Agriculture and Food Security in Asia: The Role of Agricultural Research and Knowledge in a Changing Environment

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Keywords: Agricultural Growth, Climate Change, Food Security, Development Policy

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), we find that changes in investments in agricultural research and knowledge (ARK) are required to boost 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 further strengthened.

1. 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, etc.) 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. Figure 1 presents key 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 148 million malnourished children in developing countries (WDI 2005) and, under most scenarios of business-as-usual progress in technological change, will still remain home to 49 million children in 2050. Research on and development of agricultural technology will be 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 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). The first alternative looks at higher levels of investments in agriculture over the period 2005-2050. The second set of variations analyzes the implications of even more aggressive 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.

2. Challenges for Asia

Since the 1970s, Asia 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,

[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).

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). 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.

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. Asia accounts 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. The region's meat production increased by 18 percent over the last 20 years (1980-2000), reaching 88 million metric tons in 2000, accounting for 39 percent of global meat production (FAOSTAT 2007). Asia's food production systems are directly related to indicators of human welfare. Key agricultural production systems and welfare indicators of Asia are summarized in Table 1.

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

[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.

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 enhanced water management under climate extremes and on 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 can set in more easily increasing the incidence of pest and diseases. Overall these impacts are heavily borne by poor farmers, who cannot respond to these conditions with their meager resources—resulting in famine, 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 could be particularly severe in South Asia.

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

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 together with enhanced natural resource management. 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.

3. Selected Challenges and Opportunities

3.1 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 2 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 Figure 2 with a malnutrition map allows farming systems to be prioritized not only in terms of their extent 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.

[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).

3.2 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 3 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.

According to a study by Ortiz et al. (2007) 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.

4. Global Trends and Futures for Agriculture

4.1 Modeling Global Futures

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] 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 balance food supply and demand. 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 (for more details, see Rosegrant et al. 2001).

4.2 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 (Figure 4). This implies rapid growth in demand for cereals as feed, particularly maize and other coarse grains.

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

[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 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.

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 Asia is expected to drop to 0.91 percent annually. As shown in Figure 5, 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 East and South Asia and Pacific (ESAP) region.

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 6). 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.

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 148 million children in 2000 to 130 million children by 2025 and 99 million children by 2050 (Figure7). While results for Asia are impressive, by 2050, the region will still be home to the largest concentration of malnourished children.

4.3 Considering Alternative Investments

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, including in Asia.

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 higher levels of investments in agriculture from 2005 to 2050 that are projected to result in higher (ARK_high) crop yield and livestock numbers growth. The second set of variations analyzes the implications of even more aggressive 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. 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 the two variants are described in Table 3 below.

Results of the two alternative variations are presented in Figures 8 to 12. The ARK_high variant results in higher food production growth which, 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 an increase by 17 percent. Yield growth will continue to contribute more than area expansion to future cereal production growth under the ARK_high variant (Figure 8).

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 9 and 10). For meats, Central and West Asia and North Africa (CWANA) and East and South Asia and Pacific (ESAP) increase their net import positions, while Latin America and the Caribbean

(LAC) and North America and Europe (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 the ARK_high and ARK_high_pos variants, the per-capita availability of calories increase (Figure 11) and 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 12). 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. 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.

5. Meeting Future Challenges

The substantial increase in food prices under the baseline 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 IMPACT projections clearly demonstrate the significant benefits of increasing investment in agricultural research and supporting services that can contribute to increasing the productivity of each hectare of land and each drop of water in the face of growing scarcity

5.1 Formulating Policy 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, however, is 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. 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.

5.2 Increasing Investments to Improve Food Security and 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. Moreover, the private sector can and will have 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.

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 change, 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.

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.

5.3 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 by 2010. Yet, if government policies continue as usual, that number would drop to 113 million children. But if governments were to become 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.

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.

5. 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 remains 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 number is declining in Asia, but slowly as a result of slow improvements in South Asia. Appropriate investments in ARK and other complementary sectors, however, can greatly improve human well-being on a much wider scale.

