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Climate Change, Food Security and Informatics

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Abstract

Increasing scientific evidence emphasizes the importance of addressing climate changes worldwide. While the relative roles of human versus natural causes continue to be disputed, evolving evidence supports the hypothesis that human activities have significantly contributed to substantial changes in climatic events, and these impacts are expected to continue (and increase) if activity patterns remain unchanged. The extent to which human activities must be adjusted to slow and reverse this trend remains under debate, but it is widely agreed that actions now will mitigate climate change impacts both in the near term and into the more distant future. This point is at the core of arguments for timely mitigation through various means to reduce the projected longer-term effects of climate change, including impacts on food security for the burgeoning human population. Efforts to adapt to climate change are under way, and further concerted planning and implementation strategies are needed.

This paper explores implications of climate change for global food security due to increased variability in production year-to-year from droughts, extreme rain events and other weather-related phenomena. It addresses the shifts in climatic zones already being experienced and related impacts on the spread of plant and animal diseases; the potential impact of weather events on invasive pathogens and other species that threaten food production; and considerations for food safety as a primary element of food security in both developed and developing countries. The role of informatics in addressing private sector and public policy decision-making challenges to food security from the impacts of climate change is discussed. The emphasis is on how informatics can be used to better manage agricultural and natural resources for sustainable food production and to assure food security for the future.

1. Key climate change issues for food production

The impacts of climate change include hotter temperatures, extreme rain events, more severe droughts. These and other environmental threats are expected to increase annual variability of agricultural and food production worldwide. For example, expansive areas of drought experienced over the past three years in the United States have decreased production of major commodities for domestic and export markets. With the world population expected to reach 9+ billion people by the year 2050 according to widely referenced United Nations estimates, there is widespread concern about the ability to assure food security for consumers worldwide. This concern is exacerbated by climate change, with significant implications for food production due to increased temperatures and intensity and variation in rainfall depending upon geographic location, as well as ecosystem effects.

Yield declines are projected in developing countries for the most important crops. With irrigated yields varying across regions, South Asia is anticipated to experience the largest declines. Calorie availability in 2050 is projected to be lower in the developing world than it was in 2000, resulting in higher child malnutrition compared to projections without climate change. It has been estimated that investments to increase agricultural productivity through research and technology development would need to grow by at least $7 billion to offset the projected negative impacts of climate change on children (Nelson et al. 2009).

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Although the relative roles of human versus natural causes are yet to be definitively settled, evolving evidence supports the hypothesis that human activities have significantly contributed to substantial changes in climatic events, and these impacts are expected to continue (and increase) if activity patterns remain unchanged. The extent to which human activities must be adjusted to slow and reverse this trend remains under debate, but it is widely agreed that actions now could mitigate climate change impacts extending into the more distant future. Agriculture represents a key opportunity for timely mitigation through various means to reduce the projected impacts of climate change.

Recent estimates indicate that agriculture accounts for approximately 13% of global greenhouse gas emissions (Allen et al. 2011). However, agriculture also contributes to mitigating future impacts of climate change through modification of land use and management practices. These land uses and management practices can be designed to (1) sequester carbon (C) in soil organic mass and plant biomass, thereby removing carbon dioxide (CO_2) from the atmosphere; (2) reduce nitrous oxide (N_2O) through more judicious use of nitrogen fertilizers; and (3) minimize methane (CH_4) through improved livestock husbandry and manure management. Thus, agriculture has the potential to contribute to both near-term and longer-term mitigation of climate change. While the current state of CO_2-induced warming due to past emissions is irreversible, future increases in warming from CO_2 emissions will depend upon current and future emissions. Furthermore, the rate of warming can be influenced immediately by CO_2 emission cuts (Matthews/Solomon 2013).

