THE SITUATION FACING AGRICULTURE ACROSS ASIA: CHALLENGES AND OPPORTUNITIES

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Prepared for Policy Forum

Agricultural and Rural Development for Reducing Poverty and Hunger in Asia: In Pursuit of Inclusive and Sustainable Growth

Session D on "Growth and Structural Changes in Asian Agriculture"

Organized by
International Food Policy Research Institute (IFPRI)
and Asian Development Bank (ADB)
ADB Headquarters, Manila, Philippines
August 9–10, 2007

The situation facing agriculture across Asia: challenges and opportunities

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Abstract

Asia has made significant progress in increasing its agricultural productivity and reducing poverty since the 1960s. Yet real world food prices of most cereals and meats are now projected to rise, reversing a long-established downward trend with adverse impacts on poor consumers in Asia and elsewhere. Growing resource scarcity, particularly of water, will increasingly constrain food production growth, and climatic stresses will likely shrink Asian farmers' abilities to produce grains, as is predicted for the Indo-Gangetic plains. Meanwhile, growing demand for high-value foods, such as livestock, fish, vegetables, and fruits will put further pressure on the natural resource base. Moreover, bioenergy demands will compete with the land and water resources that are used for food. The consequences of these pressures will adversely affect food security and goals for human well-being, slowing progress in reducing childhood malnutrition. Drawing on projections of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), analysis finds that changes in investments in agricultural research and knowledge (ARK) affect projected crop yields and growth in livestock numbers. If aggressive investments in ARK are combined with advances in other, complementary sectors, such as access to water and secondary education, then positive impacts could be even more strengthened. The paper concludes with a discussion of the policy implications of these investment choices on Asian development.

Acronyms

ABARE	Australian Bureau of Agricultural Resource Economics
ARK	Agricultural Research and Knowledge
CGE	Computable General Equilibrium
CGIAR	Consultative Group on International Agricultural Research
CSIRO	Commonwealth Scientific Industrial and Research Organization
CIDA	Canadian International Development Agency
CWANA	Central-West Asia and North Africa
DANIDA	Danish International Development Agency
ESAP	East-South Asia and Pacific
FFV	Fresh fruits and vegetables
HIER	Higher Effective Rainfall Use
IAASTD	International Assessment of Agricultural Science and Technology for Development
ICT	Information and Communications Technology
IFPRI	International Food Policy Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IWSR	Irrigation Water Supply Reliability
LAC	Latin America and the Caribbean
MDGs	Millennium Development Goals
MNP	The Netherlands Environmental Assessment Agency
Mt	Metric ton
NAE	North America and Europe
NGOs	Non-Governmental Organizations
SSA	Sub-Saharan Africa
WSM	Water Simulation Model

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Introduction

Asia is gearing up to become the world's largest regional economy. Similarly, Asian agriculture is increasingly influencing global agricultural markets and developments, exporting and importing large and growing quantities of food and feed. Yet despite rapid economic growth in East Asia and parts of Southeast Asia and the growth surge in India in recent years, Asia remains home to the world's largest number of poor and hungry people. Moreover, recent trends and projections[1] indicate that global change will substantially increase pressure on the agricultural production base. Under currently projected technologies, changes in key drivers affecting food production growth (such as population growth, dietary patterns) together with abiotic stresses (e.g, droughts, floods, and extreme temperatures) will adversely impact the ability of Asian farmers to produce sufficient food and to generate enough income for productive and healthy livelihoods. See Figure 1 for a representation of the interrelationships among major drivers, the agriculture sector, and human well-being. Competition for both water and land resources from rapidly expanding urban areas and production of biofuels will require an even more productive agricultural system to maintain a stable food production base. At the same time, Asia today is home to 100 million out of a total of 147 million malnourished children in developing countries and, under most scenarios of business-as-usual progress in technological change, will still remain home to 49 million children in 2050. Research and development in agricultural technology is crucial to address these challenges.

This paper sets out the major challenges and opportunities facing Asian agriculture over the next several decades following "business as usual," maintaining current rates of investment

[1] See, for example, recent global reports including the International Assessment of Agricultural Science and Technology for Development (IAASTD) draft report (2007), the World Bank's World Development Report 2008: Agriculture for Development (2007), and the Millennium Ecosystem Assessment Synthesis Report and associated papers (2005).

in agricultural research and knowledge (ARK). The authors then simulate alternative developments in some of the key drivers affecting agriculture globally and in Asia using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). Two alternatives using two sets of changing parameters are presented. The first set of variations looks at different levels of investments in agriculture over the period 2005-2050. The second set of variations analyzes the implications of even more aggressive or reduced growth in agricultural research and development together with advances in other, complementary sectors, such as irrigation, access to safe water, and education. The paper concludes with a discussion of the policy implications of these investment choices on Asian development and their potential implications on childhood malnutrition and food security.

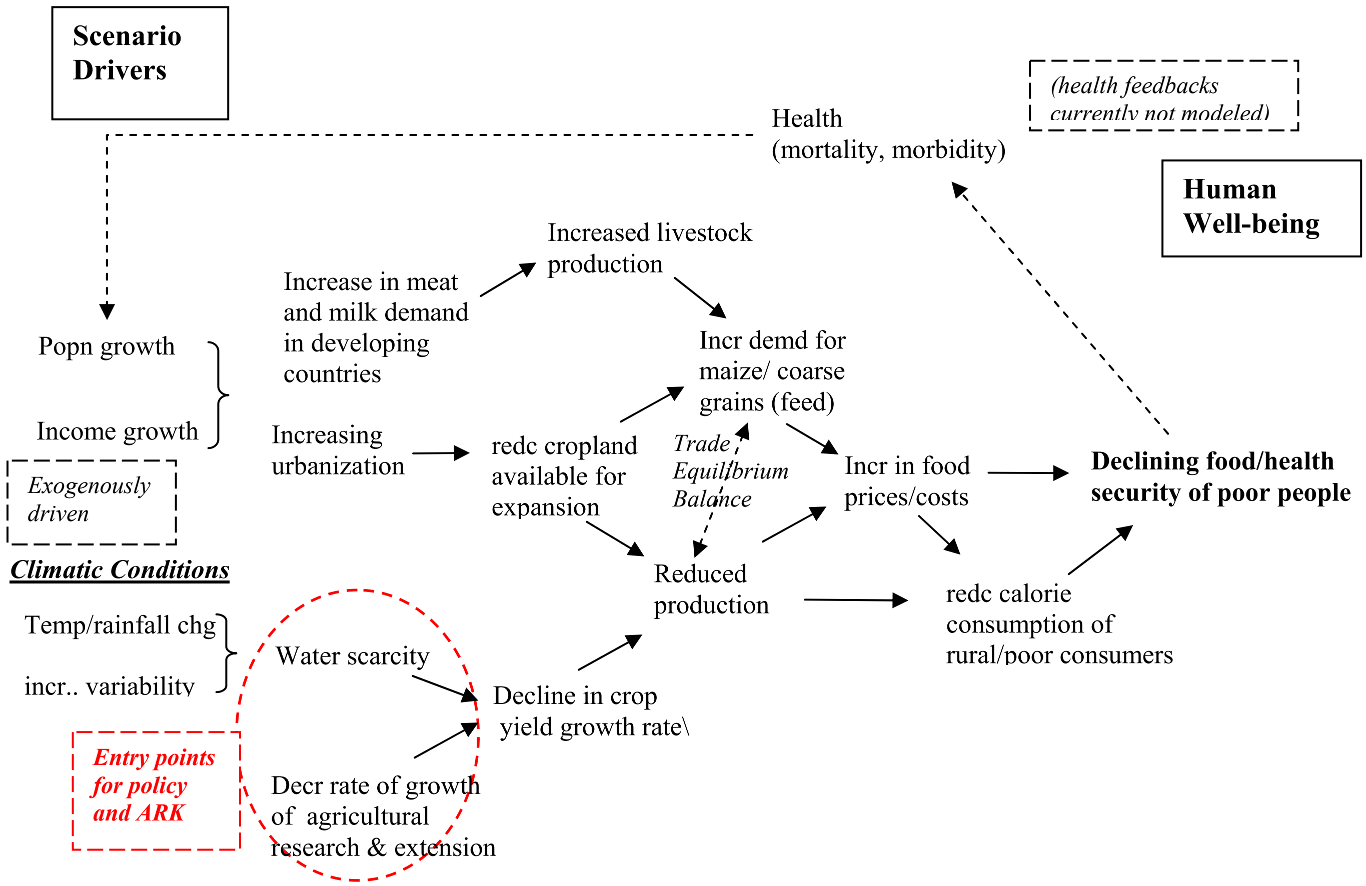
Constraints and challenges: The present and future of agriculture in Asia

Despite the economic crises of the late 1980s and since the food crises of the 1960s, Asia, as a whole, has taken remarkable strides in improving human well-being, compared to other regions of the world. Improvements in food security, poverty reduction, and per capita income initiated by the Green Revolution have been substantial and lasting. In 1975, one out of every two Asians lived in poverty. By 1995, this ratio had fallen to one in four. For those living in rural Asia—2.3 billion today and an additional 55 million people by 2020[2]—and depending more directly on agriculture, forestry, and fishing for their livelihoods, the decline in poverty was also impressive, from one in two to one in three in the same time period. And despite a substantial increase in population, the total number of rural poor also fell by 7 percent (Rosegrant and Hazell 2001).

[2] UN 2007. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2006 Revision and World Urbanization Prospects: The 2005 Revision. <http://esa.un.org/unpp> Accessed Monday, July 09, 2007.

Although life has improved for most rural Asians, about 670 million still live in poverty and experience lower levels of health, education, and well-being than their urban counterparts.

Figure 1 The interrelationships between climatic conditions, agricultural productivity, food prices, and human well-being



Today, Asia both produces and consumes a great proportion of the world's food in order to feed its own large and growing populations, as well as to supply its expanding export sectors. Both developed and developing countries within Asia, account for 91 percent of global rice production and for 42 percent of global cereal production. Asia is the largest exporter of fish and fish products. Its meat production increased by 18 percent (1980-2000), reaching 88 million metric tons by 2000, accounting for 39 percent of global meat production (FAOSTAT 2007). Asia's food production systems are directly related to human welfare indicators. Key agricultural production systems and welfare indicators of Asia are summarized in Table 1.

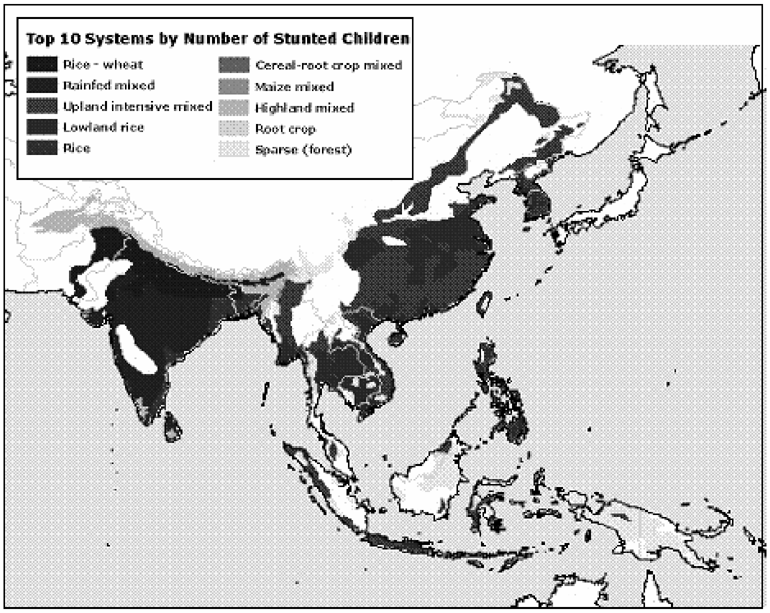
The first five of the eighteen major farming systems of Asia identified in Table 1 account for over 80 percent of the rice and wheat harvested areas, and include over three-quarters of the population of Asia as well as three-quarters of the incidence of child stunting. Figure 2 highlights farming systems ranked by the overall prevalence of stunting in each. Poor Asian consumers typically consume basic staple crops, like maize, rice, and wheat. This crop production, although using a a relatively high level of irrigation (even though a large share is from non-sustainable groundwater pumping), is still very much affected by climatic variability. Moreover, given declining levels of funding for irrigation development and rapidly growing demands from competing urban and industrial water users, Asian staple foods cannot continue their previous dependence on full water control. Research and development efforts must focus on enhancing the contribution of rainfed areas to food production. Location-specific agricultural technologies must be developed to expand the agricultural base.