Basic staple crops 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 as well as biotic 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, 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 number of malnourished children in the group of developing countries is projected to decline from a 2050 baseline number of 99 million to only 74 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 43 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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Figure 1. The interrelationships between climatic conditions, agricultural productivity, food prices, and human well-being

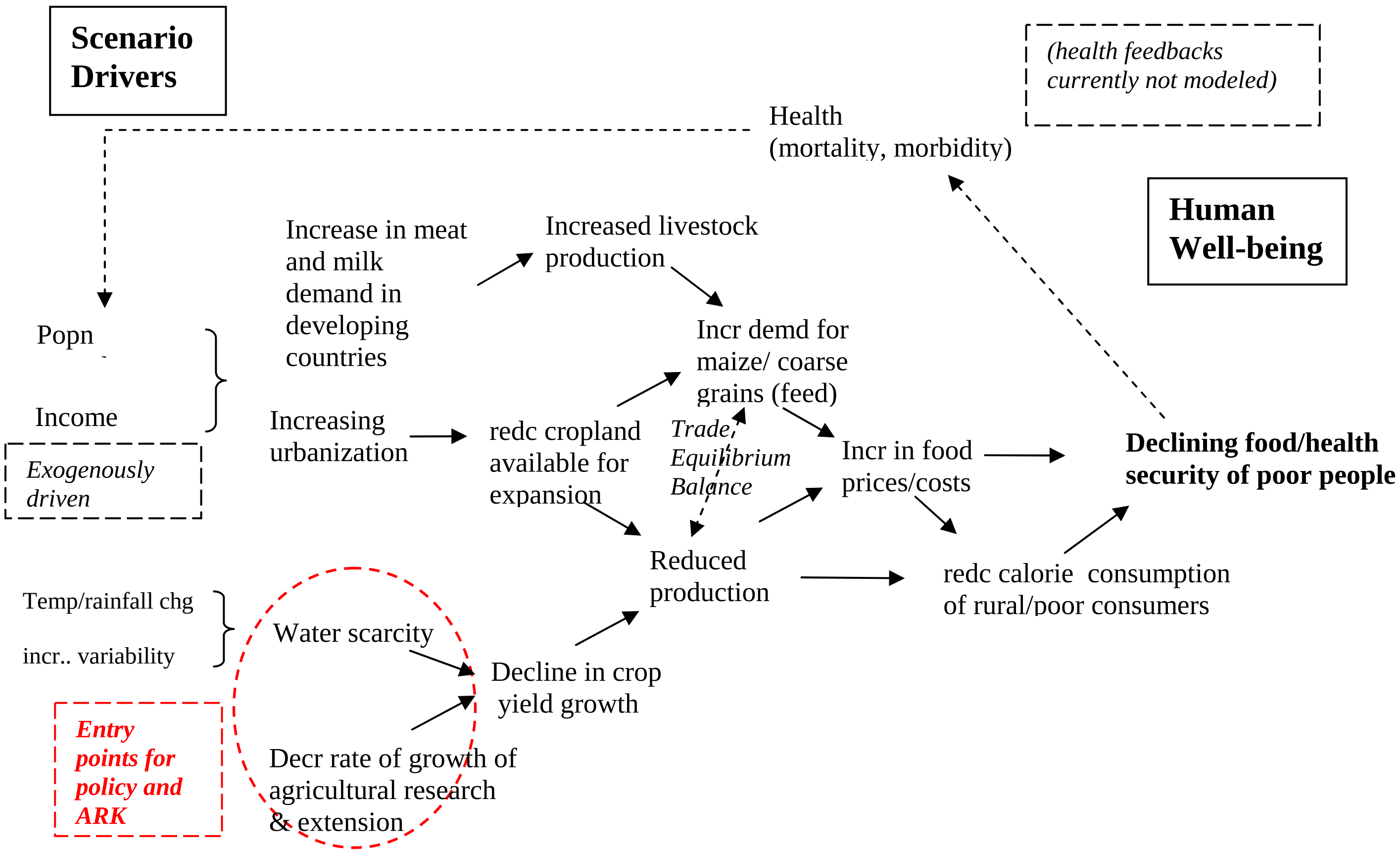
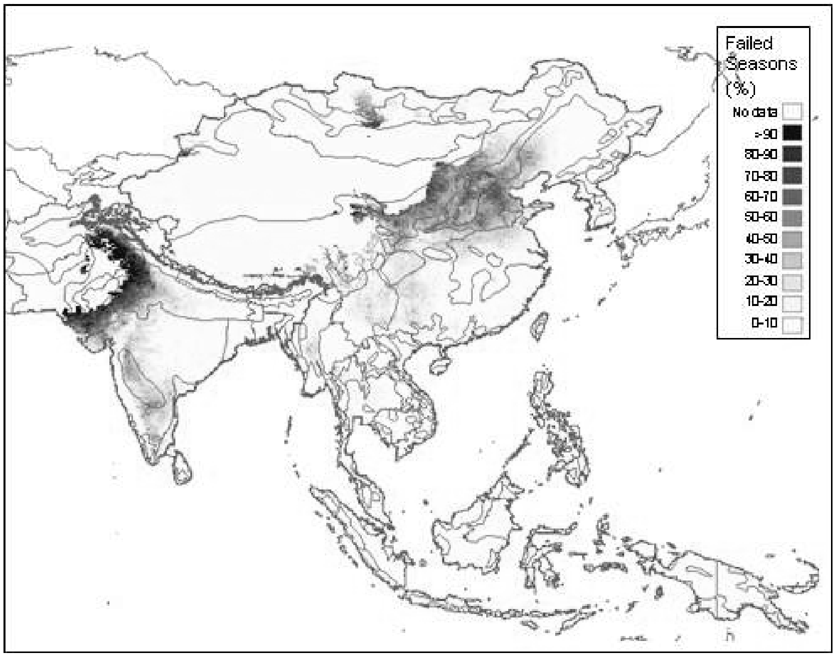
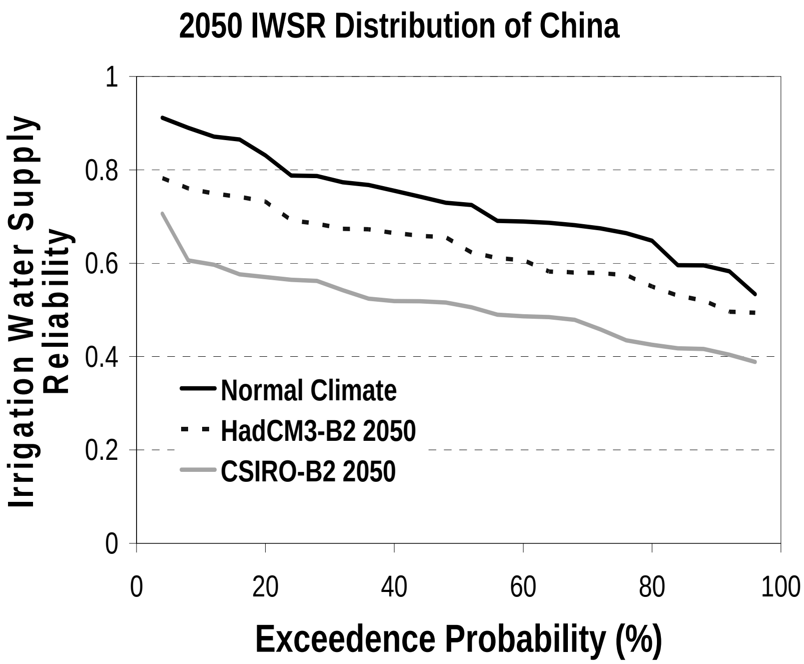


