Realizing the potential benefits of climate prediction to agriculture: issues, approaches, challenges☆

James W. Hansen

International Research Institute for Climate Prediction, Palisades, NY 10964-8000, USA

Abstract

Advances in our ability to predict climate fluctuations months in advance suggest opportunity to improve management of climatic risk in agriculture, but only if particular conditions are in place. This paper outlines prerequisites to beneficial forecast use; highlights key issues, approaches and challenges related to each; and suggests an evolutionary strategy. The first prerequisite is that forecast information must address a need that is both real and perceived. Second, benefit arises only through viable decision options that are sensitive to forecast information. Third, benefit depends on prediction of the components of climate variability that are relevant to viable decisions. Fourth, appropriate forecast use requires effective communication of relevant information. Finally, sustained use requires institutional commitment and favorable policies. It is useful to consider three phases of effort: an exploratory phase to gain understanding and assess potential, a pilot phase characterized by co-learning between researchers and target decision makers, and an operational phase focusing on engaging and equipping relevant institutions. Although examples of use and potential use, and advances in institutional support, are cause for optimism, use of climate prediction by agriculture s still too new to support strong generalizations about its value.

© 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Climate forecasts; Decision making; Research strategy; El Niño-Southern Oscillation

1. Introduction

Humanity has always been at the mercy of the weather. Rural populations are often vulnerable to the impacts of climate variability on agricultural production—“the most weather-dependent of all human activities” (Oram, 1989). Vulnerability is
not a consequence only of year-to-year variability of the climate per se, but also of its unpredictability. Many critical agricultural decisions that interact with climatic conditions must be made several months before impacts of climate materialize. Climatic uncertainty requires decision makers to prepare for the range of possibilities, often leading to conservative risk management strategies that reduce negative impacts in poor years, but often at the expense of reduced average productivity and profitability, inefficient use of resources, and sometimes accelerated natural resource degradation.

Year-to-year climate variations are strongly influenced by interactions between the atmosphere and its underlying ocean and land surfaces. Although the atmosphere fluctuates quite rapidly, surface characteristics such as sea surface temperature, snow cover and soil moisture change more slowly and are capable of influencing climate over longer periods. In particular, the global climate system interacts strongly with spatial patterns of surface temperatures of the tropical ocean basins, such as those associated with the El Niño-Southern Oscillation. The El Niño-Southern Oscillation, or ENSO, refers to shifts in sea surface temperatures (SSTs)—El Niño when warmer than normal and La Niña when colder than normal—in the eastern equatorial Pacific, and coupled shifts in barometric pressure gradients and wind patterns in the tropical Pacific (the Southern Oscillation). Although the ENSO phenomenon occurs within the tropical Pacific, its effects can be felt through much of the globe, where it sometimes accounts for a substantial portion of year-to-year variability of the climate (Ropelewski and Halpert, 1987, 1996; Kiladiz and Diaz, 1989; Stone et al., 1996; Mason and Goddard, 2001). Seasonal climate forecasts are based either on statistical relationships or on dynamical, physically based models of atmospheric response to SSTs and possibly other predictor variables reflecting the state of the earth’s surface. Growing understanding of ocean-atmosphere interactions, advances in modeling the ocean-atmosphere system, and substantial investment in monitoring the tropical oceans now provide a degree of predictability of climate fluctuations several months in advance in particular seasons in many parts of the world (Barnett et al., 1994; Palmer and Anderson, 1994; Latif et al., 1998). Given the chaotic behavior of the atmosphere, seasonal climate forecasts will always contain considerable uncertainty, and are best interpreted as shifts of the climatological probability distributions. Useful introductions to seasonal climate prediction include Trenberth (1997), Cane (2001) and Goddard et al. (2001).

