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Recalibrating Food Production in the Developing World: Global Warming Will Change More Than Just the Climate

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Key messages

An analysis of the effects of climate change on 22 critical agricultural commodities and three important natural resources in the developing world reveals a number of cross-cutting themes:

- The world's agricultural systems face an uphill struggle in feeding a projected nine to ten billion people by 2050. Climate change introduces a significant hurdle in this struggle.
- Securing and maintaining necessary levels of calories, protein and nutrients for populations around the world will be an exceptional challenge.
- Recalibrating agriculture in the face of climate change is more than planting crops that can tolerate warmer weather. Some commodities, for example, can grow in warm weather but cannot resist the insects and diseases whose prevalence will increase. Others can tolerate a lack of water but not the sporadic flooding that occurs with more common weather extremes.
- Even as global deforestation continues, trees continue to be valued as a provider of agricultural commodities like nuts and fruit; as a mitigating resource that removes carbon dioxide from the atmosphere; and also as a staple of adaptation—trees help stabilize soil erosion, better regulate water, as well as provide shade, firewood and fodder.

Photo credit: N. Palmer (CIAT)

- Production of the most common commodity staples—wheat, maize and rice—will be challenged by new weather patterns. Adjustments in production, replacement with commodities that can tolerate the new conditions in different regions, and innovations in technology are key elements of adaptation.
- Raising livestock and catching fish and other aquatic products—two of the more common sources of protein—will also be challenged by a new climate. In some areas, different plants, breeds and species can provide substitutions, but in others, adaptation is critical.
- This recalibration of agriculture will eventually extend beyond what is grown and raised. The world's many cultures must adapt to the changing dinner menu forced upon them due to climate change.

Introduction

Around the world, weather patterns are shifting and farmers are scrambling to adjust as the leading edge of climate change is arriving. In quite a few places, growing seasons have expanded, in others they have contracted. Sea levels are rising and water tables are shrinking. For agriculture, climate change is no longer conjecture but a fact of daily life.

Scientists predict that increases in temperatures and shifts in rainfall patterns will have a significant impact on agriculture during this century. The change could be both bad and good. Crops at higher altitudes could become more productive as temperatures rise. But in the tropics and sub-tropics, geographic areas that include the world's hungriest people, climate change could cause crop yields to fall 10 to 20 percent or more between now and 2050.[1] There will be more encounters with high heat, more bouts of drought, and more instances of severe flooding. The damage could come in many forms, but there is a common denominator: crops may not be able to grow where they had been grown for many generations.

What is worse, climate change will disrupt growing conditions just as farmers are being pressed to significantly boost agricultural production. Food demand can only increase as the global population grows from seven billion now to a projected nine to ten billion by 2050.[2] To feed these people, farmers now must simultaneously increase yields—even double them in many areas—while adapting to climate change. Furthermore, they are being asked to accomplish these twin feats while reducing their own greenhouse gas emissions. If they cannot, then food production will be threatened further.

Clearly, the ability of the world's many agricultural systems—particularly those in developing countries—to adapt to climate change will determine whether there will be enough food to feed an additional two billion by 2050. But first, more insight is needed into how climate change will affect the world's staple crops, livestock and the natural resources that nourish them both.

In August 2012, the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), responding to a request from the United Nations' Committee on Food Security, asked experts from CGIAR's 15 research centers to summarize the effects of climate change on 22 of the most important agricultural commodities and 3 critical natural resources in the developing world.[3] In compiling their analyses, the complexities of climate change adaptation became more apparent, and the urgency more obvious.

The analyses revealed, for example, that some crops can withstand high temperatures but are sensitive to changes in rainfall. Other crops can tolerate occasional flooding but are susceptible to new or increased levels of pests and diseases brought on by higher temperatures. Conversely, some disease-resistant crop varieties suffer when nighttime temperatures rise above certain levels. In the face of these complications and the many knowledge gaps that still exist, these CGIAR summaries offer the most coherent picture yet of what climate change adaptation could look like for agriculture in the developing world.

This brief reviews key issues raised in the crop, commodity and natural resource summaries,

1 Thornton P and Cramer L, eds. 2012. Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate. CCAFS Working Paper 23. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). p. 13. http://hdl.handle.net/10568/21226

2 United Nations Department of Economic and Social Affairs, Population Division. 2011. World Population Prospects: The 2010 Revision, Highlights and Advance Tables. Working Paper No. ESA/P/WP.220. New York: United Nations. http://esa.un.org/unpd/wpp/Documentation/pdf/WPP2010_Highlights.pdf

3 Thornton, op. cit.

each of which forms a unique piece of the jigsaw puzzle that must be assembled to ensure the viability of food production in the near future. How will rising temperatures and shifting weather patterns affect crops in the field? How will climate change affect water and soil resources, crop pests and diseases, and trees and forests?

It is important to consider the impact of climate change on diet, particularly in relation to the world's primary staple crops—wheat, rice and maize—but also for animal and vegetable sources of protein. Climate change could require large numbers of people in different parts of the world to consider new foods to meet their nutritional needs.

Finally, there are a series of recommendations for actions that could be undertaken now to lay a better foundation for what will be a decades-long endeavor. These will require a new level of collaboration among farmers, governments, researchers, consumer groups and international institutions to confront perhaps the single biggest challenge of our time.