Figure 2. Proportion of failed growing seasons for rainfed cultivation, 100 year weather simulation



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

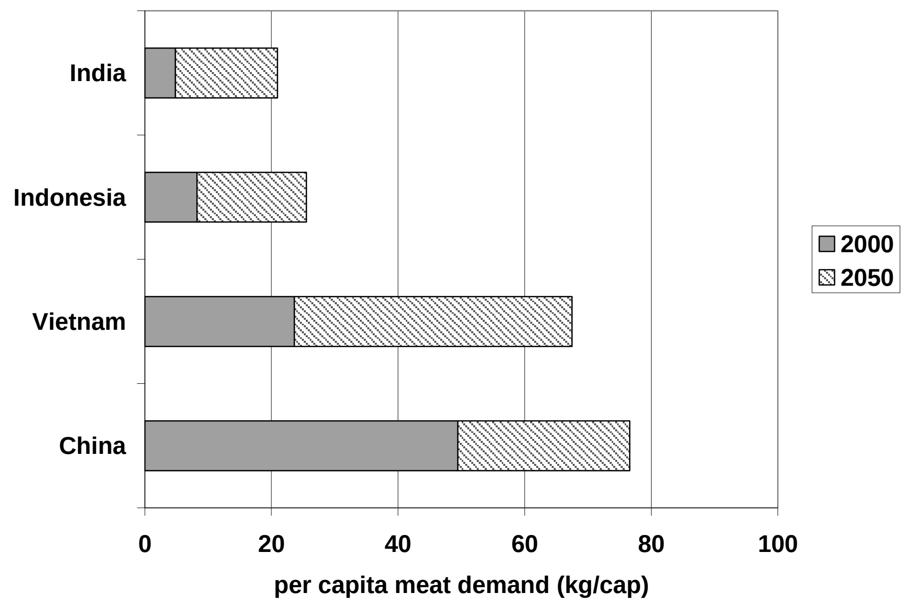
Figure 3. Exceedence probability of irrigation water supply reliability (IWSR) for China, projected 2005



