CHAPTER 15

Toward A New Approach and Expanded Cooperation in Agricultural Research and Development in Developing East Asia Plus[1]

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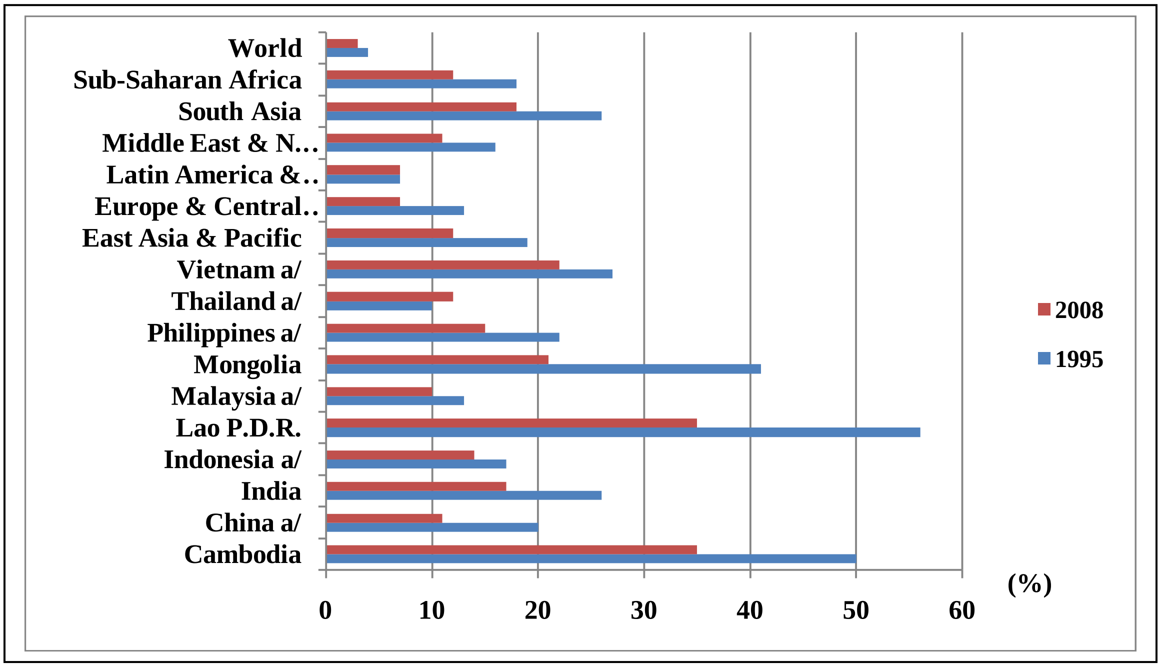
1. Introduction

Developing East Asia plus (DEAsia+), while it has exhibited significant economic growth, still faces tremendous challenges inimproving food security and reducing poverty. The agricultural sector thus continues to be of key importance as its relative contribution to the economies in the subregion (in terms of Gross Domestic Product [GDP]) is still high compared to the rest of the world (**figure 1**). Agricultural growth has been a key driver of development and much of this growth is attributable to agricultural research investments (Suphannachart and Warr 2010; Timmer 2009; Evenson and Rosegrant 2003).

[1] Developing East Asia Plus in this paper refers to the developing countries in Southeast and East Asia plus India. Southeast Asia includes (as per IMF grouping) Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Thailand, Timor Leste, and Vietnam. The East Asian countries covered in this report are Chinaand Mongolia. This country grouping is referred to here as Developing East Asia plus or DEAsia+. Unless further qualified, the word "region" in this paper would refer to DEAsia+.

Figure 1. Share of agriculture in Gross Domestic Product (GDP), 1995 and 2008



Source: 2010 World Development Indicators

Note: a/ Components are at producer prices

However, agricultural research lost some of its footing following the success of the Green Revolution. Almost everyone felt that the problem of food supply availability was already solved and that the remaining challenges posed by hunger and malnutrition were largely due to inadequacies in distribution and marketing. To date, a significant number of people in the region continue to lead lives marked by hunger and malnutrition. Even more ominously, the percentage of hungry and malnourished people has increased in the past years due to rising food prices.

Indeed, the recent food crisis sparked growing concerns that the available food supply can still become insufficient, after all. It is evident that the growth in crop yields has plateaued since the late 1980s while the emerging threats to the expansion of food production have increased. These threats include the increasing scarcity of land, labor, and water for agriculture due to the diversion of these resources to nonagricultural activities; the likely impact of trade liberalization; global climate change; rise in fuel prices; and biofuel development. There are also misguided government policies that often hurt rather than promote sustained growth in agriculture and the economy as a whole (Sombilla et al. 2010; David 2003).

The emerging economic scenarios intensify the call for more agricultural research and development (R&D) to effect higher production growth and strengthen the resilience of the agriculture sector against imminent threats like climate change. New fields of research such as genomics and nanotechnology, which could have a dramatic impact on agriculture, indicate that there will be ample opportunities to develop sustainable food production strategies capable of satisfying the needs of growing populations without placing undue stress on the environment and natural resources. These new technologies must find their way to the least developed countries (LDCs), such as those in DEAsia+, where most of the poor live. Making them work in these countries will require a paradigm shift that involves more effective institutional arrangements and strong collaboration and teamwork not only among individuals and institutions within the country but also with those outside.

Objective and Structure of the Study

The paper presents an agricultural R&D agenda for DEAsia+ that would reinvigorate the region's agriculture sector and promote its sustainable growth as well as the growth of the economy as a whole. It describes a paradigm shift in the conduct of research—the kind of research that pushes for stronger and expanded regional cooperation—to ensure that new and appropriate technologies are disseminated and adopted by the beneficiaries that need them the most (primarily the smallholder producers, including women) and in order to improve incomes and well-being, reduce poverty, and achieve greater food security.

The study analyzed information from existing literature, most of which are results of the ongoing discussion by various stakeholders on the future agenda of agricultural R&D. This paper starts with a short description of agricultural development in the DEAsia+, followed by a recounting of the huge amount of agricultural research that contributed to this growth. It then identifies the challenges that slow down agricultural development, threaten food security, and worsen poverty and hunger. Section IV identifies the gaps in past research efforts and identifies priority research areas to fill up these gaps and weaknesses and overcome the challenges. The last section presents a new paradigm for designing future research agenda in DEAsia+ and rationalizes the need for an expanded and more committed collaboration among stakeholders in agricultural research. The paper concludes by stressing that networking and cooperation can be a win-win path for DEAsia+, considering the countries' differences not only in terms of economic progress but also progress in science and technology.

2. Agricultural Growth, Food Security, and Poverty

DEAsia+ countries are still primarily agricultural. Despite having limited arable land that average 0.2 hectare per person, countries in the region have successfully staged rapid agricultural growth, enabling them to be become key suppliers of food not only for their 3 billion people but also for the rest of world. Moreover, the agricultural sector benefits slightly more than 1.8 billion people in the rural areas who derive their livelihood and income from farming, fishing, and other related activities. Livestock raising is a primary source of livelihood for about 300 million poor people in region, some 200 million in South Asia and another 100 million in Southeast Asia and China. Fisheries and aquaculture also play an essential role in the livelihoods of about 37.3 million fishers and fish farmers in Asia (FAO 2009). China has 8.1 million fishers and 4.5 million fish farmers. Other countries with a significant number of fishers and fish farmers are India, Indonesia, the Philippines, and Viet Nam. Most fishers and fish farmers are small-scale, artisanal fishers, operating on coastal and inland fishery resources

Growth in agriculture and in both the industrial and service sectors resulted in a relatively rapid rise of per capita GDP between 2000 and 2009 (**appendix table 1**). This plus the long-term decline in the commodity prices, particularly of the major staples, benefited numerous people, primarily the poor. The food security status of countries improved and the number of undernourished people was almost halved.

Growth in Agricultural Production

Agricultural production in the DEAsia+ countries exhibited quite impressive growth as indicated by the indices in **table 1**. Countries like Cambodia, China, Lao PDR, Myanmar, and Viet Nam posted food production gains of more than 50 percent from their output levels in 1990—92. Myanmar has been most prolific, almost doubling its food output levels over the two reference periods. The rest of the countries in the region (e.g., India, Indonesia, Malaysia, the Philippines, and Thailand) exhibited much more moderate increases. These countries were early adopters of the Green Revolution technology and may have exhausted potentially bigger increases in yield.

Growth in Cereal Production

Cereal production in DEAsia+ tripled, reaching an average of nearly a billion tons in 2008 (average between 2007 and 2009) as shown in **table 2**. Rice production grew at an average rate of 2.31 percent per annum between 1968 and 2008, maize at 4.3 percent, and wheat at 3.7 percent. Much of this production growth was accrued through yield improvement—a clear impact of technology research being conducted primarily to enhance agricultural production. The rate of expansion in cultivated areas was nil in rice starting from the late 1990s and declined in wheat but expanded in maize, possibly due to the increased demand for the commodity for bioethanol production.

Table 1. Agricultural Production Indices, 1999—2001=100.

Country	Food Production Index (1999—2001=100)		Crop Production Index (1999—2001=100)		Livestock Production Index (1999—2001=100)	
	1990--92	**2005--07**	**1990--92**	**2005--07**	**1990--92**	**2005--07**
Developing East Asia+						
Cambodia	82.7	139.0	82.7	145.3	82.3	104.0
China	66.3	117.7	75.7	116.0	54.7	116.3
India	91.0	101.7	95.0	100.3	83.3	112.3
Indonesia	95.3	121.3	93.7	120.3	99.3	132.3
Lao P.D.R.	73.0	115.7	77.0	117.7	74.3	109.3
Malaysia	88.0	114.7	92.7	116.7	100.3	114.3
Myanmar	71.0	139.7	68.7	133.3	66.0	180.3
Philippines	95.3	108.0	103.7	109.7	74.7	105.3
Thailand	92.0	109.0	89.7	110.0	94.7	103.0
Viet Nam	71.3	114.3	69.7	116.0	60.0	113.3
World	**78.8**	**114.3**	**82.0**	**114.7**	**83.7**	**112.2**

***Source*:** 2010 World Development Indicators

Rice accounts for more than 50 percent of cereal production in the region and maize, less than a fourth. Wheat accounts for about 20 percent, most of which comes from China and India. The other two wheat-producing countries in the region are Myanmar and Mongolia (data not shown), the combined production of which totaled close to 400,000 tons in 2008. In terms of the region's contribution to the cereal production of the whole of Asia, the figure is 82 percent and to the world, 38 percent (see **table 3**). Rice share to the total of Asia's is 86 percent, maize's is 93 percent, and wheat's is only 66 percent.