Weather Extremes and Agricultural Ecosystems

According to the United States National Academies of Sciences, "The average temperature of the Earth's surface increased by about 0.8°C (1.4°F) over the past 100 years, with about 0.6°C (1.0°F) of this warming occurring over just the past three decades."[4] This warming, which is expected to intensify another 1.8 to 4°C by 2099,[5] will have a significant impact on growing conditions. What are now "record temperatures" will become, for many regions, the new normal.

But the hotter weather—which can be a critical drag on crop survival—is just one aspect of climate change. Climate change also is expected to usher in changes in rainfall patterns and more bouts of severe weather, from storms and flooding to record droughts. Entire regions face a shift to a different climate type and the geographic range for many crops will shift accordingly. Changing weather patterns would affect all aspects of the agricultural ecosystem.

You Say Potato, I Say….Banana?

Adaptation to climate change will require an understanding of what is likely to happen to particular crops in specific parts of the world as temperatures rise and weather becomes more volatile, along with an understanding of the options available for overcoming these problems.

Potatoes, for example, rank as the world's fourth largest food crop. More than half of the potatoes grown around the world come from developing countries such as India and China. Potato cultivation is best suited to cooler climates, and the fear today is that steadily rising temperatures are likely to reduce potato yields in places where people already struggle to meet basic nutritional needs. But what crops should people turn to when their dietary staple is no longer viable?

Photo credit: N. Palmer (CIAT)

Rising temperatures may threaten potatoes, the world's fourth largest food crop.

4 National Research Council. 2011. America's Climate Choices . Washington, DC: The National Academies Press.

5 IPCC (Intergovernmental Panel on Climate Change). 2007. Summary for Policymakers. In: Parry ML et al., eds. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press. p. 7-22.

Photo credit: P. Casier (CCAFS)

Developing sustainable water management strategies will be critical for climate change adaptation.

Options are available but there are no easy answers.

Warmer winters caused by climate change could provide an opening for cultivating certain varieties of bananas in higher altitudes that soon may get much warmer—possibly even those places that currently grow potatoes. Warmer weather may increase banana productivity by shortening the time between planting and harvest. But, as with almost every agriculture-related adaptation strategy, there is a caveat: higher temperatures could also increase water demands for banana plants, so bananas might not be an option if climate change reduces rainfall amounts in these places over the long-term.

The growing conditions required by a particular crop are such a nuanced affair that even those crops that can withstand harsh conditions may not survive the worst of what climate change will bring.

Lentils, for example, are valued for their resilience. They do well in relatively dry environments and are mainly cultivated on rain-fed, as opposed to irrigated, lands. Yet their tolerance has its limits and they are in fact susceptible to both drought and heat stresses, both of which are expected to rise in intensity and frequency in ways that could severely deplete production. In South Asia, the crop is grown after the rainy season ends. If in the future the season ends early, lentil production will suffer.

West Asia presents a case in point: lentils planted at higher elevations in the spring would be vulnerable to higher heat. But farmers trying to adapt by planting crops near the end of winter risk losing their lentil crops to cold temperatures and frost.

Millet also is mentioned often as a crop whose production could be expanded in dry areas. Both pearl and finger millet can tolerate high levels of what are known as "abiotic stresses," those non-plant elements, including heat, drought, and poor soil, that can drain a crop's productivity. For millet, "biotic," or plant-induced, stresses include blast disease and the parasitic weed Striga. Climate change could intensify these stresses, diminishing millet's crop yields and its attractiveness as a resilient crop.

In short, extensive research needs to formulate targeted, region-by-region approaches that recalibrate agricultural production according to the effects of climate change. In some cases, this could require farmers to embrace entirely new crops.

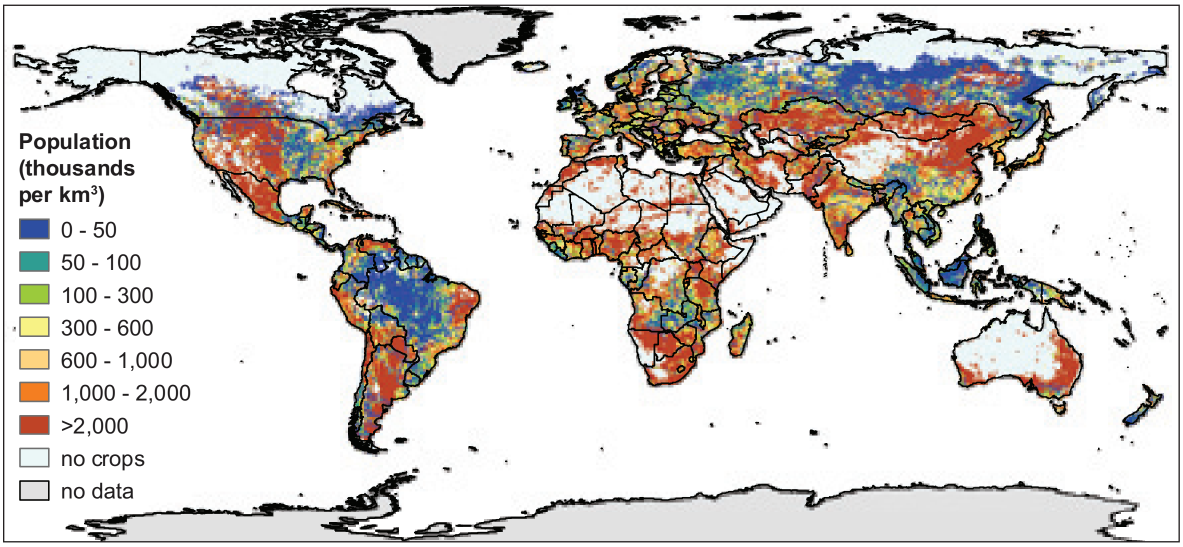
Water Management: A Familiar Fight Gets Tougher