Source: IFPRI (2007). Unpublished data.

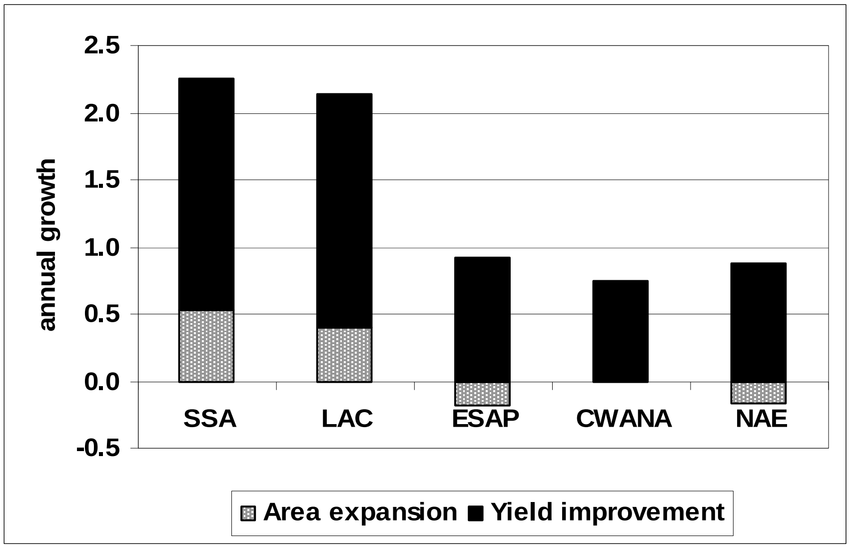
Note: 2050 level for historical climate condition and two climate change scenarios. The exceedance probability refers to the chance that an IWSR level can be exceeded in year 2050.

Figure 4. Per capita meat demand (kg/cap) for selected Asian countries



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

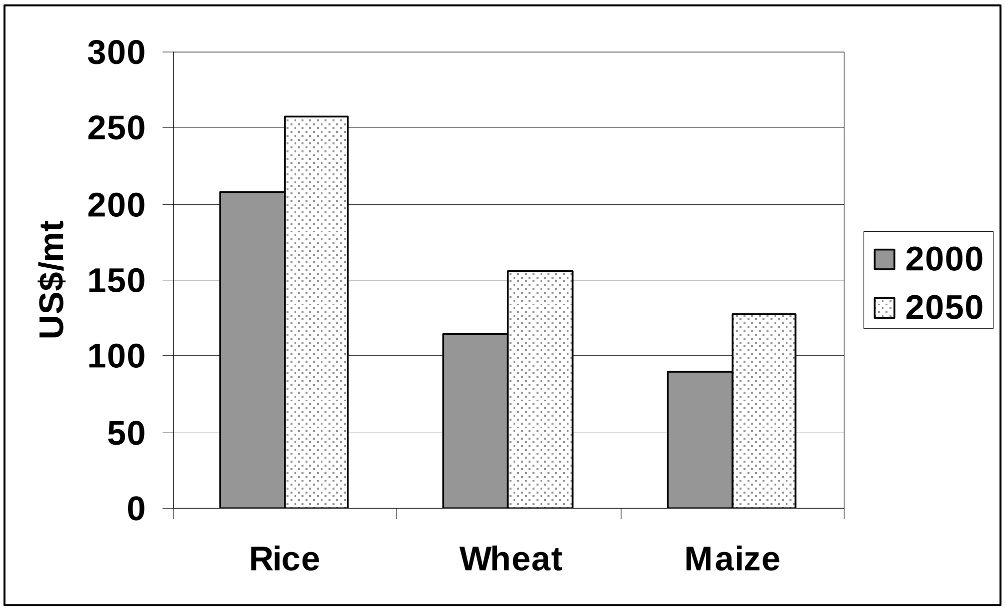
Figure 5. Sources of cereal production growth, business-as-usual, 2000-2050