Economic factors are an important driver for adopting practices that would decrease GHG emissions or stimulate carbon sequestration. Among the policy tools that could be utilized to encourage adoption are emissions taxes and market-based cap and trade. If farms faced taxes on greenhouse gas emissions, they would have an incentive to employ new technologies and other measures to reduce the emissions. Regulations could be implemented to market overall GHG emissions, with a system of regulatory credits established equal to the amount of the total emissions allowed. Markets could then trade the credits among those emitting in excess of their allocation, obtaining additional credits from those who implement a technology that allows them to operate below the regulatory credits they possess (Allen et al. 2011).

Rapid development of easily used tools that can incorporate model findings and fine-scale information on soil climate and management variables represents both a challenge and an opportunity for environmental informatics. Much progress has been made in incorporating global positioning system (GPS) technology to gather many of the needed data. More thorough integration of various system components would improve mitigation, such as by facilitating the precise application of fertilizers only where they are needed and decreasing emissions by using tractors equipped with GPS guidance systems to eliminate the small but important percentage of efficiency-reducing deviation from straight-line tillage and planting.

2. Challenges to food security

In the near term, climate change is not anticipated to pose a significant food security risk for developed countries, nor in aggregate global food production. However, food security concerns are more acute in developing regions of the world. Regional differences in crop yields as well as in the ability to adapt to climate change will likely result in regional differences in vulnerability to conditions that will be affected by changing climates, including hunger and poverty. Implications for developing countries in tropical semiarid regions are substantial, with food production and consumption likely to be significantly impacted in South Asia and Sub-Saharan Africa where large food-insecure populations exist.

In the longer run, challenges to food security are harder to predict because of potential adaptive strategies and policies that will likely be implemented over the coming years. However, the probability of food security problems related to climate change is high in the longer-term, with estimates of global undernourishment increasing as much as 15% by 2080 under the most dire projections with worst-case high population development (Walthall et al. 2013). Even if agriculture strongly embraces mitigation approaches to help reduce greenhouse gas emissions**,** a number of challenges to future food security will persist as climatic conditions continue to change. Several such challenges are highlighted below.

2.1 Warmer, wetter, and more variable rainfall

Climate change involves changes in atmospheric CO_2 concentrations, temperature and precipitation — all of which affect crop growth and evapotranspiration. Using the United States as an example, overall it is expected to warm several degrees centigrade over this century, with somewhat greater warming in the central part of the country where much of the commodity crops are produced. Coastal areas are likely to see slightly less warming while some other spots will see slightly higher warming. Accompanying this increased heat is likely to be more moisture, which varies more widely than does temperature across the United States because of atmospheric conditions which tend to create more localized rains. It is anticipated that the major commodity producing areas of the United States are likely to experience somewhat wetter conditions than in recent years. This can have positive effects on production, provided that the timing of the rains does not slow planting or delay harvest. However, it is extremely difficult to make accurate projections about moisture available for agricultural production across the entire United States (Walthall et al. 2013).

Wetter conditions, which are generally projected to be accompanied by more variable and higher intensity rainfall, could affect agricultural production in two ways: soil erosion from the heavy periods of rain, and increased irrigation costs in the intervening dry periods for those areas equipped to irrigate. The anticipated increases in heavy rains as part of the climate change scenario will likely increase soil erosion and thereby reduce productive capacity of the farmland affected. However, adaptive strategies may be undertaken by producers — such as altering planting and harvest dates, adjusting tillage practices, and adopting other conservation practices — which would mitigate the soil erosion impacts that could otherwise result from more intensive rain events (Walthall et al. 2013). In more arid regions that rely on irrigation for crop production, farm-level climate adaptation measures — such as adopting new technology to increase yields; increasing prices for some water-intensive, high-value crops; and shifting some lands to less water-intensive crops — can help mitigate potential increases in production costs, especially in regions such as the Westerns United States that face possible cutbacks in irrigated acreage due to water scarcity (Howitt/Medellin-Azuara/MacEwan 2010). There are significant roles for irrigation informatics and hydroinformatics to address the increasingly pressing issues of efficiently using available irrigation water to produce food as well as meet all other demands for scarce water in many regions of the world.