Water scarcity has always challenged food security in the developing world and it will become even more critical with climate change.

For example, 90 percent of all irrigated wheat is grown in less developed countries,[6] while developed countries mostly grow rain-fed wheat. As the planet heats up, crops that rely on water resources will come under increasing pressure. Unless farmers adapt by 2050, climate change could cause wheat yields in irrigated systems in

6 Thornton, op. Cit. page 152.

Figure 1. Current Agricultural Water Crowding – the population per km^3 of river water available for croplands with each 0.50 latitude-longitude grid cell



Source: Eriyagama N, Smakhtin V, Gamage N. 2009. Mapping Drought Patterns and Impacts: A Global Perspective. International Water Management Institute Research Report 133. Colombo, Sri Lanka: International Water Management Institute (IWMI).

developing countries to fall by around 13 percent. Similarly, climate change could cause irrigated rice yields in these countries to fall by 15 percent.[7]

Of all the fresh water used around the world, agriculture accounts for 70 percent.[8] As more water is needed to quench the thirst of the world's rapidly growing population, competition for this resource will force farmers to grow more with less water. Projected changes in water availability vary greatly by region and are lacking in specificity and certainty.

Some regions have addressed rainfall shortages by tapping surface water and groundwater. But these sources are easily depleted if water is taken out faster than it can be naturally replenished. In the Near East, North Africa, and Central Asia, for instance, irrigation systems use approximately 58 percent of existing water resources. In South Asia, the rate is 52 percent. Doubts persist as to whether or not this level of use outpaces nature's ability to recharge groundwater and surface water sources. In sub-Saharan Africa, that rate of water usage is less than three percent.[9] More can be used, but how much more?

Complicating matters further, annual average river runoff and water availability will change with the climate. Already, the amount of water that parts of the world rely on for agricultural production is stretched very thin—a concept known as water crowding. Figure 1 shows the population whose agricultural production is supported by one cubic kilometers of river water.

Understanding the impacts of climate change on water resources in different parts of the world and devising viable water management strategies that conserve this resource thus becomes a critical focus of climate change adaptation. Already,

7 Nelson G, et al. 2009. Climate change: Impact on agriculture and costs of adaptation. Washington, DC: International Food Policy Research Institute. http://dx.doi.org/10.2499/0896295354

8 Brown L. 2004. Outgrowing the Earth: The food security challenge in an age of falling water tables and rising temperatures. Washington, DC: Earth Policy Institute.

9 All three water-use percentages come from the United Nations Food and Agricultural Organization, FAO Statistical Yearbook 2012, http://www.fao.org/docrep/015/i2490e/i2490e04b.pdf

increasing water efficiency—producing "more crop per drop"—is a priority. Additionally, further research is needed to explore alternative sources of water for agriculture, such as energy efficient systems that recycle wastewater and remove salt from ocean water.

Soil Management: Green Fertilizers Wilting in the Heat

Soil health is yet another agricultural concern that climate change will impact. With livestock manure difficult to obtain in some regions and the cost of synthetic fertilizer rising (and its availability and affordability in the developing world still very restricted), smallholders are being encouraged to revive traditional practices of planting crops that can recharge depleted soils and boost yields. But changing weather patterns and shifting climates could alter growing conditions for these "green fertilizers." Strategies must be developed either to ensure current crops remain viable or to provide farmers with alternatives.

Climate-induced pests and diseases may constrain production of pigeon peas, which farmers rely on to improve soil fertility and for protein.

Fava beans are one of the crops in question. In parts of Central and West Asia and North Africa, smallholder farmers grow fava beans in rotation with wheat. In addition to providing protein, fava beans provide nitrogen for the soil. They can infuse soils with as much as 178 to 251 kilograms of nitrogen per hectare.[10] But climate change threatens the use of fava bean plants to manage soil health—and to provide dietary protein—as they are sensitive to heat and drought.

In tropical and semitropical areas, pigeon peas can play a similar role. The plant does not supply as much nitrogen as fava beans (69-134 kg per hectare[11]), though it does provide a comparable level of protein. Also, the plant's perennial, tall, bush-like growth offers additional soil protection and its deep roots help recycle nutrients.

But pigeon pea cultivation could be constrained if climate change intensifies precipitation extremes, as both drought and heavy rains can restrict its growth. The warmer weather would hasten the growth, and change the distribution of threats from pest and disease.

Other plants, such as chickpeas and lentils, also have so-called "nitrogen-fixing" properties and, in general, mixing these "fertilizer" crops with others helps rejuvenate soil.

