly parts of China and India, have endured water stress, threatening the sustainability of food production on irrigated land. At the same time, land degradation, environmental pollution, loss of biodiversity, and little or no investment in agricultural research and development have affected the agricultural potential of the region. In recent years, many ESAP countries have again become net food importers. A good understanding of past trends in agriculture and the effects of AKST in ESAP are useful in the search for appropriate AKST to meet the challenges of sustainable agricultural development and food security.

2.2 Trends in AKST: Agricultural Practices

2.2.1 Application of AKST to crop production

Over the past 50 years, the increase in land productivity has enabled farmers to feed twice as many people from less agricultural land. This productivity growth has been based mostly on generating, promoting, disseminating and adopting AKST from formal and informal agricultural extension organizations. The principal agricultural technologies adopted were mainly in water management, chemical fertilizer use, variety development and crop protection, mechanization, livestock feeding and disease control, and sustainable resource management.

2.2.1.1 Expanding irrigated areas and adopting irrigation technology

Irrigation is widely used in ESAP. In many countries, irrigation has had a long history, being closely linked to rice cultivation. Rapid population growth, limited arable land and continuous increase in demand for food in the past 50 years have driven an unprecedented expansion of the area under irrigation. Advances in modern dam construction, flow regulation and pumping equipment have provided the means to harness more water for irrigation.

Between 1961 and 2003, irrigated areas in ESAP more than doubled, with an annual growth rate of around 2.6%. In China and India, the pace surpassed the average of the rest of the EASP countries (Figure 2-1). However, since the late 1990s, the expansion of irrigated areas has slowed; even India and China appear to have a slight decrease. By 2003, about 28% of the cultivated land in the region had been brought under irrigation.

Figure 2-1. Changes in irrigated areas in ESAP, 1961–2003

The pace of irrigation expansion and the share of irrigated total cropland have varied substantially across countries (Table 2-1). Japan is the only country that has experienced a decline in the amount of irrigated land, brought about by the shrinkage of the paddy rice area, which was nearly halved during 1961–2003 (FAO, 2006a).

Table 2-1. Changes in irrigated areas by country, 1961–2003

Irrigation was important in the Green Revolution in the 1960s through the 1980s. Irrigation is crucial for stable and high yields and for increasing total food production. Crop yield on irrigated land is usually significantly higher than the yield on rainfed land.

Irrigation also enabled more intensive use of land. Double and triple cropping was able to spread to where the rainy season is long enough for only one crop a year. The high yield and increased intensity of land use resulted in a much larger proportion of food production on irrigated land than its share in total cultivated land. For the region as a whole, about 60% of the food production was from irrigated land, which was about 28% of total cropland. Irrigated areas produced about 70% in China and 50% in India of the total national food production (Lipton and Litchfield, 2003).

Traditionally, surface irrigation was the most widely used in ESAP. However, the past 50 years have seen a rapid expansion of groundwater irrigation. As electricity became more widespread and pumping and well-drilling technology improved, groundwater has become increasingly important, particularly in arid and semiarid areas. By the mid-1990s, half of China’s irrigation water came from wells (Brown, 1994). In India, about 60% of the irrigated areas rely on groundwater (IWMI, 2002).

Groundwater is a primary buffer against the vagaries of climate and surface water. Because groundwater for crops can be used on time, it is often more productive than surface water. Some locations in India showed yield on crops irrigated by groundwater 2 to 3 t ha^{-1} higher than with canal irrigation (Shah et al., 2001; Lipton and Litchfield, 2003).

The proliferation of wells has owed a lot to inexpensive groundwater technology, such as treadle pumps. Low-cost pumps have helped fuel the groundwater boom, mostly with private investment from farmers. Groundwater is available in groundwater-rich areas to anyone who can afford a pump. It has been a boon to small-scale farmers, even poor ones. In China, the number of groundwater pumps owned per hundred farm households increased from 1.69 to 22.5 between 1985 and 2005 (China, 2006).

In surface irrigation systems, flood irrigation has been dominant in ESAP countries. Its generally low irrigation efficiency leaves ample room for saving water. However, in river basins, the water-saving potential may be lower than anticipated because part of the “lost water” upstream can recharge the groundwater and become available downstream (Molden and Fraiture, 2004). Commonly used water-saving technology included furrow and border irrigation, mulch and terracing. In the Ningxia Autonomous Region in China, official statistics showed that irrigation water withdrawal from the Yellow River decreased from 8.9 to 6.7 billion m^3 between 1998 and 2004, while the irrigated area increased from 387,000 to 406,000 ha, mostly by using various water-saving measures.

More advanced irrigation technology, such as sprinkler, microirrigation and laser leveling, was seen in the region, but on a rather small scale. In Japan, sprinkler irrigation and microirrigation were about 9.5% of the total irrigated area in the late 1990s. In India, it was 1.5%. Mongolia was the only country where sprinkler irrigation was significant, as large schemes were equipped with sprinkler irrigation in the 1980s (FAO, 1999). In China, sprinklers, drip irrigation and low pressure pipes were used in about 10% of the total irrigated area in 2004 (China, 2006). In other countries, national data for the application of irrigation techniques were generally not available.

By the mid-1970s, farmers had adopted drip irrigation in some ESAP countries, such as Australia and New Zealand. Drip irrigation is especially effective in arid and drought-prone areas, where water is scarce. It does not accumulate salt in the root zone and causes little soil erosion. Drip systems use 30 to 60% less water than furrow or sprinkler irrigation (Postel, 1996). In India, crop yields from drip irrigation were about 10 to 30% higher than those from surface irrigation (Postel, 1999). Despite the efficiency in water use, drip irrigation still is used on very little of the total irrigated area. In Australia, the percentage was about 7.8%. In China and India, it was below 0.1%. The large initial investment required for the equipment is a main constraint to its use in developing countries. Drip irrigation is used primarily to irrigate high-value horticultural crops.

Supplemental irrigation is the application of water at critical times. It can substantially improve yield and water productivity in arid and semiarid environments. In dry areas, supplemental irrigation can boost productivity of irrigation water by 10 to 20% (Oweis and Hachum, 2003). Technology for supplemental irrigation ranges from farm ponds to shallow groundwater pumped with treadle pumps (Barker and Molle, 2004). Supplemental irrigation could prevent total crop failure and stabilize and improve crop yields. However, it requires comprehensive knowledge and skills in crop management. Weather forecasts reduce risk and are an integral part of such a comprehensive strategy.

2.2.1.2 Water management in rainfed crop farming systems

Compared with irrigated agriculture, rainfed systems have been given little attention in most ESAP countries. The paucity of technology for rainfed areas partly relates to decisions by government authorities to concentrate research and extension in irrigated areas because they have been perceived more likely to yield a greater return on investment. Among the many constraints that limit rainfed agriculture, unreliable rainfall is probably the biggest. Water stress at the flowering stage of maize can reduce yield 60%, even if water is adequate during the rest of the season (Molden and de Fraiture, 2004). Recent years have seen increased biological science efforts to produce traits for drought tolerance and resistance to many pests and diseases.

Rainwater harvesting to retain water has been seen in some semiarid areas in ESAP. Rainwater harvesting has shown considerable potential in semiarid areas because it could supply limited irrigation at the key stages of crop growth by using stored rainwater. A number of cases in China and India have shown significant increase in crop productivity through rainwater harvesting. In Gansu Province in China, for example, yields of maize and wheat on the experimental sites increased over 50% (Liu et al., 2005).

Rainwater harvesting technology is simple for local people to install and operate. It is convenient because it provides water at the point of consumption and family members have full control of their own systems, reducing operating and maintenance problems. The disadvantage is the limited supply and uncertainty of rainfall. In addition, numerous small-scale water-harvesting and storage systems in a basin could have similar effects on river flows and aquatic ecosystems as a large dam and canal irrigation. For example, along the Yellow River, bunds and plugging gullies were effective in encouraging agriculture and in reducing erosion, but evidence showed these practices reduced river discharge (Zhu et al., 2003).

Improved land management techniques and agricultural production systems have received growing attention for improving water productivity of rainfed systems. Such technology has been referred to as “green [soil] water management.” In some areas, minimum or zero tillage proved effective in improving soil moisture and crop yields in rainfed land (Hatibu and Rockström, 2005). Mulching, terracing, contouring and microbasins are also important in maximizing rainfall infiltration into the soil to increase yields. No-till and conservation agriculture maintains and improves crop yields and resilience against drought and other hazards, while protecting and stimulating the soil. The essential features of conservation agriculture are minimal soil disturbance and maintenance of a permanent cover of live or dead vegetative material. The cover protects the soil against erosion and water loss from runoff or evaporation. A major impediment to successfully introducing conservation agriculture is that management skills are complex. In many ESAP countries, any production system that includes crop rotation is complex because it calls for coherent management over more than one or two crop seasons. Farmers who have adopted these systems need to understand them and the reasons for the various procedures to be able to adapt them to their needs and conditions to balance crop rotation with market requirements (Box 2-1).

Recently, increasing emphasis has been on integrated rainwater and irrigation water management. Because obtaining additional water for irrigation is difficult and water in rainfed systems is unreliable, agricultural water management has shifted from pure rainfed or fully irrigated systems to emphasizing intricately connected soil conservation and supplemental, drip, ground and surface irrigation.

Box 2-1. Potential of rainfed agriculture.

2.2.2 Development and application of modern technology and inputs

2.2.2.1 High-yielding varieties—the Green Revolution

The historical focus by international and national research institutes has been food crop production technology, emphasizing improved yield varieties—the Green Revolution. Modern plant breeding and improved agronomy, including the use of inorganic fertilizer and pesticides, have been components of the strategy to increase production (Friedman, 1990). Nearly three-quarters, 71%, of production growth since 1961 has been from yield increases. Increased yields have contributed to greater food security within developing regions and contributed to declining real prices for food grains.

In the 1960s, when the International Rice Research Institute (IRRI) was formed, breeders found the main constraint to rice yield was the architecture of traditional tropical rice cultivars (Khush et al., 2001). Although tall cultivars responded positively to nitrogen fertilizers, competed well with weeds, and provided much straw for fodder, fuel and construction, they lodged and lost yield. The Japanese had realized the value of short-straw cultivars in the quest for high yield and introduced the trait into rice around 1900. By the 1950s, semidwarf rice could be found among the landraces in many Asian countries, including in subtropical China. Taichung Native 1 (TN1), a semidwarf cultivar from Taiwan (China), was first planted in the tropics in the late 1950s, but it was highly susceptible to major diseases and insects in the tropics (Peng and Khush, 2003). In 1962, IRRI introduced dwarfness into tropical rice by crossing the dwarf Taiwanese cultivar Dee-geo-woo-gen into the tall Indonesian cultivar Peta. The result was IR8 (the 8th cross), the first lodging-resistant and fertilizer-responsive cultivar. Farmers rapidly adopted it and it became the symbol of the Green Revolution in Asia. After the release of IR8, three more semidwarf cultivars, IR5, IR20 and IR22, were released during the 1960s, followed by another 17 in the 1970s and 13 during the 1980s (Peng and Khush, 2003). The release of IR8 increased the yield potential of tropical rice from 6 to 10 tonnes ha^{-1}. Its yield potential has hardly been surpassed in 40 years of breeding (Peng et al., 1999). The development of early-maturing varieties, particularly in rice, has enabled double and triple cropping in areas that previously produced only one or two crops a year. The dwarf varieties, less prone to lodging, could be grown more densely, using a smaller area (Robinson, 1996).

By 1970 almost all the area under high-yield seeds, about 94% of wheat and 98% of rice, was in Asia, of which nearly half was in India (Pearce, 1980). The maximum effect of the high-yield variety program in India was in wheat, where the coverage was 83% of the cropped area by 1985/1986. Rice was next, with about 57%. Coverage under cereals ranged between 30 and 46% (Groosman et al., 1991). Seed supply systems of new varieties replaced the traditional varieties.

High-yield wheat and rice were critically dependent on several inputs, so there was an increase in agroindustry. For example, in India, nitrogen fertilizer production increased from 0.37 million tonnes in 1967/1968 to 2.23 million tonnes in 1979/1980. Furthermore, production capacity had to be generated for tractors and other machines. Farmers had to invest their own capital to acquire these machines, which were often produced with the help of public financing agencies (Chaboussou, 2004).

Amid the wave of the Green Revolution, Chinese scientists led by Professor Yuan Longping bred the world’s first rice hybrid in 1974. Hybrid rice yields about 15 to 20% more than the best of the improved or high-yielding varieties. By 2000, about half of China’s total rice area was under hybrid rice cultivation. National average rice yields increased from 3.5 to 6.2 tonnes ha^{-1} between 1975 and 2000. Hybrid rice has particularly good potential to improve the food security of poor countries with scarce arable land, expanding populations and cheap labor. FAO, IRRI, the United Nations Development Programme (UNDP) and the Asian Development Bank supported improving national capacity in hybrid rice development and dissemination outside China (FAO, 2004).

2.2.2.2 Mechanization

Agricultural machinery is another modern technology that has contributed greatly to farming and crop production. Advances in farm machinery have changed the way people produce food worldwide. Agricultural machinery entails substantial cost to buy and operate but reduces labor considerably.

Rising wages and reduced availability of labor in many Asian countries forced farmers to mechanize, adjust cropping patterns and resort to migrant labor. In some cases, these changes were extraordinarily rapid. In the Central Plain of Thailand, the labor used in irrigated rice cultivation had declined from 57.5 person days per hectare in 1987 to just 8 person days by 1998, a decline of 86% in little more than a decade (Isvilanonda et al., 2000). The reduced labor was by mechanizing harvesting and switching from transplanting to direct seeding. Rapid changes occurred in southern China, where many farmers changed from triple cropping (rice–rice–winter crop) to a single rice crop to save labor.

Farmers often could not afford to buy agricultural machinery, so well-functioning rental markets were crucial. For example, while combine harvesting was widespread in the Central Plain of Thailand, only a small percentage of farmers owned a combine harvester. Use by owners, plus rental through cooperatives or government agencies, accounted for just 6% of use; the rest occurred in private rentals (Dawe, 2005). Rental markets often arose naturally in the absence of government restrictions.

Tractors were the most common machinery. The number of agricultural tractors in ESAP expanded rapidly, reaching 6.5 million in 2005 (Figure 2-2). It increased 14-fold from 1961 to 2005. Japan, with the most tractors in use, started mechanizing early. India’s use of tractors increased rapidly, overtaking China in the 1980s and reaching a level similar to Japan’s in 2000. In contrast, China used tractors moderately, which can be attributed to small-scale subsistence farming.

Figure 2-2. Total agricultural tractors used in ESAP, 1961–2000

2.2.2.3 Fertilization

In ESAP, fertilizer use increased sharply and had reached 275 kg ha^{-1} by 2005 (Figure 2-3). The average annual growth rate was about 6.6%. About 61% of the fertilizers applied were nitrogen based; next was phosphate (P) 24%, and potash (K), 15%. Use of nitrogenous fertilizer increased 23-fold over this period.

Figure 2-3. Chemical fertilizer use per hectare of arable land in ESAP, 1961–2005

Chemical fertilizer application varied significantly within ESAP. In East Asia, growth in usage was especially rapid, from 69 kg N ha^{-1} in 1978 to 155 kg N ha^{-1} in 2002. Growth was also rapid in Southeast Asia and South Southwest Asia, but much less than in East Asia. As a result, nitrogen use was much higher in East Asia than in Southeast Asia and South Southwest Asia. Over-reliance on this fertilizer led to nitrogen overdose in some high-yielding farmland in China. The adverse effects of excessive fertilizer use on the environment emerged as a serious concern (Zhu and Chen, 2002). Application of phosphate and potash fertilizer also grew rapidly, sometimes exceeding the growth in the use of nitrogen. On the other hand, many soil nutrients were mined, leaving many intensive rice systems exhibiting negative K balances (Dobermann et al., 2004). In some cases, reversing these imbalances would lead to higher profits for farmers.

2.2.2.4 Crop protection

Pesticide use in agriculture is on the rise in many developing countries in ESAP. Because data are often unavailable, it is difficult to paint a general picture of trends in ESAP or national pesticide use.

In China, the amount of pesticide used increased 1.8 times between 1991 and 2004. Pesticide use per hectare of sown area reached about 9 kg ha^{-1} in 2004 (Figure 2.4). Pesticide use was high in the wealthy and developed areas on the southeast coast, while poor areas, such as the northwest regions, used the least. Farmers growing grain in the North China Plain, who had used pesticides for many years, increased applications in response to pesticide resistance. Crops receiving the most applications were fruit, cotton, maize, and wheat. Pesticide use was high in greenhouses, where the chemicals were applied up to 10 times above the rate used in fields. Even in the field, it was not uncommon for farmers to double the recommended dose.

Figure 2-4. Pesticide use per hectare of sown area in China, 1991–2004

Importance needs to be placed on minimizing the negative health effects that pesticides, especially insecticides, have on farmers, who often spray with little or no protection. This can be done by educating farmers in integrated pest management (IPM) as promoted by FAO, through media campaigns and by strengthening regulatory enforcement. The perception of many farmers, extension service providers and even policy makers about the magnitude of crop losses caused by insect pests are often greatly exaggerated (Heong and Escalada, 1997) and probably contribute to pesticide overuse.

Plant breeding can also offer improved pest and disease resistance in new varieties. One example is the steady reduction in insecticide use on rice over the past 20 years in central Luzon, the rice bowl of the Philippines. Application rates are now lower than before the Green Revolution, but rice yields have increased. Another potential means of reducing insecticide use is Bt cotton, a genetically modified crop widely adopted in China and India, where collectively more than 70% of the region's cotton is produced. Reports indicate that insecticide use with Bt cotton has fallen dramatically and farmer health has improved (Pray et al., 2002).