Table 1 Dominant farming systems of Asia and key human welfare indicators (ranked by total harvested area of rice and wheat (circa 2004))

Farming system	Sub-region	Total population (person)	Rural population (person)	cum. (%)	Under 5 stunted (person)	cum. (%)	Under 5 (person)	cum. (%)	Infant Mortality (per 1000)	Pop. Density (per/km2)	Rural Pop. Density (per/km2)
Lowland rice	East Asia and Pacific	785,701,000	496,073,000	24	13,367,800	11	208,398	8	396	421	288
Rice-wheat	South Asia	491,399,000	365,498,000	41	28,310,301	33	148,226	13	795	519	420
Upland intensive mixed	East Asia and Pacific	502,323,000	358,539,000	58	15,434,700	45	343,667	26	400	162	119
Rice	South Asia	234,988,000	165,512,000	66	11,664,100	55	47,563	27	594	694	539
Rainfed mixed	South Asia	356,767,000	249,337,000	77	24,546,900	74	196,206	35	830	249	185
Temperate mixed	East Asia and Pacific	260,574,000	138,989,000	84	2,595,720	76	110,590	39	373	261	151
Highland mixed	South Asia	85,630,500	65,715,600	87	5,161,720	80	121,618	43	1,006	133	104
Tree crop mixed	East Asia and Pacific	51,025,900	32,496,200	89	3,105,960	83	98,106	47	281	63	41
Pastoral	East Asia and Pacific	58,136,700	43,622,700	91	2,420,440	85	371,427	60	571	19	14
Highland extensive mixed	East Asia and Pacific	64,048,400	51,680,500	93	2,536,590	87	105,583	64	592	75	62
Pastoral	South Asia	28,466,700	23,753,600	94	2,366,160	89	112,339	68	1,313	54	46
Dry rainfed	South Asia	45,599,900	33,544,000	96	3,609,880	92	24,050	69	623	256	201
Sparse (arid)	East Asia and Pacific	25,414,700	23,128,600	97	1,036,770	92	394,161	84	516	8	7
Sparse (forest)	East Asia and Pacific	19,418,600	17,705,500	98	4,359,630	96	236,656	92	497	11	10
Coastal artisanal fishing	South Asia	39,823,100	15,526,100	99	1,146,450	97	5,162	93	530	940	475
Sparse (arid)	South Asia	29,578,300	17,817,800	99	2,486,100	99	110,291	97	857	53	32
Sparse (mountain)	South Asia	10,049,200	9,802,730	100	1,130,930	100	58,376	99	968	35	35
Root-tuber	East Asia and Pacific	2,147,620	1,704,700	100	321,713	100	35,110	100	638	3	3
		3,091,091,620	2,110,446,030		125,601,863		2,727,528				

Source: IFPRI (2007). Unpublished data.

Figure 2 Farming systems ranked by number of stunted children (<5yrs)



Source: Adapted from Hyman, Jones, Fujisaki, Wood and Dixon (2007) Unpublished paper.

The Green Revolution of the 1960s and 1970s significantly enhanced agricultural technology in Asia through breeding of better crop varieties, the increased use of fertilizer and other complementary inputs, enhanced infrastructure development, as well as improved farm practices. These changes helped to eliminate cyclical famines in most of Asia, and contributed to significantly higher levels of food security, and improved the livelihoods of rural people. Nonetheless, despite these advances in agricultural technology and supporting investments in education, health, and access to drinking water, the number of malnourished people in Asia remains at over half a billion people (FAO 2006). While significant reductions in child malnutrition have been achieved in East and many parts of Southeast Asia, improvements in South Asia have been particularly slow.

Moreover, crop breeding has failed to achieve significant impacts in risk-prone or resource-poor agricultural regions (Gupta 2007), which are likely to be expanding in the future. Even Indian agriculture, which benefited significantly from the Green Revolution, and boasts a relatively high level of irrigation (even though a large share is from non-sustainable groundwater pumping) is still very much affected by climatic variability. Moreover, given declining levels of funding for irrigation development and rapidly growing demands from competing urban and industrial water users, Asian staple foods cannot continue their previous dependence on full water control. Research and development efforts must focus on understanding and enhancing the contribution of rainfed areas to food production. Location-specific agricultural technologies must be developed to expand the agricultural base.

Eastern India, for example, with its 27 million ha of mostly rainfed land, is currently an under-achiever in terms of rice production and yield because of strong exposure to abiotic stresses[3] like drought, floods, and poor soil fertility. Among the various unfavorable climatic and soil conditions that severely affect crop production are salinity, extreme temperatures, and flooding. Effects from these stresses compound each other and aggravate the situation further, for example, when drought is associated with high temperature, salinity with water stress, or oxidative damage is caused by excessive light, water scarcity or excess, and extreme temperatures (Grover et al. 2003). Drought, high temperatures, flooding, and wind velocity during critical stages of crop growth severely disturb the development stages and production cycle of key staple crops. Once plants are weakened from abiotic stresses, biotic stresses set in and the incidence of pest and diseases increases. Overall these impacts are heavily borne by poor farmers, who cannot respond to these conditions with their meager resources—resulting in famine,

[3] Those caused by non-living chemical and physical factors in the environment (light, temperature, water, or atmospheric gases).

rural poverty, and migration (Grover et al. 2003). Expansion of such stresses will also put increasing pressure on international food prices and on the welfare of poor consumers.

Growth in agricultural productivity of cereals is slowing and, in some cases, is even in decline; despite the continued increases in demand and the limited scope for area expansion.[4] There is, therefore, persistent pressure to enhance agricultural productivity in Asia so as to keep pace with the increasing food needs of a more urbanized and affluent population, and to reduce stresses on the quantity and quality of land and water resources from crop production (Wood et al. 2000; Cassman and Wood 2005).

Rural livelihoods place enormous pressure on natural resources. The continuing degradation of these resources could well cause social conflict over remaining resources and discontent about the widening gap between urban and rural quality of life. These problems would be particularly severe in South Asia.

Regional progress varies by country as governments have responded in different ways to their national conditions. The challenges of creating off-farm jobs for the rural poor as well as managing climatic and financial shocks remain even for those with currently productive agricultural systems and rapidly growing economies, like China and Vietnam. China's dynamic economy is projecting an annual average growth of per capita income of 5.2% (2000-2050), decomposed into 5.3% of annual income growth and 0.2% annual population growth. In the agricultural sector, irrigated and rainfed maize is increasing in both acreage and yield improvement, although yield increases will be more important over the long run. Irrigated maize is the fastest growing grain crop, at an annual average rate of growth equaling 1.2 percent from 2000 to 2050. Rainfed maize

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[4] Even where national totals of cropland appear relatively stable in Asia, this often hides the loss of good quality farmland through urban and industrial expansion being compensated for by expansion into often less productive lands.

and sorghum production are also increasing at annual average growth rates of 1.2 percent; rainfed root and tuber production is also expanding in area. Overall, for grains, however, despite these increases in absolute supply, per capita demand is decreasing for maize (-1.5 percent) and rice (-0.5 percent), and increasing only for wheat (0.3 percent annual rate). Demand for and production of livestock products are growing much faster, as are supply and demand for fruits and vegetables, a sign of the rapid changes in dietary patterns resulting from income growth and increased urbanization.

The annual average growth of per capita income for India is a strong 4.5 percent (projected for 2000 to 2050), is decomposed into 5.4 percent annual income growth (similar to China) and 0.9 percent annual population growth (larger than China). India's agricultural productivity is also rising. As in China, maize is the fastest growing grain crop in terms of irrigated production, with an annual average rate of growth equaling 1.6 percent from 2000 to2050), in contrast to China, maize is also the fastest growing rainfed crop, with an annual growth of 0.7 percent. These trends contrast with China, in some ways, but are still largely consistent with the trends for irrigated and rainfed production discussed below. Similarly to China, among grains, per capita demand is decreasing (-0.1 percent for rice, -1.0 percent for sorghum) except for wheat, which is increasing at 0.2 percent annually. The per capita demand for some animal products is also expanding quickly in India, particularly for poultry (at 3.6 percent per year).

Completing the economic transformation in rural Asia requires further growth that is more equitable and environmentally sustainable than it has been in the past. Meeting this challenge will warrant more efficient application of the lessons already learned about agricultural growth, public-sector investment, rural poverty reduction, and natural resource protection.

There are several potential strategies for increasing crop productivity, but the most sustainable long-term approach has been—and will likely continue to be—that of crop improvement. This is more so the case in densely populated, rapidly growing Asia than in any other region in the world. Improvement can be achieved, for example, through increased genetic potential that improves tolerance to abiotic stresses, and increased resistance to the effects of biotic stresses. Equally important are sustained investments in rural infrastructure, complementary services, and in capacity building and knowledge systems for rural areas.

Selected challenges and opportunities

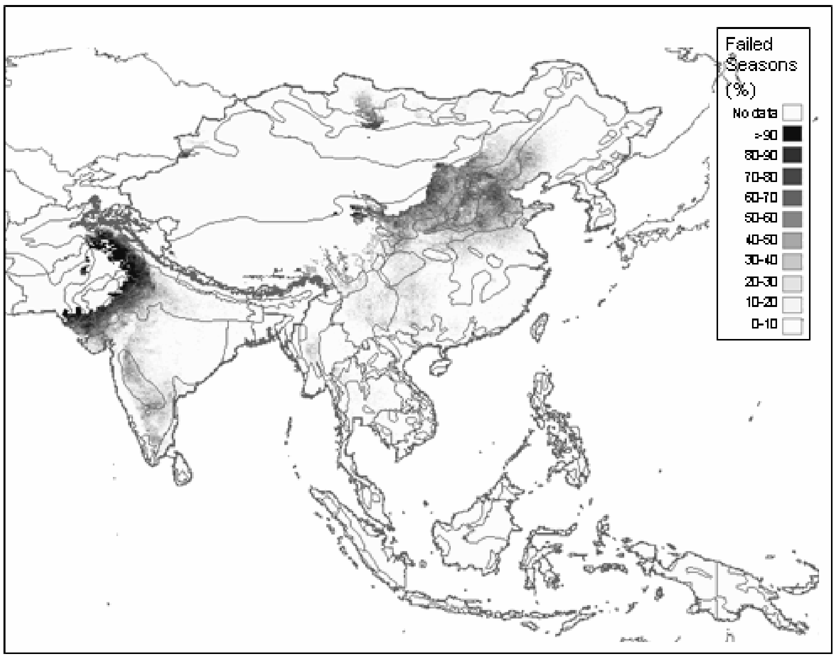
Water scarcity and drought stress

Climate variability is a major contributor to drought, which is particularly problematic for rainfed cultivation. Drought not only lowers average expected yields but also exacerbates other production uncertainties. Farmers–particularly poorer farmers–become less likely to adopt modern technologies and practices that involve greater outlays of cash and labor inputs (despite the greater profits they might offer overall), in order to avoid or minimize risk when faced with drought conditions. Figure 3 is based on an analysis of historical weather data over a 100 year period, and depicts the average number of years out of a hundred (i.e., a percentage of years) in which drought incidence would fail to provide an economic growing season for rainfed production.[5] The intersection of this map with Figure 2 (above) allows farming systems to be prioritized not only in terms of their extent

[5] A growing season is defined as one providing at least 54 days of adequate levels of soil moisture to support crop growth (Hyman et al. forthcoming).

and the incidence of poverty, but also according to how much drought constrains yields in rainfed systems. The result of such an overlay (for developing countries) is presented in Table 2, and illustrates the predominant humanitarian importance of Asian (particularly South Asian) farming systems.