Today, there is concern that the push to boost agricultural production to meet population increases will inevitably lead to wider use of synthetic fertilizer. During the Green Revolution of the 1960s and 1970s, increased access to this fertilizer facilitated a large jump in production. One issue with synthetic fertilizers, however, is their potential to increase emissions of nitrous oxide, which has much more global warming potential than carbon dioxide. Price is another issue, as the production costs for many types of synthetic fertilizer are projected to rise.

10 Thornton, op. cit. page 53.

11 Kumar JVDK and Dart PJ. 1987. Nodulation, nitrogen fixation and nitrogen uptake in pigeon pea (Cajanus cajan (L.) Millsp) of different maturity groups. *Plant and Soil* 99(2-3): 255-266.

But if farmers are to use more climate-friendly alternatives, such as nitrogen-fixing crops, then the pace of research to ensure the viability of these adaptation approaches needs to quicken.

Pests and Diseases: Battle Heats Up against Old Adversaries

Numerous studies have detailed the projected increase in pestilence and plant disease that could be caused by climate change. While pests and diseases have historically triggered catastrophic food losses—such as the potato blight that instigated the Great Famine in 19th century Ireland—the more typical pattern has involved a steady decrease in production.

The warmer temperatures that climate change is expected to bring would hasten the growth, development and distribution of many pests and diseases. This is a primary point of concern for the potato as temperature is a critical variable with potato blight. As temperatures rise, so does the pace of blight proliferation. Aside from blight, there are other emerging potato diseases that climate change can impact, including more than two dozen viruses.

Yams, which remain fundamental to sustaining the lives and livelihoods of West Africans, are also vulnerable to pests and disease that could intensify due to the effects of climate change. Mealy bugs, scale insects, beetles and nematodes, as well as several viruses, all impact the cultivation of yams. However, if these pests and diseases can be brought under control, yams could play a role in helping regions deal with climate change as they are relatively tolerant of extreme temperatures and dry seasons.

One way to control pest outbreaks is through integrated pest management procedures, which obviate the need to apply pesticides on crops. When a sudden outbreak of mealy bugs threatened the cassava crop in Thailand, for example, the government released a parasitic wasp into cassava fields that brought the mealy bugs under control. But even as climate change unbalances local ecosystems, caution must be used in introducing additional species, as this could risk creating more imbalances.

Another is through genetically modifying crops to develop or enhance their resistance to either pests and diseases or the pesticides and herbicides used to eradicate these threats. For example, crops modified to prevent *Bacillus thuringiensis*, including maize and cotton, have not been as susceptible to flies, beetles, nematodes and other insects.

As the kinds and incidences of plant diseases grow, research to develop disease-resistant crop varieties will become increasingly important. Stem rust, which severely curtails wheat production, presents the classic case in point. Another key feature of the Green Revolution was the development and dissemination of new varieties of rust-resistant wheat. A new strain of stem rust—the now-famous Ug99—has recently emerged in Africa. Scientists have marshaled a global effort to develop and introduce wheat varieties that are resistant to Ug99 before it spreads widely around the world and sparks a global food crisis.

Forest and Agroforests: A Wooded Bulwark against Climate Change

Many discussions on how to slow the pace of climate change focus on the importance of maintaining and increasing forest cover. Forests play a primary role in absorbing and storing carbon. Their destruction—often for the purpose of grazing livestock or growing crops—is a major contributor to the overall build-up of greenhouse gas emissions.

Forests also can help people adapt to climate change. Mangrove swamps, for example, protect coastal communities by serving as a buffer during storms. Inland forests help regulate the flow and quality of fresh water. Forests also provide numerous products that boost the diet and livelihoods of local communities.

Today, smallholder farmers are increasingly adding fruit, fodder trees and other arboreal varieties to their fields through what is known as agroforestry, which itself offers another avenue of adaptation to climate change. Through agroforestry, farmers diversify their food and fodder production while stabilizing their soil, reducing runoff and erosion, and improving water retention.

Unfortunately, changes in climate have severe impacts on forests, trees and the biodiversity that they house. Lower levels of precipitation leave forests more prone to catastrophic fires. In the Congo River Basin and other major forests, continued deforestation due to agricultural expansion, forest fires and the changing climate hasten their decline.

Also, just as it does with crop pests, changing weather conditions appear to allow tree pests to flourish, such as the pine beetles now plaguing forests in the western United States.

There are a growing number of initiatives focused on preserving and expanding the world's remaining forests. They include the effort to Reduce Emissions from Deforestation and Forest Degradation or REDD, which is part of the United Nations Framework Convention on Climate Change (UNFCCC), and the European Forest Law Enforcement, Governance and Trade (FLEGT) initiative that promotes sustainable forestry and reduces illegal logging. Many of these efforts attempt to generate income for impoverished communities that do not threaten wooded areas.

Also, there is an effort to construct a forested belt 15 kilometers wide and 7,700 kilometers long stretching from Senegal in West Africa to Djibouti in East Africa. The so-called Great Green Wall of the Sahara and Sahel Initiative is intended to halt desertification but it could also help moderate the impact of climate change in the region.