2.2.3 Trend in crop production and application of AKST in major farming systems

2.2.3.1 Growth of crop production and increase in food availability

Over the past 50 years, food crop production has increased remarkably because of development in agricultural science, technology and modern inputs. The harvest area has remained stable—288 million ha in 2005. However, cereal production increased threefold from 1961 to 2005, with a 2.7% annual growth rate (Figure 2-5). Among the cereal crops, paddy rice accounted for about 55% in 2005, followed by wheat 22%, and maize 19%. Among the ESAP countries, Australia, China, Indonesia, Laos, Pakistan, Philippines and Vietnam experienced rapid growth in cereal production. For example, China's cereal production had an annual growth rate of 3.1%, mainly driven by maize production the last 20 years in response to the increased demand for animal feed.

Figure 2-5. Changes in harvest area and cereal production in ESAP, 1961–2005

Figure 2-6. Average crop yield trends in ESAP, 1961–2005

With relatively stable crop areas, the growth in cereal production has come from increases in crop yields (Figure 2-6). From 1961 to 2005, the yields of maize, paddy rice and wheat increased remarkably. The yields for maize were 4.16 tonnes ha^{-1}, rice 4.16 tonnes ha^{-1}, and wheat 3.05 tonnes ha^{-1} in 2005. However, agricultural performance varied substantially across countries. In maize production, Australia, Bangladesh, China and New Zealand had the highest yields in 2005. Bangladesh had the highest annual growth rate from 1961 to 2005, followed by the Republic of Korea. For paddy rice, Australia, China, Republic of Korea and Japan were the countries with the highest yields, while the small island countries had the lowest. Laos experienced the highest annual growth rate, followed by China. With wheat production, higher yields were in China, Japan, Republic of Korea and New Zealand; China had the highest annual growth rate.

Figure 2-7. Cereal production per capita in ESAP, 1961–2005

In the ESAP countries, food production per capita increased steadily until 1990 and then began to level off (Figure 2-7). In 2005, the average cereal availability was 283 kg per capita. China had a rapid increase between the 1960s and the 1980s but tended to decrease after that, mainly from changes in the diet with the rise in income and more meat consumption. Indonesia also experienced steady increase in food provision. In contrast, India moderately improved domestic food production per capita.

2.2.3.2 AKST in major crop farming systems—three cases

Intensive irrigated rice production. Irrigation and the use of dwarfing genes in tall cultivars led to great increases in rice yield. The release and widespread adoption of short-duration, high-yielding, semidwarf cultivars triggered investment in irrigation infrastructure and allowed more farmers to grow two or three rice crops each year. Tillage and intense management increased and soil remained submerged longer. Inorganic fertilizer and pesticide use increased, but the diversity of rice cultivars in the irrigated systems shrank. Higher yields resulted from the combination of increased yield of modern cultivars compared with the landraces they replaced. Improved crop nutrition was made possible by fertilizer application and improved plant resistance and pest management to minimize losses from weeds, insects and diseases (Cassman and Pingali, 1995). In the irrigated lowlands of Asia, which accounted for 75% of the world's rice production, average yield increased from 2 to 3 tonnes ha^{-1} in the 1950s to 5.3 tonnes ha^{-1} at the turn of the last century.

Although the quest to further increase the potential yield of inbred rice after the release of IR8 was not as successful as hoped, many new cultivars were better adapted to different environments and contributed to better nutritional quality and human health (Peng et al., 1999; Peng and Khush, 2003). Considerable progress was made, for example, in managing major rice diseases, such as bacterial blight, blast and tungro, through genetic improvement. The reason few disease outbreaks occurred in the past 15 years was the result of collaborative research between international research institutions and the national extension organizations in many developing countries. Combining resistance to insect pests with ecological crop management principles (Heong et al., 1995) greatly reduced the incidence and effect of pest outbreaks (IRRI, 2006).

Modern rice cultivars with origins in breeding research in the 1960s covered about 75% of Asian riceland. In irrigated areas, that proportion was often 80 to 100%. In Bangladesh, for example, 46 new cultivars developed from 1970 to 2001 had spread to 80% of the dry season irrigated rice area by the early 2000s. These modern cultivars have contributed to a 2.3% growth in rice yield each year over the last three decades, which helped Bangladesh avoid a looming hunger crisis, despite high population growth and dwindling amount of arable land (Hossain et al., 2006). The rice-breeding programs at IRRI and its partners in Asian countries demonstrated how AKST requires continuous development of new cultivars to secure the world's food supply.

The rice–wheat system of the Indo-Gangetic Plains. Rice–wheat cropping has been practiced for a thousand years, but it expanded rapidly, particularly in northwest India and Pakistan, only since the mid-1960s, following the Green Revolution. The rice–wheat belt occupied nearly 24 to 27 million ha in South Asia and East Asia. Rice was mostly grown in flooded fields, while the ensuing wheat crop required well-drained soil (Ladha et al., 2004). The system occupied 13.5 million ha in the Indo-Gangetic Plain of South Asia in 2001 (Timsina and Connor, 2001). Rice–wheat systems evolved with the introduction of wheat into traditional rice areas in Bangladesh, eastern India and Nepal and rice into traditional wheat areas in northwest India. The driving force for expansion was the need to intensify cropping to meet an increasing demand for food. It was made possible by the development of short-duration and medium-duration rice and wheat cultivars. Their combined productivity responded to improved nutrient management, pest control and the expansion and improvement of irrigation. The rice–wheat system is complex. Overall optimum management strategies must be established for the alternating and contrasting anaerobic environment required for rice and aerobic environment for wheat. A summary of the sequence of the technology and its effect on productivity is as follows:

- Before the Green Revolution, yield was small and the system operated with few inputs and much human and animal labor.
- As short-season rice and wheat cultivars became available, management focused on expanded irrigation and improved management. During this early expansion there were no environmental issues to counteract the benefits from increasing productivity. Yields increased with further intensification.
- Further intensification included new cultivars, nutrition and mechanization. Early sowing of wheat to avoid heat stress and low yield during flowering and grain filling was a major strategy for yield improvement.
- Subsequently, yield increase slowed and yield declined in some places from a combination of causes. Evidence showed deteriorated soil structure and fertility from excessive cultivation and nutrient extraction from the more intensive system, operating with ever-increasing yields. Problems arose from irrigation with both excessive extraction of groundwater and accumulating salts in regions with low water quality. Decreased solar radiation and increased minimum temperature also contributed to yield decline (Pathak et al., 2003).

- The recent phase was to recuperate yield. Attention to water and labor use and environmental problems led to much new technology across the entire Indo-Gangetic Plain. New techniques and machines for planting enabled more rapid and timely crop establishment. Reduced cultivation and site-specific fertilizer management were reversing soil deterioration. Bed planting was introduced in some places to improve water management and diversify crops away from a strict rice–wheat system. Fertilizer requirements were more precisely defined, and soil and tissue testing enabled more effective and efficient nutrient management. Laser leveling of land, aided by more accurate water requirements, improved irrigation efficiency. Less stubble burning contributed to improved air quality and more soil organic matter. These resource-conserving technologies were to improve farmer income by increasing input efficiency, maintaining crop productivity and enhancing crop diversification (Gupta et al., 2002; Ladha et al., 2003).

Rainfed wheat production in the State of Victoria, Australia. The Australian wheat industry, exemplified by the State of Victoria, had already passed through two phases of development when the rapid development of a lucrative world market for wool following World War II provided an opportunity for significant change (Connor, 2004). It became economical to improve pasture by species composition and fertility. "Sub and super," subterranean clover (*Trifolium subterraneum* L.) and superphosphate fertilizer, became the buzzwords for pasture development. Sheep-carrying capacity of pasture increased markedly and encouraged close integration with wheat production. Pastures were managed for sheep and to build up nitrogen to extract during a cropping phase. Other technology supported the greater economic benefits that flowed to farmers from increased wheat and sheep production. Plant breeding continued, horses were replaced by tractors, and new machines were developed for tilling and harvesting. Herbicides and pesticides became available, and increasingly precise fertilization for pasture legumes, including micronutrients manganese (Mn) and molybdenum (Mo), became possible. Fallowing became less frequent. Wheat yields had risen to around 2 tonnes ha^{-1} by the 1980s. The system was mostly seen as ecologically stable.

With the application of inorganic nutrients, leguminous pastures with increased nitrogen supported profitable sheep and wheat production. The system did not, however, persist into the 1990s because the wool market collapsed. Furthermore, soil acidification and salination were unanticipated environmental effects of the system. Clover growth and nitrogen fixation were reduced, and consequently the overall productivity of pastures and wheat crops declined. The solution lay in liming and changing the water balance to keep the salt at the depth where it had accumulated under native vegetation. As a result, a more diverse system was sought, one that involved less pasture, less fallow, perennials such as lucerne and trees in agroforestry systems, and a wider range of crops including canola, lupine, field pea, fababean, chickpea and lentil. There was also increased use of zero tillage, controlled traffic, yield mapping and precision farming. Nitrogen fertilizer entered the system. Plant breeding continues, now for a wider range of species and by applying new biotechnology techniques such as marker-assisted breeding. But so far genetically modified crops (GMO) have been avoided. Although there has been some local opposition to GMOs, the dominant concern has been to maintain access to overseas markets.

Farmers now require considerable technological and economic skills to manage increasingly complex cropping systems. High yields are possible only in years of greater than average rainfall. In low rainfall years, the focus of management must be to minimize costs, perhaps even not to plant at all. Cropping is no longer a matter of applying established cropping sequences but tactically adjusting crop and management to likely seasonal and economic conditions. Nitrogen fertilization is a good case in point. The objective is to gain yield benefit in years of high potential and avoid low yield in years of low rainfall. This requires a response to weather forecasts in crops, measurement of soil water and nitrogen at sowing, and crop nitrogen content at responsive points during the growing season. Measurements and their analysis are the keys to success in crop choice, crop condition, weed and pest incidence, and the likely success of management.

2.2.3.3 Emerging trends on biofuel production

Biofuels are an important energy source in ESAP, mostly from crop residue, wastelands and wood from forests. The countries with evident pressure on forests are India, Nepal and Thailand. The agricultural and natural resource base of all countries faces a potentially much greater pressure to produce liquid biofuel. The driving forces are worldwide: energy security, climate change, and export to the many industrial countries that set mandatory goals for biofuel use. Within ESAP, India has set a mandatory minimum 5% ethanol in nine states; Thailand has tax incentives to encourage production. Australia, a low-cost sugar producer second only to Brazil, established a cane ethanol market in 2001 to overcome financial hardship among producers. The annual target is to produce 350 million liters by 2010 from a base of 30 million liters in 2001.

Modern technology is best suited to producing ethanol from sugar or starch crops or biodiesel from oilseed crops. Target crops for ethanol in ESAP are sugarcane, cassava, maize, oil palm and coconut, and for biodiesel, jatropha. Ethanol from cellulose, crop residue, biomass crops and trees is possible, but much less efficient for producing energy. Energy efficiency was not high in any case, with output-to-input ratios for ethanol from sugar and starch from mostly < 2; higher, perhaps 4 to 5, only for sugarcane under the production and cultural conditions in Brazil.

At a time when concern is being expressed for the capacity of agriculture to feed an anticipated world population of 9.5 billion, including 6 billion in ESAP, immense additional pressure will be placed on agriculture and forestry. Current technology would require 3.5 tonnes of grain to fuel a motor car with bioethanol for one year—almost seven times the annual grain equivalent needed to provide one person an adequate and balanced diet (Connor and Mínguez, 2006). Put another way, it would take 100 kg of grain to produce the ethanol used to fill a 40-liter tank of a car just once. That caloric content (100 x 4,000 kcal) is equivalent to a survival diet of 2,200 kcal a day for one person for six months.

This simple calculation exposes the enormous increase in agricultural production required if biofuel is to make any significant contribution to private motoring, and the inequality it would engender in developing countries struggling to feed all inhabitants adequately (von Braun and Pachauri, 2006). While farmers will benefit from the additional market, even a small portion of the total liquid fuel requirement produced from agriculture will place enormous strain on the environment. Even at this early stage of the biofuel boom, there have been widespread reports attributing higher food prices to the diversion of agricultural production to biofuel production, such as for maize in Mexico. The notion that there are special fuelcrops that are significantly more efficient fixers of solar energy than current crop species and will not compete with food production or will flourish on land unsuited to agriculture, jatropha is an example, is unproven.

When methods are devised to break down the cellulose for fermentation, stubble and biomass crops will also be targets for biofuel. Stubble, however, is important in maintaining soil structure and fertility. While a portion, perhaps 50%, might be removed with the highest-yielding crops, retention is generally required to sustain productivity. Witness the deleterious result of removing stubble for animal fodder and roofing and root crowns for fuel that is practiced in parts of the rice–wheat system. Energy crops will compete with food crops for land and markets. To the small extent they will be able to contribute, they will require high management and, most importantly, large inputs of water and nutrients to maintain productivity.

2.2.4 Application of AKST to livestock production

Millions of rural households in Asia and the Pacific depend on domesticated animals for food, farm power and income. Livestock is important in the economies of many ESAP countries and has particular cultural significance in India. The livestock sector has been shifting from extensive grazing to more commercial production and changing from rural to urban and periurban production.

This pattern is directly related to increased urbanization throughout the region. The rate of urbanization is highest in East and Southeast Asia and less pronounced in other parts of ESAP (Steinfield, 1998). Between 1950 and 2000 the percentage of people in Asia living in urban areas increased from 16 to 38% (UNFPA , 2001). By 2025 the urban population is anticipated to surpass 54%. In Oceania, which includes the Pacific Islands, Australia and New Zealand, the trend was the same, with a prediction that 84% of the population will reside in urban areas by 2025.

These demographic changes have been accompanied by a shift from large ruminants—buffaloes and cows—to monogastric pigs and poultry. The developing countries have had some of the highest growth rates in producing and consuming livestock and meat products. Asia has had some of the highest growth rates in pork and poultry production, with an estimated 150% increase between 1991 and 2003. ESAP also more than doubled its egg production and accounted for about 50% of world production (Steinfield et al., 2006).

2.2.4.1 Livestock production systems

Animal production systems are of three main types: grazing, mixed farming, industrial. Of these, the mixed farming system dominated in ESAP countries. Grazing systems use native grasslands with little or no integration with crops. Mixed farming involves integrating livestock and crops and provides an opportunity to intensify by using crop residues and manure. Industrial production is capital and labor intensive, detached from land for feed supply and waste disposal (Steinfeld, 1998).

Industrial production systems are increasingly important, particularly for pigs and poultry. Livestock production systems vary from country to country. Sri Lanka has small-scale dairy and poultry producers, with buffalo as the main source of draft power. Nepal also uses buffaloes and bullocks for draft power and ghee production. Sheep and goats are mainly kept for wool and meat. In Southeast Asia swine and poultry dominate livestock production. In Thailand, more than three-quarters of pigs are produced on large industrial farms with more than 500 animals. In Guandong, China, on the other hand, half the pigs are produced on farms with fewer than 100 animals and in Vietnam, very small operations of three or four pigs dominate.

The growth in the production and demand for poultry and pork has resulted in a growing shift away from pasture systems. As livestock production becomes more intensified, there has been a shift from locally available feed to commercial feed concentrates, particularly in pig and poultry production (Steinfeld et al., 2006).

Only three countries in ESAP—Japan, Mongolia and Singapore—have not increased meat production over the last 20 years. Countries registering more than a 100% increase in production are Brunei, Cambodia, China, Fiji, India, Indonesia, Lao PDR, Malaysia, Pakistan, Philippines, Sri Lanka and Vietnam. China's share of meat production in the world total increased from about 10 to over 28% in the last 20 years (FAO, 2006a)

2.2.4.2 Changes in dietary patterns on livestock production

Though livestock food products are still not a significant part of the diet in developing Asia and the Pacific, consumption is growing rapidly. Developing Asian countries have the world's highest growth rates of production and consumption of food from livestock (FAO, 2006a). The growth in livestock production across ESAP comes from changes in demand and new technology, which have enabled producers to move into more intensive industrial production, thus greatly increasing the supply of pork and poultry meat.

Poultry consumption has shown the fastest growth throughout ESAP. China stood out for its impressive growth in beef consumption, which increased by more than 500% between 1985 and 1995. Growth patterns in South Asia have been more balanced, with poultry showing significant increase in consumption but consumption of other meat products—beef, mutton and goat—increasing only modestly (Steinfield, 1998).

Pork was the most-produced meat. In 1961, it was 30% of total meat production. Beef and veal were next in importance, followed by mutton and lamb. Pork became even more dominant by 2000, when it was over 55% of the meat produced. Poultry meat took second place, beef and veal were third.

Dramatic changes occurred in Asia: protein from livestock in human diets increased more than 130% between 1980 and 2002. The increase in animal products in the human diet was part of a dietary transition that also included higher intake of fat, fish, vegetables and fruits, and a decrease in cereals and tubers (Steinfeld et al., 2006). This transition was directly related to growing urbanization and increasing standards of living throughout ESAP and many of the developing regions of the world. Urbanization, coupled with income growth and increasing globalization, generated a major shift in Asian diets away from staples and toward livestock and dairy products, vegetables, fruits, and fats and oils.