Figure 3 Proportion of failed growing seasons for rainfed cultivation, 100 year weather simulation



Adapted from Hyman, Jones, Fujisaki, Wood and Dixon (2007). Unpublished report.
Notes: The figure illustrates 100 year weather simulation based on historic data analysis

Drought impacts are mitigated by investments in irrigation, so the extent to which the national share of production is irrigated affects the overall scale of potential productivity increases that can be achieved through improved performance of rainfed crops. Rainfed rice production is very extensive in India, Myanmar, Thailand, and Indonesia, while rainfed wheat production is focused in China, India and, to a much lesser extent, Afghanistan. However, irrigated areas are also prone to droughts (and floods), and irrigation requirements will increase with increasing temperatures under climate change. Thus, irrigated crops in water-scarce river basins will also require new technological approaches. To provide some scale to the relevance of key rice and wheat production areas within a national context, Table 3 summarizes estimates of the distribution of rural populations with the major rice and wheat areas of each country.

Table 2 Ranking of fifteen global priority farming systems where drought most threatens the poor (ranked by absolute numbers of stunted children), indicating major crops within each system

Priority Farming Systems	Stunting	Principal Crops	Global Rank	Regional Rank
SA rice wheat	28.3	***rice,*** pulses (chickpea) millet, ***wheat,*** maize, bean	4	2
SA rainfed mixed	24.5	***rice***, millet, sorghum, chickpea, bean, groundnut, maize, ***wheat***	1	1
EA upland intensive mixed	15.4	Maize, ***rice, wheat,*** sweet potato, potato, bean	5	2
EA lowland rice	13.4	***rice,*** maize, ***wheat,*** sweet potato, groundnut	2	1
SA rice	11.7	***rice***, pulses (chickpea)	7	3
SSA cereal-root	6.3	sorghum, millet, pulses (cowpea), maize, groundnut, cassava	3	1
SSA maize mixed	6.3	maize, cassava, sorghum, pulses, groundnut, millet, bean, sweet potato	8	3
SA highland mixed	5.2	***rice,*** maize, ***wheat***, potato , groundnut, pulses (chickpea)	24	5
SSA root	5.0	maize, cassava, rice, sweet potato, cowpea, sorghum, groundnut, bean	10	4
SA dry rainfed	3.6	Sorghum, millet, chickpea, groundnut, bean	14	4
SSA agro-pastoral millet sorghum	3.1	millet, sorghum, pulses groundnut, , maize	6	2
LA maize beans	2.8	maize, bean, sorghum	15	4
SSA high temperate mixed	2.8	maize, wheat, sorghum, barley, millet, pulses	21	7
EA temperate mixed	2.6	maize, ***wheat,*** potato, groundnut, millet	23	3
EA highland extensive mixed	2.5	***rice***, maize, ***wheat,*** potato, groundnut, pulses	28	5

Source: Adapted from Hyman, Jones, Fujisaki, Wood and Dixon (2007). Unpublished report.
Note: Highlighted systems are in Asia.
Abbreviations: SA–South Asia, EA–East Asia, SSA–sub-Saharan Africa, LA–Latin America.
Global ranking number is of the farming system according to a "potential drought impact index" (failed season probability x crop area). Regional ranking number is the rank of the farming systems' potential drought impact index within the specified region.

Table 3 Rural population (million persons) inhabiting lands cultivated in rice and/or wheat for selected Asian countries

Country	Total extent	Irrigated rice	Rainfed rice	Irrigated wheat	Rainfed wheat
			Million persons		
Bangladesh	96.1	69.0	95.7	50.2	56.2
Bhutan	0.6	0.1	0.3		0.2
Cambodia	9.9	4.7	9.9		
China	678.7	499.8	3.1	361.6	300.4
India	568.0	264.5	336.2	211.1	196.4
Indonesia	77.7	44.4	58.1		
Laos	2.1	0.6	1.9		
Malaysia	2.3	0.8	1.8		
Mongolia	0.0			0.0	
Myanmar (Burma)	28.1	2.2	27.8	0.5	
Nepal	18.1	3.0	16.0	2.9	2.0
Pakistan	64.0	18.4	0.3	31.4	16.3
Philippines	25.7	18.2	14.3		
South Korea	3.1	2.5	0.8	0.0	
Sri Lanka	10.5	6.2	9.5		
Taiwan	0.4	0.4	0.1		
Thailand	34.5	13.6	33.6		
Vietnam	50.2	35.2	49.3		
Overall average	**1,680.7**	**984.7**	**659.0**	**660.3**	**580.8**

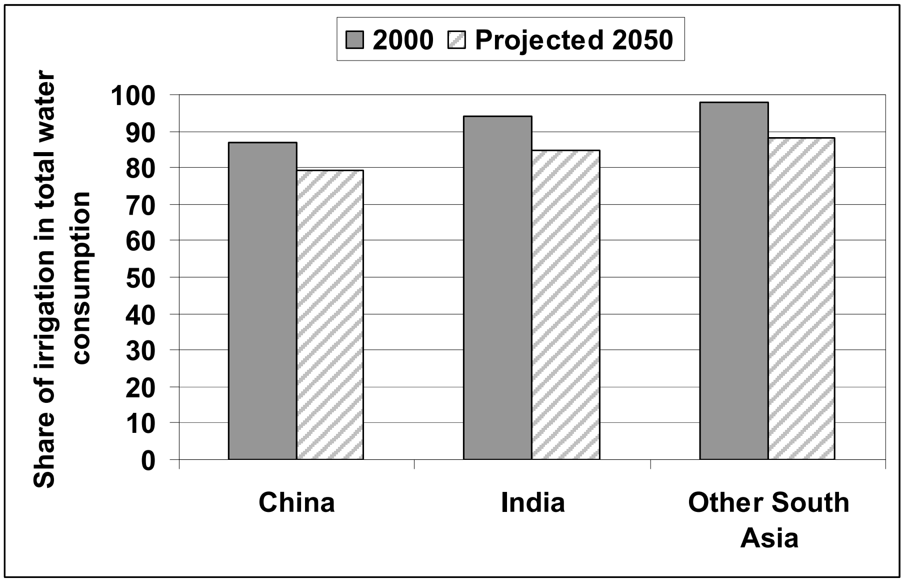
Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

Notes:

1. Figures include any 10 x 10 km cell with 1% or greater area cultivated under rice and/or wheat.
2. List includes all countries for which complete data from IFPRI's (crop) spatial allocation model (SPAM) is available.

Water available for agriculture has declined sharply over the last several decades, particularly in Asia. The situation is particularly challenging for China and India, where water is increasingly transferred out of agriculture to meet growing demands from domestic and industrial sectors. As decision-makers and the general public become more aware of the value of maintaining water for the ecosystem, increasing allocations are also made to enhance environmental and aquatic ecosystem health. Figure 4 shows the estimated share of irrigation water consumption in total water consumption in selected Asian countries and regions. The share of total water consumption represented by irrigation declines from 2000 to 2050 imposing challenges for future food production of rice and wheat as well as other irrigated crops.

Figure 4 Irrigation water consumption as a share of total water consumption, 2000 and projected 2050, selected Asian countries and regions



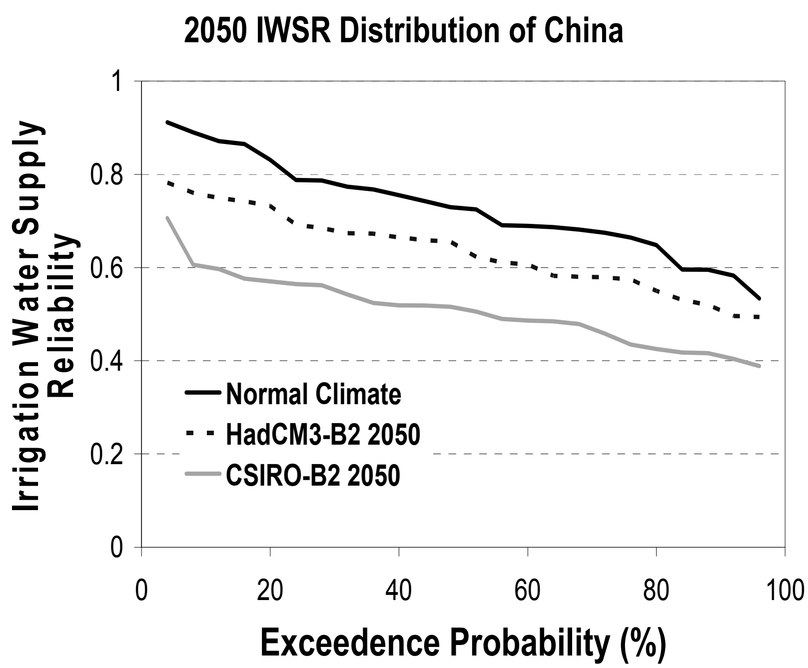
Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

Climate change

Climate change exacerbates stresses on agricultural production, particularly for low- and mid-latitude developing countries, including those of Asia. In these regions, higher growing season temperatures tend to adversely affect rice and wheat growth and also increase demand for evapotranspiration. The combined increase in heat and drought stress limits opportunities of further improving agricultural production.

Figure 5 shows three scenarios of estimated irrigation water supply availability distribution in 2050 for China. The scenarios are for normal climate conditions based on historical climate data, and two additional scenarios of climate change using the Commonwealth Scientific Industrial and Research Organization (CSIRO)-B2 model results and Hadley Center (HadC) M3-B2 simulations. These climate change scenarios were derived from the Special Report on Emissions Scenarios (SRES)-B2 scenario runs by the Hadley and CSIRO climate models, respectively. As a result of climate change, increasingly unreliable irrigation water supply is expected to considerably reduce future crop production.

Figure 5 Exceedence probability of irrigation water supply reliability (IWSR) for China, projected 2005



Source: IFPRI (2007). Unpublished data.
Note: 2050 level for historical climate condition and two climate change scenarios. The exceedance probability refers to the chance that an IWSR level can be exceeded in year 2050.

According to a study by Ortiz et al. climate change could strongly affect wheat productivity in South Asia's breadbasket region, the Indo-Gangetic Plains. By 2050, as much as 51 percent of that region, currently part of the favorable, high potential, irrigated, low rainfall mega-environment accounting for 15 percent of global wheat production, might be reclassified as a heat-stressed, irrigated, short-season production mega-environment as a result of possible climate shifts. This would represent a significant reduction in wheat yields, unless appropriate cultivars and crop management practices were offered to and adopted by South Asian farmers (CIMMYT 2006: 10).

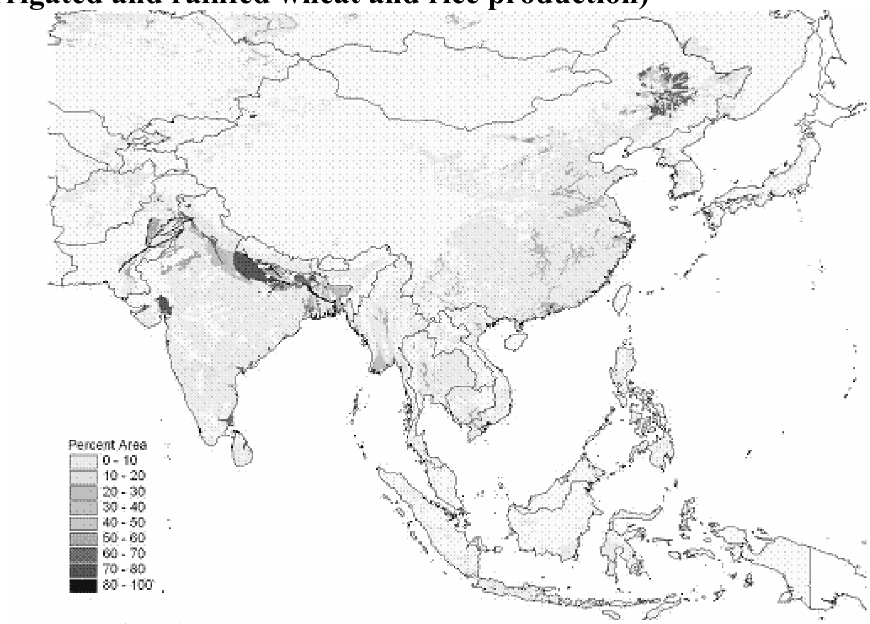
Peng et al. (2004) report a close linkage between rice grain yield and mean minimum temperature during the dry cropping season (January to April). Grain yield declined by 10 percent for each 1°C increase in growing-season minimum temperature in the dry season, whereas the effect of maximum temperature on crop yield was insignificant. The authors thus provide direct evidence of decreased rice yields from increased nighttime temperature associated with global warming.