Yield trends of the cereal commodities are also exhibited in **table 2**. Average rice yield reached in DEAsia+ is slightly higher than that of Asia as a whole. This is especially true for China whose average yield reached 6.5 tons per hectare in 2008, followed by Vietnam with an average yield of 5.2 tons per hectare. China likewise demonstrated the highest average yield levels in wheat and maize. Malaysia's maize yield of 5.2 tons per hectare ranks second and Lao PDR's, third. The variability of cereal yields across the countries in DEAsia+, and in the whole of Asia for that matter, is quite telling of the great potentials of further technology development to enhance production through yield improvements.

Table 2. Cereal Production in DEAsia+ countries, 1969—2008

Rice, paddy	Area Harvested (1000 ha)					Yield (tons/ha)					Production (1000 tons)					Growth Rates, % (1968-2008)		
	1969	1979	1989	1999	2008	1969	1979	1989	1999	2008	1969	1979	1989	1999	2008	Area	Yield	Production
Developing East Asia+	100,548	108,833	112,248	118,324	120,798	2.22	2.72	3.58	3.99	4.34	223,493	295,873	401,918	471,759	524,151	0.49	1.84	2.31
Cambodia	2,222	1,071	1,847	1,982	2,618	1.43	0.96	1.38	1.95	2.73	3,189	1,085	2,557	3,859	7,163	0.29	1.70	2.00
China	31,655	34,739	33,051	31,170	29,535	3.25	4.12	5.50	6.32	6.52	102,939	143,249	181,847	196,930	192,670	-0.10	1.82	1.72
India	37,413	40,016	42,196	44,891	43,957	1.64	1.87	2.59	2.90	3.22	61,208	74,799	109,399	130,339	141,368	0.44	1.86	2.30
Indonesia	8,056	8,913	10,391	11,829	12,447	2.25	3.05	4.22	4.28	4.87	18,171	27,235	43,860	50,667	60,602	1.08	2.09	3.19
Lao PDR	662	667	590	685	826	1.29	1.32	2.19	2.90	3.54	857	881	1,300	1,993	2,927	0.58	2.80	3.39
Malaysia	683	679	672	688	667	2.29	2.75	2.64	2.96	3.62	1,569	1,879	1,775	2,041	2,413	-0.02	1.26	1.25
Myanmar	4,748	4,751	4,673	5,991	8,200	1.70	2.41	2.92	3.25	3.76	8,057	11,431	13,648	19,509	30,975	1.37	2.00	3.39
Philippines	3,241	3,552	3,403	3,736	4,422	1.60	2.12	2.78	2.90	3.72	5,162	7,514	9,438	10,910	16,441	0.73	2.63	3.38
Thailand	7,018	8,930	9,526	9,791	10,772	1.89	1.89	2.06	2.50	2.95	13,223	16,865	19,686	24,489	31,738	1.08	1.27	2.37
Vietnam	4,849	5,516	5,898	7,561	7,354	1.88	1.98	3.12	4.10	5.15	9,118	10,933	18,407	31,023	37,854	1.04	2.83	3.91
Asia	119,513	128,243	131,755	138,330	141,703	2.30	2.74	3.52	3.93	4.31	274,963	351,557	463,656	544,278	611,023	0.47	1.69	2.17
Maize																		
Developing East Asia+	28,115	33,988	35,779	39,562	47,662	1.54	2.25	3.08	3.92	4.47	43,344	76,406	110,202	154,962	213,128	1.32	2.64	4.26
Cambodia	101	80	48	52	173	1.37	1.05	1.29	1.85	3.92	136	84	61	100	686	0.92	2.57	3.51
China	15,960	20,172	20,563	24,769	29,953	1.89	2.96	4.11	4.94	5.36	30,225	59,637	84,749	122,554	160,523	1.57	2.83	4.45
India	5,810	5,828	5,905	6,412	8,272	1.08	1.07	1.51	1.80	2.26	6,287	6,253	8,947	11,567	18,662	0.94	2.19	3.15
Indonesia	2,864	2,784	3,169	3,597	3,931	0.96	1.39	2.06	2.69	3.99	2,761	3,875	6,526	9,684	15,747	0.55	3.62	4.19
Lao PDR	14	28	35	45	167	1.77	1.06	1.53	2.37	4.80	25	30	54	108	805	6.78	2.56	9.51
Malaysia	9	8	19	27	6	1.86	1.13	1.77	2.12	5.21	16	9	34	57	33	-0.83	2.96	2.11
Myanmar	73	109	123	199	345	0.72	1.11	1.56	1.70	3.23	52	123	191	339	1,114	3.65	3.71	7.49
Philippines	2,368	3,231	3,751	2,502	2,664	0.81	0.96	1.23	1.72	2.59	1,918	3,099	4,601	4,306	6,900	0.41	3.10	3.53
Thailand	678	1,361	1,680	1,267	1,046	2.43	2.12	2.53	3.52	4.06	1,661	2,884	4,263	4,457	4,252	1.37	1.56	2.94
Vietnam	238	385	484	691	1,103	1.11	1.07	1.60	2.59	3.99	263	411	775	1,790	4,405	3.95	3.30	7.39
Asia	31,089	37,206	39,190	43,491	52,001	1.55	2.23	3.05	3.79	4.43	48,351	83,092	119,609	164,849	230,218	1.29	2.85	4.18
Wheat																		
Developing East Asia+	41,001	51,407	53,476	55,757	52,092	1.13	1.76	2.65	3.21	3.66	46,450	90,367	141,672	179,183	190,748	0.65	3.16	3.73
China	25,072	29,232	29,794	28,428	23,849	1.12	1.96	3.07	3.79	4.71	27,985	57,263	91,492	107,747	112,237	-0.11	3.70	3.59
India	15,861	22,090	23,558	27,235	28,144	1.16	1.49	2.12	2.62	2.78	18,428	33,029	50,043	71,334	78,352	1.58	2.36	3.97
Myanmar	68	85	124	94	98	0.53	0.88	1.11	1.08	1.61	37	75	137	101	158	0.25	2.61	2.86
Asia	67,345	79,578	83,682	99,359	99,817	1.10	1.64	2.31	2.58	2.88	74,023	130,574	193,390	256,617	287,725	0.99	2.42	3.43

***Source*:** FAOStat (accessed 2010).

***Note*:** Figures are three-year averages centered in the year shown.

Production of Other Food Crops, Fruits, and Vegetables

Table 3 shows the production performance of DEAsia+ in other food crops like fruits and vegetables. The growth performance in these commodities was equally remarkable. From the period 1989 to 2008, fruit production almost tripled. The 2008 production level was reported at 225 million tons. Expansion of vegetable production in DEAsia+ more than tripled; the latest production figure available was 576 million tons in 2008. Table 3 also shows the relatively high share of the output of DEAsia+ of these commodities vis-a-vis world production—39 percent for fruits and 62 percent for vegetables. These shares have increased by almost 20 percent from the reported shares in 1989. While production is dominated by China and India, other countries like Indonesia, the Philippines, Thailand, and Viet Nam have closely followed behind.

Table 3. Production of Other Food Commodities (000 tons)

Countries	Cereals		Fruits		Vegetables		Meat		Milk		Fish a/	
	1988-1990	2007-2009	1988-1990	2007-2009	1988-1990	2007-2009	1988-1990	2007-2009	1988-1990	2007-2009	1988-1990	2007-2009
Developing East Asia+	694715	956381	72113	224838	191320	576256	37627	92641	59219	151064	20623	53608
Cambodia	2618	7849	231	307	472	487	117	213	17	24	87	469
China	374625	473849	20184	108728	126179	455030	28421	74381	6668	40186	8599	28336
India	192400	258094	25808	65974	47985	89279	3533	4353	51162	107440	3212	6519
Indonesia	50386	76350	5560	16578	4269	8789	1341	2549	562	1055	2566	5519
Lao PDR	1353	3733	120	206	93	896	42	113	5	7	28	105
Malaysia	1809	2446	1104	1410	321	630	560	1269	38	47	712	1275
Myanmar	14110	32267	940	1880	2073	4087	271	1434	570	1216	720	2779
Philippines	14040	23341	8750	15228	4171	5349	1023	2727	22	14	1774	2843
Thailand	24192	36192	6237	8804	2529	3717	1277	2220	116	785	2109	2664
Vietnam	19182	42261	3178	5721	3228	7991	1042	3382	59	290	815	3099
World	1850328	2454551	349502	576222	453476	928908	175012	276735	535867	689983	85245	107913
% to World	**38%**	**39%**	**21%**	**39%**	**42%**	**62%**	**21%**	**33%**	**11%**	**22%**	**24%**	**50%**

***Source*:**FAOStat (accessed 2010).

***Note*:** a/ includesDiadromous, Freshwater, and Marine Fishes

Growth of the Livestock Subsector

The livestock production indices in table 1 clearly show how this subsector has significantly expanded in the last two decades from 1990—92 to 2007—09. Myanmar's livestock production increased by 275 percent during this period as did China's livestock sector at slightly more than 200 percent. Production increases in other countries were not bad, ranging from 8 percent in Thailand to 88 percent in Viet Nam. This trend is in response to the so-called "livestock revolution" that has been taking place in the region because of the greater consumption of meat and dairy products. This shift, however, is not advantageous all the time. It could raise a number of new concerns. One example of such a concern involves the necessity of balancing crop output between that intended for food against that intended to be used as livestock feed. Another concern has to do with the increasing incidence of obesity and other illnesses resulting from the excessive consumption of livestock products.

Meat and milk production in DEAsia+ more than doubled from 1989 to 2008. The share of the meat output of DEAsia+ vis-à-vis the world's meat production increased from 22 percent to 34 percent while that of milk increased from 11 percent to 22 percent. China accounted for most of the meat produced in the country group. India, on the other hand, has been the milk production center of the region. It should be pointed out that milk production in DEAsia+ has grown more rapidly than anywhere else in the world, primarily due to the performance of India and China.

Fisheries and Aquaculture Subsector

Marine and inland capture fish as well as aquaculture production in DEAsia+ is estimated to have averaged 54 million tons in 2008 (**table 3**). This was about 50 percent of the world's total,which averaged 108 million tons. China leads all other countries in the region in the production and supply of fish from all three types of sources (i.e., marine, inland, and aquaculture) with its share of 28 million tons. DEAsian+ countries that are among the top ten producers of capture and aquaculture fish include Indonesia, India, Viet Nam, and the Philippines. These countries' combined fish catch accounted for about 17.8 million tons in 2007—09. Myanmar and Thailand followed with a combined fish catch of about 5.3 million tons in the same period.

Aquaculture is the fastest-growing of the three fishery subsectors. It has helped safeguard food and nutrition security as a supplementary source of protein, especially in remote areas. Aquaculture compensated for the production slowdown in capture fishery to adequately meet the increasing demand for fish in the region and the world. China, India, Viet Nam, Thailand, Indonesia, and the Philippines were among the top producers of aquaculture fish in 2006,contributing 42.5 million tons or about 82 percent of the world's total production (FAO 2009). China's aquaculture output increased at an average annual rate of 11.2 percent between 1970 and 2006. However, this growth rate recently declined to 5.8 percent from 17.3 percent in the 1980s and 14.3 percent in the 1990s.