The dynamic Asian livestock sector is growing between 3.5 and 5% each year—more rapidly than crops, such as cereals, vegetables and pulses—driven partly by increasing population, rising income and change in consumer lifestyles. Since animal products are expensive to import, most countries plan to meet the rising demand through increased domestic production. Hence, livestock growers in periurban areas are increasing production and modifying management to respond to the rapid rise in demand. Structural changes are also led by the growth in urban supermarket vendors, intensifying the need to examine opportunities for vertically integrating vulnerable producers. Small-scale producers are not generally a part of the rapid rise in intensive animal production. Yet more than half of the small-scale farmers in Asia rely on livestock as a major source of income and nutrition (FAO, 2006a).

Although most ESAP countries are technically capable of increasing meat, milk and egg production, most face shortages of key feed ingredients, particularly maize and soybean meal. As a result, there is a large and burgeoning trade in feed crops worldwide.

2.2.5 Application of AKST to forest production

Although ESAP contains only about 5% of the world's forests, it had an estimated 25% forest loss over the last decade. The proportional loss (the amount lost relative to the remaining forest) was greatest in Asia (UNFPA, 2001). The cumulative loss of forest cover across Asia and the Pacific between 1990 and 2000 was estimated at about 1.1% (FAO, 2006a). The Philippines had the highest rate of deforestation, followed by Pakistan, Thailand and Malaysia. However, the largest losses occurred in Indonesia and Myanmar (Waggener, 2001). Between 1990 and 2000 the region experienced considerable reduction in forest cover, with the greatest decline in the Southeast Asian islands, followed by continental Southeast Asia and the Pacific Islands. Population pressure and the resultant conversion of land to agriculture was the dominant cause of deforestation across the region. While in percentage the most forest lost was in the smaller Pacific Islands, the forests of insular and mainland Southeast Asia had the greatest population pressure (Brown and Durst, 2003). Because tropical forests contained about half the remaining biodiversity in the world, their destruction was of particular concern (UNFPA, 2001).

2.2.5.1 Native forest management

Native forests cover about 25% of the area across Asia and the Pacific. The Pacific Islands, with 65% forest cover, and the Southeast Asian islands with 53% cover, have the highest proportion of land-user forest. Papua New Guinea has the largest rainforest coverage in the Pacific, accounting for the third largest block of tropical rainforest in the world (Chatterton et al., 2000). South Asia has relatively little forest cover.

Native forests are not limited to terrestrial environments. Asia and the Pacific are also home to the greatest concentration of mangroves. Once thought of as coastal wasteland, mangroves were destroyed at an alarming rate for agriculture, aquaculture and firewood. Almost half the mangrove destruction in recent years has been prompted by the desire to create shrimp farms (UN Atlas of the Ocean, 2002). Over the last 20 to 30 years, with help from the UNESCO Mangrove Programme and other international initiatives, government planners and fisheries experts have become more aware of how mangroves are a nursery for many coastal and aquaculture fish, a buffer that reduces sediment flows to offshore reefs and a barrier against storm surges and tsunamis (Vannucci, 1997). About 90% of all marine organisms spend some portion of their life within mangrove systems (Adeel and Pomeroy, 2002).

Most countries in the region have well-defined policies, laws and programs to regulate the use of forests and the development of forestry activities, although they are rarely consistently enforced. As a result, corruption and illegal logging are significant in many ESAP countries. Indonesia loses $1.4 billion a year as a result of the trade in illegal logging (DFID, 2007). Historically, most ESAP countries have regulated forest management by assigning management responsibilities to government agencies and attempting to enforce strict controls on forest access. Transient upland populations and traditional tenure systems based on common access to forests have often conflicted with government policy initiatives.

Asia and the Pacific had over 552 million ha of forests, of which 477.7 million ha, 86%, were natural forests. (Note: The FAO 2001 figures were 709 million ha. This could be an overestimate due to the forest cover classifications used.) However, only about 249 million ha, 45%, were available and suitable for harvesting (Waggener, 2001). The natural forests throughout ESAP had, until very recently, been seen mostly as a vast source of raw timber to generate export income. However, there is now general agreement on the need to change from a focus on timber exploitation to emphasizing management for sustainable, multiple-use natural forests (Enters, 1997). In the face of increasing deforestation China, New Zealand, Philippines, Sri Lanka, Thailand and Vietnam have imposed several total, partial, temporary or selective bans on logging in natural and old-growth forests. The results of these restrictions have been mixed. Several case studies indicate that such bans could have unanticipated effects on timber supply, forest harvesting, transport, processing and consumption of forest products. The restrictions affect forest residents and those who depend on forestry for their livelihoods (Waggner, 2001).

The need for sustainable forest management has been clearly recognized throughout ESAP, but few examples of effective management have been implemented on a large scale. In some areas, improved practices such as reduced-impact logging, forest and timber certification and log tracking systems have been introduced as avenues for more sustainable management. Forest certification involves certification by a third party that an area of forest is being managed in accordance with a defined set of standards. Chain of custody certification tracks wood products from a certified forest to the point of sale. However, incorporating social criteria and indicators into forest management and harvest practices was criticized as difficult to assess and interpret in the field (Wollenberg and Colfer, 1996). Although there was no significant effect of timber certification on loss of tropical forests over the last two decades, timber certification is expected to create greater awareness among forest managers of the need to protect the environment and minimize the loss of biological diversity (Thang, 2003).

In addition to the limited use of technology to reduce the effect of logging on the environment and the forest soils, different governments in the region have put in place policies designed to reduce environmental damage and increase the economic returns from forestry. Thailand has a total ban on logging within its borders, the Philippines has banned the export of unprocessed logs and Bhutan has mandated that the country must keep 60% of the land under forest cover (UNEP, 2005). However, the effectiveness of these laws and plans is often greatly reduced because of limited resources, shortage of skilled staff, corruption and weak law enforcement. Rather than the need for new technology, the critical issue has been the lack of political will in most countries to enforce existing policies and regulations (Enters, 1997).

Outside reforestation, natural forest management has focused on forest harvest techniques to minimize the adverse effect on natural regeneration, ground cover and underlying forest soils. In some places traditional cut-and-drag systems have been replaced by less-damaging methods. In Malaysia skyline cables and helicopters are used to minimize degradation from harvesting timber on steep slopes. These and other technologies developed for forestry in temperate areas could be adapted for tropical forests. The real constraint is that most forest harvesting in ESAP is done by private companies, where profit is the driving force in management practice. Portable wood chippers are available, but there are few or no economic incentives for extracting or on-site processing harvest waste. Helicopter logging and cable and skyline yarding represent a large capital investment that might not be justified by the value of the timber, especially if there are no impositions upon the harvester to conserve soil and water or limit the damage to the residual stand. Although cable yarding systems damage soils and understory less than cut-and-drag systems, they may be more difficult to use in the selectively harvested forests common in Asia, rather than clear felling, common in temperate forests.

2.2.5.2 Nontimber forest products

Managing native forests to collect and produce nontimber forest products has received little attention, other than as a component of agroforestry and a traditional agroforestry practice. There is not even clear agreement on what nontimber forest products are. The broadest definition would include all biological material harvested from forests for human use. Scale, mode of harvesting and market distinguish nontimber forest products from forest wood products. Nontimber products are usually harvested by individuals, households or small groups and marketed directly by the harvester or through small-scale processing operators. Nontimber forest products generally are forest plants and animals used for food, beverages, forage, medicine and fiber. Although many upland households harvest, process and sell nontimber products to augment household income, few data relate to the number of people employed and the value of the outputs across the region. Nontimber forest products have generally been collected and consumed by those who collect them, others traded and processed before reaching the market. Women and children generally collect and process the nontimber products.

In response to strong market demands, some nontimber products, such as rattan in Malaysia, are domesticated and grown in plantations for commercial use. Such practices meet consumer needs without further depleting natural forest stock (Poh, 1994). Forest products formerly grown in the wild are now grown commercially, including tropical fruits, cocoa, coffee, tea, cardamom, cinnamon, cashew and pepper. While domestication of some species could expand to meet growing market demand, for many rural and upland residents collecting nontimber products remains a significant contribution to subsistence farming. In principle, the harvesting of nontimber products from natural forests should be sustainable. However, in practice this has often not been the case, particularly where changes in land tenure, hydropower projects and logging roads have given outside populations easy access to remote areas (Enters, 1997).

2.2.5.3 Plantation forestry

Plantation forestry is another form of management found in the region. Five ESAP countries, China, India, Indonesia, Japan and Thailand, ranked among the world's top ten plantation forestry countries. Together, these countries accounted for 55% of the world's forest plantation resources, 91% within Asia and the Pacific (Brown and Durst, 2003). The average age of Asia's industrial plantations is less than 15 years (FAO, 2001). This has come primarily from the rapid acceleration in plantations in China and the short rotations generally used in that country. Older plantations were mostly in Japan (FAO/RAP, 2003).

With the diminishing availability of large-diameter timber from natural forests in the region, plantation forestry is fast becoming the alternate source for wood in ESAP. The region accounted for more than 80% of forest plantations in the tropics (Enters, 1997). Most of the legally produced industrial wood in the region has come from plantation forests. Most plantation forestry is intensively managed monocultures, mainly pine, teak, poplar, acacia and eucalypts, cultivated for a relatively narrow range of products and species (Enters, 1997).

Plantation forests have considerable diversity in ownership, management, scale and products. Plantation systems have been established to meet the need for fuelwood, poles, wood chips, furniture wood and estate crops, including rubber, oil palm and coconut. Until the last 25 years, forest plantations were largely smallholder or government operated. The growing trend has been increasing private investment and management of forest plantations in response to increasing demand for wood for pulp, furniture and particleboard. Smallholder plantations have sprung up to meet this market in the some ESAP countries, such as the Philippines (Garrity and Mercado, 1994; Pasicolan et al., 1997), Laos (Roder et al., 1995), India and Thailand.

The technological innovations in plantation forestry depend on the production objectives—conservation, fuelwood, fiber, or sawlogs. The technology and management adopted by plantation operators include improved seedling production by using polyethylene bags, centralized nurseries, thinning and pruning for sawlog production. Breeding programs and improved planting material from tissue culture were still relatively minor (Enters, 1997). Improved trees have been limited to large commercial plantations, particularly in China. Virtually no improvement has been done for species commonly used in multipurpose small farm operations. Harvesting technology ranges from manual to completely mechanized, mostly in response to rising labor costs and increasing concern about minimizing soil disturbance.

Although the reduced species diversity and the younger tree age associated with plantation forests provide conditions favorable for pests and diseases, uniform products often compensate for these risks. Plantation forestry is seen by many as a way to address environmental objectives, such as soil conservation, mitigation of erosion, carbon sequestration, and rehabilitation and protection of habitats for important wild flora and fauna.

2.2.5.4 Wood-processing technology

Wood-processing capacity in the region has increased significantly over the past 30 years, concentrated in the most industrialized countries. Most of the technological improvements in wood processing have come through adapting technology from industrial countries, such as medium-density fiberboard. Most modern processing machinery has been imported from Europe (Enters, 1997). It has generally been adapted for processing small-diameter trees from forest plantations. Medium-density fiberboard production emerged as a response to shortages in raw material and the newly developed ability to use untapped resources to produce a plywood-like product. Medium-density fiberboard and similar products became price-competitive alternatives to plywood, particleboard and hardboard (Adhar, 1996). Within ESAP, Malaysia is the number one exporter of veneer sheets, Indonesia the number one exporter of plywood, followed by Malaysia, China and New Zealand.

With many governments banning or severely restricting the export of unprocessed logs, a demand has developed for efficiently processing and converting sawn timber into particleboard and other panels. Likewise, some wood previously considered to have little or no value, such as rubber wood, is now being processed for the furniture industry. Largely as the result of the research at the Forest Research Institute in Malaysia, a major market has developed for rubber wood in furniture and panels. More recently, the technology for processing rubber wood has been applied to oil palm stems and research is looking at using oil palm fiber as an ingredient in wood-based boards, pulp and chipboard. Compared with natural wood and plywood products, composite, defect-free fiberboard can be easily produced in large, uniform sizes (Yayah et al., 1995). When the supply of natural fiber begins to dwindle, the panel processing industry will likely introduce nonwood fibers. Most major nonwood fiber processing facilities are in China and India (Enters, 1997).

2.2.5.5 Agroforestry

Agroforestry in its simplest form means integrating trees with crops or livestock enterprises in a farming system. Tree farms and nut plantations managed as a monocrop are not considered agroforestry (Beetz, 2002). This approach, used primarily on smallholder systems, has gained widespread attention by government agencies and NGOs to address conservation objectives. Because of its potential for enhanced food security, poverty reduction and environmentally sound land management, an internationally supported research center, the World Agroforestry Centre (ICRAF), is devoted to this research and development.

Technology and management associated with agroforestry include 1) alley cropping, 2) improved fallow systems, 3) silvopasture, 4) windbreaks, 5) mixed agroforests, including breadfruit systems in the Pacific Islands and 6) riparian buffer strips. The technology most widely associated with agroforestry has been alley cropping. This involved incorporating tree hedgerows within crop fields to act as a fallow and improve soil fertility through nitrogen fixation (Craswell et al., 1997). In Asia hedgerows were promoted on sloping fields to reduce soil erosion (Garrity, 1986). While there were some significant success stories on the positive effects of alley cropping, particularly in Alfisols not deficient in phosphorus (Sanchez, 1995), it was not widely adopted because it was designed as a conservation approach rather than meeting the needs of upland dwellers. It was labor intensive and in most cases did not result in sufficiently high economic return to justify the labor. Tree and crop competition for light, water and nutrients led to the failure of many alley-cropping systems to outperform traditional cropping (Sanchez, 1995).

Different views regard the future of agroforestry. One view holds that 1) agroforestry cannot be widely adopted for forest rehabilitation so long as farmers do not have secure land tenure and use rights, 2) resource poor farmers will receive only marginal benefit from expanded agroforestry and 3) future agroforestry effort should focus more on intensively managed small-scale plantations that produce only one or two products for commercial use, including coffee, cacao, and neem (Enters, 1997). In Malaysia, small-scale farmers grew rubber for its wood, rather than its latex. Other options included fodder crops, living fences and shade trees. The other view, held by Leakey and Tchoundjeu (2001) and others, suggested that the future of agroforestry in much of the developing world lay in intensifying and commercializing the management of traditional homegarden forests. Given the less than optimal adoption of research-designed systems, improving traditional practices that build upon farmer knowledge, skills and resources may be a more successful strategy.

2.2.5.6 Community and social forestry

In the narrowest perspective, community forestry is the governance and management of forest resources by communities for commercial and noncommercial purposes. The core of community forestry is the recognition that communities living adjacent to or in forests have rights to manage them and extract resources to support their livelihoods and traditional knowledge. As such, community forestry has become the focus of policy and training initiatives, rather than technological interventions. In India and Papua New Guinea customary and village ownership of forests has been recognized. Community forestry programs focus on educating villagers to become better stewards of forest lands. As a development strategy, community forestry has become a way many governments in the region involved rural communities in protecting and managing forests (Nurse and Malla, 2005). In practice, community forestry was often interchangeable with social forestry, referring to many activities that involve local people, from managing woodlots, growing trees as a cash crop to household processing of forest products (Casson, 1997).

Over the last 40 years community and social forestry has expanded from a way to meet the fuel and income needs of the rural poor and reducing deforestation and desertification to empowering a community (Poffenberger, 1990; Hidayat, 1998). Examples include community forest management and participatory conservation in the Philippines (Utting, 2000). Other variations include joint forest management in India (Fisher, 2000), village forestry in Lao PDR and collective forest management in China (Gilmour et al., 2004). One model example of community forest management came from Nepal, where over 12,000 recognized forest user groups managed more than a million hectares of forest. One challenge to community management is resolving issues related to forest tenure, ownership, user rights and common access. Another key issue that had not been effectively addressed is how local participatory approaches can be scaled up to affect landscapes (Nurse and Malla, 2005).

Farm forestry has received little if any attention in developing and transferring improved technology. Farm forestry is growing trees on private agricultural land, wasteland and degraded forests. There is an important perceptional difference between social forestry and farm forestry. Planners of social forestry projects emphasize the subsistence return to farmers in fuelwood and fodder, while forest farmers place priorities on trees for cash income. Areas where farm forestry is most successful are where small farms have a long history of producing for the market, where cash returns from trees and agricultural crops can be easily seen (Pasicolan et al., 1997). Examples of this can also be seen in the industrial countries of the region. Australian farm forests often provide ecosystem services similar to agroforestry and community forestry. In Australia, the nature and the size of small-scale forestry differ from county to county but can be classed into two types. The first is based on growing *Eucalyptus globules* for pulp and the second involves producing native hardwoods for saw and veneer logs (Herbohn et al., 2002).

2.2.6 Application of AKST to fisheries production

In ESAP, fisheries have always been vital to food security, supplying animal protein, minerals and vitamins; generating employment, reducing poverty and earning revenue through trade. It is part of the cultural heritage in many parts of India and Bangladesh; fish is important in matrimonial and other social customs and celebrations. Globally, fisheries production from 1950 to 2004 increased steadily with the ESAP contribution. ESAP countries contributed at least 64% to total global production in 2004 (FAO, 2007),

ESAP had about 87% of the 38 million people in global fisheries (FAO-SOFIA, 2006). This possibly represents only those who are full-time fisherfolk and aquafarmers. The number of persons who provide labor for the various stages of fishing and aquafarming and the ancillary industries, including net making, boat and transport carrier construction, fish processing, feed milling, ice making and trading must be immensely more. Bangladesh alone employed about 12 million people in the fishing and aquaculture industry (Department of Fishery of Bangladesh, 2003).