Note: SSA = sub-Saharan Africa, LAC = Latin America and Caribbean; ESAP = East and South Asia and Pacific; CWANA = Central and West Asia and North Africa; NAE = North America and Europe.

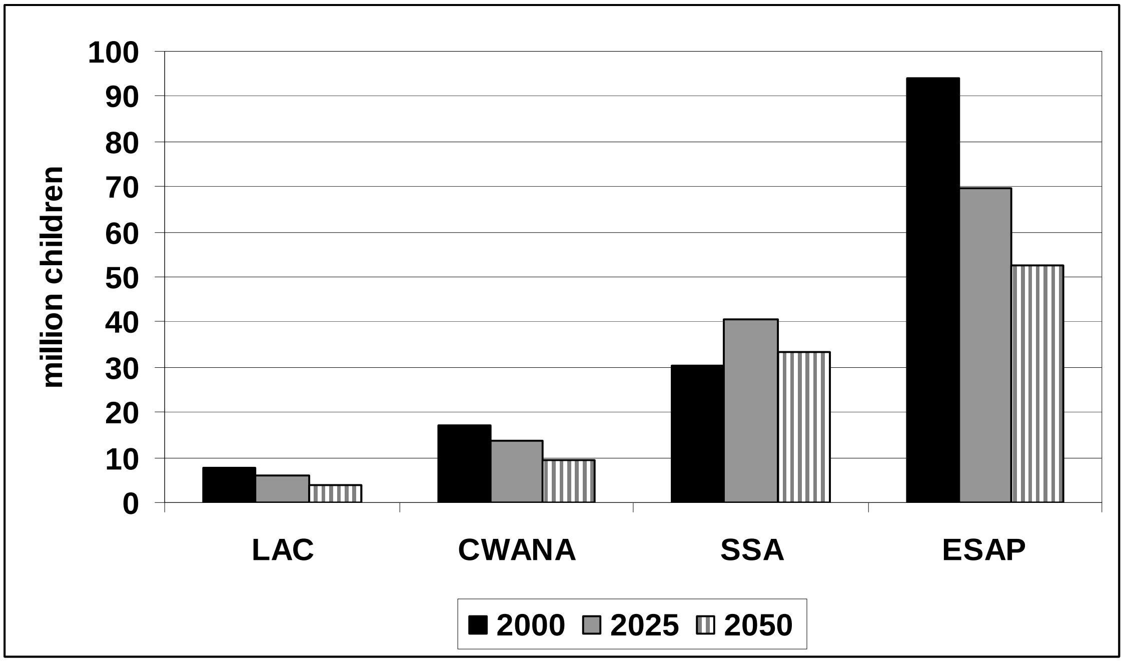
Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

Figure 6. Projected changes in international rice and wheat food prices, business-as-usual, 2000-2050



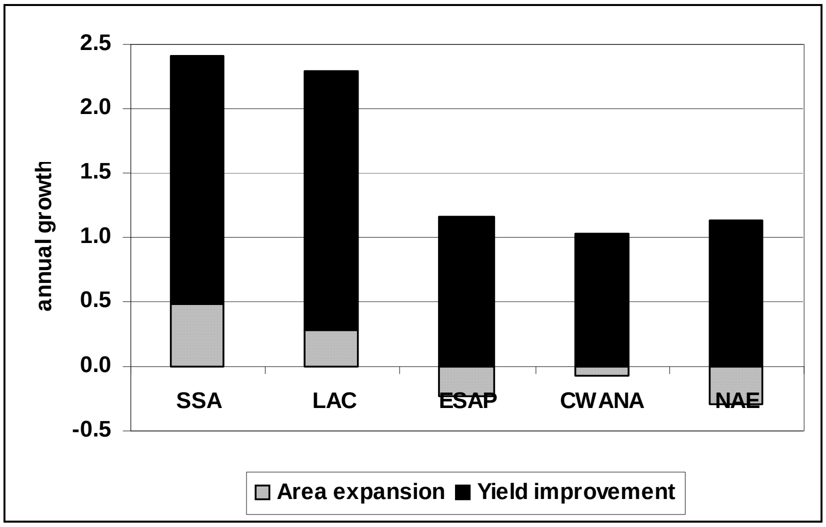
Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