DEAsia+ Countries as Major Suppliers of Food

The impressive production performances exhibited by the DEAsia+ countries enabled the region to become huge suppliers of food and other agricultural products.**Table 4** shows the net position of the countries in the trade of agricultural products. Except for milk and milk products, the region is a net exporter of other key food items like cereals (primarily rice), fruits and vegetables, and meat and fish.

Table 4. Net Trade Value in Agricultural Products (US$1000)

Countries	Cereals		Fruits + Vegetables		Meat		Milk		Fish		Total Agricultural Products	
	1999	2008	1999	2008	1999	2008	1999	2008	1999	2007	1999	2008
Developing East Asia+	(32,876)	4,149,475	4,917,075	13,250,924	949,150	1,292,439	(1,283,938)	(2,750,355)	3,224,020	6,209,294	7,754,520	16,891,048
Cambodia	(17,099)	17,036	(6,168)	(26,763)	(64)	(3,515)	(9,898)	(32,343)	26,019	28,514	(289,427)	(712,347)
China	(77,278)	(1,690,437)	2,429,864	9,480,128	256,657	(676,572)	(282,990)	(677,806)	1,436,558	2,970,071	(1,087,414)	(36,687,600)
India	514,233	3,481,687	464,941	(452,679)	187,350	1,235,475	(17,935)	143,114	226,870	430,883	672,374	8,166,476
Indonesia	(1,868,753)	(2,411,079)	170,028	(152,771)	(26,232)	(126,314)	(200,874)	(563,795)	550,120	618,811	399,551	17,389,217
Lao PDR	(2,470)	3,763	(380)	(7,175)	-	-	(6,500)	(9,802)	(1,085)	(2,656)	(44,649)	(182,171)
Malaysia	(639,568)	(1,977,648)	(219,900)	(515,994)	(140,172)	(336,812)	(189,238)	(341,495)	(137,354)	(189,251)	3,386,056	13,303,426
Myanmar	(140)	7,794	180,015	473,962	(213)	(696)			69,686	183,176	(79,969)	4,925
Philippines	(686,804)	(1,570,149)	428,611	1,342,843	(148,366)	(353,408)	(279,751)	(644,744)	92,453	140,341	(1,287,408)	(2,890,921)
Thailand	1,821,599	5,874,313	1,303,462	2,109,318	707,475	1,848,787	(190,072)	(327,648)	715,082	900,141	4,837,414	16,533,420
Vietnam	923,404	2,414,195	166,602	1,000,055	112,715	(294,506)	(73,965)	(249,529)	245,671	1,129,264	1,247,992	1,966,623

***Source*:**FAOStat (accessed 2010).

Rice is major export commodity and a big foreign-exchange earner for Thailand, Viet Nam, and India. Many countries in the region are also net exporters of fruits and vegetables (e.g., Thailand, China, and the Philippines), meat (e.g., pork from China and chicken from Thailand) and fish (especially those from aquaculture production in China, Thailand, and Viet Nam). China exports tilapia to as far as Africa while Viet Nam exports catfish to the developed world, particularly to the United States. Malaysia and Indonesia export palm oil.

Among the countries in DEAsia+, China, the Philippines, and Cambodia are net importers of agricultural products. The Philippines is now a major importer of rice. China is a huge importer of soybean products, palm oil, rubber, cotton lint, and, more recently, maize.

Importance of Continued Agricultural Growth

As has been previously discussed, agriculture is still very much the backbone of the economies of many countries in Asia, including those in DEAsia+. Its share of GDP, which averages 20 percent, can increase when the forward and backward links to agriculture (extended agriculture) are added. About 43 percent of the total labor force is in the agriculture sector, working mostly in the rural areas as smallholder producers or as laborers either in farms or in farm-related activities. Their incomes need to be raised to further reduce the incidence of poverty and malnutrition,which is still widespread in these countries, especially in the rural areas (**appendix table 1**).

Strong evidence has shown that there is no greater engine for driving overall economic growth and reducing poverty and hunger than investing in agriculture. For China, aggregate growth originating in agriculture is estimated to have been 3.5 times more effective in reducing poverty than growth outside agriculture. In fact, rapid agricultural growth in China as well as in India and Viet Nam was the precursor to the rise of these countries' industrial sector, similar to the way agricultural revolutions predated the industrial revolutions that spread across the temperate world from England in the mid-

18th century to Japan in the late 19th century (World Bank 2008; Bairoch 1973). Christiaensen et al. (2005) likewise estimated that a 1 percent increase in agricultural growth can lead to a 1.6 percent decline in poverty incidence in all low-income countries, 1.44 percent in Southeast Asia, and 1.73 percent in South Asia. Using cross-country regressions per region and taking the US$2-a-day poverty index, Hasan and Quibriam (2004) found larger effects from agricultural growth on poverty reduction efforts in Sub-Saharan Africa and South Asia.

3. Agricultural Research: Its Impact on Agriculture and Rural Development

The most valuable portion of investment in agriculture is that which is channeled to agricultural research. In the developing countries, this kind of investment has primarily come from the public sector and has been directed mainly towards technology development to increase food production. The greatest proof of such an achievement was the Green Revolution technology in cereals that took place in many countries, but especially in DEAsia+. The Green Revolution technology accounted for the unprecedented success of food multiplication and lower prices; it made food more affordable, especially for the poor (Swaminathan 2000). Agricultural R&D has indeed paid handsomely, yielding high rates of return of up to 43 percent in the developing countries (Alston et al. 1996; Alston et al. 2000; Evenson2001; Evenson and Gollin2003). Alston et al. (1996) additionally found that not only are the rates of return on agricultural R&D high but also that these rates are less likely to be below acceptable levels. A meta-analytic cost-benefit analysis showed that the benefit-cost ratios of agricultural research investments of the International Agricultural Research Centers (IARCs) under the umbrella of the Consultative Group of International Agricultural Research (CGIAR) are more than one, ranging from 1.96 to 17.94.

More recent estimates of rates of return to investments in agricultural research are shown in **table 5**. These figures are taken from Alston et al. (2000), and they are shown according to the "commodity" orientation of the research being evaluated. A total of 1,772 rates of return are included. The mean is 81 percent per year, and the range is from -100 to 5,645 percent per year. The median—44 percent per year—might be more meaningful. Over half of these rates of return (916 estimates) are for crops research, for which the distribution of rates of return is similar to that for the entire sample (although within that group, the results for wheat show a lower mean and a narrower range). Suphannachart and Warr (2010) recently estimated a 30 percent rate of return on Thailand's public investment in agricultural research, which is well above the opportunity cost of public funds.

Economic Gains from High-Yielding Rice and Other Grains

The Green Revolution has been one of the major success stories in scientific plant breeding, particularly with the development and widespread adoption of the short but sturdy high-yielding rice varieties (HYV) from the 1960s. Varietal development and improvement has continued since then not only for rice but also for other crops (**appendix table 2**). The relatively higher rates of varietal releases in rice, wheat, and maize are due to the research support of developed countries, which shared their technological backlog—both in germplasm and knowledge—to help expand grain yields and stave off the widespread hunger that almost happened in the 1960s and 1970s. The improved rice varieties were estimated to have accounted for as much as 50 percent of yield growth in the 1980s and 1990s compared with the 21 percent yield growth in the preceding two decades (i.e., 1960s and 1970s). Furthermore, the yield increases were estimated to have provided an annual economic benefit exceeding US$19.5 billion (Evenson and Gollin 2003). The adoption by farmers in Asia of the modern rice varieties developed by the International Rice Research Institute (IRRI) was estimated to have yielded an annual return of US$10.8 billion, nearly 150 times the combined annual investment in rice research by IRRI and the national systems.

Table 5. Estimates of Rates of Return of Investments in Agriculture Research per Year

Commodity	No.of Observations	Mean	Mode	Median	Min	Max
Multi commodity[a]	436	80.3 *(110.7)*	58.0	47.1	-1.0	1219.0
All agriculture	342	7.0 *(110.9)*	58.0	44.0	-1.0	1219.0
Crops and Livestock	80	106.3 *(115.5)*	45.0	59.0	17.0	562.0
Unspecified[b]	14	42.1 *(19.8)*	16.4	35.9	16.4	692.0
Field Crops[c]						
Maize	170	134.5 *(271.2)*	29.0	47.3	-100.1	1720.0
Wheat	155	50.4 *(39.4)*	23.0	40.0	-47.5	290.0
Rice	81	75.0 *(75.8)*	37.0	51.3	11.4	466.0
Livestock[d]	233	120.7 *(481.1)*	14.0	53.0	2.5	5645.0
Tree Crops[e]	108	87.1 *(216.4)*	20.0	33.3	1.4	1736.0
Resources[f]	78	37.6 *(65.0)*	7.0	16.5	0.0	457.0
Forestry	60	42.0 *(73.1)*	7.0	13.6	0.0	457.0
All studies (Total)	1772	81.2 *(216.1)*	46.0	44.0	-100.0	5645.0

***Source*:** Alston et al.(2000).

***Notes*:** Standard deviations are given in parentheses. Samples exclude two outliers and include returns to research only and combined research and extension.

[a] Includes research identified as "all agriculture" or "crops and livestock" as well as "unspecified"

[b] Includes estimates that did not explicitly identify the commodity focus of the research

[c] Includes all crops, barley, beans, cassava, sugarcane, groundnut, maize, millets, other crops, pigeon pea or chickpea, potato, rice,sorghum, and wheat

[d] Includes beef, swine, poultry, sheep or goats, dairy, other livestock

[e] Includes "other trees" and "fruits and nuts"

[f] Includes forestry and fishing

The enormous progress in raising the productivity of Asia's rice farmers has ensured the availability of high-quality and safe rice at more affordable price levels. One simple but telling example of progress is the rise in rice consumption per capita in the poorestquintile of India's rural households—arguably among Asia's most food-insecure families—from 0.90 kilograms per week in 1983 (all of India) to 1.43 kilograms per week in 2004—05 (Timmer et al. 2010). Without the yield gains, world cereal prices would have been 18 percent to 21 percent higher in 2000, caloric availability per capita in developing countries would have been 4 percent to 7 percent lower, and 13 million to 15 million more children would have been classified as malnourished.

Another key impact of the significant yield improvement was the slowdown in the expansion of areas cultivated for rice into marginal and fragile areas. Again, IRRI rice research alone has spared 13 million hectares of natural ecosystems from being brought under cultivation, with attendant environmental benefits (Asia Society and IRRI 2010).