Another concern that has received considerable attention in recent years is the U.S. policy mandate to incorporate ethanol into the fuel supply system in an effort to reduce greenhouse gas emissions. The concern regarding increased use of corn as a major source of ethanol production is not only the competition with corn as a supplier of human food and animal feed, but also the immense amounts of water involved in producing one litre of ethanol. Significant amounts of water are used first to grow the corn and second to process it into ethanol. Dominguez-Faus et al. (2013) applied simulation models to estimate how climate change would affect water use in irrigated corn ethanol production and found that irrigation rates would increase by 9% but corn yields would decrease 7%, even if irrigation increased sufficiently to meet crop water needs. The projected increases in water intensity — as litres of water required during corn cultivation to produce one litre of ethanol from corn — suggest the need to re-evaluate corn ethanol as a major contributor to the U.S. renewable fuel standards intended to reduce greenhouse gas emissions.

2.2 Shifting climatic zones

Changes in climatic zones have both positive and negative effects. Longer growing seasons in northern latitudes provide an opportunity to increase total production to help improve food security. However, regional shifts in crop acreages require technical advances and other adjustments to develop and implement tailored systems in areas being altered by climate change. Crop varieties will need to be adapted to better suit the different regional climatic conditions, and this adaptation requires substantial research investment. At the same time, budget pressures have slowed government support of relevant research in developed countries, which have been the traditional drivers of increasing productivity. Although private-sector investment in this area has grown, it has focused more narrowly on selected high-volume crops. Incentives do not currently exist for this sector to provide the public goods research, which has been so important to growth in the productivity of agricultural resources needed to provide abundant food and feed.

An example of potential implications can be illustrated by a single crop from Ghana and Cote d'Ivoire, which together produce 53% of the world's cocoa. Ongoing climate change could affect the climatic suitability for cocoa in this West African region, which could significantly affect global cocoa output as well as the respective economies and growers' livelihoods. There would also be environmental implications as cocoa growing regions expand, shrink, or shift. Global circulation models were applied by Laderach/Martinez-Valle/Schroth/Castro (2013) to predict relative climatic suitability for cocoa production in 2050 in this area. They found that some current cocoa-producing areas will become unsuitable and need to change crops, other areas will be able to adapt agronomic practices to continue production, while yet other areas will experience increased suitability for growing cocoa. The authors concluded that site specific strategies will be needed by the affected farmers to reduce vulnerability to future climate change.

In general, collaborative efforts between growers and researchers will be needed to adapt plants to changing climatic areas, given that factors such as water prevalence, soil types, and length of growing season all require some adaptation of varieties for efficient production.

2.3 Migrating weeds and diseases

Weeds in generally southerly regions of countries such as the United States likely have origins in tropical and subtropical areas. As climate warming expands the geographic range of warm season crops, it will likewise favor expansion of the range of tropical or subtropical weeds. In the United States, maize and soybeans are cropped in the southernmost states as well as in the most northern states. As warmer climatic zones extend farther north, it can be anticipated that additional costs will be incurred by more northerly producers of these major crops to control weed species new to those areas. Meanwhile, certain current cold-tolerant weeds in the heart of the Midwest corn belt could become less problematic as conditions warm. Likewise, drought conditions will induce responses from weeds as well as crops.

Even more disconcerting than existing weeds is the specter of new invasive weeds that could crowd out desirable plants in range lands, pastures, and other perennial agricultural systems. Such invasion would affect both food production and biological diversity. Warming climates and precipitation changes will influence the nature and extent of weed invasion, with more pronounced effects anticipated in certain areas. Recognizing that the combined effect of multiple stressors related to climate change is very difficult to be predict, serious impacts are anticipated for certain perennial agricultural crops. Researchers are using biogeographical models to estimate future climate-driven weed pressures on food production (Walthall et al. 2013), and informatics tools including Bayesian updating will be crucial to useful predictions.