2.2.6.1 Capture fisheries

Capture fisheries have either stagnated or dwindled in most of the world. Historically, the vast seas and the inland lakes, rivers and canals were rich sources of fish. With relatively little effort, people could harvest plenty of fish from waters close to the shore and meet their demand. They thought the sea was an inexhaustible source of food. As the human population increased and the demand for fish grew, people gathered more and more knowledge and technology to quickly and safely go farther into the ocean in search of more fish. The modern fishing fleet, with cold storage, processing facilities, fish-scouting airplanes and sophisticated acoustic technology, can detect the size and nature of fish schools in the open sea and at various depths. This technology, coupled with extremely efficient fishing gear, including the purse seine and trawl nets, increased marine production dramatically. But unscrupulous application of technology eventually resulted in overfishing and depletion of the oceans' fishes (FAO-SOFIA, 2006). Despite caution from scientists, many of the rich marine fishing grounds all over the world, including ESAP, were excessively exploited for human food, industrial raw material for fish meal in farm animal feed, vitamin oils, soap, isinglass for wine purification and other uses. As a result, 8% of the marine fisheries have been depleted, 16% overexploited, and 52% fully exploited; 21% moderately exploited and only 3% remain underexploited (FAO-SOFIA, 2006).

The inland lagoons, rivers, canals, floodplains and other open waters were not excepted in many countries (FAO, 2007). Effective enforcement of conservation rules for marine or inland open water fisheries resources is seldom possible. Aquatic habitat change or destruction from massive construction of embankments for flood control, drainage and irrigation, construction of ibarrages in rivers, excessive surface water withdrawal, aquatic pollution from agricultural pesticides or indiscriminate release of industrial effluents and unplanned construction of rural roads and culverts that obstruct fish movement have all contributed to the destruction of marine fisheries. In at least six ESAP countries, China, India, Japan, New Zealand, South Korea and Thailand, fish catch clearly declined (FAO, 2007).

2.2.6.2 Aquaculture fisheries

As opposed to the decline in capture fisheries, aquaculture production since the 1950s increased steadily, with the 1980s described as spectacular, largely from the significant development of aquaculture knowledge, science and technology (FAO, 2007). Significant increase in the global human population, the reduced supply of food fish and the high price of exportable aquatic species from open water because of the increased demand stimulated aquaculture practices to quickly develop and flourish. Farming various aquatic organisms became profitable.

Within global aquaculture, ESAP aquaculture rose from 54% in 1950 to 90% in 2004. ESAP aquaculture contributed 54 to total fishery production of 99,844,154 tonnes of the region in 2004 (FAO, 2007). The first seven ESAP countries in gross aquaculture production by volume, including aquatic plants, in 2004 were China, India, Philippines, Indonesia, Japan, Viet Nam and Thailand . China alone produced 41,661,660 tonnes, accounting for 78%; the next six countries accounted for 17%; the remaining countries 5%.

The value of ESAP aquaculture products was estimated at nearly US$56 billion, which was about 80% of the global value. Although the rest of the world produced 10% of the global production volume, ESAP contributed 20% of the value, indicating they produced more higher-value items. Within ESAP, China alone accounted for 66% of the total value; six other top countries, Japan, India, Vietnam, Indonesia, Thailand and Bangladesh, together with China, exceeded 92% of the ESAP value (FAO, 2007).

The estimated numbers of employment in aquaculture of ESAP countries varied greatly, depending on the production and its socioeconomic importance. China had the highest numbers, reflecting its production. In some countries employment could be broken down according to the species involved. For example, shrimp aquaculture in Bangladesh employed about 600,000 people (Karim, 2003).

In many ESAP countries, fish was a major source of animal protein: Cambodia 75%; Bangladesh 63%; Philippines 52%; and China 32% (FAO-SOFIA, 2006). It was not easy to get reliable data on per capita fish consumption, since fisheries products were varied, were not just for human consumption, and often it was hard to separate imported and exported fish products. Fish consumption per capita in selected ESAP countries stayed the same from 1969 to 2002 for some countries, like Japan, while in others, such as Cambodia and China, it increased three- to fivefold. The inference is that the increase in ESAP population increased fish consumption tremendously.

Finfish from freshwater, marine and diadromous species—species that use both marine and freshwater habitats during their life cycle—constituted 46% (24,526,070 tonnes), aquatic weeds 25% (13,453,710 tonnes), mollusks 22% (12,022,658 t), crustaceans 6% (3,324,779 tonnes) and miscellaneous aquatic animals less than 1% (393,037 tonnes) of total production. Value from freshwater, marine and diadromous finfish was 49%, crustaceans 23%, mollusks 14%, aquatic weeds 12% and miscellaneous aquatic animals 2%. Of the total finfish production in 2004 of 24,526,070 tonnes, carp accounted for about 64%; by value, it contributed 48%.

In most ESAP countries, aquaculture started in the freshwater ecosystem with mainly carp and carp-related species. In Indonesia and the Philippines, it started in the brackish water ecosystem, mainly for culturing milkfish in the tidal flats.

When aquaculture began, it was simple and entirely based on stocking wild fry. It used no liming, fertilization, artificial feeding or aeration of the pond. It depended on either rainwater or high tide for its water supply. With time, AKST gradually developed and aquaculture underwent rapid changes. An important milestone was the development of artificial spawning technology. That made it possible to produce quality fish and crustacean fry in an artificial environment on a commercial scale. The technology was first developed and commercially used in the 1950s in China. It soon spread to Bangladesh, India, Thailand and most other Southeast Asian countries. While low levels of aquaculture were the general practice in the beginning, the trend has been toward intensifying pond culture and has been driven by an increasing demand for fish and decreasing amount of land suitable for expansion.

Intensification entailed any combination or all of the following:

- developing artificial spawning techniques to produce fry of desired species on a commercial scale
- developing superior brood stock by selective breeding to produce superior genetic quality fry
- liming and fertilizing the pond to induce the growth of natural food organisms
- formulating and using balanced artificial feed to promote good growth
- using pumps to ensure and stabilize the water supply
- using artificial aeration to ensure oxygen is supplied in all layers of the water to increase carrying capacity
- using pesticides to control predatory or harmful organisms
- using probiotics to maintain the quality of pond environment
- using genetically improved broodstock
- ensuring freshness of the produce and a good market price with good postharvest care

Aquaculture in Asia has become characterized by its wide diversity in species and culture systems. It includes freshwater, brackish water and marine ecosystems. The species used for aquaculture production includes many finfish, shrimp, crab, oyster, mussels, abalone, sea cucumber and even seaweed. Aquaculture has been practiced in various systems: earthen ponds, tidal flats and paddy fields with peripheral dikes, concrete tanks, raceways, pens, cages and racks. Monoculture, polyculture and integrated aqua-agriculture have been developed to suit the region’s diversified aquatic environment. However, pond culture remains the main source of aquaculture production in most countries.

Pen culture appears to be extensive in lakes and lagoons in the Philippines, where it is used mainly for milkfish and tilapia. The pens are enclosures made of synthetic or noncorrosive metallic mesh resistant to salt and sun and to crab cuts. The pen area may be enclosed by mesh on one to all four sides, depending on the topography. The bottoms and the tops of the enclosures are open, with no netting. Aquaculture of tilapia, catfish, sea bass, some species of carp and marine eel in fish cages has been popular in Japan, the Philippines, Thailand and

Vietnam. Like pens, fish cages are also made of synthetic, metallic or plant material, but unlike pens, the cage bottoms are closed. The tops of submerged cages are also closed. The cages are set in large ponds, lakes, rivers and bays. Racks made of synthetic fibers are hung in protected areas in the sea or in backwaters for oyster culture; the practice is common in the Philippines and some other Southeast and East Asian countries.

Aquaculture in seasonal monsoon water and floodlands, either in association with or alternating with paddy rice, has rapidly gained importance in Bangladesh, Cambodia, China and Vietnam. The favored species are carp, tilapia and prawn. In Bangladesh, about 50,000 ha of low-lying land that allowed only one crop of paddy rice during the dry season from January to May is now under prawn and carp aquaculture during the wet season. This multiple use has created excellent opportunities for rural farmers to enhance their income and nutrition. Some studies have suggested that this culture area should increase to at least 80,000 ha by 2015 (Karim,2003)

2.2.7 Organic agriculture

Organic agriculture had two faces in ESAP. On one side, a small sector grew certified organic produce for the home market and for export to industrial countries. On the other side, a larger proportion, mostly subsistence farmers, farmed organically because they could not purchase or afford synthetic inputs. Organic farming could still be considered fringe farming and would only benefit a few producers for domestic or export markets. However, in recent years, driven by the rising popularity of organic products and the often higher financial return, many conventional farms are converting to organic farming.

Concerns about the environment and food safety in the use of agrochemicals in agriculture, especially pesticides, have led groups of farmers to form the organic movement and rely upon traditional methods of soil, nutrient and weed management. These methods have been designed to make the best use of natural cycles of nutrient flow, pest and disease control and competition to control weeds. To them, modern organic farmers add new technology not based on synthetic fertilizers or chemicals, and more recently, not on genetically modified organisms. The organic movement spread worldwide and now includes biological agriculture, ecological agriculture, nature farming, permaculture and biodynamics (IFOAM, 1996; FAO-WHO, 1999).

The area under commercial organic cultivation in ESAP is generally less than 1%. It lags behind Europe and Latin America, in part because development and uptake by farmers have been hampered by lack of supportive government policy in many countries (ESCAP, 2002). Bangladesh had the largest proportion of land, 1.9%, devoted to organic agriculture, with Sri Lanka 0.65%, China 0.6%, and Japan 0.56% also relatively large contributors (Willer and Yussefi, 2006). All other countries fell below 0.2% and most below 0.1%. This analysis omitted Australia because it was hard to compare with other data. Australia had, by far, the largest area of certified organic agriculture in the world, 13 million ha and 40% of the world area, but it was not a country with large organic fruit, vegetable or cereal production. The reported area included 11 million to 12 million ha of extensive zero-input grazing land of low productivity, with few products that enter the certified organic market.

2.2.7.1 Crop organic farming

A wide range of cropping techniques was employed to replace external chemical inputs with ecosystem functions (FAO, 2002). Organic management techniques were devised to support an integrated and holistic agroecosystem, which inhibited the growth of weeds, pests and diseases but enhanced favorable biological activity. The holistic and integrated approach fosters beneficial processes and interactions like those occurring in natural ecosystems, encouraging internal stability rather than relying on external control measures. It aims to recycle nutrients, conserve energy, soil and water and to preserve biodiversity.

Developing good soil structure, biological activity and fertility is central to organic farming, because they are crucial to good plant health, which is important in resisting pests and diseases. For example, comparison of soil under organic management and conventional management in kiwi fruit orchards in New Zealand revealed that organic orchard soils had higher pH, higher soil cation exchange, more calcium and magnesium, more potentially mineralizable nitrogen and biomass carbon, greater size and activity of the microbial population and greater earthworm populations, although it had lower phosphate (Pearson et al., 2005). Some of the known organic cropping techniques include:

- selecting crops and varieties that best suit the climate and agroecological system and have disease resistance or tolerance
- rotating crops, including fallowing and herbal leys
- intercropping and using undercrops, including mulching and animal grazing, for controlling weeds and preserving the habitat for beneficial insects
- using solarization
- applying animal and green manure, especially legumes, turning in crop residues, composting and using effective microorganisms
- if necessary, using approved mineral-bearing rocks and foliar fertilizers to help return nutrients in organic matter
- using biopesticides like neem and parasitic insects for managing biological pests
- using mechanical barriers

FAO warned that comparing yields between organic and conventional systems were meaningful only over time because high yields in conventional farming are often based on “exploitative systems that degrade land, wa1ter, biodiversity and ecological services on which food production depends” (FAO, 2002). Conversion to organics from high-yielding conventional systems often results in a drop in gross yield of the marketable commodity; the degree of drop might vary considerably. Conversion from low-input, often traditional systems could raise productivity by optimizing the use of local resources (FAO, 2002; IFAD, 2002). Additionally, conversion to organics in medium-potential areas in the tropics could show good performance (FAO, 2002).

2.2.7.2 Organic livestock

In organic agricultural systems, similar to traditional approaches to agriculture, animals are incorporated into mixed animal agriculture and cropping, often with the addition of agroforestry. At the other end of the spectrum are large single-animal enterprises, such as the dairy industry in New Zealand. To the unpracticed eye, these would look like conventional farms. The difference lies largely in the organic management of pasture, manure disposal, inputs permitted and practices that allow animals to express their innate behavior. Organic animal agriculture practices include:

- managing the soil based on appropriate stocking rates and sympathetic grazing regimes to minimize damage to soil structure and compaction
- providing good-quality drinking water
- providing organically grown feed
- giving all animals conditions that allow them to perform all aspects of their innate behavior, including free access to graze and range on a wide variety of pasture and browsing species
- using natural health remedies as much as possible, with resort to synthetic veterinary medicines as a last option to prevent suffering

Intensive raising of animals on feedlots and battery cage confinement of hens are definitely not organic agricultural practices.

2.2.7.3 Organic aquaculture

Organic aquaculture has lagged behind the development of other organic agriculture. Organic aquaculture can take place in fresh water, brackish water and the sea to produce fish, crustaceans, mollusks and plants. New Zealand has been one of the largest producers outside Europe, with one salmon farm producing 500 to 800 t of organic salmon. Other organic aquaculture in the region includes shrimp in Indonesia, Thailand and Vietnam; mussels in New

Zealand; and salmon in Australia. One constraint has been sourcing acceptable nutrients for the farmed species (FAO, 2002).

Conventional shrimp farming in Southeast Asia has caused a great deal of concern about its negative social and environmental effects. The challenge for organic aquaculture has been to provide much-needed protein-rich food without damaging the environment. Food for the farmed species needs to come from sustainably managed fisheries. It should come from local fishery products not suitable for direct human consumption, free from synthetic additives and contaminants and be fed only to aquatic species with naturally piscivorous feeding habits (FAO, 2002). FAO concluded that with the "introduction of appropriate water and nutrient management techniques, the prospect for the increased production of farmed organic aquatic plants and mollusks is considerable" (FAO, 2002).

2.3 Trends in AKST: Organization and Institutions

2.3.1 Organizations and institutions that helped shape AKST in ESAP

Agricultural development often depends upon the actions of a large number of different actors and organizations, including those involved in agricultural production and marketing, as well as those concerned with research and development, training, extension and public policy. This subchapter provides a discussion on who these major actors are and what "institutions" (rules, norms, habits and practices) govern their relationships (interactions) between and among each other. The roles of these actors in building up, sharing and applying agricultural knowledge and information is also looked at. The shift in the research and development agenda of most formal ESAP research and development organizations in response to the various challenges and opportunities confronting the agricultural sector is examined.

2.3.1.1 Composition of different AKST organizations in ESAP and their institutional behavior

Knowing the different AKST actors and how they behave is important for understanding how these actors and institutions interact with each other in response to challenges and opportunities. This is especially vital as the nature of farming in this region and elsewhere constantly changes under the backdrop of a fast-paced knowledge economy. Plateauing crop yields, compounded by declining water and land availability, accelerated global trade liberalization, concerns on food safety and demand for standardization of agricultural practices all make the production, marketing and trade of agricultural produce more complex (see chapter 3).

National public research and development institutions within ESAP. Most national agricultural research systems (NARS) in ESAP were established in the 1960s. They are typically organized under a ministry, as an autonomous agency or as a coordinating council (Dar, 1995). Although they differ in operation, they are similar in policy and program formulation. Each has research agencies and stations dedicated to a specific commodity, and they are usually attached to the ministries of Agriculture, Natural Resources, Science and Technology or Higher Education. Most NARS are organized top-down and are government funded but have the autonomy to craft their own research programs.

NARS are organized nationally, regionally and locally. The national research organizations conduct basic and applied research, national in scope and importance. Regional centers undertake applied research of regional significance and local research stations perform adaptability verification trials and fine-tuning of technology generated by the national or regional research centers. This system allows for work specialization and complementarity and provides for location-specific technology. Collaborative research is common among members, as well as with the private sector, civil society, Consultative Group on International Agricultural Research (CGIAR) centers and international donors. Collaboration fosters task sharing to provide scientific solutions to common agricultural problems, expands the sources for research and development investment and cultivates long-term partnerships and links.

Private sector participation in research and development with AKST is quite limited and mostly complements, rather than substitutes, for continued public research. The bulk of private research and development has been in developing new crop hybrids, animal breeds, chemical pest and disease controls, veterinary medicines, commercial livestock feeds, food storage, packaging and processing technology. The technology is often most suited to a small subset of the needs of small-scale farmers, is typically capital intensive and is covered by intellectual property rights.

National extension systems within ESAP. Every country in the region has a public department that provides agricultural extension services. Four models of extension systems prevail in most ESAP countries (Sulaiman and Hall, 2005) with approaches that are centralized, decentralized, NGO led or private sector led.

Centralized approach. Under this scheme, extension services are centrally planned, funded and implemented by units attached to the Ministry of Agriculture. Programs are mainly donor driven and use the top-down approach, with little participation from farmers or other stakeholders and with little or no accountability to the clients. Technology dissemination is the primary objective. It is unclear if extension has been responsive to the drastically changing information and support needs of farmers in recent decades (Sulaiman and Hall, 2002; van den Ban, 2005).

This is true in India, China and a number of other Asian countries where extension policy is developed centrally in a fairly prescriptive fashion. Although approaches have evolved over the long term, it is not clear how lessons from their experiences are used in developing policy. In fact, development fads and encouragement from international donor agencies seems to be a major source of implementation. While these programs might be conceptually laudable, making them work on the ground is much harder. Furthermore, these major shifts often lock up extension until yet another new idea comes along.