Shifting Climate, Changing Diets

As climate change continues to take hold, the effects on food production will require reexamining what's in the cooking pot, especially in regions where people already do not get enough to eat. In fact, climate change will diminish yields of the world's three primary dietary staples: maize, wheat and rice.

According to the United Nations Food and Agriculture Organization (FAO), more than half of the calories consumed globally come from these three crops.[12] But maize, wheat and rice production will be severely challenged by climate change. In some places, it may be possible to overcome the challenges by breeding more resilient varieties, such as those that can withstand high heat, drought or flooding. In other areas, adaptation strategies could involve replacing

Photo credit: N. Palmer (CIAT)

Maize is not well-suited for changes in growing conditions—specifically, higher average temperatures.

12 Thornton, op.cit. page 124.

one of the “big three” with equally nutritious food crops more likely to provide adequate yields under the new growing conditions.

Turning up the Heat on Maize

By 2050, the demand for maize in the developing world is expected to double,[13] according to studies by the International Maize and Wheat Improvement Center (CIMMYT).[14] Maize is a critical source not only of food for people but also of feed for animals (the grain is used in rich countries and the stover, or stocks, in poor countries to feed ruminants) and of ethanol and other materials for industries.

Unfortunately, maize is not well-suited for the changes in growing conditions—specifically, higher average temperatures—that appear to be in store for many regions where it is currently cultivated. Field tests and historic data show that temperatures above 30°C and drought conditions reduce crop yields. Estimates show that in Africa, climate change could depress harvests by 10 to 20 percent.[15] Without varieties that can survive higher temperatures, the only choice for farmers wanting to maintain their maize production is to move it to cooler regions.

But doing so would leave big gaps in both local food and feed supplies. And while improved roads and other transportation infrastructure could help transport maize back to where it had been previously cultivated, it seems likely that some maize-producing regions will have to consider switching to planting and consuming a different crop that is more likely to survive in the growing conditions of the near future.

Without adaptation to this problem at the local level, both the number of malnourished children and people at risk of hunger will climb.

Photo credit: N. Russell (CIMMYT)

A researcher and farmer in Ecuador examine a new drought-tolerant wheat variety.

Wheat: Humanity’s Oldest Crop at a Climate Crossroads

Wheat is the world’s most important plant-derived protein and calorie source. One of the first domesticated food crops, it has been a staple food for people in Europe, West and South Asia, and North Africa for more than 8,000 years.

Climate change will have significant impacts on wheat yields, as the crop suffers under extreme heat and drought. The developing world in particular will be hard hit. Irrigation might help wheat survive stressful conditions, but the amount of water needed to do so would place an unsustainable demand on current water sources. Planting wheat earlier and developing improved varieties that have a shorter growing cycle may also help wheat farmers adapt to climate change.

13 CIMMYT and IITA. 2012. What the World Eats: MAIZE – a sustainable strategy for food security. Texcoco, Mexico and Ibadan, Nigeria. International Maize and Wheat Improvement Center (CIMMYT) and International Institute for Tropical Agriculture (IITA). www.cimmyt.org/en/about-us/partnerships/countries/doc_download/1392-what-the-world-eats-maize

14 CIMMYT and IITA. 2012. What the World Eats: MAIZE – a sustainable strategy for food security. Texcoco, Mexico and Ibadan, Nigeria. International Maize and Wheat Improvement Center (CIMMYT) and International Institute for Tropical Agriculture (IITA). www.cimmyt.org/en/about-us/partnerships/countries/doc_download/1392-what-the-world-eats-maize

15 Thornton, op. cit. page 102.


Photo credit: N. Palmer (CIAT)

Rice production will face multiple threats such as higher temperatures and more flooding.

Rising prices for maize, cotton, soybeans and rice are likely to complicate wheat adaptation efforts, as they have pushed wheat production to marginal lands where the crop is more vulnerable to stresses induced by climate change. Eventually, many wheat farmers may have to seek out a replacement food staple that can be cultivated in the many places that, in the near future, may no longer support wheat production at levels required to maintain food security.

Rice Crops at Risk from Deluge of Climate Stresses

Although rice production is spread among 114 countries, Asian farmers produce more than 90 percent of the world's total. In Bangladesh, Cambodia, Indonesia, Laos, Myanmar, Thailand and Vietnam, rice provides 40 to 70 percent of the total calories consumed. So much rice is consumed locally that only 7 percent of the world's rice production is traded internationally.[16]

Much of the international trade in rice flows toward Africa. During the past 50 years, people in West Africa (and Madagascar) have adjusted their diets to include more and more rice. In Côte d'Ivoire, for example, the share of calories obtained from rice has grown from 12 percent in 1961 to 22 percent in 2007.[17]

Climate change is expected to bring a host of challenges for rice-producing regions, including higher temperatures, more flooding, higher soil and groundwater salinity from rising seas, and more frequent droughts. Many of these problems are expected to appear concurrently.

Researchers are working to develop rice varieties that can tolerate these stresses more effectively. While the economic benefit of more resilient rice has been calculated—about $1.8 billion for South Asia alone—fields are still being sown with older varieties that will not flourish in the new conditions.

In Search of High-quality Calories

With the dominant status of the world's three major food crops potentially imperiled by climate change, agricultural experts see an urgent need to identify new sources of calories for the human diet.