Figure 7. Number of malnourished children in selected developing country regions, business-as-usual, 2000 and projected 2025 and 2050



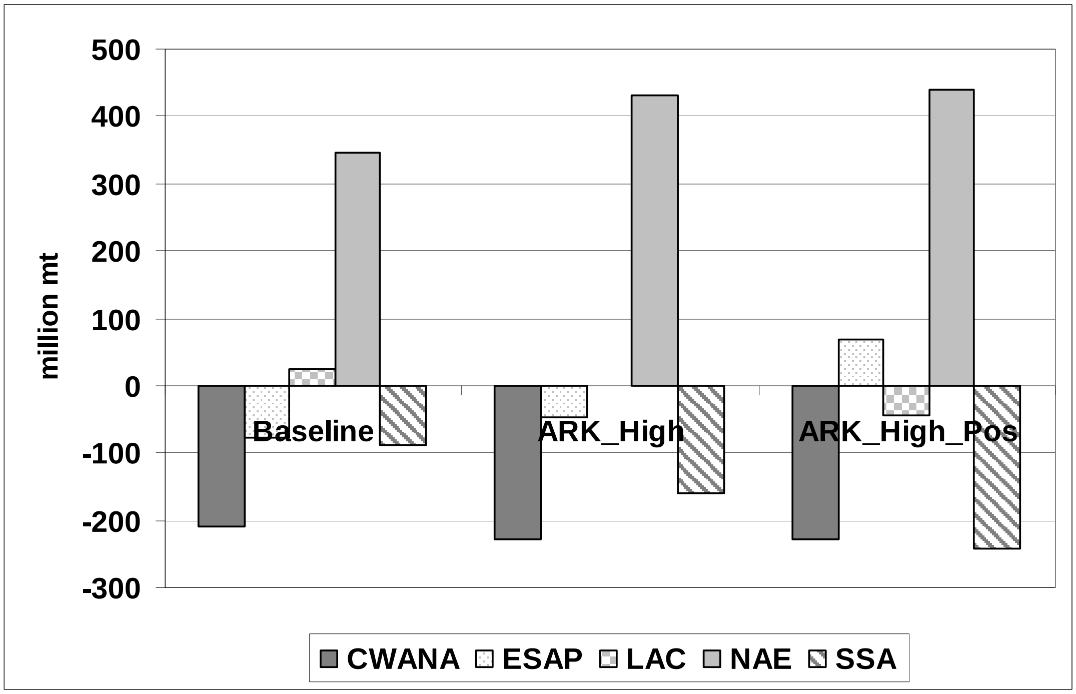
Note: SSA = sub-Saharan Africa, LAC = Latin America and Caribbean; ESAP = East and South Asia and Pacific; CWANA = Central and West Asia and North Africa; NAE = North America and Europe.
Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