China illustrates quite a different and interesting approach to agricultural extension. The National Agricultural Extension Center under the Ministry of Agriculture formulates national extension policy. The center draws up extension strategies that link agricultural programs with other agencies and provides training and supervision over provincial agents. With the country's move toward a market-oriented economic system, rural extension services have expanded and diversified according to local resource and market development needs (Yonggong, 1998). Arrangements have been restructured to help farmers relate to new market opportunities more effectively. An incentives structure has been developed to allow profit sharing between extension workers and farmers. The policy, while insufficient to provide specific courses of action, allows extension agents and farmers to pursue local, pragmatic innovations. This has been important in responding to the rapid economic and social change.

Decentralized approach. In response to demand for decentralized governance, this approach promised to improve farmer control and make extension services more demand driven. However, the lack of sufficient preparation by extension management and the institutional inertia in most government bureaucracies has failed to deliver on these promises. Despite this, widespread clamor for decentralization suggests implementation problems might eventually be overcome.

The cases of Indonesia and the Philippines highlight the complications of making broad policy prescriptions. The foreseen benefits of decentralization, primarily the devolution of authority and decisions locally, have not yet been fully realized. The effectiveness of this approach depends on the skills and vision of local government officials. This suggests that policy instruments such as decentralization need to be accompanied with capacity development. Also, local stakeholders need to understand the importance and rationale for strengthening local knowledge networks. Since the performance of extension is dependent on these systems, stakeholders need to have the skills to analyze them, diagnose system failure and design remedial measures. Capacity development is not only necessary to successfully implement decentralized approaches; it is indispensable if local stakeholders are to be more active in the policy process.

For the Philippines, inadequate funding curtailed the effectiveness of devolved extension. Experience suggests that with decentralization came a trade-off between the effectiveness of technology transfer, which seems to have suffered, and the accountability of the system to its clients, which seems to have improved. This has led to the emergence of pluralistic extension, such as that provided by private input suppliers, NGOs, farmer associations, agroprocessing companies and private consultants.

NGO-led approach. NGOs have long articulated the needs of small farmers and other socioeconomically vulnerable groups. They have advocated more equitable and sustainable economic development and poverty alleviation programs in Bangladesh, India, Nepal, the Philippines, Thailand and Vietnam. The range of their activities has varied: agroforestry in Nepal, tea production and vaccine research on cattle disease in India, soil and water conservation techniques in the Philippines. The extent of NGO inputs in research and extension, especially in technology adaptation and dissemination, has been quite large, as has been the magnitude of their organizational network.

In most countries, the relationship between NGOs and the government has often been adversarial rather than cooperative. But, whenever cooperation is possible, results can be extremely fruitful. In India, the government has taken concrete steps to establish close ties with NGOs. The Indian Council for Agricultural Research (ICAR) set up farm science centers to serve as centers for demonstration and training in “scientific farming” to open NGO access to the public research system (Sulaiman and Hall, 2005).

The central role of NGOs and farmer organizations in reducing poverty has chiefly focused on building social capital, catalyzing entrepreneurship and disseminating public information. NGOs rely on the concept of participatory research, where all stakeholders play a role in setting and implementing the research agenda. Initial attempts at conducting participatory research gave greater priority to involving poor people in evaluating new technology, rather than in setting priorities for the research (Hazell and Haddad, 2001). Their involvement in diagnosing problems and field testing technologies has provided national researchers with useful information, resulting in useful products (Hazell and Haddad, 2001).

Participatory research promotes organizational and skill-building capacity to communities to help solve collective problems and resolve conflicts. However, it is constrained by the need for multidisciplinary teams willing to work together, respect and value each other’s knowledge and appreciate the high initial cost of many personal interactions among team members. In a project to develop pest control measures in Ghana, costs increased 66% and accounted for 80% of researchers' time, although this might lead to higher returns in reducing time needed to identify promising technology (Hazell and Haddad, 2001). Also, developing the farmers' own capabilities in developing improved pest management systems, conducting field trials or breeding could be cost effective in adapting technology to diverse local needs. Participation might mean the difference between success and failure in technology development.

Private sector-led approach. Extension services can be completely privatized (Siamwalla, 2001). New Zealand is the only ESAP country with fully privatized extension. Farmers and extension agents sign profit- and risk-sharing contracts. The extension agent serves as a consultant, selling services to farmers for a fee. Thus, consultants are important sources of information and advice to large commercial growers and are valued for customizing advice to individual farms. They also provide expert counsel to international development agencies because they have a collective memory of what worked in formulating new initiatives. There is, however, the risk that employing the same consultants and advisers will lead to adopting old recommendations, some of which have failed in the past.

Technology transfer by the private sector through the system of contract farming is popular in Thailand and the Philippines. The Thai case, depicting the soybean trader sitting astride commodity input and credit markets, is an example of informal contract farming. More formal contract farming exists. A well-known example is in poultry farming pioneered in Thailand by the Charoen Pokphand Company, a firm that later became a large conglomerate, with agribusiness interests in other Asian countries. Charoen Pokphand forged contract growing arrangements with small poultry growers. The arrangements varied from a guaranteed wage contract to a guaranteed price. Charoen Pokphand brought in a hybrid breed from the Arbor Acres Company in the US and set up large automated feed mills, which remained the core of their operations. In Australia, the Grain Growers Association supports the grains industry through direct research and development funding, largely in plant breeding and grain-quality testing. In recent years, the Grain Growers Association has supported research on developing commercially viable biological control agents and development of best management practices.

While these approaches have their strengths, innovations in providing extension services should be viewed not only from an institutional perspective but also from a functional one. Extension can still occur even without organizations, since imparting knowledge has always been between individuals who trust each other, rather than from an external agent. Extension was once understood as "extending the knowledge imparted in class to those who cannot attend the class," suggesting that extension is not just the mechanical transfer of technology or information, but also instructive.

Regional and international research and development institutions. Regional and international research organizations have been set up to meet regional and global demands in agricultural research. In 1960, CGIAR set up 15 international commodity research institutes, a third of which are based in Asia. These international agricultural research centers (IARCs) and many others based elsewhere have done considerable work within ESAP. Aside from making headway in global research on frontier and cutting-edge science, the greatest achievements of these centers have been to encourage open germplasm exchange, support human resource development and training, and create links with the national agricultural research systems.

Traditional, local and indigenous knowledge systems. Traditional knowledge, indigenous knowledge and local knowledge are often used interchangeably to refer to the matured and long-standing traditions and practices of regional, indigenous or local communities, which encompass their wisdom, knowledge and teachings accumulated through generations of experience, careful observation and trial-and-error experiment. In many cases, traditional knowledge has been orally passed on for generations through stories, legends, folklore, rituals, songs and laws. In agriculture, these are built up through generations of farming and managing forest and water ecosystems. While traditional knowledge is entrenched in these communities, it is also considered dynamic because it adapts to and incorporates new knowledge from outside sources to suit gradually changing environments (Grenier, 1998).

Traditional knowledge has helped maintain and improve the livelihood of farming communities. In many rural communities, it governs local decisions in agriculture, health care, food preparation, education and natural resource management (Warren, 1991). Traditional knowledge is being recognized as a base for many sustainable development initiatives, such as sustainable agriculture and natural resource management, enriching global agricultural knowledge. It has produced lessons and insights in addressing rural hunger and poverty and accounted for on site crop genetic conservation, crop diversification, regenerative soil and water management, organic agriculture and ecological pest management. Much sustainable agriculture has roots in traditional and indigenous practices that are viable because of generations of innovation and improvement.

In general, traditional systems are perceived to have great potential because (1) they are inexpensive and may be paid for in goods or services, (2) they are readily available and accessible even to those who do not have cash income, (3) people are more comfortable using them than western technology and (4) when combined with modern practices they provide more options for innovation in dealing with complex agricultural problems. However, traditional agriculture is labor intensive. This may be viewed as either a disadvantage or an advantage, depending on the social circumstances. For example, the additional labor might keep people from other economic activity. On the other hand, it could provide meaningful employment for rural people who would otherwise migrate to urban areas, thus creating adverse social effects such as leaving behind a household without its male head and potentially contributing to urban unemployment and poverty.

In most cases, traditional knowledge is not only socially desirable but also economically affordable and sustainable and poses little risk to rural farmers. Since traditional knowledge evolved gradually within the community, it is appropriate to the needs of the local people (Rouse, 1999). Traditional systems are more directed toward self-reliance and self-sufficiency than some modern technology (Fernandez, 1994). However, traditional agriculture has not been able keep pace with increased population pressure, evidenced by the great famines of the 1950s, 1960s and 1970s in Bangladesh, China and India. Traditional systems appear unable to provide sufficient food for current urban populations. What they can do, however, is provide product diversity equal to, if not greater than the total biomass production of conventional equivalents, while conserving scarce resources and providing food security for the producers (FAO, 2002). In general, the greater the biological diversity of the agricultural system, the greater is its ability to withstand adverse climatic and pest events (FAO, 2002). In addition, there is historical evidence of wetland rice yields in India higher than present yields supported by chemical fertilizers and pesticides. In the 1700s, the yields in 800 villages near Madras were reported to have averaged 3.6 t ha^{-1}, surpassing 10 t ha^{-1} in some areas, whereas the current yield in that region averages 3.1 t ha^{-1}. Genetic diversity was the main weapon against pests and diseases; but, from using about 30,000 traditional rice varieties, India now uses only a few, with 75% of rice produced coming from only 10 varieties (ESCAP, 2002).

Today about 70% of the world’s indigenous peoples live in Asia and the Pacific, where they are a major subgroup of the rural poor. Indigenous knowledge and traditional agricultural systems can provide answers to their food security needs. However, resource access is important. Marginalizing many indigenous communities could lead to the eventual loss of traditional knowledge. Many of these communities are being deprived of the ability to lead the lives they value (IFAD, 2002.

Traditional knowledge is increasingly becoming acceptable to the scientific community. In fact, “informal” research is being done in local communities by using traditional knowledge (Stanley and Rice, 2003). In contrast, much past research failed from the lack of knowledge and understanding of local practices. Technology generated by formal research institutions can complement and improve indigenous methods.

Before modern agricultural practices were developed, indigenous communities had already devised methods to ensure the success of their agriculture. A common example of traditional knowledge emanating from communities is use of the neem tree (*Azadirachta indica*) in India as a natural insecticide, fertilizer, pesticide and medicine. Knowledge of indigenous practices on crop protection and fertilization can be appreciated when developing appropriate programs for pest and soil management within the capability of farmers and that do not cause adverse effects on either the community or the environment (Varisco et al., 1992). It was estimated that in 1985, plant-based medicines, many first discovered by indigenous peoples, valued at US$43 billion were sold in industrial countries (Posey and Dutfield, 1996). As advances in biotechnology broaden the range of life forms containing attributes with commercial applications, the full market value of traditional knowledge will definitely increase.

Traditional knowledge is also important for food security and genetic conservation. In Nepal, a centuries-old seed management system allowed farmers to grow and protect their seeds (Timsina and Upreti, 2002). Modern plant breeding owes much to the landraces bred, conserved and developed by traditional communities over the millennia. These local varieties have been the continuous source of genes used to develop and improve high-yielding varieties.

In India, a study revealed that traditional health control and treatment systems were effective in curing ailments in animals, including dysentery, arthritis, dog bites, coughs and colds, anestrus, wounds, bloat and diarrhea. Although modern veterinary medicines provide quicker cure, traditional treatments are cheaper, locally available, and have fewer side effects (De Amitendu et al., 2004).

Indigenous people have practiced sustainable forest use and management for centuries. Jackson and Moore (1998) found that although forest fire is often destructive, indigenous use and management of fire were significant in forest management and conservation. For instance, in Indonesia and Nepal, fires were intended to maintain grasslands for animal agriculture. In central and northern Australia, aboriginal communities had sophisticated applications of fire that took into account seasons, patterns of burning, specific effects on wildlife and plants, and exclusion of fire from particular areas and vegetation (Jackson and Moore, 1998). Aboriginals also used fire to encourage growth of grasses for target wild animal species, particularly kangaroos and wallabies.

In China, communities in Yunan developed a system of classifying forests and forest systems according to their function and products, such as forests for building materials, cash crops, landscaping and graveyards, and protected rattan (Table 2-2).

Table 2-2. Known indigenous agricultural practices emanating from traditional knowledge by sector

2.3.1.2 Roles of different organizations in generating, disseminating and adopting AKST

Agricultural entities in ESAP vary in number, capability and performance. These entities include the stakeholders that NARS serves and affects or that can affect NARS. The main roles of stakeholders are varied and their interrelationships evident (Table 2-3). The research agenda crafted nationally reverberates in the activities of research and extension personnel, affecting the decisions of farmers to adopt a technology. Feedback mechanisms allow the refinement of technology and the accompanying research and extension. Collaboration among stakeholders influences investment, research decisions and information dissemination.

Table 2-3. National agricultural research system actors and roles in generating, promoting, disseminating and adopting AKST

Organizations realize that research, development, training and extension services need to develop and maintain partnerships with farmers, NGOs, producer organizations, agroprocessors, agribusiness houses, traders, retailers and consumers (van Mele et al., 2005; Hall, 2006). Developing wider links is essential for improving the performance of organizations involved. The optimum use of AKST can be best facilitated by addressing the barriers to change caused by some institutional rigidities (Box 2-2).

Box 2-2. Barriers to change arising from institutional rigidities

2.3.1.3 Transformation of AKST institutions

As production agriculture became increasingly informed and scientific, new researchable areas have emerged in biotechnology, sustainable agriculture, and information and communications technology (ICT). A diversified institutional structure in agricultural research, development and extension has emerged nationally and globally with profound effects on our ability to produce food and manage our natural resources and the environment.

Most research efforts have been done by national public research institutes, state colleges and universities and international research centers. The private sector has played a marginal role, especially in basic research. In recent years, farmer organizations, NGOs and the private sector have emerged as key players. As farmers became more organized, experience gained from participatory research schemes and other rural development projects has been used. This has allowed new approaches to research to emerge that put the farmer at the center of development, not just as a user of the technology. NGOs have complemented the role of the state or filled a gap generated by weakness in public extension agencies. Incentives for research and development have increased private sector biological research. The sector accounts for approximately 80% of plant biotechnology research worldwide (Chaparro, 1999). The private sector has become important in basic and adaptive research, changing members' role from users of the knowledge generated by the public sector to generators of knowledge. Issues of property rights and plant breeder's rights and their effects have also emerged. This evolving institutional environment needs to be considered in strengthening AKST for sustainable agriculture and in developing new approaches of cooperation. Faced with diminishing funds from traditional sources, partnerships among stakeholders should be founded on collaboration and mutual benefit.

In the past 25 years, many ESAP countries have changed how agricultural research and extension is organized and funded. Toward the end of the 1990s, roles of public and international research organizations shifted and support for public agricultural research slowed down (Pardey et al., 2006) (see subchapter 2.3.3). Public agricultural research became less understood and more closely scrutinized. Some considered the world's food supply problem solved; some thought that public research was constrained by factors other than research or that the private sector should take over the job (Pardey and Beintema, 2001). Government decisions to continually underinvest in public research exacerbated the global gap in scientific knowledge. For instance, new cultivars carry forward not only the genes of earlier varieties but also the crop breeding and crop selection strategies used by earlier breeders.

Policies and practices that facilitate and encourage accumulating knowledge and adopting technology are equally important. Without them, discoveries and data improperly documented or inaccessible are lost when researchers leave or institutions are unstable. This happens in fund-strapped research agencies in most developing countries; inadequate and irregular funding results in fast staff turnover and limits the functioning of libraries, state-of-the-art laboratories, nurseries, databanks and gene banks.

The limited public funding for agricultural research shifted from the traditional agenda of improving productivity to new concerns. For example, in 2000, NARS began promoting commercially viable technology to accelerate research use (APAARI, 1999).

2.3.1.4 Interactions and links among AKST organizations

Since the early 1990s, research managers have recognized the need to work with nontraditional partners and engage in more meaningful research consultations. Donors and policy makers recognized partnerships as a strategy for agricultural development. The advantages of partnerships are obvious: pooling diverse expertise, leveraging scarce resources and enhancing competency. Technology innovations are seldom generated by individual research agencies; they come from transnational knowledge generation, dissemination and application (Chaparro, 1999).

In the same vein, the relationship between public and private sectors in agricultural research and development has changed around the world (James, 1996; Byerlee and Echeverria, 2002; Speilman and von Grebmer, 2004; Hall, 2006). This change arose from the diversity of actors outside the public sector, increasingly complex agricultural development needs, declining financial capability for research investment in developing countries and re-evaluation of the role of the state in research and extension. However, only a few cases of public and private partnerships in agricultural research and extension were successful. Problems included insufficient accounting of the actual and hidden costs of partnership, conflicting goals, lack of transparency, persistent negative perception across sectors, undue competition over financial and intellectual resources, and lack of working models from which to draw lessons and experiences (Spielmen and von Grebmer, 2004). The unresolved issues on intellectual property rights and genetically modified organisms made public and private partnerships increasingly difficult.

In Australia and New Zealand, farmer organizations provided a framework for partnership between researchers and farmers. Farmer organizations were also equal partners in extension in South Korea and Taiwan. The Bangladesh Rural Advancement Committee (BRAC), an NGO, worked with small-scale farmers on projects in poultry, feeds, diagnostic laboratories, bull stations, fish and prawn hatcheries, planting materials supply and vegetable cultivation extension. Partnership arrangements with farmer organizations for promoting technology were common. Farmer field schools initiated to address pest problems in rice became a platform for joint learning in several Asian countries. Most emerging challenges in agriculture in new marketing arrangements, contract growing, quality management and certification needed community mobilization. Continued learning, problem solving and collectivity supported by the farmer field school, albeit with a changed focus, remained important (van de Fliert, 2006).