Other Technologies and Their Impact on Agricultural Growth

In addition to HYV development, many other technologies have been developed that successfully raised production. These include the farm-management practices that reduce production cost, promote more efficient use of inputs, and protect natural resources and the environment. The zero-tillage technology now used in the rice-wheat production systems of South Asia is an example of a technology that helps increase farm output while promoting the efficient use of inputs and protecting the environment. The technology has helped save water, fuel, and other inputs; facilitated timely planting; reduced tillage needs and burning of crop residues; and allowed farmers to diversify the cropping system (Hobbs et al. 2010, online). The wider adoption of zero tillage in a million-hectare area could save as much as 100 million cubic meters of water per year plus 60 million liters of diesel fuel. The use of zero tillage for wheat saves more than 50 liters of diesel per hectare, representing savings of 75 million liters of diesel fuel, which is worth more than US$40 million region-wide, and substantially reduces the emission of greenhouse gases. Other beneficial technologies developed and adopted are the alternate wetting and drying of rice farms, integrated crop and resource management, integrated pest management, and water-harvesting technologies that are not only environment friendly but are also efficient in terms of labor, water, energy, and nitrogen use.

On-farm conservation of coconut genetic resources has safeguarded the characteristics of local coconut varieties and, subsequently, the economic base of coconut farmers in the Philippines whoare primarily dependent on the coconut industry for their livelihood. The project,which was aimed at protecting the biodiversity of the commodity, also helped generate coconut-related technologies that doubled the incomes of poor farmers and reduced poverty in the project communities from 44 percent to 6 percent (Bioversity

Center 2005). A similar effort in vegetables led to the accession of indigenous vegetable cultivars, which are now kept in the World Vegetable Center.

Capacity Building, Networking, and Policy Advocacy

Almost all research projects have capacity building as a key component. Capacity building comes in many forms:training from short-term (knowledge transfer) to long-term (degree programs) in the form of bilateral scientific exchanges, networking and development of research consortia to facilitate technology dissemination, and community mobilization to create public awareness, among others.The capacity-building component enabled a huge number of local scientists to gain knowledge and expertise on a wide array of subjects and fields of critical concern to increasing production: applied genomics (marker development, phenotyping and genotyping, and data analysis); biotechnology tools; seed production technologies; new production management technologies, including integrated pest and nutrient management; and others. Quite a significant number of women were likewise trained as scientists and managers although empirical studies have repeatedly shown a disproportionately low number of them working in senior scientific positions (Beintema and Stads 2008).

Regional research institutions and networks, such as the Asia-Pacific Association of Agricultural Research Institutions (APAARI), Cereal and Legume Asian Network (CLAN), Consortium for Upland and Rainfed Environment (CURE), Council for Partnership on Rice Research in Asia (CORRA), Plant Genetic Resources Network, Rice-Wheat Consortium (RWC), and others like these that are organized as vital components in agricultural research have become key repositories of valuable data and information and are excellent venues forthe exchange of information. The returns to these networks are likely to be substantial considering the small investment cost incurred (Pray2006). These regional networks help disseminate technologies and inform partners on new developments in agriculture.

Another vital component of some research projects is policy advocacy to inform policy makers on research results. Science-based policy recommendations have helped guide and facilitate development activities to achieve inclusive and sustainable growth. A few key ones that country governments have responded to are the adoption of zero-tillage technology in India and other South Asian countries; the call for public-private partnership in the promotion of hybrid rice; the promotion of aquaculture to reduce dependence on capture fisheries; and the institution of more friendly trade reforms to strengthen the linkage of domestic to international markets.

Technologies Generated and Adopted by National Agricultural Research

There are also significant technologies developed by the national research institutions of DEAsia+ that similarly helped boost the performance of their respective agriculture sectors. Some of these are purely local initiatives while others received either financial or technical foreign assistance.

China's postrevolution reforms in research and technology resulted in ten major scientific and technological achievements by 1996. These technologies include the (1) development of high-yielding and high-quality multiresistant crop varieties, including the Hybrid and Super rice; (2) transgenic, insect-resistant cotton; (3) large-scale adoption of high-yield integrated crop technologies; (4) energy-saving solar greenhouses for vegetables, fruits, and flower production; (5) management of migratory bollworm, brown plant hopper, and pest forecast; (6) livestock and poultry breeding and disease management; (7) new feeds and additives; (8) information and communication development technology; (9) efficient use of water and fertilizer resources resulting in water conservation; and (10) large-scale use of regulation technology in fertilizer application (Yinlong 2009). The success of hybrid rice in China is so impressive that other nations have adopted the technology. China is now producing about 118 million tons of paddy rice from a total of 18 million hectares planted to hybrid rice. In comparison, India produces an equivalent amount from almost 42 million hectares.

Other successful technologies primarily produced by national research centers are shown in **table 6.** Gains from Thailand's baby corn technology and the Philippines's tilapia technology are briefly discussed in **box 1**.

Table 6. Some Successful Technologies Produced by the National Agricultural Research System (NARS)

Technologies	Country	Technologies	Country
Baby corn production	Thailand	Oilseeds	India
Tilapia farming	Philippines	Integrated pest management in rice	Indonesia
Hybrid rice	China	Bivalve mariculture	India
Dairying	India	Farming carrageenophytes	Philippines
Hybrid cotton	India	Resource conserving technologies in rice -wheat systems	Indo- Gangetic Plains
Palm oil industry	Malaysia	Newcastle disease in native chicken	Bangladesh
Cotton production	Pakistan	Classicla biological control of pests	India
Orchids	Thailand	Sustaining the Green Revolution	India
Wheat production	Iran	Rainbow trout culture	Nepal
Direct seeded rice	Malaysia	Bt Corn commercialization	Philippines
Groundnut	China	Bt cotton	India

***Source*:** APAARI

Box 1. Some Successful NARS-led Research and Technology Development Efforts

The Baby Corn Industry in Thailand. Behind the success of the baby corn industry in Thailand was the development of composite baby corn varietiescharacterized by high yield, yellow color, good row arrangement, and resistance to downy mildew,which affected the industry prior to 1976 when the breeding work started. The strong support of the Thai government for the breeding work led to the development of good hybrid and open-pollinated hybrid corn varieties, which are now widely used. The strong participation of the private sector in promoting the production, processing, and marketingof baby cornadded to the success of the industry. Indeed, the production of baby corn helped farmers diversify from rice and gain additional profitsamounting to US$273 per hectare. Baby corn has also become a major export commodity,bringing in significant foreign exchangefor Thailand.

Tilapia Technology in the Philippines. Breeding improvement and improved farming practices in the Philippines for tilapia are another success story for NARs-led research efforts. The adaptation of the sex-reversal technology on the Nile tilapia and its commercial production in floating cages made the country one of the top aquaculture producers in the region and the world. The extension of the technology to small farmers through solid government programs did not only provide additional income but also an inexpensive source of protein for communities. The engagement of the private/commercial sector, on the other hand, helped enhanced fish production, which, in turn,alleviated the shortfall from capture marine fisheries.

Source: APAARI Publications

Total research investment in DEAsia+ reached US$5.1 billion in 2002 from US$2.9 billion in 1991 (**table 7**). Half of the latest figure was spent in China and more than a quarter in India. Malaysia reported the third largest expenditure, followed by Indonesia, Pakistan (not shown in the table), the Philippines, and Bangladesh (also not shown in the table). The remaining five other countries in the sample surveyed (i.e., Laos, Nepal, Papua New Guinea, Sri Lanka, and Viet Nam) spent slightly more than US$100 million on public agricultural research in 2002. Despite the benefits gained, public investment in agriculture and agricultural research has slowed down in all countries in DEAsia+ except in China and India (**figure 2**).

The growth rate in public spending on agricultural research between 1991 and 2002 was 4.6 percent per year. Rapid growth started only in the late 1990s when China and India accelerated their spending on agricultural research. The 4.6 percent annual growth rate was primarily due to China, which more than doubled its spending on agricultural research as it pursued reforms to invigorate its economy through increased agricultural productivity. India's agricultural R&D expenditures likewise grew at 8.4 percent per year during the period 1996—2002, reflecting the Indian government's commitment to all fields of research, including the agricultural sector (Pal and Byerlee 2006). The financial resources of other countries in DEAsia+ for agricultural research were greatly affected by the Asian financial crisis in the late 1990s. In Indonesia, real agricultural R&D spending fell by one-third in 1997—98 alone and spending levels remained below precrisis levels in 2003. Laos suffered mass inflation in recent years,which greatly reduced spending on agricultural research. The strong increase in agricultural-research spending in Viet Nam, however, resulted from the national government's prioritization of agricultural and rural development.

Table 7. Public Agricultural Research Spending, 1991—2002

Countries	Total Spending (million 2005 international $)			Growth Rates (%)[a]		
	1991	1996	2002	1991-96	1996-2002	1991-2002
China	1,174	1,531	2,574	4.4	7.9	5.4
India	746	861	1,355	2.8	8.4	6.5
Indonesia	220	255	177	3.6	-7.9	-4.4
Laos[b]	*na*	*na*	13	*na*	-5.1	0.4
Malaysia	227	267	424	2.6	6.9	4.4
Philippines	80	121	141	9.2	0.7	4.4
Vietnam	8	22	56	18.8	19.6	19.1
12 Sample countries (includes China)	2,854	3,438	5.125	3.5	6.8	4.6

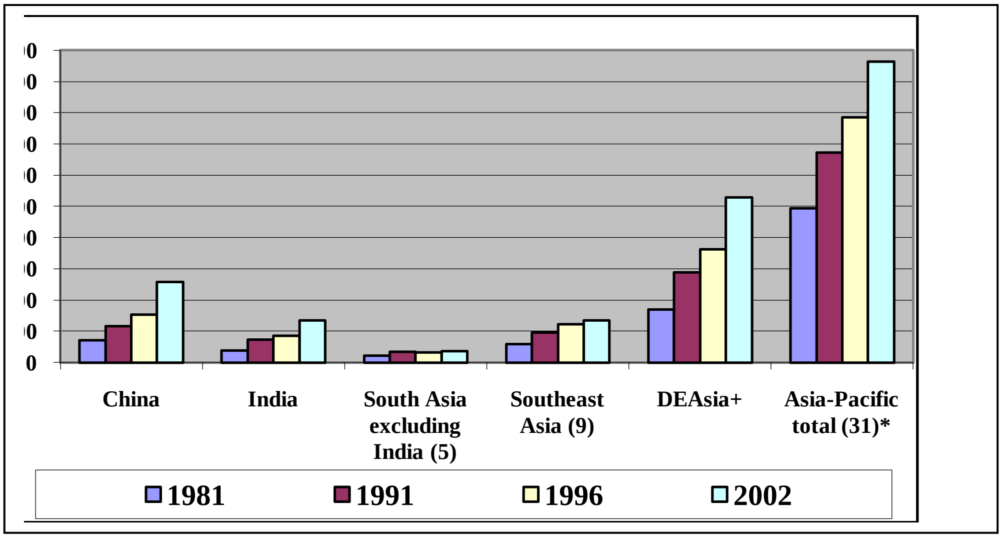
***Sources*:**Derived from table 7 of Beintema and Stads2008b; authors also compiled data from datasets underlying the ASTI country briefs and reports (ASTI 2005--08); revised PPP indices and GDP deflators from the World Bank (2007, 2008); data for China are from MOST (various years); 1991 research staff for India and Indonesia were estimated using ASTI data and information from Pal and Byerlee (2006) and Fuglie and Piggott (2006),respectively.