Already, almost one billion people around the world—one in seven—do not eat enough food to meet their energy requirements. As noted earlier, this problem will rapidly intensify as an additional two billion people populate the planet during the next 40 years. The dramatic increases in food production that are needed must also account for the impact of climate change on farming regions and crop varieties.

Climate change will have an impact on calorie intake around the world. Even residents of developed countries will have fewer calories available for consumption, but their diets will remain for the most part at healthy levels. In the developing world, there is clear need for more food.

16 Thornton, ibid. page 122.

17 Thornton, ibid. page 123.

One of the crops that can be used to fill this calorie gap is cassava, which is both a cash crop and a food staple in Africa and Asia. More importantly, cassava tolerates numerous stresses, ranging from infertile soils to heat and drought. Certainly, cassava could help to meet food needs in South Asia, where higher temperatures and prolonged dry periods will reduce the viability of wheat and rice.

Bananas are another crop that could fill regional agricultural gaps. Plantains and cooking bananas provide some 70 million Africans with more than a quarter of their calorie requirements.[18] They are currently grown in the humid and sub-humid tropics, the tropical highlands and drier sub-tropics.

Climate change may affect banana cultivation in certain areas, but its range is expected to adjust, not shrink. In the near future, it may be possible to cultivate bananas at higher altitudes with a shorter time between planting and harvesting (although bunch size may decrease). The effect of climate change on banana pests and diseases is less certain. Though biotic stresses will probably also expand in range, it is not clear whether the pests and diseases will thrive at higher altitude.

The important point is: agriculture has to adapt beyond maintaining the viability of wheat, maize and rice in the face of climate change and finding replacement crops. And given the thicket of technical, environmental, cultural and political issues involved in shifting dietary staples, this adaptation work needs to rapidly accelerate to keep pace with climate change.

The Future of Animal Protein

Poor people in less developed countries typically subsist mostly, and in some cases almost exclusively, on calories obtained from cheap cereals and tubers, such as maize and cassava. According to the United Nations Food and Agriculture Organization (FAO), these diets are frequently deficient not only in the overall quantity of calories consumed but also in the quality of those calories, as they often lack protein, iron and Vitamin A.[19] Given the availability of these nutrients in meat, dairy and eggs, livestock could address this dire need in the developing world. Figure 2 shows the current regional disparities and trend lines in how livestock contributes to daily diets.

Increasing the productivity of (and production of) livestock can have trade-offs, however. Livestock producers in poor as well as rich countries will increasingly be encouraged to reduce the amount of greenhouse gases that their farms produce.

Complicating matters further is the impact of climate change on livestock. In particular, increased drought frequency could put many farm animals at risk. Also, climate change coupled with the intensification of livestock production has the potential to intensify transmission of "zoonotic" pathogens, which can jump from animals to humans.

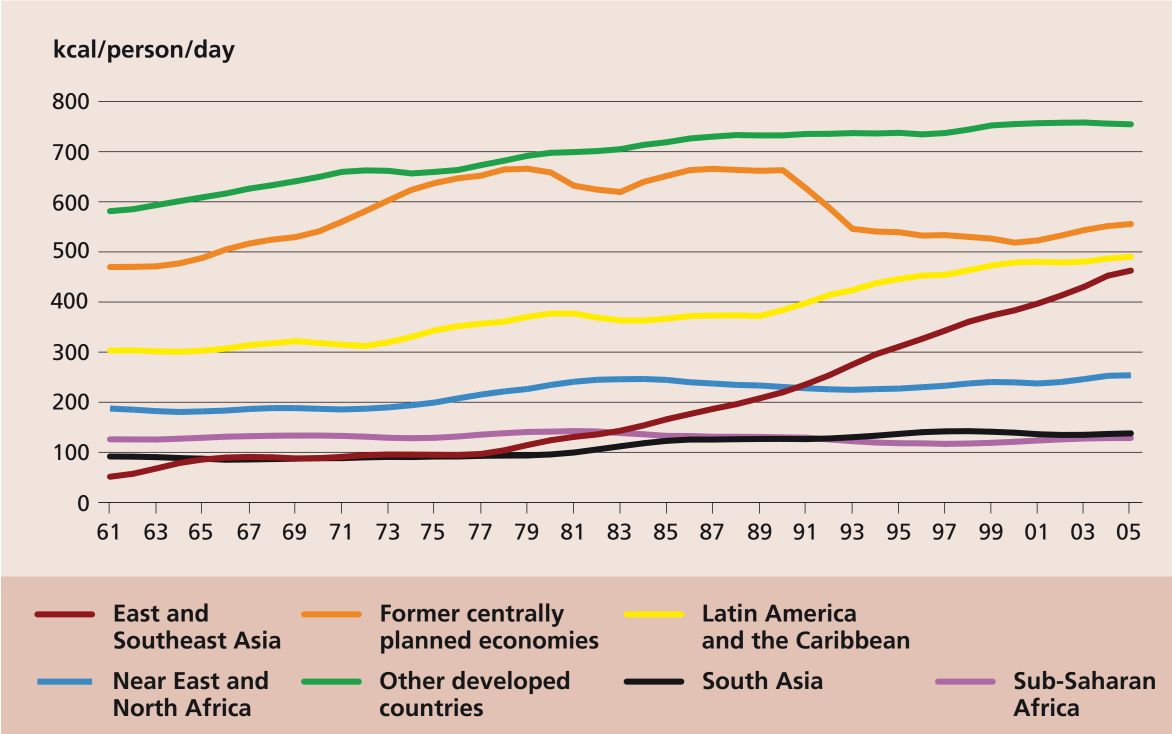
Climate change will also intensify problems with feeding livestock. The demand for maize and coarse grain for this sector is expected to account for nearly half the grain produced in the years 2000-2050,[20] but the prospects for maize, as discussed earlier, are not optimistic. Pastures are expected to decrease in quality, with increased temperatures forcing the grasses to become more fibrous and less nutritious. Soybeans, another crop used as animal feed, will