Other stresses from climate change include an increased incidence of floods, which not only affects human lives and damages property, but also wipes out entire harvests in many Asian countries. Another important climate change-related stress is from rising sea levels, often combined with increased soil salinity. Several studies have attempted to study the adverse food production impacts in low-lying but highly productive Delta areas of the Mekong in Vietnam (Wassmann, Hien, and Hoanh 2003) and for Bangladesh.

Soil fertility constraints

From a regional perspective, the share of cropland *free* of soil constraints ranges from 6 to 7 percent in South Asia and Sub-Saharan Africa to around 25 percent in North America and the Former Soviet Union, with an average of around 16 percent globally (Wood et al. 2000). Within Asia, from a sub-regional perspective, East and Southeast Asia each exhibits significant problems with poor drainage (around 20 percent of cropland area), aluminum toxicity (21 percent and 38 percent respectively), and low potassium reserves (20 percent and 44 percent respectively). Soil acidity is a major problem in both South and South East Asia (around 32 percent of cropland), where it is even more prevalent than in Latin America and the Caribbean. Salinity affects around 6 to 8 percent of cropland in East and South Asia but is much more prevalent in some locations. Furthermore, shallow or gravelly soils and soils of low moisture-holding capacity – often vulnerable to even moderate droughts - can be found on between 6 and 20 percent of cultivated soils.

Figure 6 Percent of cultivated area free from soil constraints (within the extent of irrigated and rainfed wheat and rice production)



Source: IFPRI (2007)..

Long-term cultivation of agricultural commodities in Asia appears to have had some negative impacts on soil fertility in the region, although less so in irrigated rice lands. In the rice and wheat cultivated areas of Asia, only some 7 percent of cropland is free from soil constraints (Figure 6 and Table 4). In the three largest countries (China, India, and Indonesia) only 5, 11, and 3 percent respectively of their total rice and wheat areas are free from soil constraints. Problems include drought susceptibility through shallow or low moisture holding capacity of rice/wheat lands in India (10 percent), Thailand (9 percent), Cambodia (8 percent), and Indonesia (5 percent). Acidity is a major problem in Nepal (52 percent), Sri Lanka (46 percent), Indonesia (39 percent), India, and the Philippines (both at 36 percent). Salinity of rice and wheat areas is most prevalent in Pakistan (36 percent).

Table 4 Share of extent of cultivated area for rice/wheat affected by major soil constraints for selected Asian countries.

Country	Free of constraints	Saline soils	Poor drainage	Low moisture holding capacity	Acidity	High P-fixation	Low K-reserves
				Percent of total area			
Bangladesh	16.2	3.0	56.5	2.1	21.4	1.3	11.4
Bhutan	0.0	0.0	0.0	2.5	63.3	0.0	40.0
Cambodia	3.8	0.5	42.3	7.6	15.3	5.8	49.7
China	5.4	6.9	23.2	1.5	13.4	20.9	24.4
India	11.5	6.3	5.3	9.7	35.9	0.1	9.7
Indonesia	2.5	0.0	8.9	5.2	39.7	7.1	32.2
Laos	0.0	0.0	8.5	2.1	22.3	20.5	73.4
Malaysia	0.7	5.7	30.7	2.2	31.0	10.2	45.0
Mongolia	22.4	22.4	0.0	0.0	0.6	0.0	0.0
Myanmar	4.6	2.2	19.2	0.0	27.8	14.1	44.3
Nepal	4.5	0.0	8.2	1.2	51.8	0.0	15.6
Pakistan	23.2	35.7	1.5	3.3	3.4	0.0	0.0
Philippines	0.2	0.0	11.4	1.4	36.7	3.4	42.7
South Korea	0.4	0.0	8.6	0.0	26.7	9.0	22.2
Sri Lanka	3.6	1.4	20.7	2.9	46.2	0.0	19.5
Taiwan	15.4	4.1	40.7	0.0	13.0	12.3	19.5
Thailand	1.9	1.5	33.3	8.9	25.7	6.2	54.3
Vietnam	3.0	2.0	28.8	5.5	17.0	9.9	47.9
Overall average	**7.1**	**6.2**	**16.9**	**4.6**	**23.3**	**10.6**	**23.1**

Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

IMPACT: A Tool to Enhance Policy Choices

IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) was developed in the early 1990s by researchers at IFPRI in response to the prevailing lack of long-term vision and consensus about the actions that are necessary to feed the world in the future, reduce poverty, and protect the natural resource base.[6]

[6] For publications reporting on IMPACT results on various topics, see M.W. Rosegrant, M. Agcaoili-Sombilla and Perez 1995 on the global food supply; M.W. Rosegrant, N. Leach, R.V., and Gerpacio 1999

IMPACT is a partial equilibrium agricultural sector model representing a competitive agricultural market for crops and livestock. Demand is a function of prices, income, and population growth. Growth in crop production in each country is determined by crop and input prices and the rate of productivity growth. World agricultural commodity prices are determined annually at levels that clear international markets. IMPACT generates projections for crop area, yield, production, demand for food, feed and other uses, prices, and trade; and for livestock numbers, yield, production, demand, prices, and trade.

Refinements were made in 2001-2 to explore the relationships among water, environment, and food production. In particular, a Water Simulation Model (WSM), which incorporates water availability as a stochastic variable with observable probability distributions, was combined with the food projections model (Rosegrant, Cai, and Cline 2002). More recently, the representation of climate variability and climate change has been improved in IMPACT. The model simulation results presented here are the outcome of a linkage of IMPACT with other key modeling groups, including a global computable general equilibrium (CGE) model, housed at the Australian Bureau of Agricultural Resource Economics (ABARE) in Australia, and an Integrated Assessment model, housed at the Netherlands Environmental Assessment Agency (MNP) in the Netherlands. Integration of the model has enabled IMPACT to take account of the validation of agricultural growth within wider economic growth considerations (through the CGE model) and to incorporate biofuel and climate change considerations linked to energy modules and climate models.

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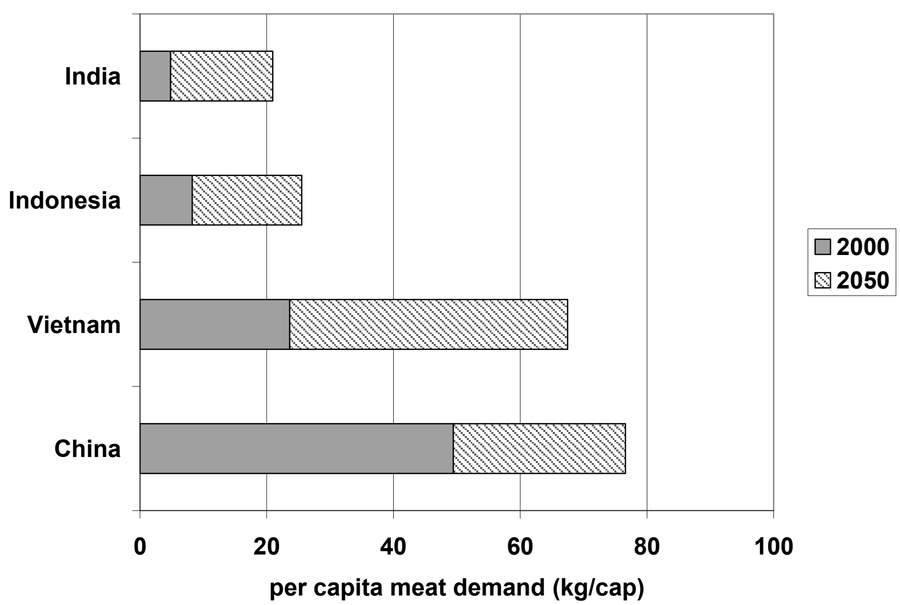
on factors influencing food security and nutritional status; J.G. Scott, M.W. Rosegrant and C. Ringler 2000 on tubers and roots; C. Delgado, et al 1999 on the livestock revolution; and Delgado et al 2003 on changing supply and demand for fish products.

Future Global Trends on Food Prices and Food Security

At the global level, total cereal demand is projected to increase to 1,111 million mt or by 60 percent during 2000 to 2050. As a result of income growth and increased urbanization, dietary changes will shift from coarse grains and maize to increased consumption of rice; other areas will see secondary shifts from rice to wheat. Consumption of livestock products is expected to increase even more rapidly, particularly in Asia. This implies rapid growth in demand for cereals as feed, particularly maize and other coarse grains.

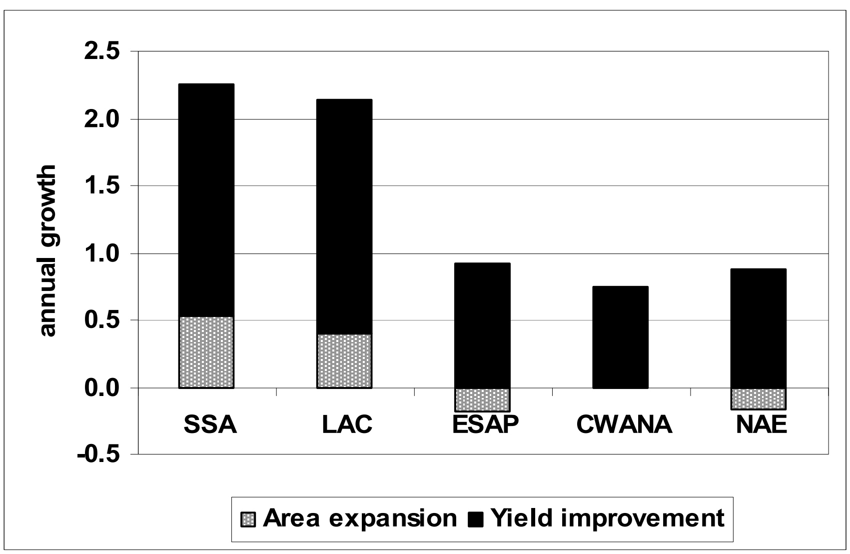
Figure 7 Per capita meat demand (kg/cap) for selected Asian countries



Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

With declining availability of both water and land that can be profitably brought under cultivation, expansion in area is not expected to contribute to future production growth. Under business-as-usual, the global cereal harvested area is expected to expand from 662 million ha in 2000 to 685 million ha in 2025 before contracting to 654 million ha by 2050. In Asia, the contraction will start much earlier: Asian harvested area for cereals is expected to hold nearly steady from 266 million ha in 2000 to 265 million ha in 2025 and then shrink to 243 million ha by 2050. The projected slow growth in crop area places the burden to meet future cereal demand on crop yield growth. Although yield growth will vary considerably by commodity and country, in the aggregate and in most countries, growth is projected to continue slowing. The global yield growth rate for all cereals is projected to decline from 1.96 percent per year in the period from 1980 to 2000 to only 0.97 percent per year form 2000 to 2050; and in the Asia region growth will drop to 0.91 percent annually. As shown in Figure 8, area expansion contributes to food production growth only in sub-Saharan Africa (24 percent) and in the Latin America and the Caribbean region, whereas yield growth is projected to compensate for area contraction in the Asia (ESAP) region.