Private and private partnerships have also been forged to better serve new markets. A reliable supply of quality produce in supermarkets is of prime importance. Contractual arrangements along the supply chain ensure reliability in volume and quality. Many companies provide seeds, inputs and credit to participating growers and procure the produce at set prices. They have also brought in new technology and provided technical advice to growers. This arrangement appears beneficial, but its success lies in enforcing contracts and maintaining trust. For farmers to gain advantage, they need to understand contracts and negotiate better arrangements.

A different partnership is emerging strongly in ESAP. NGOs formed or strengthened alliances and networks to advocate pressing issues. For instance, PABINI in the Philippines, a network of farmers, academics and researchers, opposes introducing genetic engineering technology. Organizations in research and extension might link with networks to enhance innovation.

The linear model of technology development and promotion—research to extension to farmer—continues to set patterns of interaction and alliance. However, the concept of a national innovation system offers a novel framework in how institutions help innovations feed into economic growth. Partnerships remain important in agricultural development. Forging partnerships, however, requires resources. Nonetheless, new modes of partnerships contribute to institutional change.

Although there is no blueprint for promoting partnerships, supporting stakeholder meetings or holding collaborative activities may help develop them. These partnerships have to be supplemented with effort to evaluate progress and outcomes, and participants must have the vision and willingness to make needed institutional changes (Table 2-4).

Table 2-4. Potential ways for facilitating institutional change

2.3.2 Capacity of AKST organizations in generating, accessing, disseminating and adapting knowledge and information

Science and technology drive economic growth. Yet ESAP countries struggle to increase research spending, upgrade their scientific workforce and improve agricultural research facilities. While accomplishing these aims reflects capability, it does not guarantee contribution to knowledge and economic development without support systems that encourage public access, dissemination and application of the knowledge and information gained (Tables 2-5, 2-6).

Table 2-5. Rank of world competitiveness, by factor, of selected countries, 2006

Table 2-6. Overall world competitiveness rank of selected countries, 2003–2006

Agricultural research in ESAP still suffers from lack of political support, insufficient funding, minimal links between researchers and users, and inadequate library and information services (Rao, 1994). Most of the research infrastructure and institutional capacity is also weak (Dembner, 1994). The World Competitiveness Yearbook 2006 placed many developing countries at the lower rung because of inadequacies in science and technology infrastructure and capability. Korea and Singapore had relatively high scientific infrastructure, compared with the lower-ranked Indonesia, Philippines and Thailand. From 2003 to 2006, Indonesia, Malaysia, the Philippines, and Thailand did not improve in the overall world competitiveness ranking. India made a significant upgrade, from 50 to 29. These results stressed the strong need for ESAP countries to develop their own agricultural research capability.

2.3.3 Investment in AKST

Throughout the 1900s, growth in agricultural productivity considerably reduced poverty and hunger and fueled economic progress. Technological advances over the past 50 years have allowed farmers to feed twice as many people from less cropland. A large body of evidence closely links improved productivity to investment in agricultural research and development, averaging rates of return of over 40%, particularly for commodities with short production cycles (Byerlee et al., 2006). It is not surprising that in 2000, US$731 billion was invested in sciences worldwide, including public and private research. This represents less than 2% of the world's US$42.4 trillion gross domestic product for that year and an increase of nearly one-third over the inflation adjusted total of just five years earlier (Pardey et al., 2006).

ESAP, excluding Australia and New Zealand, spent about US$142.4 billion or nearly 25% of total global expenditures on research and development, a spending increase of about US$52 billion from 1995 to 2000. This regional trend hid two extremely disturbing developments—a large and growing gap between industrial and developing countries and the miniscule percentage of gross research and development spending for domestic AKST. The overall growth in ESAP masked that this investment was concentrated in only a handful of countries. China, India and Japan accounted for nearly 85% of the region's scientific spending in 1995, climbing to 87% by 2000. In contrast, research spending by most of the other 24 ESAP countries declined about 2%. Agricultural research and development expenditure in 2000 was a mere 5% of global science spending. Funding for AKST within ESAP, with the exception of six industrial countries, Australia, China, India, Japan, New Zealand and South Korea, could be characterized as perennially dismal and declining, if not outright stagnant, with the public sector shouldering the bulk, 92%, of the expenditures. Three typical major funding sources for public research and development were production or export taxes, direct government appropriations and external sources (Dar, 1995).

All national agricultural research in the region received direct government appropriations to finance their activities. In addition, Malaysia and the Philippines had either a production or an export tax on export commodities, which they partially used to augment limited funds for agricultural research and development. In Malaysia, this was done for rubber and palm oil. The

Philippines taxed coconut, sugarcane and tobacco for the same purpose. External fund sources consisted of 32 bilateral donors, multilateral organizations and nongovernment foundations who generously supported the establishment of some national research, particularly in Indonesia, Korea, Myanmar, the Philippines and Thailand.

With the globalization of science, the private sector reportedly spent US$663 million on agricultural research in 2000, roughly 8% of the US$8.19 billion total agricultural research investment in ESAP countries. If private firms have limited opportunity to appropriate profits for themselves from providing agricultural technology, they lack the incentive to invest. Hence, the private sector also often relied on knowledge provided by public research. Because of this market failure and long-term risky payoff, the public sector funded most agricultural research and development, especially in developing countries (Tables 2-7 and 2-8).

Table 2-7. Total gross domestic expenditures on research and development in ESAP, 1995–2000

Table 2-8. Estimated global public and private agricultural research and development, circa 2000

The International Food Policy Research Institute (IFPRI), using pooled time series and cross-sector data, conducted several studies on the impact of government spending on agricultural growth and poverty reduction in China, India and Thailand. Results showed additional public expenditure on agricultural research and extension improved agricultural productivity the most and was the second most powerful way to reduce rural poverty. Some studies indicated that in low-income countries, a 1% increase in agricultural yield led to a 0.8% reduction in the number of people living below the poverty line (Fan et al., 2002; Byerlee et al., 2006). Over the long term, food prices were especially important because food was a large share of the expense in poor households. Employment and wages in labor-intensive production and value-added processing were also important for poor people, who depended more on wage labor.

Most previous studies on return to investment considered only public research and development expenditure, which made it difficult to compare returns to productivity growth and poverty reduction across investment portfolios. Both China and India have made great strides in reducing poverty dramatically over the last several decades. With more than 500 million people lifted above the poverty line, these two countries contributed a major share of the overall global decline in poverty (Thorat and Fan, 2007). Yet together, they still accounted for more than 40% of the world's poor. Therefore, to reach the millennium goal of halving the global number of poor by 2015 largely depends on their performance in alleviating poverty. Thailand for the past several decades has experienced rapid economic growth that has transformed the country from a predominantly agrarian society to a newly industrialized economy, much like Singapore, South

Korea, Taiwan (China) and Hong Kong (China). Since the early 1960s, the Thai economy has achieved one of the highest long-term growth rates among all countries, with gross domestic product growth rates ranging from 5.5 to 11% each year from 1960 to 1995 (Fan et al., 2004). Lessons should be learned from the investment experiences of these three countries. Considering that the estimated returns were fairly recent, the results should be useful in deciding how the public sector can better allocate its limited resources to achieving economic growth, food security and poverty alleviation.

2.4 Effects of AKST on Development and Sustainability Goals

2.4.1 Effect of modern AKST on livelihood, poverty and hunger

2.4.1.1 History of agrarian change and development

Science and technology, especially irrigation and chemical inputs, have been responsible for increased agricultural production and decreased rural poverty in parts of ESAP. However, for resource-poor farmers in drought-prone areas, the benefits have been minimal and have had environmental and social costs. These costs include adverse effects on human and animal health from pesticides, decreased genetic diversity of food crops, intensive use of chemicals, loss of traditional knowledge and practices, loss of local biodiversity, loss of soil fertility and farmer dependency on external inputs. In recent years, this dependency also perpetuated indebtedness, especially among poor farmers, and further inequality of benefits. Much of the ESAP population depends on rice as a staple. There has traditionally been much diversity in rice—50 kinds were cultivated in one part of India, many with cultural importance (Dharampal, 1971). These varieties were lost with the introduction of high-yield varieties and associated farming practices. Some estimates suggest that of the 30,000 strains of paddy rice a few years ago, no more than a dozen are expected to dominate three-quarters of the riceland in Asia (Development Forum, 1989).

2.4.1.2 The Green Revolution, food security and poverty alleviation

The introduction of modern AKST, associated with the Green Revolution, more than doubled cereal production in Asia between 1970 and 1995. Poverty steadily declined and nutrition improved through increased income. However, debates on the effects of modern inputs on the poor include common questions: Do modern varieties help poor farmers absolutely or relatively compared with rich farmers? Do rural workers gain or lose income? Do poor consumers gain or lose nutritionally? Has the economic benefit of using modern varieties been uniformly distributed across the farming families? How has a focus on increasing productivity affected social and ecological systems? No easy general and clear conclusions regarding the consequences of the Green Revolution can be based on the literature. The effects have been hotly debated and different researchers have come to different conclusions (Box 2-3).

Box 2-3. Impact of Green Revolution in India

Greater production came with a price for social and economic systems and was well substantiated from observations from different countries in Asia. Also, considerable contradictory evidence demonstrates that increasing the productivity of smallholders by providing greater farming inputs did not necessarily alleviate their hunger and poverty (Ladeginsky, 1969a,b; Brown, 1971; Frankel, 1971; Rudra, 1971).

Some studies have shown that in some ESAP countries, the population living in poverty increased despite a rise in the production of cereal per head, the main component of the diet of the poor (Lappe et al., 1982). In the Philippines, rice production increased faster than the growth in population, but it had the most widespread undernutrition in all Asia. Similarly, the government of India, in 1979, was holding 16 million tonnes of surplus food grain in storage, while the per capita consumption of food grain in 1975 to 1977 had fallen below that in 1970 to 1972, even below 1960 to 1962 consumption (Lappe et al., 1982). In India, the total food available to each person actually increased, but greater hunger prevailed because of the unequal access to food and resources.

The remarkable difference in China, where the number of hungry dropped from 406 million to 189 million, begs the question, which has been more effective in reducing hunger, the Green Revolution or the Chinese revolution (Rosset, 2003). It has been suggested that the Chinese revolution's broad changes in access to land paved the way for rising living standards.

Assessments on the effect of the Green Revolution on food security and poverty resulted in mixed conclusions, from using different approaches, methods, locations and periods. Agrarian studies in Asia on the effects of agricultural modernization on poverty and food security varied widely in style and temper, but they generally subscribed to three viewpoints (Mohanty, 1999):

- Modernization further exacerbated the inequities.
- Improvement of the economic conditions of the poor and the landless in agriculture reduced existing inequalities.
- Modernization of agriculture had mixed effects.

These views indicate that the measurement of poverty is complex. Different proxy indicators measure economic analysis, welfare and food security. The choice of indicators and their use and interpretation should be considered, along with other factors:

- the loss in diversity and the equivalent monetary value when farmers switch from diverse systems to monoculture

- the extra costs of Green Revolution systems, in chemical inputs and the cost of environmental degradation
- who will benefit from the surplus

For awhile, the Green Revolution contributed to increased agricultural production (Janvry and Sadoulet, 2002). Since the main objective was to generate more food, little attention was directed to how the benefits would be distributed equitably. The Green Revolution was intimately tied to the purchase of seeds, chemical fertilizers, pesticides and intensive irrigation—all external inputs. Its effect included the high dependency it created on external inputs and the debt that farm families incurred. Alternative knowledge was neglected. The approach seemed to assume that farmers were ignorant; it devalued local and indigenous knowledge (Gadgil et al., 1996). The introduction of pesticides and chemical fertilizers diminished land productivity, creating a need for more and more inputs to reap the same yield, adding an extra financial burden on the farmer (Pereira, 1996). Rosset and Collins (1998) reported that in Central Luzon, Philippines, rice yield increased 13% during the 1980s, but it came at the cost of a 21% increase in fertilizer use. They reported that in the central plains yields went up 65%, while fertilizer use increased 24% and use of pesticides jumped 53%. In West Java, the benefit of a 23% yield increase was virtually cancelled by a 65% increase in use of fertilizers and 19% in pesticides.

The Green Revolution was not neutral. The real wages during 1970/71 to 1973/74 in Uttar Pradesh, when the Green Revolution was making a big impact on yields, showed that wages decreased 18% because large landowners brought in more machinery and migrants to compete with local labor and the landless. In many areas, the Green Revolution failed to raise incomes of the rural poor appreciably or contribute substantially to their effective purchasing power. Also, larger-scale farmers had greater access to subsidies for irrigation and credit from the government (Dogra, 1990).

Credit became a major factor in Green Revolution technology and the consequences of debt repayment took their toll on farmers. Cheap credit in one market may merely have the effect of subsidizing and maintaining expensive credit elsewhere. Some landlords in the Philippines who borrowed cheap credit with land as collateral from the rural banks lent the money to their tenants at interest rates left to their own discretion (Palmer, 1976).

Overall, far less research was done on integrated technology for diversifying the livelihoods of small-scale farmers in developing countries and increasing the sustainability of land use. Little was understood, for instance, about the role of organic matter in soil, reduced tillage systems, use of farm organic resources in combination with inorganic fertilizers and the role of legumes in biological nitrogen fixation. Similarly, research was limited in integrated pest management and in weed and pest control. These were topics of little interest to the private sector and were also in danger of neglect by public research institutions.

India was among the first countries in the world to pass legislation granting farmer rights, protecting them in the Plant Varieties and Farmers' Right Act 2001. Farmers' rights were not just an alternative to breeders' rights (Rammanna, 2006). Their rights should be multidimensional, including rights to conservation of biodiversity and to affordable inputs, rights to equity and justice, and above all, the right to reliable quality seeds. The value of conservation of indigenous diversity was implied. The Plant Variety Protection Act of 2002 did not explicitly include in its definition of breeders, farmers and farming communities who continuously nurture, conserve and improve crop varieties. It subsumed farmers under persons who bred or discovered and developed a new plant variety. To give an example, the Philippines Plant Variety Protection Act of 2002 neither recognized nor protected farmer rights to seeds and to participate in the agriculture of the country. Like most policies and laws that directly affect their lives, farmers in many of the countries were generally unaware of the existence of such a law.

A plant variety protection system is an administrative procedure that an applicant complies with to secure a form of intellectual property rights, called the plant breeder's rights. This right is awarded in recognition of the intellectual creation of innovative citizens, as applied on plant varieties, particularly the transformation of plants through breeding, whether done the classical way or through modern technology, such as genetic engineering.

2.4.1.3 Effects of biotechnology

Biotechnology and genetic engineering are increasingly used in a few countries in ESAP, for example, China and India but these two countries together account for only 8% of GM crop production worldwide (FAOSTAT, 2004). Despite the perceived advantages, serious reservations persisted about health and environment implications of large-scale application of biotechnology.

Genetically engineered crops can be sprayed with a herbicide to kill weeds without killing the crop plants (Steinbrecher, 1996). Intensified spraying boosts weed resistance to the herbicide. As weeds become resistant, higher and higher doses of herbicide are needed, leaving larger and larger amounts of chemical residue on the crops and the soil. In addition, the engineered crop may itself become a weed. Alongside the development of herbicide tolerance and pest resistance, some scientists have sought to engineer plants to be resistant to pathogens, such as fungi, bacteria and viruses. The immediate hazard from herbicide-resistant crops is the spread of transgenes to wild relatives by cross-pollination, creating superweeds (Ho, 1998). Although it is true that in certain cases, pesticides have reduced the effect on nontarget organisms, biodiversity, evolution of resistance and genetic contamination are some of the concerns.

In Bt crops, if insects developed resistance to the engineered Bt toxin, conventional farmers would revert to chemical insecticides, while organic farmers would have lost one of their most valuable pest control agents. In addition superbugs could emerge—insects that have adapted their behavior and genetics in unpredictable ways to survive in the constant presence of toxins (Stone, 2002). In certain cases, effects on nontarget organisms have been observed (Hilbeck et al., 1998).

Some studies indicate the presence of transformation-induced mutation in commercial crops poses a potentially large biosafety risk (Wilson et al., 2006). This has led to a call for a transparent manner for testing for each individual product before market introduction (Pryme and Lembcke, 2003).

The difference in approach is wide between farmers acting on their traditional knowledge and the new biotechnologists. The first take a broad and holistic approach to a specific agronomic and socioeconomic situation; the latter tend to look for universal, deep-down, molecular solutions. They offer widely differing solutions for problems dealing with pests, diseases, weeds, water, plant nutrients, soil degradation and yield (Table 2-9).

Table 2-9. Sustainable agriculture: farmers and biotech approaches

Genetic modification for disease or pest resistance cannot solve the problem of disease or pest attack because intensive agriculture created the conditions for new pathogens (Ho, 1998). For example, a variety of rice hybrid, IR-36, created to be resistant to eight major diseases and pests including bacterial blight and tungro, was attacked by two new viruses, ragged stunt and wilted stunt.

2.4.1.4 Agricultural sustainability

The idea of agricultural sustainability centers on the need to develop technology and practices that do not have adverse effects on the environment and human health and at the same time lead to improvement in food and productivity. Sustainable agriculture approaches come under many names: agroecology, organic farming, low external input farming, ecological agriculture, biodynamic agriculture and permaculture (Ho and Ching, 2003). Sustainability in agriculture has been defined as having two dimensions: natural resource sustainability and socioeconomic sustainability.

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Sustainable agriculture requires site-specific technology. For example, organic farms vary in complexity and diversity. Studies show that a particular technology can be successful in one site but not in another (Niggli and Ogorzalek, 2007). Evidence from many grassroots development projects also has shown that increasing agricultural productivity with agroecological practices, including organic agriculture, increases not only food supplies but also incomes, thus reducing poverty, increasing access to food, reducing malnutrition and improving livelihoods of the poor.