A further issue is the spread of animal and plant diseases, both of which are anticipated to increase as the range of crop and livestock production expands to new areas. A number of such diseases in the past are widely acknowledged to be a direct result of globalization. Imports of various products used in farming or nearby industrial areas often serve as a vehicle for introducing new, invasive species with no domestic predators or established control methods or treatments. Non-native invasive plant species and pathogens will likely complicate the challenges confronted by producers in the face of increased heat intensity, drought and wet conditions in various geographic areas. Non-native pests can translate to massive agricultural production and marketing losses, both in domestic markets and in international trade. Thus, large investments in eradication and control programs are needed to minimize their ecosystem and economic harm (Peck 2013).

Another example can be found in the recent northward shift of climatic zones for growing fruit in the eastern United States. Growers in these newer zones have experienced significant problems with insects and diseases that were not previously adapted to colder northern climates (Eddy 2013). Such pests and diseases now survive the milder winters, which might increase in frequency with increased climatic variability. This situation poses a real challenge for the research community and producers of those commodities. Given the limits of how quickly researchers will be able to identify effective control methods for new pests and diseases, growers might struggle to continue producing crops with which they are familiar. It appears that some of the newer invasive pests have adapted to the U.S. climate much more quickly than others that were expected to spread more rapidly than has been experienced. This finding illustrates the need for widespread collection and rapid analyses of large quantities of data to track the distribution of and potential future impacts of invasive pests and diseases. That is, a marked opportunity exists for informatics to play a strong contributing role in reducing potential harm to food production and food security from globalization of markets and the interaction with changing climatic conditions for food production.

2.4 Food safety

Developed and developing countries alike will be challenged to provide food security in the face of food safety concerns associated with climate change. Providing safe foods to prevent starvation and famine is one hurdle. Another daunting challenge is the need to address rising expectations of growing middle classes demanding greater variety in safe, nutritious and appealing foods. This demand will strain existing systems and put a premium on novel technologies, sound policy, and innovative private-sector strategies.

Food safety broadly is also directly influenced by climatic changes that result in hotter and drier production areas, as well as changes in other areas that must grapple with excessive moisture occurring during different time periods than previously experienced. Risk assessment has played an important role in modern agriculture, particularly in keeping harmful products out of the food and feed supply chains, to address the ongoing need for safe and reliable food supplies.

One significant problem likely to be exacerbated by climate change involves controlling or eliminating the impact of aflatoxins on food safety and security. Aflatoxins are a group of chemicals produced by certain types of fungi, and these toxins can be acutely harmful or fatal to animals and are carcinogenic to both animals and humans (Hurburgh/Loy/Robertson 2012). Aflatoxin contamination is more prevalent during years with hot and dry growing conditions in the Midwestern United States, where substantial maize and soybean crops are produced for export. Extensive testing is required to prevent entry of highly contaminated crops, particularly maize, into the food and feed supply channels. Rapid tests at delivery points for the crop can determine possible aflatoxin presence. However, to pinpoint dangerous levels of aflatoxins requires specific analytic tests based on numerous samples taken to determine whether discrete lots of maize — which vary depending on agronomic practices, soil conditions, weather and other environmental conditions — are contaminated (Hurburgh/Loy/Robertson 2012). The handling of such analyses, especially in high-risk years requires massive data gathering, recording, and tracking efforts — making this a problem particularly well suited to environmental informatics approaches and systems.

2.5 Maintaining ecosystem and human health

Feeding the world's burgeoning population will require both intensification of production on existing agricultural land and expansion of agricultural land. This intensification and expansion may have significant environmental and ecosystem implications. Increased water stress, greenhouse gas emissions associated with land clearing, and loss of natural systems and ecosystem services can be harmful alone, and collectively they could increase adverse effects on food production and security. Associated increases in pesticide use and nutrient loading can have negative implications for human health. Given limitations in available data and modeling approaches, economic impact studies are generally inadequate for addressing such concerns (Antle/Capalbo 2010).