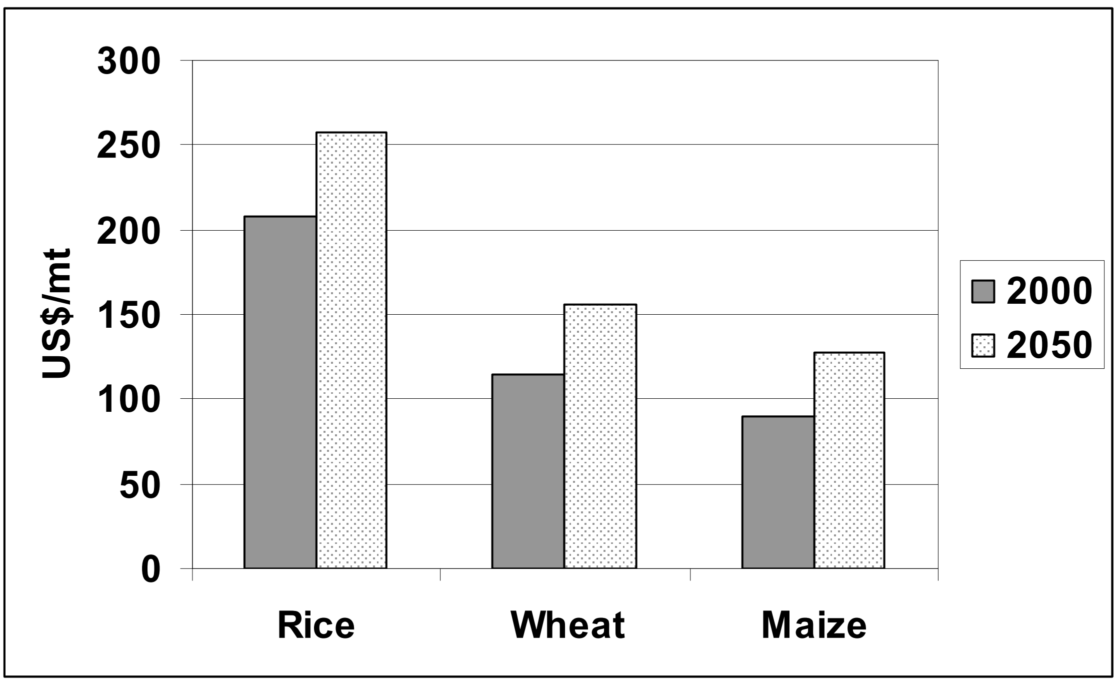
Figure 8 Sources of cereal production growth, business-as-usual, 2000-2050.



Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

Despite continued advances in agricultural technology under business-as-usual, real world prices of staple foods are projected to increase in the coming years—in stark contrast to the trends over the past 40 years. Prices of cereals like rice, maize, and wheat are projected to rise by 24 to 41 percent in from 2020 to 2050 (Figure 9). These changes are driven by new developments in supply and demand—including much more rapid degradation of natural resources on the food production side, particularly as a result of rapidly growing water scarcity and growing heat and drought stress, combined with slowing yield growth that is unable to catch up with market dynamics. On the demand side, dietary shifts that are driven by population and economic growth fuel rapid increases in demand for high-value products that put additional pressure on food production systems.

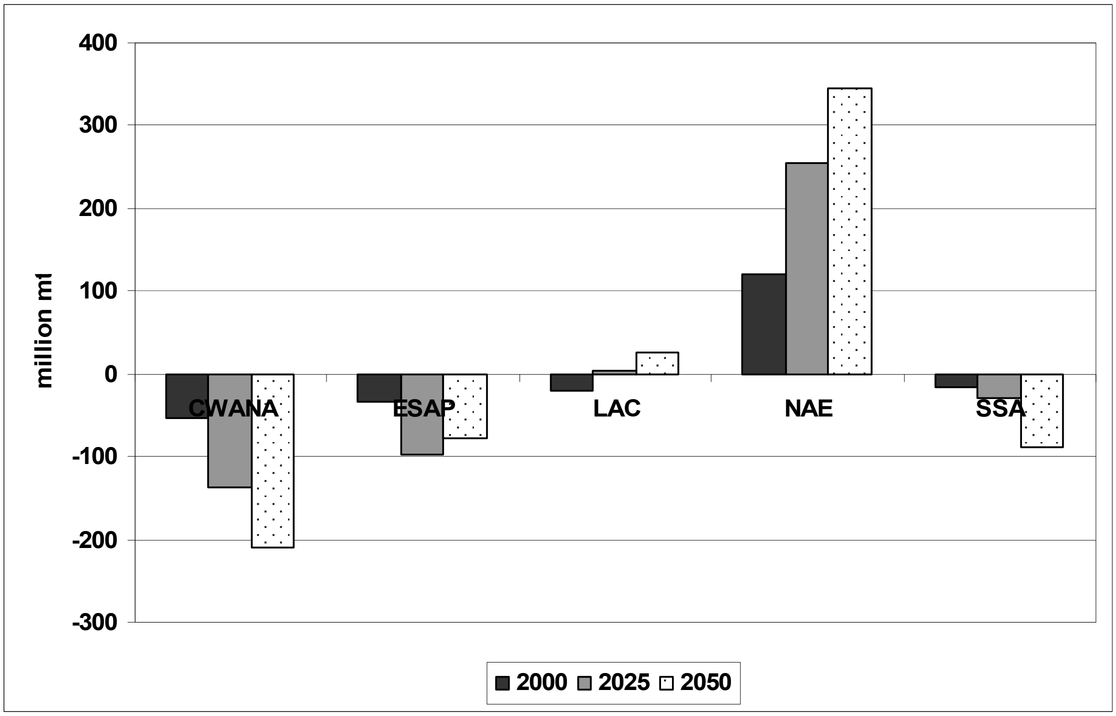
Figure 9 Projected changes in international rice and wheat food prices, business-as-usual, 2000-2050



Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

World trade in food will continue to increase, with trade in cereals projected to increase in volume from 229 million mt annually in 2000 to 612 million mt in 2050, and trade in meat products rising from 15 million mt to 55 million mt. Expanding trade will be driven by the increasing import demand from the developing world–particularly from Asia–but also from Africa (Figure 10).

Figure 10 Net trade in cereals, million metric tons, business-as-usual, by region, 2000, 2025, and 2050

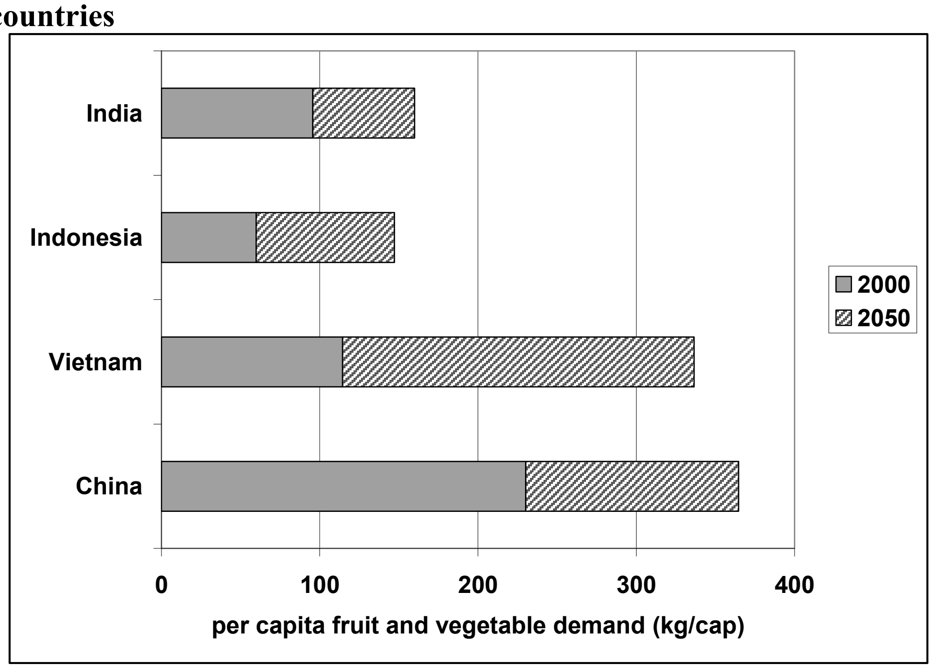


Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

In the last decade, regional and global marketing of fresh fruits and vegetables (FFV) has changed dramatically. Research on the rise of supermarkets (e.g., Berdegué et al 2005, Shepherd 2005, Weatherspoon and Reardon 2004) documents their influence on marketing chains across the developing and developed world, engineering a shift from local wet markets to complex global market linkages, for Asia most notably in China, Malaysia, and Thailand. The benefits to consumers of supermarkets' higher quality and safety standards that may set the barriers to entry into these changing market relationships too high for smaller farmers with fewer resources, and there are many questions about the impact of these new marketing practices on local food availability and food security. Overall, there is little understanding of the costs to the environment and human health of the increased levels of pesticides, herbicides, and irrigation used to achieve better looking products.

At the same time, the change of diets in Asia is due to a process stemming from both increasing per capita incomes and the influence of globalization (Pingali, 2006). Similar to the shifts in meat production and consumption mentioned earlier, fruits and vegetable are becoming increasingly important in diets across Asia. IMPACT projections for all of developing Asia see a doubling of per capita fruit and vegetable demand to an average of over 200 kg annual demand per person. Projected changes for representative countries are shown in Figure 11.

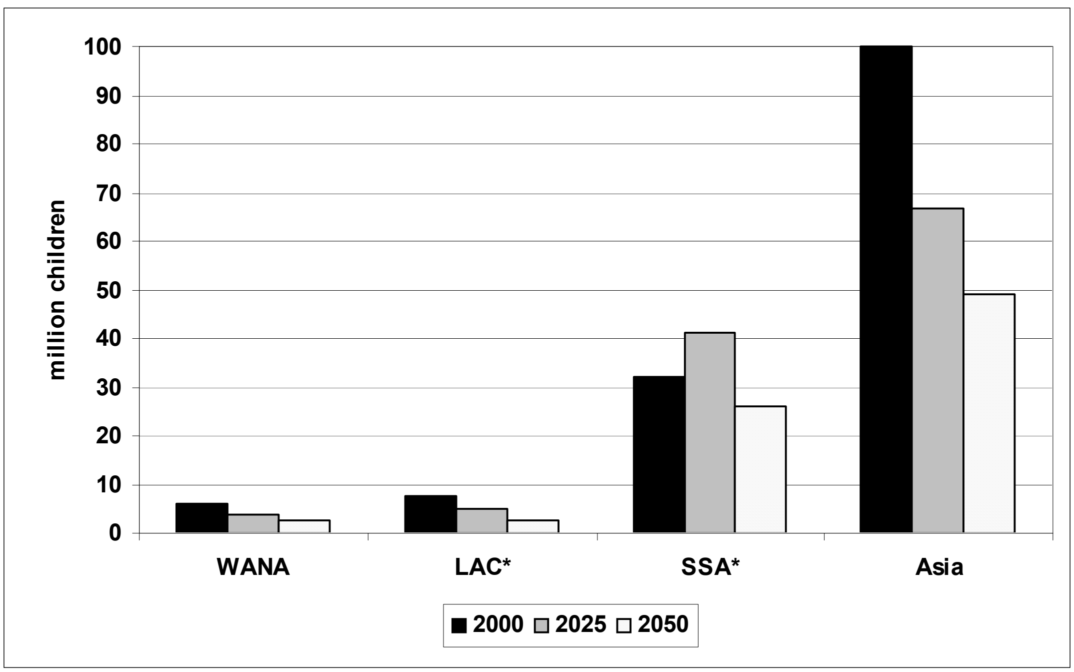
Figure 11 Per capita fruit and vegetable demand (kg/cap) for selected Asian countries



Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

The dramatic reversal of earlier food price declines will slow growth in calorie consumption, with both direct price impacts and reductions in real incomes for poor consumers who spend a large share of their income on food. As a result, there will be little improvement in food security for the poor in many regions, particularly in Sub-Saharan Africa and South Asia which see the lowest improvement in calorie availability. As a result of limited improvements in calorie availability and inadequate investments in supporting sectors, such as education and health, child malnutrition levels are projected to only decline from 147 million children in 2000 to 117 million children by 2025 and 80 million children by 2050 (Figure12). While results for Asia are impressive, by 2050, the region will still be home to the largest concentration of malnourished children.

Figure 12 Number of malnourished children in selected developing country regions, business-as-usual, 2000 and projected 2025 and 2050



Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

Alternative scenarios with greater or lesser investments in agricultural research and knowledge (ARK)

The "business-as-usual" projections describe a global food scenario in which increasing population, land pressure, water scarcity, and environmental degradation lead to increasing food prices with potentially dramatic, negative consequences for poor rural populations, particularly in Asia, and for the nutritional status of Asian children.

More aggressive investments and better management of agricultural research and knowledge, however, can make significant improvements in food security goals. In the following section, two alternative variations are analyzed using two sets of changing parameters. The first set of variations looks at different levels of investments in agriculture from 2005 to 2050 that are projected to result in either higher (ARK_high) or lower crop yield and livestock numbers growth (ARK_low). The second set of variations analyzes the implications of even more aggressive or reduced growth in agricultural research and development together with advances in other, complementary sectors. The label ARK_high_pos refers to higher investments in complementary infrastructure and social services while ARK_low_neg refers to decelerating growth in these services. Complementary sectors include: irrigation infrastructure, represented by accelerated or slowing growth in irrigated area and efficiency of irrigation water use; accelerated or reduced growth in access to drinking water; and education, in particular, secondary education for females, an important indicator for human well-being. Details of all four variants are described in Tables 5 and 6, below.