***Notes*:** The figures came from the responses of the 12 countries surveyed. The other countries included are Bangladesh, Nepal, Pakistan, Sri Lanka, and Papua New Guinea. *na* indicates not available.

a Annual growth rates werecalculated using the least-squares regression method, which takes into account all observations during a period;the resulting growth rates therefore reflect general trends that are not disproportionately influenced by exceptional values, especiallyat the end-point of a period.

b 1991--2002 growth rates for Nepal and Laos were based on estimated time-series data for 1991—95 and 1991—97, respectively.

Figure 2. National and regional trends in public spending on agricultural R&D, 1981—2002, in 2005 international dollars of total spending



***Source*:**Beintema and Stads(2008a)

***Notes*:** Asia-Pacific total includes those of the Pacific Islands and the OECD countries in the region (e.g., Japan, Brunei, Singapore, etc).

Decline in Investments in Agriculture and Research

Private-sector involvement in agriculture and agricultural research remains small in Cambodia, Lao PDR, and Viet Namgiven their weak funding incentives (Singh 2009). In Malaysia, private sector-led scientific research was mainly in the manufacturing sector. The limited involvement of the Malaysia's private sector in agricultural research (5 percent of total public and private spending in 2002) was focused on plantation crops (e.g., oil palm, coconut palm, sugarcane, and rubber) and much of this involvement was linked to the government. The promotion of private-sector involvement is gaining impetus, however, with the Malaysian government's increasing recognitionof the importance of agriculture in sustaining economic growth.

The involvement of the private sector in agricultural research is relatively high in India, the Philippines, and Indonesia compared to the rest of the developing world. This involvement has been primarily in biotechnology research. Private-sector involvement in Chinese agricultural research has also rapidly risen in recent years. Zhang, Fan, and Qian

(2006) estimated that about one-fifth of these agribusinesses are involved in agricultural research. As a result, the share of the private sector in total spending on agricultural R&D was 9 percent in 2003. Most of these agribusiness firms, however, were still at least partially state-owned but this is rapidly changing with the government's adoption of policies that encourage private-sector participation in agricultural research.

4. Emerging Issues and Challenges

The decline in investment in agricultural research has been creating great apprehension, considering the continuing challenges to be overcome and the emerging threats that have to be met head on.

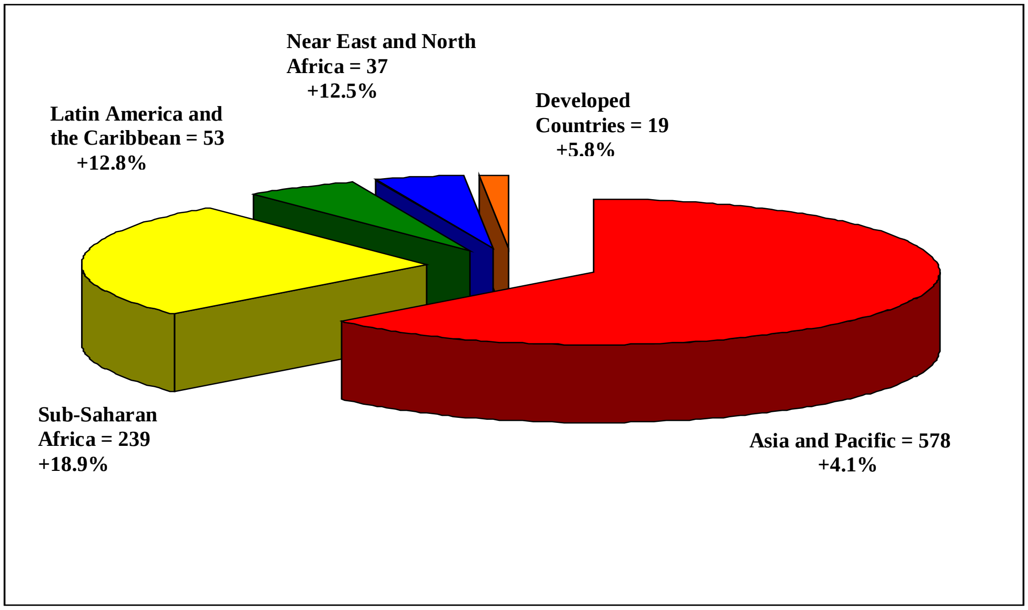
Continuing Challenges

Population growth and rapid urbanization continue to put pressure on agricultural production and its resources, especially in the light of the persistence of undernourishment and poverty in the region. The numbers have remained stubbornly high (appendix table 1) and even recently increased with the food crisis (von Braunet al. 2008).

Asia-Pacific, as a whole, is still the home of 578 million hungry people (**figure 3**).[2] The DEAsia+ countries account for most of them with the inclusion of the two most populous countries, China and India, as well as countries that continue to have relatively high population growth rate like the Philippines. China and India account for 42 percent of the

[2] This is smaller than the 2009 figure of 642 million people.

Figure 3. Estimated Regional Distribution of Hunger in 2010 (in millions) and Increase in Hunger Incidence from 2008 levels (in %)



Source**:** State of Food Insecurity 2010, FAO.

world's hungry. India is home to 39 percent of the world's underweight children, the prevalence of which is twice as high as that found in Sub-Saharan Africa. China also accounts for 129 million of the region's undernourished people, majority of whom are in rural and landlocked provinces where productivity is relatively low. Other countries in the group have experienced rising incidence of poverty and malnutrition, which draw them farther from meeting the Millennium Development Goals (MDGs), especially Goal 1, which is to halve poverty and hunger by 2015.

In addition to increasing population and persistent poverty and hunger, agricultural productivity is slowing down due to several factors, including the (1) continued contraction of farmholdings; (2) exhaustion of the potentials of current technology to further increase yield levels; (3) degradation of land and water quality as well as forest cover due to unsustainable production practices; and (4) increasing competition overinputs such as land, water, and labor from nonagricultural sectors. The migration of men to the cities for more lucrative income opportunities has left the burden of farm work primarily to women.

Emerging Threats to Production and Agricultural Growth

There are a number of emerging threats to production and agricultural growth. The three most important threats are briefly discussed in this subsection. The first threat pertains to rapidly rising fuel prices that increase the cost of production (which, in turn, translates to lower net profits for farmers or higher food prices for consumers) and the competition for the same production resources resulting from the expansion of the biofuel subsector. The second threat relates to climate change. The third threat is the increasing globalization of markets, which has threatened the competitive stance of DEAsia+ countries and hindered small farmers from participating in world trade.

Energy security and the expansion of the biofuel subsector. The rise in fossil fuel prices has influenced the fluctuation in, and volatility of, food prices because of the heavy linkage of agricultural production to energy in terms of the inputs used (primarily fertilizers and fuel-run equipment and machinery). Increasing food production to meet higher demand equates to increased reliance on fossil fuels. The challenge in DEAsia+ (or anywhere else, for that matter) is to develop appropriate renewable-energy technologies that address broader socioeconomic and environmental issues.

While the current scope and nature of biofuels production and use in the DEAsia+ countries are still unlikely to have a negative impact on food security, there is a clamor to further increase biofuel production, and this may compound many of the problems that have rippled throughout the international food market. Further research on the potentials of biofuels is needed. At the same time, long-term R&D on increasing the energy yield of potential crops for feedstocks, an important determinant of future biofuel development, would (1) contribute greatly to productivity and control the land area used for energy cropsand (2) promote the use of wasteland or underutilized land to grow productive food and energy crops for biofuel feedstock through theapplication of intercropping techniques.

Impact of climate change. Increased intensity andfrequency of storms, droughts and floods, altered hydrological cycles, and precipitation variance have serious implications on future food production, particularly in DEAsia+ where many countries are hard hit by these disasters. According to the Intergovernmental Panel on Climate Change (IPCC), cereal production Asia as a whole is expected to suffer severely with climate change (IPCC2007). Rice production alone could decline by 3.8 percent by the end of the twenty-first century as a consequence of the combined influence of the fertilization effect and the accompanying thermal stress and water scarcity (Murdiyarso 2000).[3]

The challenge posed by climate change to food security is indeed considerable. Hence, the need to strengthen the natural foundations ofagriculture, such as water, land, and ecosystems, through sound management of natural resources in order to enhance the resilience of the sector to the impacts of climate change.

Trade liberalization and globalization of food markets. Trade liberalization opens up domestic markets so that more, and possibly cheaper,goods become available, which could then help ensure food security across countries (Sen 1997). While this can be beneficial to consumers, it puts pressure on local producers who will have to improve production efficiency to compete with cheaper imported goods. The key challenge that these countries face would be to improve production efficiency to lower cost and, at the same time, aim for the production of safe and high-quality food. Alongside improving production efficiency is the need to adopt the least trade-distortive policiesthat will open new trading opportunities but leave enough flexibility (i.e.,policy space) to allow interventions when market and economic circumstances change. Such policies should increasingly enable even the smallfarmers to take part in the globalized and commercialized agrifood systems.

[3] This is one of the projected climate-change scenarios based on those predicted by global circulation models.

5. The New Approach in Agricultural Research and Development(AR&D)

AR&D is needed to overcome the numerous constraints and challenges. However, more of the same will no longer be enough. AR&D should be refocused to address the weaknesses and gaps of past research efforts that have surfaced because of changes in the political, social, and economic frame conditions that are also affecting agriculture.

Past Research Focus

Table 8 shows the research focus of Southeast Asian countries by commodity. Crop research has the largest share followed by forestry, livestock, natural resources, and postharvest researches. **Appendix table 3**indicates that rice attracted the largest share in crops research in most Southeast Asian countries. Nonetheless, work has also been done on other commodities although on a limited scale. Malaysia focused on oil palm, for example. Vegetables, fruits, bananas and plantain, and corn each had a share in crop research intensity that ranged from 8.1 percent to 9.6 percent. Similarly, in India, crops (primarily rice) accounted for 58 percent of research studies (Beintema and Stads 2008b). The remaining 42 percent was devoted to livestock research (15 percent), forestry (7 percent), fishery (5 percent), postharvest (4 percent), natural resources (6 percent) and other areas (5 percent).

Table 8. Commodity Focus of Agricultural Researchers

	Indonesia	Laos	Malaysia	Myanmar	Philippines	Vietnam	Total	Share (%)
	in full time equivalent (FTE) researcher							
Crops	1,995.8	35.4	664.5	416.1	1,923.4	1,208.7	6,243.9	46.1
Livestock	452.2	15.8	131.6	111.1	376.9	398.3	1,485.9	11.0
Forestry	640.1	21.7	175.3	52.6	370.2	386.8	1,646.7	12.2
Fisheries	187.9	14.3	82.4	29.0	243.1	242.5	799.3	5.9
Postharvest	198.4	3.0	71.7	0.0	0.6	72.1	409.9	3.0
Natural Resources	491.1	24.7	37.6	6.9	123.1	264.4	947.8	7.0
Others	1,153.7	10.5	37.6	3.0	424.6	377.9	2,007.3	14.8
Total	5,119.3	125.4	1,200.7	618.7	3,525.8	2,950.8	13,540.7	100.0

***Source*:** ASTI database (shown as table 3.5 in Raitzer et al. 2009).

***Note*:** The reported number of full-time equivalent (FTE) researchers is often somewhat lower than the actual totals due to the fact that some agencies failed to complete the research focus section of the questionnaire. The data presented here represent all sectors, including the private sector.