The question that arises is whether sustainable agricultural practices such as organic farming can be the solution for the future. The debate on the merits and disadvantages of organic versus conventional agriculture continues to influence decision makers. The benefits of organic agriculture are several:

- There is a thriving demand for organically grown food in urban centers of many Asian countries. The premiums paid for organic food offer an opportunity for poor farmers to increase their income (IFAD, 2002). Organic agriculture has the potential to improve household food security and meet the goals of poverty alleviation and environmental sustainability in ESAP (ESCAP, 2002).
- There may be employment effects: Some organic systems may require more labor, which can be negative or positive. The crop diversification that generally happens on organic farms distributes labor throughout the season. This can contribute to stabilizing employment, reducing turnover and alleviating many problems relating to seasonal migration (FAO, 2002).
- There are environmental benefits. Contamination of ground and surface waters by synthetic fertilizers, especially nitrate leaching, and pesticides are avoided and sedimentation of waterways from erosion is reduced (FAO, 2002). Calculations on comparative energy use in Organisation for Economic Co-operation and Development (OECD) countries indicate that energy consumption on organic farms is 64% that of conventional farms (FAO, 2002). In a three-year comparative study on organic and conventional strawberry production in China, 98% of the energy inputs in the organic systems were from renewable sources, such as animal manure and biogas, whereas 70% of the energy inputs into the conventional system were nonrenewable, such as electricity, chemical fertilizers and pesticides (FAO, 2002).
- Organic agriculture also makes a positive contribution to dealing with climate change: “Organic agriculture may not only enable ecosystems to better adjust to the effects of climate change but also offer a major potential to reduce emissions of agricultural greenhouse gases. Moreover, mixed farming and the diversity of organic crop rotations are

protecting the fragile soil surface and may even counteract climate change by restoring the organic matter content. The carbon sink idea of the Kyoto Protocol may therefore partly be accomplished efficiently by organic agriculture" (FAO, 2002).

- Organic agriculture can be considered more flexible, especially when labor is more readily available and high inorganic inputs or mechanization are limited.

The expansion or benefits of organic agriculture, especially on the need to meet increased food demand, raises major doubts:

- Available technology cannot greatly increase the productivity of organic agriculture because it is constrained by nutrient supply. Agriculture of any type is an extractive activity that cannot retain high fertility and productivity without replacing nutrients exported with the products or lost from the site during production. Although high-yielding crops can be produced organically, this is achieved, once natural fertility has been exploited, only by bringing in nutrients from other areas, as plant remains or animal feces, or by accumulating them in situ in long fallows, as in slash-and-burn farming. The consequence, not evident to most consumers and overlooked by many proponents, is that a much greater land area than is immediately apparent is involved in successful organic production. In contrast, crops can be grown more frequently and often repeatedly with fertilizers on the same land, as in the examples of intensive rice and rice–wheat systems.
- It is the shortage of land that will restrict the contribution that organic agriculture can make to the world food supply. Organic agriculture was the norm at the beginning of the 1900s, when the world population was 1.5 billion. Now there is not enough land or organic matter to support the crop production needed for the present, let alone the anticipated world population.
- Adoption of organic agriculture rates are less than 0.1% of arable and permanent agricultural land in nearly all developing economies in Asia and the Pacific, suggesting that most farmers do not believe organic agriculture can produce food at competitive costs (FAO, 2005). Sometimes production costs per unit of land in organic agriculture are lower than in conventional agriculture. Usually they are higher, which means organic farming is profitable only if the produce can be sold at higher prices. Indeed, prices for organic output are higher, but in developing countries this higher price consigns such produce to niche markets.
- Organic agriculture cannot be the solution to food production for a heavily populated planet. Poor households benefit from greater yields by adopting improved practices. Yield gains from a low base are usually the greatest, but productivity of these systems is probably insufficient to meet future food demand. Nevertheless, the principles of organic

agriculture will remain as an important contributor to safe and environmentally friendly food production, since they remain firmly embedded in integrated agriculture.

2.4.2 Improving nutrition and human health

With rapid increase in food production and rise in income, food consumption per capita in ESAP countries has risen significantly during the past 50 years. Since 1990, direct cereal consumption leveled off for the whole region, mainly from the decline in direct cereal consumption in China (Figure 2-8). On the other hand, meat consumption rose in ESAP, led by China's steady increase. The same change was, however, absent in India and Indonesia (Figure 2-9).

Figure 2-8. Food consumption per capita in ESAP, 1990–2005

Figure 2-9. Meat consumption per capita in ESAP, 1990–2005

In spite of the remarkable growth in agricultural production within ESAP during the last four decades, hundreds of millions of people still live in hunger and poverty. The proportion in developing countries of underfed population—with dietary energy consumption inadequate to sustain more than light activity—was estimated to have fallen substantially in the last 15 years, from around one in three people in 1975, to one in five in 1989. This implies a considerable reduction, from nearly 1,000 million people to just below 800 million. This was considerably influenced by the improving situation in China. South Asia probably improved slowly, according to recent results from India and elsewhere, at around a 0.5% reduction in underweight children each year.

The prevalence of underweight children in South Asia remained the highest in the world, over half the total. Calorie consumption remained low throughout the 1980s, with little change, although this might have improved slightly for some poorer groups, such as the landless. Nutrition in many countries of Southeast Asia improved, reducing underweight prevalence about 1% each year. Food consumption rose during the 1980s, along with marked success in food production. A number of countries changed from net food importing to exporting.

Iron deficiency, a cause of anemia, is the only nutritional problem that increased in many parts of the world. Prevalence is especially high in South Asia, where more than 60% of women are anemic. The worsening anemia is from downward trends in intake of dietary iron and has been caused by reduced production and consumption of legumes with the Green Revolution. Deficiency of vitamin A affects at least 40 countries. Out of an estimated 14 million with resulting eye damage, vitamin A deficiency blinds up to half a million preschool children each year. Important recent research shows that improving vitamin A status in children in deficient populations reduces mortality among young children by almost one-quarter. Vitamin A supply in some parts of South Asia is so low that deficiency is almost inevitable. The extent of stunting, underweight and wasting in women in developing countries shows that these problems are extensive in developing countries of Asia, particularly low body weight and thinness. Malnutrition in women is generally associated with low birth weight. This has intergenerational effects; malnourished women have small babies, who grow up to be small mothers.

Poverty is clearly a major determinant of nutritional outcome. Rapid economic growth has been a major solution to malnutrition in Southeast Asia. China has far less malnutrition than India. Their average incomes are similar, although allowing for price adjustments puts China considerably ahead. Within India, the relatively low rate of malnutrition in Kerala, one of the poorer states, was parallel to China. The percentages of underweight preschool children were 58.5% in South Asia, 31.3% in Southeast Asia and 21.8% in China in 1990. In 1990 South Asia had 101.2 million underweight preschool children, Southeast Asia had 19.9 million and China 23.6 million (Martorel, 2002). Technology and access to technology and innovation did not benefit many poor people in South Asia. Technology development was geared to market pressure and the needs of the industrial world, not to the needs of countries that had little purchasing power.

Monocropping negatively affected human nutrition. Little-known mammals, birds and snails, which had traditionally served as cheap protein, were killed by pesticides. Traditional plant foods were eliminated because farmers did not prefer them. For example, in South India, sorghum was intercropped, with each acre yielding about 70 kg of different pulses and 10 kg of local oilseeds. The new uniform planting of sorghum varieties reduced the availability of local and household protein and fat. The nutritious millets largely grown in semiarid tracts under drought were mostly lost because they were neglected or bypassed.

The chemical pesticides used to protect crops from pests had a direct bearing on human health. Though pesticides may prevent damage by pests and disease and increase production, they are poisons. Pesticide poisoning has always been associated with pesticide use. The developing countries use less than one-quarter of the world's pesticides, but they suffer three-quarters of all pesticide fatalities—about 375,000 people in developing countries are poisoned and 10,000 killed by pesticides each year (Bull, 1982). These figures do not include chronic or long-term effects, such as anemia, leukemia, cancer, birth defects, sterility or suicide. Pesticide use has expanded more rapidly in developing countries than elsewhere. Pesticide imports quadrupled in the Philippines between 1972 and 1978. In 1979, 25% of pesticides the USA exported to developing countries were banned or unregistered in the USA itself.

Some pesticides used were persistent organic pollutants. Despite being present in minute quantities in water and soil, they accumulate in biological systems and, ultimately, in humans, adversely affecting health and reproduction. In addition, pest resistance to pesticides escalates pesticide use, which causes damage to human health, animal health and ecosystems (Nair, 2000; Joshi, 2005).

2.4.3 Effect of AKST on environmental sustainability

Agricultural production and natural resource extraction in forestry and fisheries profoundly intensified throughout ESAP over the past 50 years. Intensified food production has increased food availability but has had trade-offs on sustainability. Often, outside effects of modern agriculture have been masked and their sustainability has been ignored.

2.4.3.1 Effect on soil sustainability

Soil fertility has been declining: soil physical properties have been degraded and nutrients changed adversely, including less availability of major nutrients, deficiency of micronutrients, nutrient imbalances and acidification. The degradation was brought about by incorrect fertilizer use, intensive cropping, depletion of soil organic matter and a decline in soil biological activity. Depletion of primary minerals and organic matter has resulted in micronutrient deficiency in iron, manganese, zinc, copper, boron, nickel and molybdenum. Over time, heavy crop demand intensifies the severity of the deficiency and exhausts the soil's ability to supply sufficient other micronutrients.

Soil physical degradation has led to accelerated erosion, compaction, crust formation and excessive overland flow. India, Bangladesh, Nepal, Sri Lanka and Bhutan have 140 million hectares, or 43% of the total agricultural area of the region suffering from several forms of degraded soil quality (UNEP, 2005). Soil erosion is the most pervasive problem, especially in sloping and unstable agricultural land. Erosion removes the topsoil, where much of the nutrient reserve exists, and consequently causes loss of nitrogen and other nutrients. In China, about one-third of the land, 367 million hectares, faces erosion problems (UNEP 2005). In India, 25% of agricultural land has degraded soil, with about 30 million hectares of fragile land under cultivation progressively degrading (Dudani and Carr-Harris, 1992).

In intensive agricultural systems in the region, natural soil fertility has declined as a result of crop nutrient removal, nutrient leaching, chemical deficiencies and imbalances. Depletion of plant nutrients nitrogen, phosphorus, potassium, zinc and sulfur has been the most common chemical degradation. Increasing nutrient imbalances leading to micronutrient deficiency or toxicity of trace elements have been common in continuously irrigated paddy fields.

Soil acidification is enhanced by heavy nitrogen fertilization and adversely affects soil nutrient availability. Oldeman (1994) reported that many parts of Bangladesh and northern India have acidified and salinized, with a consequent loss of nutrients. Also, many agricultural lands in Cambodia, Malaysia, Thailand and Vietnam have experienced chemical soil degradation (Oldeman, 1994). In Australia, Bangladesh, Nepal and Sri Lanka, poor soil nutrient balances were not uncommon. Test plots in IRRI revealed that rice varieties yielding 10 t ha^{-1} in 1966 produced 7 t ha^{-1} in the mid-1990s.

As desertification encroaches, most prone are the arid and semiarid areas. Improper farming techniques of intensive farming and too many animals foraging each unit aggravate the situation. More than half of the 1,977 million hectares of dryland in Asia are affected by desertification. Central Asia has more than 60%, South Asia more than 50% and Northeast Asia about 30%. The Gobi Desert in northern and western China expanded by 52,400 km^2 over five years (UNCCD, 1998). Every year, deserts eat up 2,460 km^2 more. Relentless land reclamation, deforestation and overgrazing have led to continued loss of vegetative cover and topsoil. The excessive withdrawal of water upstream in many rivers in arid and semi-arid areas cuts off flows downstream, destroying the riparian ecosystems that rely on the rivers. The denuded land smoothes the way for wind to blow, intensifying sandstorms in areas where the sand originated and in the eastern part of the country and beyond (Yang, 2004).

Soil organisms are important for soil fertility, health and sustainability because they facilitate nutrient cycling and help improve soil structure. Continuous cropping, without considering the capacity of the soil to regenerate, usually results in decline in the amount of soil organisms. Heavy chemical inputs alter the chemical properties of the soil and cause decline in organic matter and humus, the food for microorganisms. Sound soil resource management technologies for efficient and sustainable nutrient cycling such as rotating crops, green manuring and encouraging nitrogen-fixing bacteria and mycorrhizhae were not widely practiced because the dominant production systems focused on short-term productivity.

Soil contaminated by cadmium (in fertilizer), hexavalent chromium, lead, arsenic, trichloroethylene, tetrachloroethylene and dioxin increased, mostly in the northern parts of the region and parts of Australia and New Zealand (UNEP, 2005). Contaminants affecting health from agricultural land in the northwest Pacific and northeast Asia were common in the 1970s (Japan, 2000). Soil contamination from lead and arsenic was prevalent throughout South Asia and Southeast Asia. Irrigation with untreated effluent caused contamination and soil acidification in many areas; in Mongolia, for example, waste disposal and wastewater discharges have been the main causes of soil contamination (UNDP, 2000).

Soil productivity is closely linked with soil organic matter. In some ESAP areas, long-term experiments have shown declining rice and wheat yields (Nambiar, 1994; Cassman et al., 1995; Brar et al., 1998; Yadav et al., 1998, 2000; Duxbury et al., 2000). The major causes observed were a gradual decline in soil nutrients because of inappropriate fertilizer application, a decline in soil organic matter, atmospheric pollution, pest and disease infestation and negative changes in the biochemical and physical composition of soil organic matter (Nambiar, 1994; Yadav et al., 1998, 2000). Observations also have shown that accumulation of nitrogen in soil was better in farms using organic fertilizer than synthetic fertilizer, possibly from a slow release of nitrogen reducing losses (Bhandari et al., 1992; Yadav et al., 2000). Organic fertilizers are known to stimulate nitrogen fixation in soil and may also be responsible for increasing total soil nitrogen (Roper and Ladha, 1995).

2.4.3.2 Water resource depletion and intensification of water scarcity

Increasing water withdrawal for irrigation has led to serious environmental consequences, particularly water resource depletion and ecosystem degradation. In an area representing 21% of the world's land, ESAP has 28% of its freshwater resources. However, as the region is home to 53% of the world's population, the water resources for each inhabitant are only slightly above half the world's average.

The hydrology of ESAP is dominated by the monsoon climate, which induces large interseasonal variations in rainfall and river flow. In the absence of flow regulation, most of the water flows during a short season, when it is usually less needed. In Bangladesh, for example, the surface flow of the driest month represents only 18% of the annual average; in Indonesia, 17%. In India, flow distribution of some rivers during the monsoons is 75 to 95% of the annual flow. In north China, about 70 to 80% of the annual rainfall and runoff is concentrated between May and September (FAO, 2006b). This means that irrigation is important for crops produced the rest of the year. For example, winter wheat, which accounts for over 90% of total wheat sown areas and production in China, is grown between October and the following June. As there is little rainfall during this period, production is heavily reliant on irrigation, which is the largest water user in the water-stressed North China Plain (Yang and Zehnder, 2001).

In many rivers in the region, annual discharge declined from increasing water withdrawal. Some rivers have been completely tapped out during the drier part of the year. The Yellow River, the cradle of China's civilization, stopped flowing in its lower reaches for several months every year during the 1990s. The longest dry-up occurred in 1997—a record of 226 days (Postel, 1999). The consequences of reduced river flows and river dry-ups are serious. The capacity of the river to carry sediment load is reduced, potentially increasing the risk of floods in the lower reach. The dry-ups also adversely affected the aquatic, wetland and estuary ecosystems downstream, in particular the coastal fisheries.

Overextraction of groundwater and consequent groundwater depletion have been widespread problems, especially in semiarid areas. In the North China Plain, the groundwater table has declined over one meter each year (Yang and Zehnder, 2001). In Punjab State in India, the situation has been similar. The rapid decline in groundwater tables reduces availability, on the one hand, and increases the cost of accessing the groundwater, on the other. Poorer farmers have been the most affected. When near the sea or in proximity to saline groundwater, overpumped aquifers are prone to saline intrusion.

Water scarcity has become a major concern in many countries in the region. Increased competition for water between sectors has affected agriculture in China, India, the Republic of Korea, Malaysia and Thailand. The problem is intensifying, mainly from population growth and rapid expansion of the domestic and industrial sectors. Major interbasin transfer programs have been reported in many countries, notably China, India and Thailand.

2.4.3.3 Water-quality degradation and nonpoint-source water pollution

Agricultural activities have significantly affected the environment. Water quality is threatened by intensive application of fertilizers, herbicides and pesticides that percolate into aquifers. These nonpoint sources of pollution from agriculture have often taken time to become apparent, but their effects can be long lasting, particularly with persistent organic pollutants. Wetlands are also affected by overextraction of river water and dropping groundwater tables.

Fertilizer runoff from agricultural production, especially nitrogen, contaminates water supplies. For example, Chinese rice farmers often use inappropriate ammonium bicarbonate instead of urea and excessive quantities of nitrogen, 180 kg ha^{-1} or more, leading to low recovery, 35% or less. In addition to reducing farmer profits, the nitrogen lost from crop and livestock production has contributed "dead zones" being created in the East China Sea at the mouth of the Yangtze River (Li and Daler, 2004). Dead zones can devastate fishing grounds and the livelihoods of those who depend on them for sustenance and income. Improving recovery efficiencies will require investment in human capital, for both extension agents and farmers.