Table 5 Assumptions for high/low agricultural investment scenarios.

Parameter changes for growth rates	2050 REFERENCE RUN	2050 High ARK variant (#1)	2050 Low ARK variant (#2)
GDP growth	3.06 % per year	3.31 % per year	2.86 % per year
Livestock numbers and yield growth	Base model output numbers growth 2000-2050 Livestock: 1.13 Milk: 0.41	Increase in numbers growth of animals slaughtered by 20% Increase in animal yield by 20%	Reduction in numbers growth of animals slaughtered by 20% Reduction in animal yield by 20%
Food crop yield numbers and growth	Base model output yield growth rates 2000-2050: Cereals: /yr: 0.97 R&T: %/yr: 1.021001 Soybean: %/yr 0.42 Vegetables: %/yr 1.30 Sup-tropical/tropical fruits: %/yr 1.91 Sugarcane: %/yr 1.72	Increase yield growth by 40% for cereals, R&T, soybean, vegetables, ST fruits & sugarcane, dryland crops, cotton Increase production growth of oils, meals by 40%	Reduce yield growth by 40% for cereals, R&T, soybean, vegetables, fruits & sugarcane, dryland crops, cotton Reduce production growth of oils, meals by 40%

Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

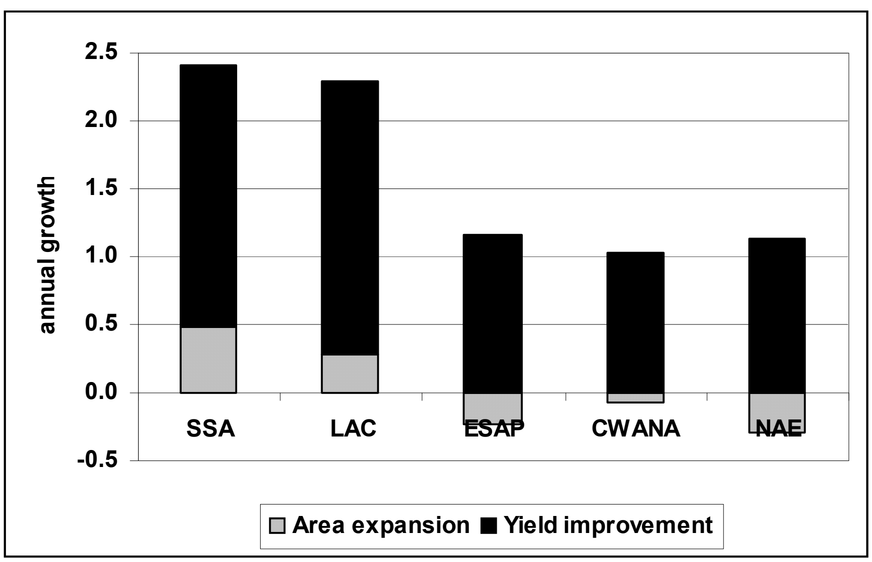
Table 6 Assumptions for high/low agricultural investment combined with high/low investment in other ARK-related factors (irrigation, clean water, water management, and education).

Parameter changes for growth rates	2050 BASE	2050 High ARK combined with other services (#3)	2050 Low ARK combined with other services Low (#4)
GDP growth	3.06 % per year	3.31 % per year	2.86 % per year
Livestock numbers growth	Base model output numbers growth 2005-2030 Livestock: Milk:	Increase in numbers growth of animals slaughtered by 30% Increase in animal yield by 30%	Reduction in numbers growth of animals slaughtered by 30% Reduction in animal yield by 30%
Food crop yield growth	Base model output yield growth rates 2005-2030: Cereals: /yr R&T: %/yr Soybean: %/yr Vegetables: %/yr ST fruits: %/yr Sugarcane: %/yr	Increase yield growth by 60% for cereals, R&T, soybean, vegetables, ST fruits & sugarcane, dryland crops, cotton Increase production growth of oils, meals by 60%	Reduce yield growth by 60% for cereals, R&T, soybean, vegetables, fruits & sugarcane, dryland crops, cotton Increase production growth of oils, meals by 60%
Irrigated Area Growth (apply to all crops)	0.06	Increase by 25%	Reduction by 25%
Rainfed Area growth (apply to all crops)	0.18	Decrease by 15%	Increase by 15%
Basin efficiency		Increase by 0.3 by 2050, constant rate of improvement over time	Reduce by 0.3 by 2050, constant rate of decline over time
Access to water		Increase annual rate of improvement by 50% relative to baseline level, (subject to 100 % maximum)	Decrease annual rate of improvement by 50% relative to baseline level, constant rate of change over time
Female secondary education		Increase overall improvement by 50% relative to 2050 baseline level, constant rate of change over time unless baseline implies greater (subject to 100 % maximum)	Decrease overall improvement by 50% relative to 2050 baseline level, constant rate of change over time unless baseline implies less

Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

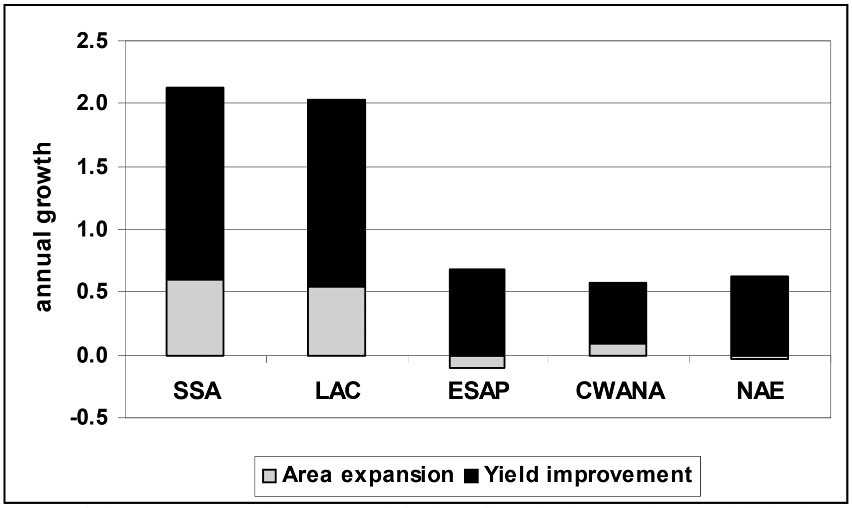
Results of the four alternative variations are presented in Figures 13 to 20 and Table 7. The ARK_high variant presumes increased investment in ARK results in higher food production growth that in turn reduces food prices and makes food more affordable to the poor when compared to business-as-usual. Demand for cereals (both as food and as feed) thus increases by 249 million mt or 8 percent. The combination of even more aggressive investment in ARK with sharp increases in expenditures for supporting social services results in even higher demand for cereals (both as food and feed) to 517 million mt or 17 percent. Similarly, if levels of investment in ARK drop somewhat faster than in recent decades and if investments in key supporting services are not strengthened, food prices would rise, and demand would be depressed. Despite these strong changes in ARK behavior, yield growth will continue to contribute more than area expansion to future cereal production growth under both the ARK_low and ARK_high variants (Figures 13 and 14).

Figure 13 Sources of cereal production growth, High_ARK variant, by IAASTD region.



Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

Figure 14 Sources of cereal production growth, Low_ARK variant, by IAASTD region.



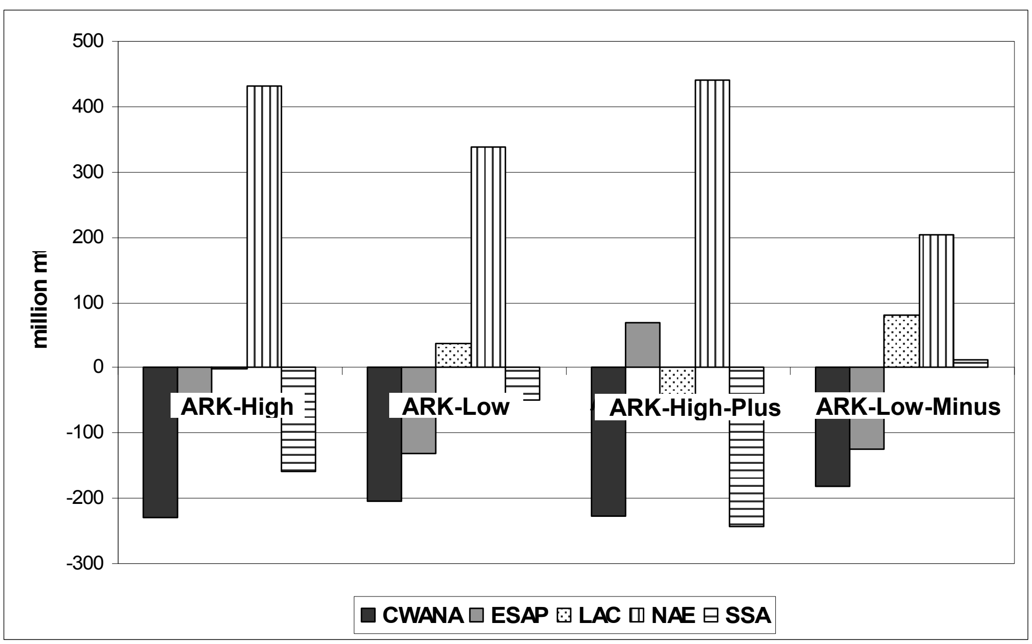
Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

Under a scenario of lowered investments in ARK, area expansion would contribute 28, 27, and 17 percent to cereal production growth in SSA, LAC, and CWANA, respectively, compared to 24, 19, and 0 percent in the baseline reference case. This situation could lead to deforestation as forests are converted to agriculture. At the same time, rapidly expanding livestock populations under ARK_high require expanding grazing areas in SSA and elsewhere, potentially exacerbating deforestation.

Growing water constraints affect future benefits of ARK. In the reference world, irrigation water supply reliability declines out to 2050, reducing the future benefits from ARK for the development goals. Water scarcity is expected to increase considerably in the ARK_low_neg variant as a result of a sharp degradation of irrigation efficiency. Irrigation will continue to be the largest water user in 2050 for all regions. However, it is estimated that the share of irrigation consumption in total water depletion will decrease by about 10 percent from 2000 to 2050. The decline in irrigation water use is largely due to the more rapid growth of non-irrigation water demands that compete for water with irrigation, and also because of projected declines in irrigated areas in some parts of the world. Future ARK investments and directions increasingly need to take into account growing variability and reduced availability of water resources.

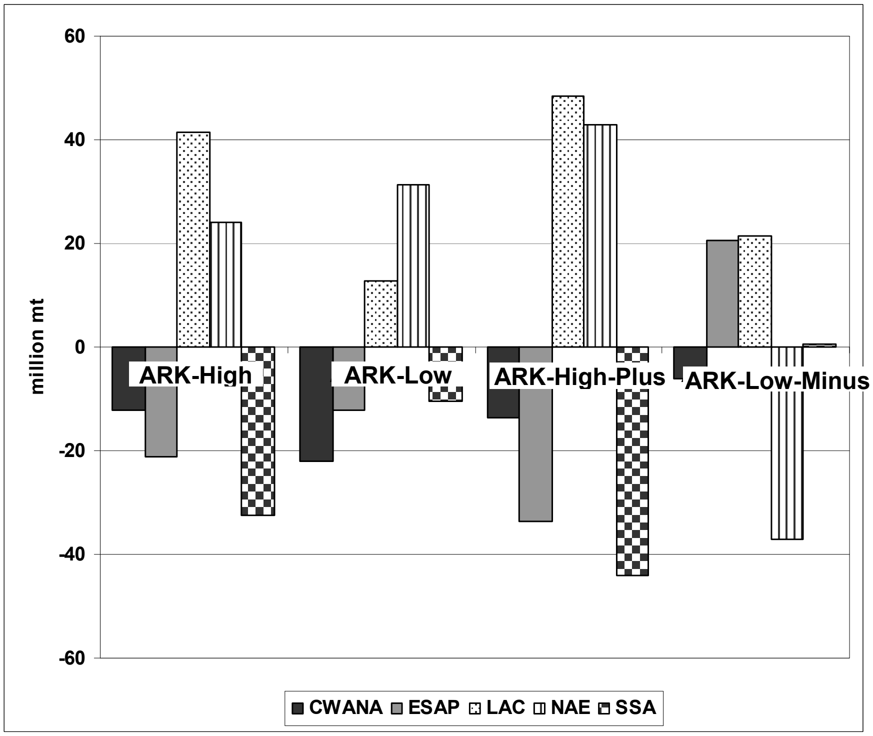
What are the implications of more aggressive production growth on food trade and food security? Under ARK_high, SSA cannot meet the rapid increases in food demand through domestic production alone. As a result, imports of both cereals and meats increase compared to the reference run, by 79 and 113 percent, respectively (Figures 15 and 16). Under ARK_high, CWANA and ESAP increase their net import positions, while LAC and NAE would strengthen their net export positions for these commodities. For cereals, CWANA and LAC would increase imports, while NAE and ESAP would increase their export positions. Under ARK_low_neg, high food prices lead to depressed global food markets and reduced global trade in agricultural commodities.