Appendix table 4 shows the distribution of research activities related to livestock development. Beef cattle and poultry garnered the biggest number of research work followed by research on sheep and goats, dairy, and swine.

Research studies undertaken based on thematic area is shown in **table 9.** The major research themes identified in both national and international agricultural research were genetic improvement and natural resource management. National research institutions focused on pest and disease control and postharvest technologies while international research centers did significant work related to policy and institutional issues.

Table 9. Thematic Focus of Past Research Studies in Southeast Asia

Themes	National Agricultural Research Institutions (2002-2003)	International Agricultural Research Instituions (2008)
Crop genetic improvement	14.6	18.6
Livestock genetic improvement	4.4	
Crop pest and disease control	9.8	
Livestock pest and disease control	2.7	
Other crop	14.6	
Othe livestock	7	
Diversification and high value commodities		13.7
Soil, water, other natural resources/ Integrated natural resource mangement	16.3	28.6
Sustaining biodiversity		8.3
Post harvest technologies	4.7	
Policies and institutional innovations		22.8
Others	25.9	8.0
Total	**100**	**100**

***Source*:** ASTI database (as cited in Raitzer et al. 2009).

Jha and Kumar (2006) also revealed that nearly 35 percent of research resources in India were focused on germplasm improvement, 26 percent on agro-chemicals, and 21 percent on soil and water research. More than 55 percent were devoted to raising the productivity of natural resources. Material resources (such as agro-chemicals, power, and machinery) collectively claimed about one-third of research resources. The rest was spread across socioeconomics and other resources.

Filling the Gaps and Responding to the Challenges[4]

The bias on rice, especially in the conduct of basic research which is critical for scientific breakthrough, is clear from past research efforts. These efforts also dwelt on developing and promoting farm-management practices that boosted production but with less regard

[4] Discussion in this section is taken primarily from the e-consultation and face-to-face consultation with various stakeholders initiated by the Global Forum for Agricultural Research (GFAR) on the future focus of agricultural research; also from Singh 2009.

for the environmental consequences of such production. These biases have to change if agriculture in DEAsia+ has to respond to changing economic and environmental structures such as the shift in demand for more diverse diets that increasingly include fruits, vegetables, meat, dairy products, and fish; increased vulnerability to shocks; and globalization of markets. A research reorientation is required to build competitive advantage in high-value subsectors; design new production systems that are more well-aligned with the carrying capacity of the natural resources; broaden the growth base in rainfed and marginal areas; and adjust the price equations of production and technology decisions. The same reorientation will have to continue factoring in the needs of smallholders and marginal farmers not only in rice but also in other crops. Social science (policy analysis, policy interfacing, agricultural markets/trade/value chain analysis), natural resources management research (NRM), maintenance research, and human capital formation also need to be given greater priority in defining future research agenda.

Table 10 shows the translation of these challenges and gaps into the necessary research and development agenda for Southeast and South Asia. Examples of more specific research activities are listed in **appendix table 5**.

Basic Research for Technology Development

Intensified basic research on rice, wheat, and maize (the Green Revolution crops) must continue as these are the foundation of food security and livelihoods particularly of small and marginal farmers (Chand2009). However, the pitfalls of the Green Revolution that adversely affected natural resources (e.g.,loss of biodiversity, environmental pollution, land and water degradation, and enhanced pestilence) and which resulted from inappropriate/injudicious use of technology should be avoided. In addition, basic research on the development of the horticulture, livestock, and fisheries (aquaculture, in particular) subsectors needs to be enhanced. The demand for these high-value commodities is growing rapidly on the global market and, as such, these commodities have a great deal of potential to raise incomes, reduce poverty, hunger, and malnutrition.

Productivity and nutritional quality should also be enhanced through genetic improvement. Biotechnology, nanotechnology, and other related sciences can help address the various productivity challenges, especially in terms of preventing, avoiding, and diagnosing diseases of plants, animals, and marine life. These fields may also be able to offer new pathways to food and nutritional security and poverty alleviation. Developed countries should help the developing countries. The more developed countries in DEAsia+ (e.g., China, India, Indonesia, Malaysia, the Philippines, Thailand, and Viet Nam) that are making major investments in biotechnology should also lend technical assistance to their less-developed neighbors. Ongoing biotechnological programs that have previously been country- and commodity-specific have to be linked to one another as well as to programs that ensure biosafety and the conservation of biodiversity (and, therefore, biosecurity).

Table 10. Projected Agricultural Research Agenda in South and Southeast Asia

	South Asia	Southeast Asia
Increased Productivity		
Food Staples	Rice, wheat, local staple cereals, pulses	Rice
Diversified crops/livestock	Horticulture, fisheries, livestock	Vegetables, fruits, aquaculture
Thru science and technology	Germplasm conservation and improvement	Genetic improvement, management of biotic and abiotic stresses
Improved Value-Chain Development/Bioecosystem Research (weak links in the chain; food-feed-fuel-fiber nexus)		
Infrastructure: farmer-market links	Postharvest, agro-processing, Management; ICT Safety and Quality	Postharvest ICT Safety and Quality
Markets andnetworks/partnerships	Public-private-partnerships (PPPs); south-south cooperation	PPPs South-south cooperation
Increased Resilience		
Climate change management	Adaptation and mitigation	Adaptation and mitigation
Economicshocks	Rural and nonfarm jobs Risk management	Resilience to market volatility

***Source*:**Singh(2009).

Research on Natural Resources Management

Research on appropriate and sustainable production and management practices has to be enhanced and directed towards the development of farming systems that also help (1) conserve the use of natural resources, particularly land, water, and natural ecosystems and (2) improve the resilience and competitiveness of farmers, especially against climate change and various economic shocks. Work on improving rice-based systems has to continue while future research in the following areas—crop-livestock-farming systems based on integrated food-fodder-feed-breed-health and biosecurity management to reduce threats from transboundary animal diseases and epizoonotics—needs to be enhanced. Diversification of aquaculture will also have to be done through breeding and development of feeding and seeding technologies. There is a need to pursue agroecological and biodiversity-based farming technologies with great potential in meeting the region's food security, productivity, environmental, and social-sustainability goals.

<u>Integrating Local/Indigenous Knowledge with Science</u>.Farmers' indigenous knowledge and traditional technologies,especially those on conservation (e.g., plant propagation, seed storage, etc.), sustainable management and use of natural resources (e.g., schedules of field preparation and crop establishment, knowledge and use of forest plants and animals, selection of fodder and forage species for animal feeds, pest management and plant-protection methods), and the production systems that go with them (e.g., rice-based farming systems like rice cultivation-fish culture, rice cultivation-duck raising, etc.) should be strongly related to basic research.

<u>Postharvest Handling, Processing, and Value Adding</u>. R&D on postharvest handling to prevent losses and on efficient agro-processing interventions should be emphasized so as to add value and make locally grown or –raised products more attractive or appealing to local and international markets. The same R&D effort has to be done for fish processing and marketing to sustain the profitability of thesmall fishermen who derive income from coastal resources.

Climate Change and Bioenergy Research

Research on climate adaptation and mitigation is still quite inadequate in most countries. There is a need to identify more appropriate intervention measures in order to reduce the expected impacts of climate change. **Appendix table 6** shows the research studies on genetic and resource management that need to be undertaken to identify appropriate and sustainable measures that will strengthen the resilience of the agriculture sector against climate change and protect the small and vulnerable farmers. The recommended research activities include enhanced breeding work, improvement of farm/production practices, information dissemination and public awareness campaigns, and adoption of effective regulatory measures and policies to correct human- and industry-induced malpractices.

In the case of bioenergy development, research is important to develop alternative feedstocks for biofuel production. At the same time, more efficient and sustainable production processes have to be explored and experimented on. The key issue in biofuels development is minimizing the environmental footprintresulting from the biofuels production process. Public-private partnership in research and investment should be pursued in developing sustainable production technologies in biofuels.

Socioeconomic Research

The importance of socioeconomic research will have to be intensified to quickly analyze and understand issues critical to formulating policy and provide information to decision makers. Policy- and decision makers need to balance food supply and demand in a way that will benefit all stakeholders. At the same time, they face conflicting views on the environmental consequences of increasing productivity, controlling growth in demand, the environmental and human health impacts of transgenic crops, the consequences of bioenergy development on the environment and on the long-term availability and price offood, and the implications of climate change on agricultural production. Socioeconomic research includes impact assessment, risk evaluation, market and trade analysis, and similar efforts that provide science-based information for policy formulation and decision making. Of critical importance is the analysis of high-value markets that are increasingly organized in retail chains and which are becoming threats to small-scale producers because of the possibility of them (small-scale producers) being marginalized. Analysis of the commodity value chains can provide opportunities for upgrading small-scale production through value-added activities, organization of small farmers into cooperatives, acquisition of necessary capital andtechnology, development of management skills, and overcoming problems in relation to scale requirements, including certification.

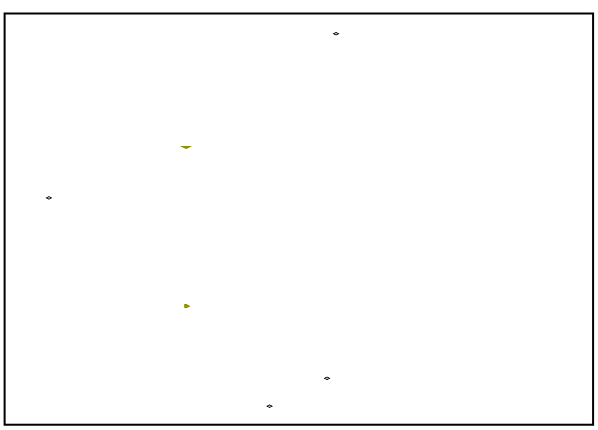
6. A Holistic Approach to Agriculture Research and the Need for Expanded Cooperation

Unlike in the past when research activities could be done by individual scientists working in isolation, the complex challenges that confront the achievement of more equitable and sustainable development require that agricultural research be now conducted in a holistic manner involving a pool of multidisciplinary experts and the cooperation of institutions within and outside the country.

A Holistic ResearchApproach

Figure 4 shows a holistic approach to the development of an agricultural research framework with four dimensions: the socioeconomic, science/knowledge, institutional, and global dimensions. The dimensions are shown as a continuum with cross-linkages to indicate the need to consider all four dimensions in the design of research projects.