In arid and semiarid areas, waterlogging, salinity and alkalinization are serious constraints on agricultural development in irrigated land. The principal effect of salinity is to reduce the amount of water available to the plant by high osmotic concentration of salts in the soil solution. Saline and alkaline cultivated land in China covers about 7 million hectares. In India, waterlogging from irrigation covers about 2.46 million hectares. Salination has also been a serious problem in the Murry-Darling Basin in Australia and a number of other countries in the region. Data for areas actually damaged by salination are sporadic and vary widely among sources.

Animal waste has become a major problem in East Asia and Southeast Asia. With the rapid increases in pig and poultry production in China and Vietnam, waste runoff from intensive livestock systems has become a major source of nutrient pollution in the South China Sea, one of the most biologically diverse shallow water marine areas. Pig and poultry production has been the primary source of this pollution. Most of this intensive production has been located around periurban centers along or close to the coastline of the East China Sea and the South China Sea. Major hotspots, with the highest concentrations of nitrogen and phosphorus overloads from livestock systems, have been found in the Mekong Delta, the mouth of the Red River and along the whole Chinese coast of the South China Sea. One report has suggested that animal manure accounts for 47% of the phosphorus and 16% of the nitrogen in these areas. In addition, a World Bank analysis has shown that the chemical oxygen demand from untreated piggery effluent accounted for 28% of the current urban industrial chemical oxygen loads in 1996, with the expectation that this estimate would raise to 90% by 2010 (LEAD, 2006).

Increasing concern about management of animal wastes has increased attention by ESAP governments to minimize the effect of nutrient pollution on the landscape and coastal marine systems. While anaerobic digest works on small-scale production systems, such as in the Pacific Islands, large-scale commercial livestock farmers of Southeast Asia will require different technology to adequately treat, dispose of and recycle livestock waste.

Discharge of water excessively laden with organic matter into rivers and canals, especially from intensive aquaculture ponds, was a cause of river water pollution in leading aquaculture countries. However, most destructive aquaculture has been the result of ignorance or nonadherence to “responsible aquaculture practice,” also known as good aquaculture practice or best aquaculture practice.

2.4.3.4 Loss of agrobiodiversity

ESAP harbors one of the world’s richest reservoirs of biodiversity. It is the point of origin of many crop and livestock varieties economically important to humankind. Resource-poor farmers are hugely dependent for their livelihoods on this agrobiodiversity of minor crops, wild plants, wild animals and medicinal plants, They might be insignificant in national statistics but are critically important locally. Biodiversity has been associated with farmer production choices and food security and is a mechanism for coping with environmental uncertainties by spreading and reducing potential risks.

Genetic variability of species comes from genetic resources. Breeders identify desirable genetic traits from genepools and incorporate them into mainstream varieties to produce crops with desirable characteristics, such as improved yield, quality, pest resistance and tolerance to environmental constraints. It is estimated that half the increase in yield of major crops is from genetic improvements through breeding (Chang, 1984).

Agrobiodiversity is being threatened by simplification of ecosystems and species and by varietal replacement. Monocropping has displaced many local and traditional varieties, resulting in genetic erosion. In Indonesia, 1,500 rice varieties disappeared from 1975 to 1990. High-yield rice replaced traditional varieties in about 80 to 82% of fields in Burma, Indonesia, the Philippines and Thailand. The thousands of farmer-developed rice varieties planted in mosaic pattern in agricultural landscapes are no longer planted. Likewise, genetically uniform livestock and poultry breeds have replaced many traditional breeds (Thrupp, 1998). The predominant agricultural approach of monocropping and specialization has often been reinforced by government policies using input subsidies, agricultural extension messages or widespread distribution by governments of modern seeds (Cromwell et al., 1997).

Loss of forest cover, coastal wetlands and other wild, uncultivated areas has further exacerbated the loss of wild relatives and wild foods essential for providing food (Cromwell et al., 1997). Habitat loss has been serious in China, India, the Philippines, Thailand and Vietnam (ESCAP, 1995.

Cultural diversity, a fourth dimension of biodiversity, has been least appreciated. Traditional and local knowledge is key to using and conserving biodiversity because it embodies the coping mechanisms of local people under the varied and rigorous circumstances that make unique areas productive and sustainable. Local knowledge has been ignored in dominant agricultural systems and much of it is rapidly disappearing (Cox, 2000).

AKST in aquaculture has had both positive and negative effects on the environment. Technology to produce fry of cultivable species obviated using wild fry for farming, saving biodiversity. Many previously fallow water bodies covered with water hyacinth, which used to be the abode of mosquitoes, were now free of the insects. However, coastal shrimp aquaculture was responsible for mangroves being destroyed in many ESAP countries.

2.4.3.5 Pest and disease incidence and pesticides

Pests, diseases and weeds have remained significant problems, despite the use of more pesticides. Pesticides may even cause pest problems, when beneficial insects are eliminated or if pest resistance to pesticides evolves. Agronomic practices have their share in causing greater incidence of pests and diseases. For example, outbreaks of the brown planthopper in rice during the 1980s occurred because pesticide use, high nitrogen fertilization, dense planting and continuous irrigation had eliminated their natural enemies (Ishii and Hirano, 1959; Heinrichs et al., 1982). Currently, some 500 insect pests, 150 plant pathogens and 133 weed species already have become resistant to insecticides (Brattsten et al., 1986; Altieri and Rosset, 1999).

IPM, developed in the 1980s, was quite successful on selected crops in the ESAP region. Indonesia officially adopted IPM as national policy in 1986, and after five years, it reported a 70% reduction in pesticide use while rice yield increased by 10%.

The drive by livestock growers to serve urban markets has led to intensive production, bringing problems of livestock waste, land management and distribution. Greater awareness rose for the potential for transmission of disease from animals to humans. Major diseases that can be transmitted from animals to humans include bovine tuberculosis, Creutzfeldt-Jakob disease and various internal parasitic diseases (Steinfeld et al., 2006). Other examples of the potential dangers of disease transmitted through increased food trade include a 1997 outbreak of foot-and-mouth disease that virtually ruined the pig industry in Taiwan (China). The strain was closely related to strains found in Hong Kong (China) and the Philippines (WHO, 2002). There were also concerns about the rising demand for livestock feed, increased need for veterinary services and training, loss of genetic resources and the need to extend opportunities to small-scale producers to earn cash from livestock (FAO, 2006c).

In ESAP, avian influenza emerged as the most serious threat to animal and human health. The first case of avian flu was reported in a farmed goose in Guangdong, China. The H5N1 avian flu virus spread rapidly across the region, creating transboundary animal disease epidemics. Avian flu outbreaks were reportedly in Cambodia, China, Indonesia, Japan, Laos, South Korea, Thailand and Viet Nam. Countries in the region made massive efforts to cull infected chickens and ducks and to vaccinate healthy birds. In spite of these efforts, incidents of human infection and death occurred among people who worked and lived in close contact with poultry. By 2006–

2007, H5N1 had been detected in Bosnia-Herzogovina, Ghana, Hungary, Saudi Arabia, Turkey and the United States.

Effect of agriculture on climate change. Agriculture is a significant contributor to climate change. About 20% of global carbon dioxide emissions, 60% of methane gas emissions and 80% of nitrous oxide come from modern agriculture. By another estimate, livestock accounts for 18% of greenhouse gas emissions, including 9% of anthropogenic carbon dioxide and 37% of anthropogenic methane. Land use, including deforestation, expansion of pastures and land cultivated for feed crops, are the largest contributors to total livestock-related greenhouse gases (Steinfeld et al., 2006). Action should be taken to reduce the overall effect of livestock production on global warming. Both methane and nitrogen emissions can be reduced by better livestock diet and manure management.

2.4.4 Gender, equity and sustainability

2.4.4.1 AKST, workload and time allocation for agricultural production

Women are major stakeholders in agricultural production. This fact is supported through time-use surveys conducted in selected countries, both industrial and developing, in Asia and the Pacific. Women's time contributed to agricultural production is much higher than men's (Table 2-10). In Nepal women work longer than men in all seasons in both rainfed and irrigated agriculture (Sharma, 1995).

With increased migration of male laborers to cities, the agricultural workload of women and children has increased (Balakrishnan, 2005). But the introduction of new agricultural technology decreased the agricultural workload for some women, as in southern Vietnam, where workload fell about 30% (Ba and Hien, 1996). This saved time was used in other subsistence activities, such as aquaculture on homestead land, home gardening and crafts, sometimes shifting from one activity to another (Felsing and Baticados, 2001). Although additional income might be gained by additional activities, a study in Indonesia and Malaysia showed these additional activities, including aquaculture, added to women's workload, while the profits went to the men (Burgere, 2001).

Though women were the managers and workers, their economic contribution was either not counted or undercounted in the national economy. The agricultural census did not reflect the actual contribution of women in agriculture because of inadequacies in conceptualization, definition of terms and data-gathering methods. After analyzing the gender division of labor, it was found that women contributed much more than men (Joshi, 2000).

Despite women's greater contribution, the predominant image of a farmer in both developing and industrial ESAP countries was male; therefore, policies and programs ignored women's needs and concerns as farmers (ADB and UNIFEM, 1990; Alston, 2004). National statistics, however inaccurate, served as the principal data in framing development policies. These inaccurate data led to undercounting women, both as workers and as those available for work. Women's contributions were either unrecognized or undervalued (Alston, 1998; Siason et al., 2001). Many ignored concerns still need to be understood. Gender-disaggregated data would be necessary for appropriate intervention and policy change. Disaggregated data were lacking or underreported in both developing and industrial countries such as Australia (Alston, 1998; Siason et al., 2001).

2.4.4.2 Gender roles and AKST

Women contributed more time than men in both agricultural production and household activities. The double burden of work reduced the time women had to participate in and benefit from development activities.

The time women and men spent for productive, household, social and religious activities differed significantly by season and environment. It was also significantly influenced by the introduction of technology (Kolli and Bantilan, 1997). Gender division of labor prevails in all social systems. Traditionally, women are allotted most domestic jobs and time-consuming drudgery in the fields. People are slow to percieve what women and men actually do. For instance, both women and men consider fishing a man's job; in fact, women were almost equally involved in fishing in Yunan, China (Yu Xiaogang, 2001). Gender division of labor is not static but changes with time and circumstance (Kusakabe, 2002). Gender division of labor in work outside the home is changing with introduction of agricultural technology, environmental change or economic change. However, it is hard to see drastic change in division of labor in households. Women take on more and more responsibility in production, but their household work remains. This overburdens women with work. It creates physical and psychological problems, there is lack of time for self-development and it enforces gender inequality. Little recognition of women's contribution also prohibits their participation in making decisions.

2.4.4.3 AKST and changes in decision patterns

Women take part in agricultural production, but they make few decisions on technology. Decisions on how to use and manage a technology differ according to the technology used and the activity. According to studies conducted in different countries, women have lagged behind men in making agricultural technology decisions. Examples can be seen in decisions on adopting modern technology in Bangladesh and India (Singh et al., 2000; Rahman and Routray, 2001). Improved technology developed by research and development institutions mainly focused on male workers (Singh et al., 2000). Not involving women in decision making regarding technological production has negative implications for livelihoods and sustainability.

To build women's decision-making capacity, it is important that women have the same access to information as men. Traditional assignment of market-oriented activities means that introduced technology helps reinforce stereotyped gender roles and reduces the control of women over resources (Kolli and Bantilan, 1997). The rice–fish farming system in Indonesia resulted in increased income (Wardana and Syamsiah, 1990). Although women transplanted, weeded and harvested rice, they made few production decisions and were not involved in farmer meetings and classes.

2.4.4.4 Employment opportunities and income distribution

New AKST in ESAP has created jobs for poor farmers, women and indigenous people and in some cases has helped to reduce poverty. However, the benefits from these new opportunities have varied among gender, class, ethnicity and caste. In most cases, the poorest of the poor did not get equal benefits, compared with richer or middle-income groups. A study conducted in Bangladesh on employment and modern agricultural technology in crop production found the demand for labor increased because of technological changes. However, this demand was mostly met by hiring male laborers; the few women hired were paid significantly lower wages than men. Furthermore, opportunities for women were unequal, and they had less bargaining power both in the conventional hired labor market (Rahman and Routray, 2001) and in contract farming (Singh, 2003). The effect of new technology on women varied by category. In Vietnam promoting plastic row and drum seeders in rice planting displaced poor women from farming households, who worked as wage laborers in hand weeding and filling gaps. Poor and landless women faced the worst consequences because of lack of alternative jobs and increased debts. Women from better-off families had more time for leisure and other income-generating activities. Progressive men farmers, who had more frequent contact with extension workers, had better-educated wives and used low seeding rates. This group of women was more likely to benefit from a new technology (Paris and Ngoc Chi, 2005). The farming system also affected the gender decision pattern and income benefits. Female farmers were more involved in farm production and management on vegetable farms and mixed livestock and cash crop farms than in mechanized and capital-intensive production (Hall and Mogyorody, 2007).

Studies of household income distribution revealed that women benefited from small-scale and integrated farming within homesteads, whereas men benefited more from other than subsistence farming (Berman, 2003). Studies in Bangladesh showed that some women involved in growing vegetables had negligible income, but most of their income and vegetables were used for home consumption. Another study showed that women in fish production in Bangladesh got no benefit, because men did the trading and women never knew how much money was earned (Naved, 2000). New groundnut technology in India and intensified aquaculture in Thailand and Vietnam showed that, while additional income gained was small, women did gain control over it and generally used it for daily expenses (Kolli and Bantilan, 1997; Kusakabe, 2002). If the increased production was more than needed for the home, the extra would be used for trading, and eventually, men benefited from it. Though new technology was likely to change traditional farming into more entrepreneurial systems and add to family income, it was necessary to examine in detail the equity implications of the benefits derived by each member of the farm household. Usually the household was considered as a unit and benefits from certain activities were distributed equally among members. However, case studies showed that to increase weaker groups' choices, it was important that household income have several sources to negotiate priorities. Diversification of sources of income is desirable for addressing risks, increasing household income and controlling economic activities among household members (Kusakabe, 2001).

2.4.4.5 Ownership and control over resources

The effect of AKST also depends upon the ownership and control over the agricultural land, the most basic resource of agricultural production. Land ownership and control is important because it influences the negotiations and decisions of women within the household (Crowley, 2001). It was the single most important contributor to women's economic wellbeing, social status and empowerment (Agarwal, 1994). However, ownership of land may not always give women control over the land, as a study showed in Kerala, India (Arun, 1999). Women's control over key economic resources was more important than economic ownership and was critical to their power within the family. It was important that women had direct access to critical farm inputs to enable them to maximize outputs, challenge ideas of "women's work," gain control over other factors of production and change social norms. Most importantly, there should be a concerted effort to enable women to function as independent farmers who control their own land (Arun, 1999). Enhancing land rights of women requires that those rights become a political priority and a legal possibility; it also requires administrative viability, social acceptability, and moral legitimacy (Crowley, 2001). Complementary policies must address women's limitations in exercising and enjoying their land rights. Control over land is essential because, even with assured land rights, investments in property require access to financial markets, information, extension and other services. Agricultural technology that requires large assets to adopt is more likely to exclude women from the direct benefits. When women earn and control their income, they can use it as a bargaining chip, with the implicit threat of withdrawing it from the household economy (Naved, 2000).

The effect of AKST depends upon the differences in control over assets and technology. The study in Bangladesh showed the choice of new technology and its effect (Meinzen-Dick et al., 2003). The improved vegetables were disseminated to poor women, who could grow them on their homestead, so poor families with only homestead land could also participate. In contrast, one fishpond program focused on those with private fishponds, who were often not poor. Moreover, homestead land was more under women's control; farmland, including fishponds, was more likely to be under men's control. The vegetable program reached women and the very poor, while the output of the private fishpond program went mostly to men.

2.4.4.6 Measures taken for equity and sustainable development

In ESAP, being aware of gender issues and incorporating women's needs and priorities in planning is increasing and some steps have been taken to integrate women's concerns (Kelkar, 2005). Some positive results have been seen. However, there is a long way to go meet the goal and there have been limitations (Rahman, 1999). Some initiatives are microcredit programs in ESAP, such as Grameen Bank in Bangladesh, India and the Philippines (Amin et al., 1998; Milgram, 2005; Holvoet, 2006).

Another effective tool used to empower women is by training poor women in management, trading and marketing, such as managing a small-scale aquaculture enterprise in Vietnamese integrated farming, using a garden, a pond and animal husbandry. In two northern provinces of Vietnam it was shown that after training, women gained knowledge that helped them make decisions in managing the aquaculture. Once they made such decisions, their position in the household strengthened (Voeten and Ottens, 1997).

In addition to training, group meetings, and saving and credit programs, there was potential for information and communication technology to improve women's and children's access to information and knowledge, enhance their education and accelerate technology transfer. Radio and television were used extensively in several countries to inform and educate rural women about health, nutrition and agriculture. The best-known case studies of information technology's potential benefits for rural women's livelihoods are Bangladesh Grameen Communications' venture of rural women's cell phone enterprises; Pondicherry Village Information Shops; e-Chaupal for market information; SEWA's program on skills development to support women's work in the informal sector; Sri Lanka's Kotmale Project; and information kiosks and telecenters (Balakrishnan, 2005).

Despite the potential, the threat is that an increased digital divide will widen inequality in information, education and knowledge between women and men, rich and poor, urban and rural communities (Kelkar et al., 2005). Therefore, it is necessary to ensure that new agricultural technology is appropriate for the groups of people who most need assistance. Furthermore, it is necessary to assess whether the new technology actually reduces poverty and inequality.