Even in the shorter-term, ecological and human health are likely to be impacted through increased incidences of global hunger among the world's poorest and most at-risk populations. Inabilities to readily adapt to climate change will lead to greater pressures on ecosystem services and potentially on health from increased intensification of agricultural production practices and expansion into areas not now cultivated. To maintain ecosystem and human health over the intermediate and longer-term will require substantial research investments to develop adaptation strategies workable for even the most vulnerable populations. As indicated above, non-native invasive pests and diseases must be controlled at significant expense to importing countries to not only protect production capacity but also to protect against zoonotic disease transmission harmful to human health (Knutson/Armbruster 2013). The benefits of closely coordinated data sharing has been illustrated by acute health threats such as the severe acute respiratory syndrome (SARS) outbreak a decade ago, and informatics will continue to play a crucial role in maintaining health protection as climatic conditions affect the nature and extent of diseases related to agricultural production.

3. Increasing data volume and informatics

The challenges discussed above will require substantial data gathering, sharing, analysis, and storing, including for trend analyses from the local to the global scale, as researchers and policymakers work to understand potential approaches for minimizing the adverse impacts of climate change on food safety and security. The general nature of such research and policy analyses has long relied on idiosyncratic data collection and assessment as opposed to coordinated efforts that will be required across a range of scientific disciplines to grapple with the multiple challenges anticipated.

The increasing volume of data available to help producers understand various elements of food production and supply chain management to deliver food to domestic and international markets will require efficient use of informatics to facilitate sound decision making. Informatics applications for managing hydrology and irrigation to efficiently use scarce freshwater resources, to control and eradicate non-native invasive species and pathogens, and to maintain ecosystem and human health, are all key to adapting to climate change.

Integration across various fields is essential to adaptation planning and information. Communication technologies (ICT) provide a critical foundation for the sustained effort that will be needed. Increasing production of agricultural products and managing the supply chains necessary to deliver safe foods to various countries and consumer groups within each, in the forms desired, is challenging. Supply chains have evolved rapidly in recent years and continue to do so. Climate change impacts on food production in various regions of the world will challenge current abilities to manage supply chains and to redirect them to address evolving needs for distribution from new production areas that replace those where vulnerability to the impacts of climate change has reduced production.

4. Adaptation research and planning

The agricultural production systems in the United States and other developed countries have adapted significantly over the past 150 years across diverse landscapes in response to climate and other natural resource changes, as well as to changes in knowledge, technology and markets — including demands for sustainable production, organic products, and various other societal issues. To a great extent, these adaptations have been made possible by public-sector investment in research and development, with extension of the derived knowledge to agricultural producers.

Agriculture's successful adaptation to higher temperatures, wetter conditions, and more variable and extreme conditions that extend beyond patterns observed to date will very likely be affected by government policy and programs (Antle/Capalbo 2010). Adaptation measures are anticipated to reduce impacts of climate change through improved planning and better informed investment and management of resources, including perennial crops. Responses will need to find a balance between mitigation and adaptation, recognizing limits for the latter (Walthall et al. 2013). Mitigation is aimed at reducing global climate system impacts over long time periods between action to reduce warming and the results, hence it is subject to international initiatives that manage through national governments. Climate adaptation is by nature a local phenomenon which complicates government support for such efforts. One area where governments can contribute is through funding research and technology development to identify feasible strategies for adaptation, and evaluating the potential impacts and costs of the strategies to producers.