Figure 4. A Holistic Approach to Agricultural Research



***Source*:** Chaparro (1999).

The socioeconomic landscape has seen many rapid changes. On the supply side, these changes include the exhaustion and degradation of natural resources combined with the threat of climate change. On the demand side, there is continued population growth, rapid urbanization, undernutrition, and micronutrient deficiencies, among others. These changes are putting a great deal of pressure on food production. Small and marginal producers, for example, are under pressure not only to raise agricultural productivity in order to enhance food supply but also to produce the right crops to help the populace consume more nutritious food. Socioeconomic factors have likewise made it a challenge to strike an appropriate balance between food supply and demand that benefits both producers and consumers.

There are new areas in science and technology that offer additional potential to increase current capacity to respond not only to technical issues in food production but also to social and economic challenges. The use of such technologies, however, should be carefully weighed against the conventional tools of plant breeding and on-farm research experimentation primarily in terms of cost efficiency and the capacity of stakeholders to adopt them. Biotechnology and nanotechnology, for example, often carry with them proprietary tags that may be too expensive for developing countries to use. The globalization dimension can be included in the research framework to overcome these proprietary issues and to ensure that the capacities of scientists and researchers in thedeveloping countries (including some countries in DEAsia+) are strengthened to enable them to understand and apply the tools.

The institutional dimension of the research framework ensures that the necessary measures and processes are in place to help overcome proprietary issues and ensure the smooth flow of knowledge and exchange of technology. This will strengthen the capacities to learn, adopt, and use new technologies, especially among small producers who are the ultimate users. Technological innovations are now seldom generated by individual research institutions or firms. They are increasingly the product of transnational research networks, or networks of learning, that play a central role in the process of knowledge generation and knowledge dissemination and applications (Powell et al. 1996). The institutional dimension helps establish strategic alliances and partnershipsthatare essential for new science and technology to work increasingly for small farmers and achieve more inclusive growth.

The Need for an Expanded South-South Research Collaboration

DEAsia+, and developing countries as whole, have greatly benefitted from the North-South research collaboration that came about as early as the 1960s with the development and spread of technologies such as the Green Revolution. The knowledge flow (e.g.,new research tools) and technology transfer from advanced research institutes and the private sector (mostly in developed countries) to the national research institutes of developing countries helped increase food supply and, at the same time, benefitted small farmers. Furthermore, the collaboration helped improve the relevance, quality, and efficiency of research as clients' needs and the potential "market" for products werebetter understood and partners with greater knowledge and skillsor usable products or servicesassisted in the conduct of research at lower cost.

While the North-South research collaboration continues, the South–South research collaboration is expected to heighten asthe scientific hierarchy in the developing countries creates classes of leaders and followers,enabling some of them to "give" and others to "gain" through scientific collaboration (Osama 2008). Countries like China, India, the Philippines, and Indonesia, for example, have relatively more advanced scientific and technical knowledge (e.g., in biotechnology) that they are extending tobuild the capacities of their neighboring countries in new research tools and technologies. Moreover, therapid economic growth in some developing countries (e.g., China and India) has spurred more investments in research; thus, creatingmore opportunities and impetus for greater collaboration.

South-South research collaboration among the DEAsia+ countries in particular needs to be expanded and strengthened:

a) To enable countries to work together on shared problems,especially those countries that share social or geographical environments andhave similar socioeconomic circumstances and scientific standing. Examples of such collaboration would be on tropical plant pests and diseases; transboundary animal diseases; threats from challenges like climate change, rapid population growth, food insecurity, and others.

b) To broaden opportunities for researchers working in developing countries and to open avenues for professional advancement, especially for those countries with poor international relations and limited resources.

c) To encourage countries to help one another develop their indigenous capacity to generate, manage, and use science and technology to address their needs; attune research to their particular needs; and create a critical mass of scientists either on a sectoral or regional level with the necessary momentum to solve challenging problems.

d) To ensure greater participation of small producers in the region and to enhance their competitiveness so that they will thrive in the more commercialized markets that used to be the domain of large and export-oriented producers.

e) To increase the impact of research by drawing on the experience of partners and bringing in more technical or cultural knowledge to the investigation process.

Public-Private Sector Partnership

The new agriculture that is characterized by far-reaching technologies and innovations and dynamic markets in extensive value chains clearly suggest the importance of private sector involvement in AR&D. Private-public sector alliance has to be promoted by putting in place appropriate policies, institutions, and investments to enable them to work on areas where they have comparative advantage so that they can help strengthen agriculture (primarily the agribusiness sector) and support the greater inclusion of smallholders and rural workers. Public-private sector partnership will work best in areas where the interests of both are matched, such as in the: (1) acquisition, exchange, distribution, and improvement of genetic stocks of crops, forest species, livestock, and fish using conventional and biotechnology applications; (2) production and distribution of improved seed and livestock; (3) production of fertilizers and development of more efficient managementpractices to optimize crop production; (4) development of diagnostics to detect diseases in crops, animals, and fish; (5) production of pesticides and pesticide application within the context of chemical control or integrated pest management; (6) development of strategies to ensure responsible deployment of resistance genes in crops that will optimize the durability of genes; (7) development and production of vaccines and other disease-control agents for animal diseases; (8) processing, storage, and use of food and feed products, including control of postharvest losses; and (9) global strategic planning and policy analysis aimed at developing commercial agriculture-based products to meet global needs.

Institutional Modalities for the Expanded DEAsia+ Research Collaboration

Getting the right institutional mix in place is one instrument that can be used to help achieve the move towards an expanded DEAsia+ research collaboration. Such institutional modality need not be developed from scratch but could be built or patterned on existing successful ones. The organization and institutional mechanism can be patterned after APAARI, and the core members can be the DEAsia+ countries. Other suitable partners would be the private sector and some relevant institutions from developed countries.

Othersmaller but more focused networks that can find complementarities or align strategies can be pursued. There are a number of successful networks/consortia of this nature such as the CURE, the RWC, the Asian Maize Biotechnology Network (AMBIONET), and the Collaborative Vegetable Research Network in Cambodia, Lao PDR, and Viet Nam (CLVNet), to name a few.

Considering the differences of DEAsia+ countries in terms of economic and technical development, expanded collaboration in DEAsia+ can definitely facilitate exchange and access of research tools and knowledge within the region. The nurturing principle where the more developed and technically advanced countries teach their weaker neighbors could work here. China, India, and the Philippines can share their capacities in biotechnology with Cambodia, Lao PDR, Myanmar, and Viet Nam to facilitate interactive learning between stakeholders that result in joint analysis, planning, and collective action on issues and problems. Countries that are relatively more advanced in other technologies could do the same for their country neighbors. It should always be remembered that support for expanded South–South research collaboration or stronger public-private sector alliance should be always based on a clear understanding of the reasons and the validity for collaboration. The objective should be the development of a solid, evidence-based research arrangement that ensures maximum usefulness, benefits, and sustainability.

7. Concluding Section

The emerging challenges that threaten agricultural growth, food security and worsen poverty and hunger will have impacts that will transcend national and even regional boundaries. The right balance between food supply and food demand has to be achieved for the benefit of all stakeholders from both the socioeconomic and nutritional aspects. This is one key reason for countries to support one other, including in the conduct of AR&D to meet the challenges of further improving food security.

Expanded research collaborationis a win-win solution and is becoming more effective than traditional “aid” programs, especially now that funds from development partners and donors are becoming scarce. The impressive economic growth performance of a number of countries in DEAsia+ can make expanded collaboration in agricultural research work in the region.

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Appendix

Appendix Table A.1. Economic and Welfare Improvement

Countries	Growth Rates (%)				GDP Per Capita (PPP)*		Per Capita GDP Growth Rates (%)	Proportion of population living below $2 PPP per day	Gini Coefficient (%)	Undernourishment		
	Real GDP	Agriculture	Industry	Services						(no. in millions)	Proportion to total population (%)	Progress in prevalence towards MDG
	2000-2009	2000-2009	2000-2009	2000-2009	2000	2009	2000-09			2005-07	2005-07	target = 0.5
Developing East Asia+												
Cambodia	8.1	4.6	14.6	9.9	1,010	1,735	6.6	58 (2007)	0.44 (2007)	3	22	0.6
China	10.3	4.0	11.2	11.2	2,667	6,200	9.6	36 (2005)	0.42 (2005)	130.4	10	0.5
India	7.3	2.4	7.9	8.8	1,776	2,970	5.6	76 (2005)	0.37 (2005)	237.7	21	1.1
Indonesia	5.1	3.4	4.2	6.7	2,727	3,813	3.8	55 (2007)	0.38 (2007)	29.9	13	0.8
Lao P.D.R.	7.0	3.0	9.7	9.4	1,327	2,048	4.8	77 (2002)	0.33 (2002)	1.4	23	0.7
Malaysia	4.8	3.3	3.5	6.2	10,271	12,678	2.6	8 (2004)	0.38 (2004)	ns	-	na
Myanmar	12.4	8.9	21.5	13.6	na	na	10.3	na	na	7.8	16	0.3
Philippines	4.4	3.4	3.5	5.5	2,587	3,216	2.3	45 (2006)	0.44 (2006)	13.2	15	0.6
Thailand	4.1	2.9	4.8	3.6	5,568	7,258	3.2	12 (2004)	0.42 (2004)	10.8a/	16	0.6
Vietnam	7.3	3.8	9.3	7.1	1,597	2,681	6.1	48 (2006)	0.38 (2006)	9.6	11	0.4
World										847.5	13	0.8

***Source*:** SOFI-FAO 2010; WDI 2010

***Note*:**na = Data not available; ns = not statistically significant; *constant 2005 international $; **a/** Maybe overstated (personal discussion with the project leader of the Asean Food Security Information System(AFSIS) project based in Bangkok, Thailand (Nov 2010).

Appendix Table A.2. Average Annual Releases of Improved Varieties by Crop in Asia, 1965—1998

Crops/Region	YEAR							Varieties released with inputs from international agricultural research centers (1965-98)			
	1965-70	1971-75	1976-80	1981-85	1986-90	1991-95	1996-98	IX	IP	IA	IN
Wheat	40.8	54.2	58	75.6	81.2	79.3	79.3*	0.49	0.29	0.08	0.14
Rice	19.2	35.2	43.8	50.8	57.8	54.8	58.5	0.2	0.25	0.07	0.48
Maize	13.4	16.6	21.6	43.4	52.7	108.3	71.3	0.28	0.15	0.04	0.53
Sorghum	6.9	7.2	9.6	10.6	12.2	17.6	14.3	0.16	0.07	0.06	0.71
Millets	0.8	0.4	1.8	5	4.8	6	9.7	0.15	0.41	0.09	0.35
Barley	0	0	0	2.8	8.2	5.6	7.3	0.49	0.2	0.01	0.3
Lentils	0	0	0	1.8	1.8	3.9	3.98*	0.54	0.05	0.01	0.4
Beans	4	7	12	18.5	18	43	43*	0.72	0.05	0.01	0.19
Cassava	0	1	2	15.8	9.8	13.6	13.6*	0.53	0.15	0.01	0.31
Potatoes	2	10.4	13	15.9	18.9	19.6	19.6*	0.17	0.06	0.02	0.75
ASIA (All Crops)	27.2	59.6	66.8	86.3	76.7	81.2	79.9	0.18	0.29	0.1	0.43

***Source*:** Evenson online: http://www.google.com.ph/#q=evenson+and+gollin&hl=en&biw=1276&bih-851&prmd=b7ei=4jbeTK3XF8OycOz6jZcM&start=10&sa=N&fp=71dc2b26726ed4e2.