Figure 15 Cereal trade, alternative ARK variants, IAASTD regions



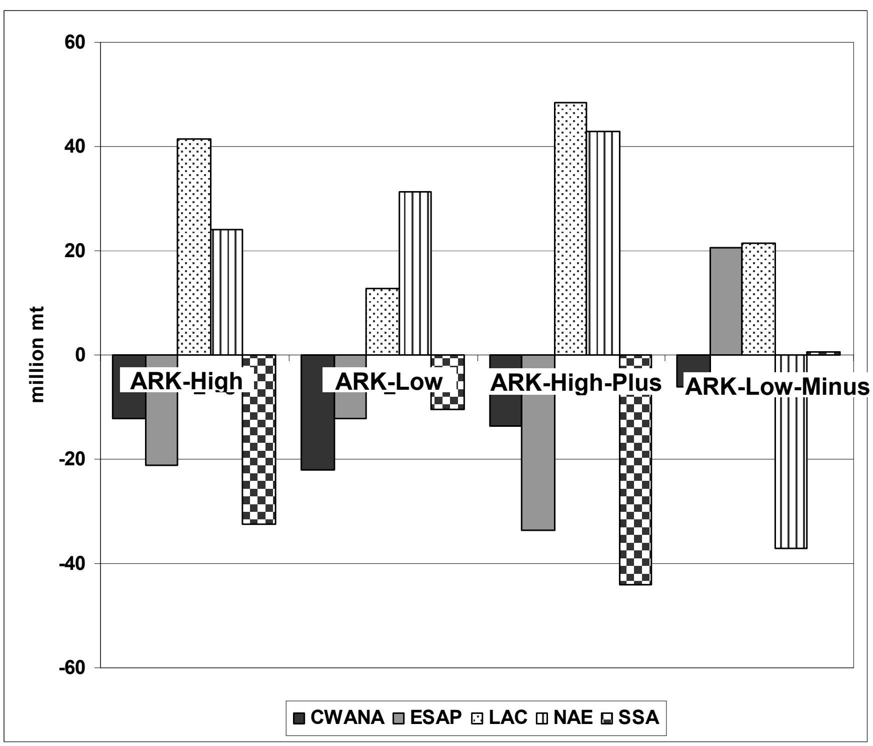
Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

Figure 16 Cereal trade, alternative ARK variants, IAASTD regions.



Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

Figure 17 Cereal trade, alternative ARK variants, IAASTD regions.



Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

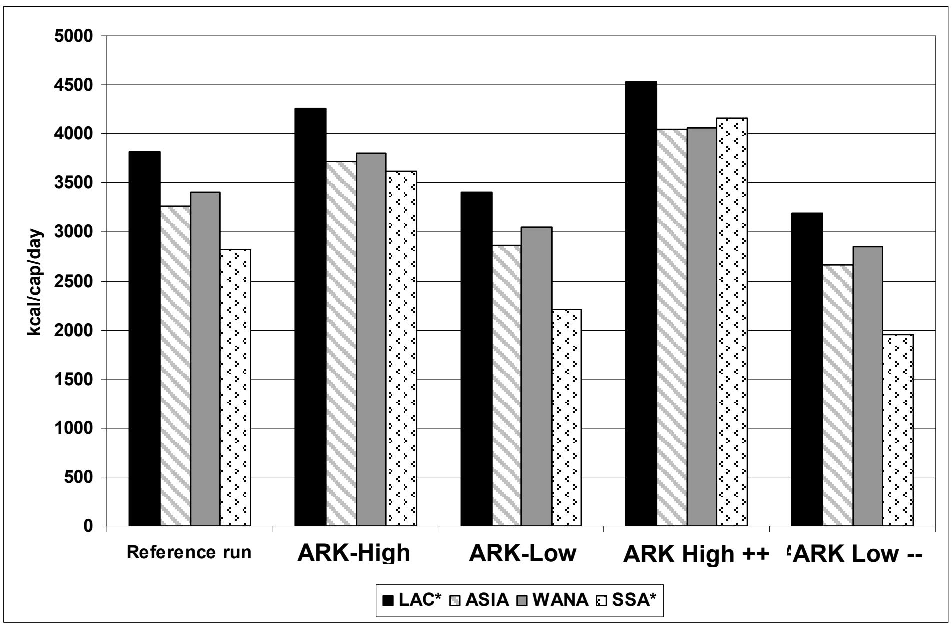
Sharp increases in international food prices as a result of the ARK_low and combined variants as shown in Table 7 depress demand for food and reduce availability of calories as shown in Figure18. In the most adverse, ARK_low_neg variant, average daily kilocalorie availability per capita declines by 669 calories and average calorie supply in Sub-Saharan Africa falls below the minimum of 2,000 calories and thus below the levels of the year 2000. Similarly, the group of Asian developing countries would fall below the 2000 calorie level under this policy variant. Calorie availability together with changes in complementary service sectors can help explain changes in childhood malnutrition levels (see also Rosegrant, Cai, and Cline 2002). Under the ARK_high and ARK_high_pos variants, the share of malnourished children is expected to decline to 12 percent and 9 percent, respectively, from 15 percent in the reference world and 27 percent in 2000 (Figure 18). This translates into absolute declines of 17 million children (21 percent) and 33 million children (42 percent), respectively under the more aggressive ARK and supporting service variations. On the other hand, if investments slow at at a faster rate, and supporting services degrade as well, then absolute childhood malnutrition levels could return to nearly their 2000 values: 127 million children under the ARK_low_neg variation. Under the ARK_low variation the levels would be 99 million children malnourished. Within Asia, child malnutrition levels decline by more than half for India under the ARK_high_pos variants, and decline by a factor of 3 and 5, respectively for Other South Asia and Southeast Asia. In East Asia, the declines would be most rapid, from 11 million children in 2000 to an estimated 0.6 million by 2050 (Figure 19).

Table 7 Selected international food prices, projected to 2050, reference run and ARK variations.

	Reference run	ARK-high	ARK_low	ARK_high_pos	ARK_low_neg
	US$ per metric ton				
Beef	2,177	-18	14	-26	42
Pork	997	-24	19	-33	56
Sheep & goat	2,420	-22	22	-31	50
Poultry	1,343	-26	22	-36	66
Rice	257	-37	50	-57	132
Wheat	156	-37	43	-54	141
Maize	127	-44	60	-59	208
Millet	243	-39	57	-48	131
Sorghum	136	-42	56	-53	164
Other coarse grains	89	-54	90	-66	319
Soybean	231	-30	26	-42	92

Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

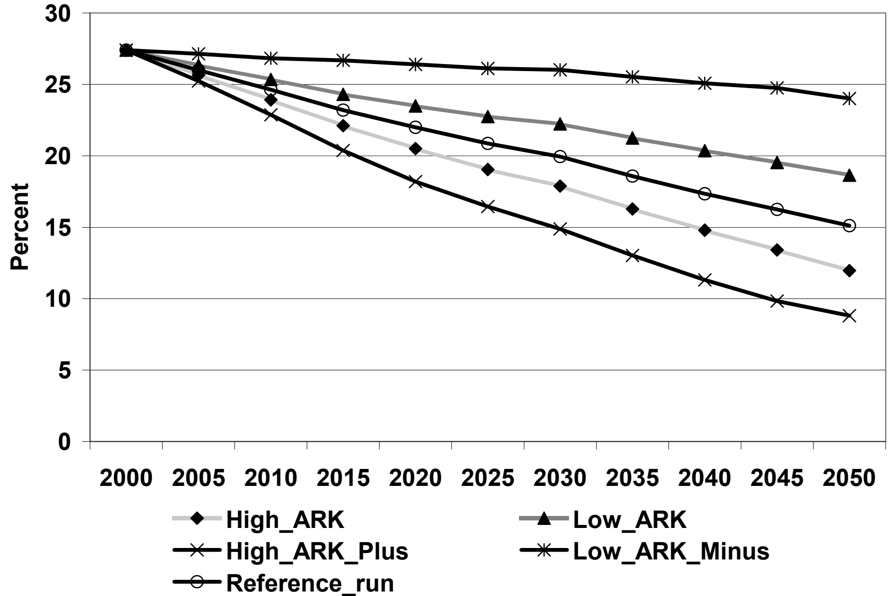
Figure 18 Average daily calorie availability per capita, selected regions, ARK variants.



Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

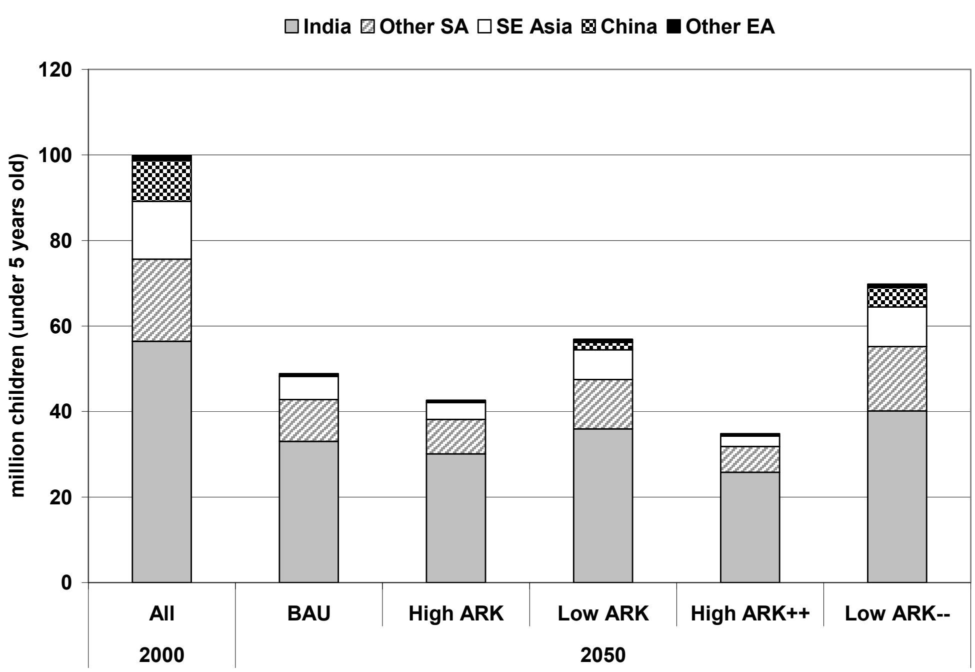
Note: 2025 and 2050 are not three-year averages. Asia does not include developed countries in the region (Japan, Australia); WANA (West Asia and North Africa) does not coincide with CWANA, and SSA* and LAC* do not coincide with the IAASTD SSA and LAC regions.

Figure 19 Share of malnourished children across scenarios, alternative ARK variants, developing countries



Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.
Note: 2025 and 2050 are not three-year averages. Asia does not include developed countries in the region (Japan, Australia); West Asia and North Africa does not coincide with CWANA.