18 Thornton, ibid. page 15.

19 Otte J et al. 2012. Livestock sector development for poverty reduction: an economic and policy perspective – Livestock's many virtues. Rome: United Nations Food and Agriculture Organization (FAO). p. 161. http://www.fao.org/docrep/015/i2744e/i2744e00.pdf

20 Rosegrant MW et al. 2009. Looking into the future for agriculture and AKST (Agricultural Knowledge Science and Technology). In: McIntyre BD et al, eds. Agriculture at a Crossroads. Washington, DC: Island Press. p. 307–376

Figure 2. Per capita intake of energy derived from livestock products by region, 1961–2005



Note: Livestock products include meat, eggs and milk and dairy products (excluding butter). FAOSTAT 2009

Source: FAO. 2009. The state of food and agriculture. Livestock in the balance. Rome: United Nations Food and Agriculture Organization (FAO). http://www.fao.org/docrep/012/i0680e/i0680e00.htm

not tolerate higher temperatures in many parts of the world.

Fish and other aquatic products potentially could help fill the protein gap of the poor. For a third of the world's population, this sector already accounts for about 20 percent of their protein intake.[21] But the impact of climate change on fisheries may be severe, and the aquaculture sector is not yet sufficiently developed to replace losses from natural fisheries.

Coastal reef systems, which support numerous valuable fisheries, are especially sensitive to climate change impacts. Higher concentrations of carbon dioxide in the atmosphere will continue to increase the oceans' acidity, which eats away at the coral. Rising temperatures will also affect the range of many fish, further altering the underwater ecosystem. And continued overfishing in many parts of the world will exacerbate these climate-related stresses.

In the more affluent countries, the amount of animal protein consumed can be scaled back; this would not only help populations in these countries eat more balanced diets but would also help lower the emissions footprint of their diet. In the developing world, however, increasing—rather than decreasing—the very low amount of calories from meat in the diets of these populations would have a significant positive impact on their health and well-being.

In South Asia and sub-Saharan Africa, for example, nearly one billion people living on less than two dollars per day keep livestock;

21 Béné C, Macfadyen G, Allison EH. 2007. Increasing the Contribution of Small-scale Fisheries to Poverty Alleviation and Food Security. Rome: United Nations Food and Agriculture Organization (FAO).

two-thirds of those are women.[22] Fisheries and aquaculture support an additional half-billion people around the world.[23] There is no easy answer for adapting these sectors to changing climates. But the benefits to people from eating fish and animal protein—as well as raising livestock for their livelihoods—will not evaporate as the planet warms; answers must be found in securing their continued availability.

Seeking More Protein from Plants

While livestock and fish have a key role to play in maintaining food security in a fast-growing, fast-changing world, increasing production of vegetable protein must be examined as well. But here too, climate change could make it difficult to expand cultivation.

One of the more common sources of vegetable protein is the soybean. While widely grown in the United States, Brazil and China, soybean is a relatively new crop in sub-Saharan Africa. But it has been adopted with some success in the savannah regions. Some African cultures are already adding the soybean, high in protein and vegetable oil, to their traditional recipes.

Soybeans, however, are extremely susceptible to increased temperatures. The areas in the US and Brazil that cultivate proteins for export would face steep declines once the temperature exceeds 30°C. There are estimates that US soybean production alone could decrease by as much as 80 percent in this century.[24]

Chickpeas, another traditional source of vegetable protein, are grown and eaten across five continents, including regions where hunger is a constant concern. The chickpea may be vulnerable to climate shifts, in part because it is usually grown on marginal lands and with minimal amounts of fertilizer and irrigation. In

Photo credit: A. Habtamu (ILRI)

Climate change may threaten the livelihoods of nearly one billion people living on less than two dollars per day who keep livestock.

these settings, the crop is already vulnerable to attacks from pests and environmental stresses. Climate change is likely to have a mixed effect on chickpeas. The anticipated increase in carbon dioxide levels could be beneficial, but higher temperatures will hinder their growth.

Cowpea, known in sub-Saharan Africa as a "poor man's meat," is an essential part of the diet in many regions. Not only does it have ample protein, but several varieties contain an exceptional amount of micronutrients. The crop is grown mostly in the dry savannahs and is generally more drought-tolerant than other plants. Cowpea vines play a valuable role in providing dry-season feed for ruminant livestock.