***Notes*:** * These are 1991--95 rates because of insufficient data.

** IX: Variety based on IARC Cross

IP: Variety based on NARS cross with at least one IARC parent

IA: Variety based on NARS cross with at least one non-IARCparent

IN: Variety based on NARS cross with no IARC ancestors

Appendix Table A.3. Focused Crop Research, 2002--2003

Crop	Indonesia	Laos	Malaysia	Myanmar	Philippines	Vietnam	Total	Share
	(FTE researchers)							(%)
Rice	299.1	15.8	63.1	96.1	532.6	333.3	1,340.0	21.5
Vegetables	172.6	4.5	55.8	75.6	175.8	114.6	598.9	9.6
Fruits	47.7	5.1	109.2	10.3	218.7	137.9	528.9	8.5
Bananas and plantains	78.4	0	5.2	0.5	422.1	12.6	518.9	8.3
Corn	150.5	4.2	4.8	50.6	178.9	119	508	8.1
Oil palm	125.1	0	264.2	67.3	2.4	5.2	464.3	7.4
Soybeans	155.4	2.8	0	2.5	8	53.4	222.1	3.6
Coconut palm	146.8	0	6.8	0	48.7	2.6	204.8	3.3
Sugarcane	92.5	0	6.7	11.1	53.3	40.1	203.6	3.3
Ornamentals	48.8	1.1	37.3	0	31	33.5	151.7	2.4
Cotton	41.2	0	0	52.3	8.5	47.3	149.3	2.4
Nuts	53	0	2.7	2.7	16.5	47.4	122.3	2
Tobacco	92.7	0	5.2	0	24.2	0.2	122.3	2
Coffee	17.6	1.1	3.7	0	12.7	52.2	87.2	1.4
Potatoes	23.4	0	0.8	1.8	26.6	28	80.5	1.3
Cocoa	39.7	0	22.9	0	0	15	77.6	1.2
Cassava	35	1.1	0.3	0	13.6	24	73.9	1.2
Tea	22.2	0	0	0	0	44.7	67	1.1
Wheat	14	0	0	0	0	7.1	21	0.3
Sorghum	8.8	0	0	0	2.6	7.6	18.9	0.3
Yam	0.6	0	0.3	0.3	10.5	2.9	14.5	0.2
Barley	2.4	0	0	0	0	4.5	6.8	0.1
Millet	1.5	0	0	0	0.3	4.3	6.1	0.1
Other crops	326.9	0	75.4	45.1	136.4	71.4	655.2	10.5
Total crops	1,995.80	35.4	664.5	416.1	1,923.40	1,208.70	6,243.90	100

***Source*:** Raitzer et al. 2009. Basic data came from a survey of 11 countries,excluding Thailand.

Appendix Table A.4. Focused Livestock Research

Crop	Indonesia	Laos	Malaysia	Myanmar	Philippines	Vietnam	Total	Share
	(FTE researchers)							(%)
Beef	121.7	2.1	30.9	21.9	127	43.4	347	23.4
Poultry	108.8	1.1	25	21.9	65	95.5	317.2	21.3
Sheep and goats	83.6	2.8	21.6	11	50.7	26.1	195.8	13.2
Dairy	42	0	15.3	21	17.1	67.9	163.3	11
Swine	13.1	1.7	1.4	21	37.2	58.8	133.3	9
Pastures & forages	33.4	4.2	2.1	0.9	30.5	32.5	103.5	7
Other	49.6	4	35.3	13.3	49.3	74.2	225.8	15.2
Total livestock	452.2	15.8	131.6	111.1	376.9	398.3	1485.9	100

***Source*:**Raitzer et al. 2009. Basic data came from a survey of 11 countries,excluding Thailand.

Appendix Table A.5. Research Priorities for Crops and Natural ResourcesManagement

Crops and Horticulture

- Crop varieties with the following characteristics: (a) tolerance to abiotic and biotic stresses; (b) can raise crop yield ceilings, particularly in irrigated areas; (c) better product quality, nutrition, value added, shelf life, and high suitability for processing; and (d) multipurpose use
- Other crops (e.g., legumes, vegetables, and flowers) to be incorporated in the cropping systems of short-duration, period-bound, high-yielding varieties of rice, wheat, and maize to enhance cropping intensity and resourceproductivity
- Diversifying production systems consistent with land, water, social, economic regimes, and market demand, particularly integrated management for off-season vegetables, flowers, and periurban cultivation
- Improving input-use efficiency (especially of fertilizers, nutrients, water, and energy) through ICM, IPM, INM, fertilization, precision farming, etc.
- Designing and improving cropping systems for higher yields, pest management, natural resource conservation, and integration with livestock and trees
- Sustainable production and distribution of quality seeds and planting materials and a technology-transfer system, including *in vitro* methods
- Small-farm mechanization and protected cultivation of vegetables and flowers.
- Postharvest handling and value addition through processing and storage
- Crop- and horticulture-based farming systems suited to distinct agro-eco-regions, such as arid, hilly and mountainous, coastal, and hot-humid zones

Livestock including poultry

- Improving nutrition through the quality of crops residues and the removal of antinutritional factors; strategic supplementation and improved varieties of fodder crops and feed balance and formulation; and reduction in methane emission

- Animal health enhanced by science-based capability in the epidemiology and diagnosis of, and vaccine production for, major diseases, disease-nutrition interactions and genetic resistance to major diseases, and overall capacity in the management of cross-border diseases and zoonotics
- Characterization and improvement of local breeds through selective breeding and evolution of a science-led policy on cattle breeding
- Market development, product processing, and biosafety of products with focus on smallholders
- Animal-waste management and socioeconomic and environmental impact of crop-livestock systems, including pastoral systems

Coastal Fisheries

- Sustainable integrated management of coastal systems and protected marine areas, including mangroves
- Sustainable management of marine shrimp farming (feed, nutrition, health, and seed distribution), including effluent management
- Management of reef fishery systems, crab culture, and ornamental fishes

Inland/Aquaculture Fisheries

- Genetic improvement for growth enhancement and disease resistance
- Aquaculture systems management, including deep-water rice-fish/freshwater prawn; integrated fish farming and open-water, culture-based fishery; and cold-water fish culture
- Fish-health management, particularly for the intensive culture of fish and crustaceans

Forestry

- Management of felling-cutting cycles in natural forest, timber utilization, second-growth forests, and forest health
- Inventory, evaluation, and development of forest resources and biodiversity
- Promotion and management of agro-forestry, landscape forestry, alley cropping, and carbon sequestration and trading
- Improvement of medicinal and aromatic plants and enhanced judicious extraction of nontimber and minor products and their marketing

Management of Natural Resources and Climate Change

- Conservation, characterization, evaluation, and utilization of genetic (crop, livestock, fish, and tree) resources for food, agriculture, energy, adaptation to climate change, and overall income and livelihood security
- Knowledge-based integrated management of the supply and demand sides of water and other nonrenewable resources under the regimes of worsening water crises, declining natural resources, and globalization
- Improving efficiency in the distribution and use of irrigation water, soil, nutrients/fertilizers (policy, technology, and institutional issues) through the enhancement of crop-animal-water-nutrient-implement synergy
- Technological, institutional, and policy options for rainwater harvesting, aquifer recharging, water pricing, watershed management, reclamation of degraded/sodic lands, control/management of saline and arsenic-contaminated water, and conjoint and multiple uses of water
- Sustainable integrated land use, organic recycling,soil fertility,water quantity and quality management to maintain crop-soil-water balance, particularly under changing climate regimes
- Developing drought, flood, and good weather codes, contingency and compensatory farming systems, and biotic stress management devices for adapting to abnormal meteorological (weather) and climate changes, duly

supported by credible early warning and information, communication, and technology (ICT) systems

Appendix Table A.6. Climate Change Adaptation Measures in the Agriculture Sector

	Adaptation Measures	**Agricultural Knowledge and Technology Challenges**
Agriculture cropping	*Choice of crop and cultivar:* Use of more heat- and drought-tolerant crop varieties in areas under water stress Use of more disease- and pest-tolerant crop varieties Use of salt-tolerant crop varieties Introduction of higher-yielding, earlier-maturing crop varieties in cold regions *Farm management* Altered application of nutrients/fertilizers Altered application of insecticides/pesticides Change planting date to effectively take advantage of the prolonged growing season and irrigation Develop adaptive farm-level management strategy	Identification of appropriate genes Lack of resources for the development of varieties Time-lag between development, field trial, farmers' acceptance, and onset of climate change Riseof new pests and diseases Needs extensive research on nutrients and fertilizer requirements of new crop varieties Changing planting date could have effect on yield. Resources and technology required at the grassroots level

Livestock production	Breeding livestock for greater tolerance and productivity Increase forage stocks for use during unfavorable time periods Improve the management of pastures and grazing,including grasslands Improve management of stocking rates and rotation of pastures Increase the quantity of forage used for grazing animals Plant native grassland species Increase plant coverage per hectare Provide local specific support in supplementary feed and veterinary service	Breeding less climate-sensitive livestock will be a formidable challenge Less climate-sensitive grass and pasture varieties need to be developed Many native grassland species are not nutritious for animals Need resources, advanced technologies for feed and veterinary service
Fishery	Breeding fish tolerant to high water temperatures Improved fisheries management capability to tackle challenges resulting from climate change	Cross-breeding with fishes from arid regions is a possibility but its effects on local varieties will be unknown for long time Technology and resources will be major obstacle
Development of agricultural biotechnologies	Development and distribution of more drought-, disease-, pest-, and salt-tolerant crop varieties Develop improved processing and conservation technologies in livestock production Improve crossbreeds of high-productivity animals	Will emerge as technological challenge for poor countries Faster technological transfer is required A new nexus between technology owners may emerge to take advantage of climate change

Improvement of agricultural infrastructure	Improve pasture water supply Improve irrigation systems and their efficiency Improve the use and storage of rain and snow water Improve the system for information exchange on new technologies at the national,regional, and international levels Improve sea defense and flood management Improve access of herders, fishers, and farmers to timely weather forecasts	Improved water storage, supply, and irrigation need new technologies and replacement of the old Dissemination of information on technology requires building institutional capacity and educating farmers Improved sea defense and flood management have potential but they have certain limits

***Source*:** IPCC 2007.