Figure 8. Sources of cereal production growth, High_ARK variant, by region



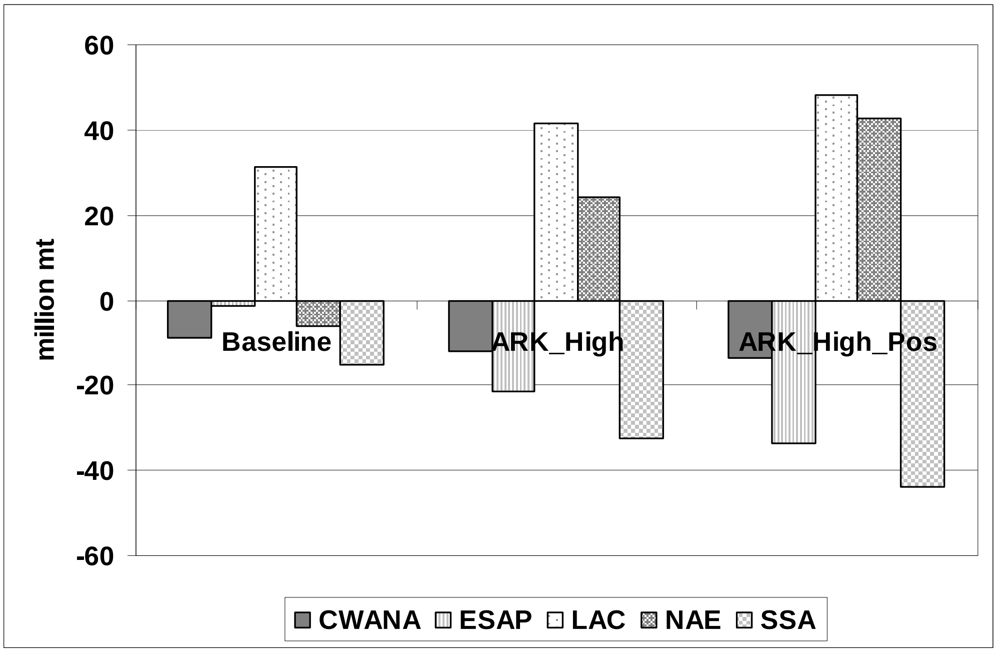
Note: SSA = sub-Saharan Africa, LAC = Latin America and Caribbean; ESAP = East and South Asia and Pacific; CWANA = Central and West Asia and North Africa; NAE = North America and Europe.
Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

Figure 9. Cereal trade, Baseline and alternative ARK variants, various regions



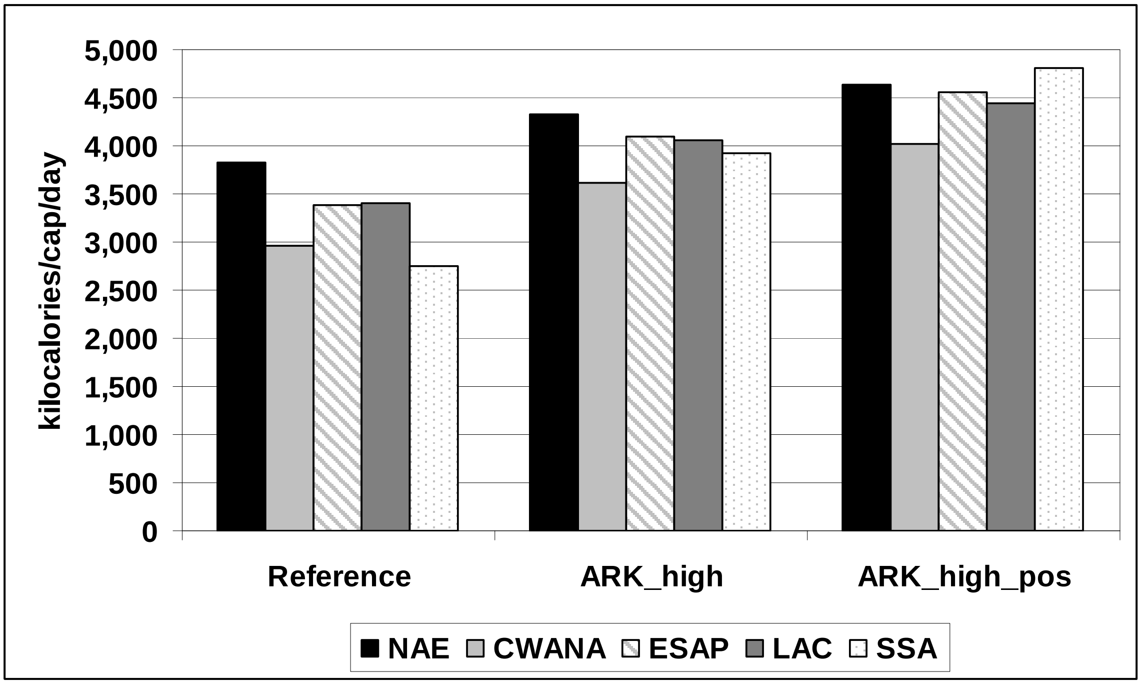
Note: SSA = sub-Saharan Africa, LAC = Latin America and Caribbean; ESAP = East and South Asia and Pacific; CWANA = Central and West Asia and North Africa; NAE = North America and Europe.
Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

Figure 10. Meat trade, alternative ARK variants, various regions



Note: SSA = sub-Saharan Africa, LAC = Latin America and Caribbean; ESAP = East and South Asia and Pacific; CWANA = Central and West Asia and North Africa; NAE = North America and Europe.
Source: Data prepared for IAASTD, Chapter 5, Global Outline draft (2007). Unpublished report.