22 Thornton, op.cit. page 93.

23 Thornton, ibid. page 55.

24 Thornton, ibid. page 145.

These characteristics make the cowpea more impervious to climate change than other crops, although it can still fail in the face of severe droughts. In response, scientists have bred varieties with shorter growing seasons that can be cultivated in certain parts of Africa between the start of the rainy season and the start of the dry season. This adaptation strategy has been taking root in Niger and Nigeria, where farmers have moved away from cotton cultivation to the cowpea.

It is not enough to measure food security strictly by calorie intake. Given the problems facing livestock and fisheries as food sources, additional research is needed to identify and improve crops that provide protein.

Adaptation and Nutrition: Fighting the "Hidden Hunger"

An analysis of food sources that can help food-challenged communities adapt to climate change must consider the overall nutritional value of different crops and livestock, along with their suitability to situations in which weather extremes become the new normal.

What is the overall nutritional profile of the food, and how many vitamins and minerals does it contain? Poor nutritional intake—micronutrients such as iron, zinc, folic acid and the vitamin complexes—in a diet that appears to provide sufficient calories is often called the "hidden hunger."

Photo credit: N. Palmer (CIAT)

Comparison of good (top) and bad millet yields, in Ghana's Upper West Region, which has suffered failed rains and rising temperatures. Millet is a highly nutritious and resilient crop but is still susceptible to climate stresses.

Barley is one cereal, though, that could help improve nutrition, especially in drier parts of the world. It contains high levels of micronutrients—especially zinc and iron—and can be used as livestock feed. Barley also can fetch a relatively high price in markets as the grain is valued in producing alcoholic beverages.

Barley could be attractive in a world of rising seas and more frequent droughts, as it is known for its ability to withstand salinity in the soil, in addition to heat and drought. There needs to be more research to determine just how much stress barley can sustain, but its ability to adapt to climate change appears to surpass many of today's most important crops.

Millet and lentils are highly nutritious foods that are similarly able to withstand harsher growing environments. They are ready-made to help poor communities maintain and increase food security as climate conditions reduce yields from other food sources. However, as noted before, they are not a bullet-proof adaptation option since certain climate stresses can reduce their yields as well.

Conclusion and Recommendations

It is often easy when reviewing the many threats facing food production in the era of climate change to become pessimistic about humanity's ability to survive this rapidly approaching storm, or to survive without condemning millions or even billions more people to poverty and hunger. The three main sources of our calories—maize, rice and wheat—face conditions that could significantly depress yields, and key sources of animal protein likewise may be imperiled.

There are crops, such as cassava, yam, barley, cowpea, millet and lentils that could fill in the gaps caused by declining harvests of other crop types. Also, science has advanced to the point where plant breeders are optimistic that they can develop new crop varieties that are especially tolerant of heat and drought or resistant to particular crop diseases.

But breeding new plant varieties is both time-consuming and costly; efforts to develop more resilient crops must be deployed strategically. Efficiently allocating resources for such climate change adaptation efforts will require a strong body of research that provides robust predictions of what growing conditions will look like in different parts of the world during the next few decades.

A key source of tension, however, surrounds adaptation that would involve abandoning a traditional food source for an entirely different one—for example, forsaking maize in the face of rising temperatures and cultivating cowpea instead. Will people embrace the new staple, however nutritious it may be? This cultural challenge is another facet of climate change adaptation that should get as much attention as plant breeding.

Despite the enormous challenges climate change will bring to food production in the developing world—and in wealthy countries as well—a number of actions can be undertaken to prevent these problems from exploding into costly crises. In its final report, issued in March 2012, the Commission on Sustainable Agriculture and Climate Change issued a number of recommendations that that can help ensure agriculture not only survives but also thrives.[25] These include:

- Financing initiatives to help agricultural production systems become more resilient to weather variability and shocks, while contributing significantly to mitigating

25 Beddington J, Asaduzzaman M, Clark M, Fernández A, Guillou M, Jahn M, Erda L, Mamo T, Van Bo N, Nobre CA, Scholes R, Sharma R, Wakhungu J. 2012. Achieving food security in the face of climate change: Final report from the Commission on Sustainable Agriculture and Climate Change. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). www.ccafs.cgiar.org/commission

climate change. This includes supporting national climate risk assessments and developing mitigation and adaptation strategies.

- Reshaping food access and consumption patterns to ensure basic nutritional needs are met and to foster healthy and sustainable eating patterns worldwide, and then promoting these changes through innovative education and outreach campaigns.
- Significantly raising the level of global investment in sustainable agriculture and food systems in the next decade. This includes increasing the knowledge of best practices and innovation by supporting revitalized extension services, technology transfers and communities of practice.
- Developing specific programs and policies to assist populations and sectors that are most vulnerable to climate changes and food insecurity. This includes creating and supporting safety nets and other programs to help vulnerable populations in all countries become food secure.
- Establishing robust emergency food reserves and a financing capacity that can deliver rapid humanitarian responses to vulnerable populations threatened by food crises.

This policy brief summarizes the study, "Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate" published as CCAFS Working Paper 23. The study contains summaries for 22 mandate commodities and for agroforestry, forests, and water and was written by scientists at each CGIAR center. The study was developed as input to The High Level Panel of Experts (HLPE) on food security and nutrition advising the Committee on World Food Security (CFS). Read the full report at http://hdl.handle.net/10568/21226.

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