Figure 20 Number of malnourished children across scenarios, alternative ARK variants,



Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.
Note: Asia does not include developed countries in the region (Japan, Australia)

Meeting the Challenges of the Future

The IMPACT projections clearly demonstrate the significant benefits of increasing investment in agricultural research that can contribute to increasing the productivity of each hectare of land and each drop of water in the face of growing scarcity. Under business-as-usual, projections show increases in real world food prices. As already noted, the substantial increase in food prices will cause relatively slow growth in calorie consumption, with both direct price impacts and reductions in real incomes for poor consumers who spend a large share of their income on food. This in turn contributes to slow improvement in food security, particularly in South Asia and Sub-Saharan Africa.

The Challenge of Formulating Policies to Achieve Pro-Poor Growth

Since poverty is largely a rural phenomenon and since many of the poor depend, directly or indirectly, on the farm sector for their incomes, growth that raises agricultural productivity and the incomes of small-scale farmers and landless laborers is particularly important in reducing poverty. Growth alone is therefore not sufficient to rapidly reduce poverty. Policies must also reach out directly to the poor by supporting investments in human capital. Investments in health, nutrition, and education not only directly address the worst consequences of poverty, but also attack some of its most important causes (see also below). Moreover, even with rapid economic growth, some of the poor will be reached slowly if at all and many of them will remain vulnerable to economic reversals. These groups can be reached through income transfers, or through safety nets that help them through short-term stresses or disasters.

In the agricultural sector, the poor benefit most when:

- land is distributed relatively equitably;
- agricultural research focuses on the problems of small farmers as well as large;
- new technologies are scale-neutral and can be profitably adopted by farms of all sizes;
- efficient input, credit, and product markets ensure that farms of all sizes have access to needed modern farm inputs and receive similar prices for their products;
- the labor force can migrate or diversify into the rural non-farm economy; and policies such as subsidies do not discriminate against agriculture in general, and small farms, in particular.

The Challenge of Increasing Investments in ARK to Improve Food Security and Environmental Sustainability

The biggest challenge that faces the agricultural sector is to achieve an increase in investments in relevant ARK to provide both greater improvements in food security and to contribute to raising incomes, and to do so without adding to existing environmental stresses. New agricultural technologies in Asia—such as technologies to implement integrated pest management and to improve the nutrient balance and the timing and placement of fertilizer applications—are increasingly complex, knowledge-intensive and location-specific; they demand continued investment to create a better and more decentralized research and extension system. Because new technologies are more demanding for both the farmer and the extension agent, they require more information and skills for successful adoption compared to the initial adoption of modern varieties and fertilizers. Decentralization of existing extension services structures that encourage a bottom-up flow from farmers to extension and research could also help farmers cope with the additional complexity of efficiency-enhancing technology. Bottom-up information flows, combined with adaptive, location-specific research, are particularly important in the transfer of complex crop-management technologies.

Some of the research effort will be led by the public sector. Governments' desires to pursue equity or poverty-alleviation objectives leads them to support improvements in basic yield potential in wheat or rice varieties adapted to Asian conditions or to investigate "orphan" commodities that are of less interest to the private sector. In Asia, however, the private sector has an increasing role, in agricultural research, especially if policy barriers can be reduced. Biotechnology innovations are likely to further the scope for private-sector involvement, and offer important potential benefits, but also risks.

There are many examples of how agricultural research continues to advance productivity. Farmers living in marginal agricultural regions of Western India have been reaping the benefits of client-oriented breeding, a process by which seed varieties are bred to meet the specific needs of client farmers. In India, the client-oriented approach has yielded the new maize variety GM-6. Because breeding is targeted to meet the requirements of farmers, seed adoption has been remarkably high. One-third of participating farmers in the state of Gujarat reported a 10 to 20 percent increase in both farm and non-farm income. Household self-sufficiency, meanwhile, has increased by as much as two months. In Western India, investment in ARK has already led to a real impact on the livelihoods of poor farmers (Yadavendra, Patel, and Witcombe 2005).

In China, approximately 74 percent of agricultural land is deficient in phosphate, a nutrient essential to plant growth and physioligy. Most poor farmers cannot afford expensive chemical fertilizers and struggle to maintain their livelihoods with poor soils and low crop yields. In response, Europe and China set up the *Mychintec* project in 2000, a collaborative effort that improves soil through the use of Arbuscular Mycorrhizal Fungi (AMF), microscopic fungi that associate with plant roots and help them gain nutrients. This new biotechnology is affordable to poor farmers and, unlike phosphate fertilizers, does not pollute the environment. AMF works well on hand-planted crops, such as the sweet potato, maize and cassava crops popular in China. Preliminary results have shown a crop yield increase of up to 11 percent in sweet potato and maize yields and quality increase of up to 26 percent. AMF may prove to be a biotechnology that is both accessible and ecologically friendly (European Commission 2007).

Population pressure on the land, agricultural intensification combined with policies that encourage inappropriate farming practices, and waste disposal from a rapidly growing livestock sector all pose significant threats to the rural environment. But water scarcity and quality are probably the most severe challenges facing developing Asia, and will reach crisis levels in many Asian countries in the next decade or two. Water is becoming scarce, not only because of growing demand from agriculture, industry, and households, but because the potential for expanding the water supply is diminishing. Deteriorating water quality will further aggravate water shortages. Much of the water needed to meet new demand must come from existing uses. The types of policies that can improve water management--for example, removal of subsidies and taxes that encourage misuse of resources and establishment of secure property rights--are broadly applicable to other environmental problems as well. The most significant water reforms involve changing the institutional and legal context in which water is supplied and used. Water users will need to have greater power to make their own decisions regarding water use and markets will need to send correct signals about the real value of water.

Nonetheless, tradeoffs are inevitably going to be required between food security, poverty, equity, environmental sustainability, and economic development. Even in the best scenarios, biodiversity may be affected by the intensification of livestock and aquaculture production systems, climate changes, and by increasing competition for farmland by alternative needs for urbanization, infrastructure, and bioenergy, as well as food production. Bioenergy—the production of liquid fuels from biomass—could meet some of the world's growing energy demand, particularly for transportation. Large-scale cultivation of biomass for energy applications could significantly change future land use and resource management strategies. In projections where more agricultural land becomes available as a result of rapid yield improvement and slow population growth, the potential for bioenergy growth is considerably higher than in land-scarce variants.

The Government of India is actively exploring options for large scale biofuel production (see The India Vision 2020), to supplement fossil fuel and to boost farmers incomes. It has, since 2003, mandated blending 5 percent ethanol made from sugarcane into petroleum in sugarcane-producing parts of the country. This bioethanol has until now remained competitively priced with refined petroleum. In India, however, most sugarcane is irrigated, so the production of the biofuel competes with higher-valued water uses in the country. The consequences of expanding biofuel production are uncertain in a country that covers only 2.4 percent of the earth's territory but supports 16% of the world's population, and in the longer run, there are likely to be impacts on the nation's food security. During a period when agricultural productivity increased 8% (from 1991 to

2001), India's rapid population growth depressed the average per capita availability of food grains by 13% during the same period.

India's second promising source of biofuel is biodiesel derived from non-edible oil seeds, such as *jatropha* and *pongamia*. To minimize the effect on food security, the Government plans to grow these seeds on wastelands, although private industries and local governments are also exploring the use of agricultural land as well. A larger supply from these plantations is expected to lower the prices of biodiesel are expected to come down after a few years, but the contribution to the country's total diesel requirement would still be a very low 0.5% by 2012.

Additional, innovative sources of biofuels for which commercially viable technologies are almost ready include cellulose-based ethandol, derived from plant stalks, leaves, and wood, as well as synthetic diesel, made from an even broader range of energy crops or waste streams. Some of these alternatives might require only a minimum of cultivation and harvest effort, compared to more input-demanding, and often less profitable cash crops; if they occupy more marginal lands, they might not compete with food crops,.

There are additional entry points for sustainable rural development in increased access to information via new information and communication technologies (ICT), potentially offering rural communities a say in the future of small-scale agriculture and facilitating greater access to financial capital via remittance investment plans. The attributes of ICTs are linked directly and indirectly with the Millennium Development Goals (MDG), especially those that relate to health and education (Torero and von Braun 2005). As internet access increases in rural areas, technological and market information will become readily available to small-scale producers if private and public institutions take up the challenge of preparing information for a diversity of user groups., Cellular phone use among national and international migrants will enhance information flows and participation in decision making, reinforcing links between migrant organizations in receiving countries and sending communities. These improved communication pathways, together with the remittances, have the potential to influence in positive ways development paths in the originating areas.

The Challenge of Reducing Malnutrition

Even though the agricultural sector has declined relative to other sectors during the course of Asia's economic transformation, agricultural output has continued to grow, as it must. Slower agricultural growth could jeopardize food security and increase child malnutrition in many countries, cause significant new unemployment and poverty (particularly in rural areas), and reduce nonagricultural growth.

If, under a pessimistic scenario, governments become even more complacent than they are today about agriculture, invest less in rural areas, and do not make needed policy reforms, projections based on IFPRI's IMPACT model show that the number of malnourished children, a good indicator of current and future poverty, will remain virtually unchanged in 2010 from the 1993 level of 140 million. On the other hand, if government policies continue as usual, that number would drop to 113 million children. But if governments were to become a little less complacent about agriculture and complete economic reform as well, the number of malnourished children would drop sharply to 76 million, 65 million less than the pessimistic scenario. The projections show that it does not take much backsliding by governments to lead to unacceptable outcomes within a decade. South Asian children would suffer most from government complacency.

Optimal ARK investments will require the application of an appropriate mix of strategies and policy interventions in order to be effective, depending on the potential and constraints in different nations. But even a modest increase in government commitment to rural investment and policy reform could save tens of million of children from malnutrition in the decade ahead. And in two decades it is feasible to virtually eradicate poverty and child malnutrition, according to the results from the IMPACT model. But to do so most of the poorest Asian economies would have to grow at rates close to the peaks experienced by the most dynamic economies in the region, agricultural productivity would have to reach the levels achieved during the heyday of the Green Revolution, and Asian governments would have to make significant new investments in agriculture and rural areas and spend 50 percent more annually on social programs. Although, realistically, South Asia would need to take a longer view, China and Southeast Asia could reasonably eradicate child malnutrition by 2020.

Conclusions

Pressures are increasing on the food production system of the world and particularly in Asia where land and water resources can be locally scarce. Though Asia as a whole has made great strides in improving human well-being, the region is home to the majority of the world's poor and hungry. While Sub-Saharan Africa is projected to see a growing number of malnourished children and people, the largest absolute number of malnourished children will remain in Asia, as progress in reducing malnutrition levels have been slow, particularly in South Asia. Appropriate investments in ARK and other complementary sectors, however, can greatly improve human well-being on a much wider scale.

Wheat and rice play more important roles in the diets of poorer consumers, but as the region increases its wealth and becomes more urban, diets will tend to diversify towards increased consumption of milk and meat products, as well as vegetables and fruits. Given globally tighter food markets, as a result of rapidly growing demands—and more importantly, increasing resource scarcity, particularly water—world food prices are set to increase over the next several decades. While there is high uncertainty over the final impacts of climate change, declining soil fertility, and other abiotic stresses on food production outcomes, it is already clear today that poor producers and consumers will be hurt the most.

With declining availability of water and land that can be profitably brought under cultivation, expansion in area will contribute very little to future production growth. The projected slow growth in crop area places the burden to meet future cereal demand on crop yield growth. The key to improving yields under increasingly constrained conditions lies in technology to improve agricultural productivity in order to regenerate productivity growth. To adapt to and mitigate the various effects from climate change, heat-tolerant germplasm for wheat and rice, as well as cultivars better adapted to conservation agriculture need to be developed. Likewise, CO_2 emissions can be reduced through new crop management practices supported by appropriate technologies. To achieve such breakthroughs, existing global and regional research-for-development networks for agricultural production technologies and knowledge need to work closely together so that technology and knowledge can flow to allow farmers to face the risks associated with future harvests.

Gains from agricultural research and knowledge (ARK) through aggressive investments and better management can make significant improvements in food security goals. Policy scenario experiments show that with higher investments in ARK, the share of malnourished children in the group of developing countries is projected to decline from a baseline of 80 million to only 64 million. If these higher investments in ARK are combined with improvements in complementary service sectors, such as health and education, the projections show that an even greater reduction, to 47 million, could be achieved. By contrast, either flat-lined or slowed rates of investments into ARK will negatively affect regional food security and exacerbate childhood malnutrition.

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