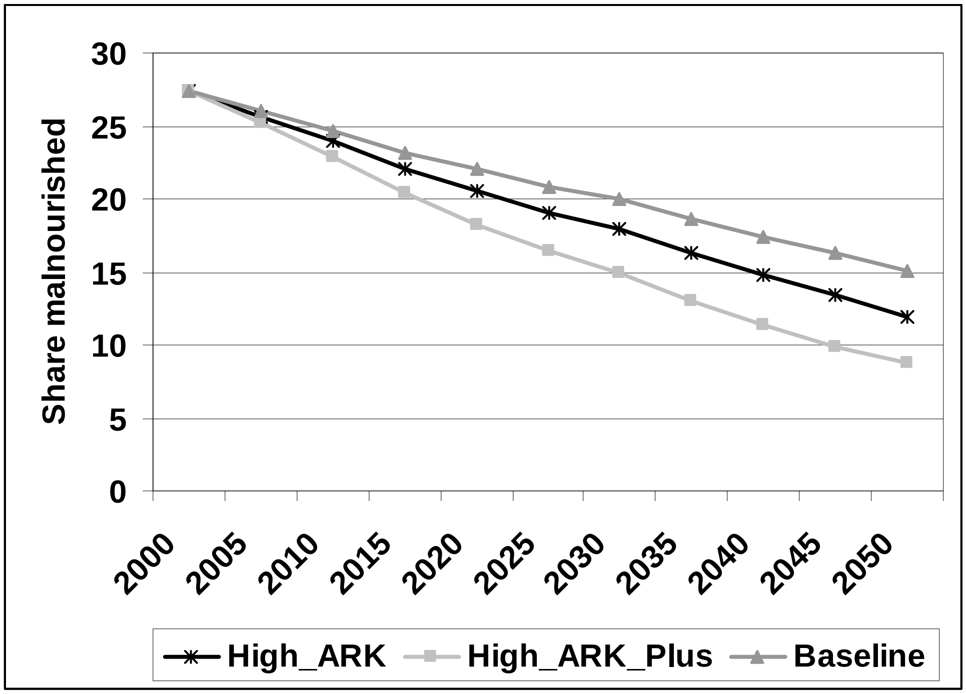
Figure 11. Average daily calorie availability per capita, selected regions, ARK variants



Note: SSA = sub-Saharan Africa, LAC = Latin America and Caribbean; ESAP = East and South Asia and Pacific; CWANA = Central and West Asia and North Africa; NAE = North America and Europe.

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

Figure 12. Share of malnourished children across scenarios, alternative ARK variants, developing countries



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

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	Rural population	cum.	Under 5 stunted	cum.	Under 5	cum.	Infant Mortality	Pop. Density	Rural Pop. Density
		(person)	(person)	(%)	(person)	(%)	(person)	(%)	(per 1000)	(per/km2)	(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.

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

Parameter changes for growth rates	**2050 BASE**	**2050 High ARK variant (#1)**	**2050 High ARK combined with other services (#2)**
GDP growth	3.06 % per year	3.31 % per year	3.31 % 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%	Increase in numbers growth of animals slaughtered by 30% Increase 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%	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%
Irrigated Area Growth (apply to all crops)	0.06	0.06	Increase by 25%
Rainfed Area growth (apply to all crops)	0.18	0.18	Decrease by 15%
Basin efficiency			Increase by 0.3 by 2050, constant rate of improvement over time
Access to water			Increase annual rate of improvement by 50% relative to baseline level, (subject to 100 % maximum)
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.

Acronyms Used

ABARE	Australian Bureau of Agricultural Resource Economics
ARK	Agricultural Research and Knowledge
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
ESAP	East-South Asia and Pacific
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
SRES	Special Report on Emissions Scenarios
SSA	Sub-Saharan Africa