However, the complexity of adaptation processes and uncertainty about climate change effects complicate efforts to estimate adaptation costs and benefits. Research on the economic response of agriculture to climate change effects indicate that benefits of adaptation more than offset the costs of these effects in temperate regions. Still, large variations across and even within regions are likely. Research involving adaptive management practices, prioritizing and sequencing adaptation investments and considering socioeconomic factors that influence adaptation efforts, have been used to develop robust frameworks in regional agricultural adaptation planning. Adaptive capacity of agriculture will undoubtedly involve a mix of economic, ecological, and social factors interacting with the effects of climate change across a range of climatic events over time and geographic areas. Changes in management practices along with development of CO_2-responsive and stress-tolerant germplasm are expected to provide resistance and resilience adaptation strategies for crop production, even though some crop-specific constraints exist for certain regions (Walthall et al. 2013). Much work remains to identify successful adaptation strategies localized to regions and extending across the globe, to achieve an effective response to climate change.

Risk management in decision-making provides lessons applicable to climate change adaptation planning. For example, given that many possible outcomes exist in risky situations, management strategies that perform well over a range of such outcomes may be preferable. Comprehensive risk management in the face of climate change requires examining risk-weighted costs and benefits of various adaptation strategies. Given that there are a number of potential investments in adaptation strategies, this approach would require quantification of enormous amounts of information about potential climate outcomes, their probability of occurring, and the resulting effects. This suite of data and decision needs represents an important opportunity for informatics to play a major societal role and provide substantial benefits in identifying effective adaptation strategies.

In the short run, adaptive behaviors will likely allow a given agricultural system to offset the effects of climate change. In the longer term, continuing changes in climatic conditions will likely strain the ability of agriculture to adapt by extending current technologies without significant impacts on producers, consumers, and ecosystem services provided by agricultural production. This situation will require public sector investment in agricultural research, which has been so important to agriculture's progress in the past (Fuglie/Heisey 2007), in order to provide the innovations needed for agriculture to successfully adapt. Key research areas that are critical to expanding the adaptive capacity of agriculture include the following (Walthall et al. 2013):

- Improve understanding of key determinants for adaptive capacity and resilience in agriculture.
- Develop methods to assess effectiveness of adaptive capacity.
- Identify and disseminate information about existing best management practices that offer adaptation options.
- Develop resilient crop and livestock production systems.
- Develop and extend effective management strategies and climate risk management tools to improve decision-making

- Improve understanding of the social limits to adaptation.
- Develop effective adaptation planning and assessment strategies useful to decision-makers throughout the agricultural system.

5. Policy challenges

Each of the food security issues highlighted above pose major policy challenges that demand attention. With changes in production and therefore prices being difficult to anticipate, crop insurance provides a mechanism for producers in developed countries to manage risk. The role of informatics in developing actuarially sound insurance is well established, and increased attention is expected in this area. Much broader approaches are also needed for adaptation in both developed and developing countries. Policy and program recommendations aimed at offsetting the anticipated impacts of climate change on food security, especially for the poor in developing countries, include the following (Nelson et al. 2009, 17):

- Design and implement good overall development policies and programs.
- Increase investment in agricultural productivity.
- Reinvigorate national research and extension programs.
- Improve global data collection, dissemination, and analysis.
- Make agricultural adaptation a key agenda point within the international climate negotiation process.
- Recognize that enhanced food security and climate change adaptation go hand-in-hand.
- Support community-based adaptation strategies.
- Increase funding for adaptation programs by at least $7 billion per year.

6. Future directions

Looking to the future, climate change threats to food security translate to threats to international stability. In addition to novel technical approaches, strong communication networks are needed to share the data that will be crucial to planning and implementing strategies for adapting to climate change and mitigating these threats, extending from rural to industrialized areas and from the local to the global scale. Environmental informatics approaches and tools provide the essential foundation for addressing critical issues related to climate change and food security; such systems facilitate the synthesis and sharing of a wide variety of data needed to support programs designed to protect environmental health and welfare. Insights from related efforts suggest that electronic connectedness will play an increasingly important role, as will the use of visualization tools and geographic information systems to share, store, update and iterate on the massive influx of data across multiple disciplines, including data collected from remote sensors extending from satellites to microenvironments. Flexible systems and tools that can be used by citizens worldwide will be important to guiding practical adaptation and mitigation measures as environmental conditions and communities continue to evolve.

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