The emerging ability to provide timely, skillful climate forecasts offers the potential to reduce human vulnerability to agricultural impacts of climate variability through improved agricultural decision making, to either prepare for expected adverse conditions or take advantage of expected favorable conditions. In the 1980s, the anticipated benefits of climate forecasts for rainfed agriculture in developing countries were heralded as “the next Green Revolution” (Cusack, 1983; Sah, 1987). Others have taken a more pessimistic stance, citing examples of lack of use and barriers to use of available seasonal forecasts particularly by smallholder farmers in less-developed countries in the tropics (e.g. Hulme et al., 1992; Blench, 1999; Broad and Agrawala, 2000). A pragmatic middle ground recognizes both the potential benefits, and the range of conditions that must be in place in order for farmers and
other agricultural decision makers to realize the potential benefits of appropriate use of climate forecasts. Although providing these conditions often presents difficult challenges, these challenges are not necessarily insurmountable. Several research efforts, including those represented in this issue, have undertaken the task of understanding and addressing the requirements for beneficial use of climate prediction for targeted groups of agricultural decision makers in targeted regions.

What role can research play in enabling farmers and other agricultural decision makers to realize the potential benefits from seasonal climate prediction? As a step towards answering this, I outline five conditions that must generally be in place in order for agricultural decision makers to benefit fully from climate forecasts. For each, I then highlight some of the issues, discuss some relevant approaches used to address the issues, and identify what I see as critical challenges that warrant concerted effort. Finally, I suggest an evolutionary strategy for advancing appropriate use of seasonal climate prediction for the benefit of targeted groups of agricultural decision makers.

2. Prerequisites to beneficial forecast use

Benefit arises when the use of forecasts results in decisions that reduce the vulnerability (in the broad sense discussed in the next section) of human populations to the adverse impacts of climate variability. The focus here is on impacts of climate variability on agricultural production systems, and decisions related to their management. We can represent the opportunity to benefit as falling within the intersection of human vulnerability, climate predictability, and decision capacity (Fig. 1). Recognizing that sustained use of climate prediction to improve decisions also depends on adequate communication and appropriate institutional and policy support, we can list five prerequisites for effective use of climate forecasts. First, climate forecasts must address a need that is both real and perceived. Second, benefit depends on the existence and understanding of decision options that are sensitive to the incremental information that forecasts provide, and compatible with decision maker goals and constraints. The third prerequisite is prediction of relevant components of climate variability in relevant periods, at an appropriate scale, with sufficient accuracy and lead time for relevant decisions. Fourth, the use of climate forecasts requires that the right audience receives and correctly interprets the right information at the right time, in a form that can be applied to the decision problem(s). Finally, sustained operational use of forecasts beyond the life of a project requires institutional commitment to providing forecast information and support for its application to decision making, and policies that favor beneficial use of climate forecasts. These conditions (particularly the first three) have been recognized for some time (Lamb, 1981; Sonka et al., 1986, 1987; Easterling and Mjelde, 1987; Barrett, 1998). They identify a set of key issues—decision makers, decision options, climate prediction, communication, and the institutional and policy environment—that must be understood and addressed if agricultural decision makers are to reap the potential benefits from climate prediction.
3. Decision maker vulnerability and motivation

The information in climate forecasts is useful only to the extent that it addresses a need that is both real and perceived. Before decision makers will use, and even make the effort to learn about, climate forecasts, they must be aware of climate risk and its impacts on them, and motivated to improve management of that risk. The primary motivation for individual farmers is an awareness of some level of vulnerability to impacts of climate variability, and opportunity to reduce that vulnerability through appropriate use of forecast information. Motivation is also conditioned by confidence in available forecasts, and sufficient knowledge and perceived flexibility to use forecast information to modify decisions to their advantage. For support institutions, motivation comes from internal mandate or external policy. Understanding and involving target decision makers is at the core of successful intervention, and is foundational for understanding and successfully addressing the remaining four issues (i.e. decision options, climate prediction, communication, and institutions and policy).

Although the concept of vulnerability as it is commonly used focuses on negative impacts of extreme events (e.g. Ribot, 1996; Vogel, 1998; Downing and Bakker, 2000) such as drought or flood, for lack of a better word, I use it here to refer to the full range of adverse effects that climate variability has on rural populations. The strategies that farmers employ to buffer themselves against downside risk may themselves contribute to persistent poverty and accelerated environmental degradation, as
they often entail reduced productivity and inefficient use of resources under favorable or average climatic conditions. For example, soil nutrient depletion is now widely recognized as the root cause of declining per-capita food production and the most critical biophysical constraint to development and food security in sub-Saharan Africa (Stoorvogel and Smaling, 1990; Sanchez et al., 1997). Climatic variability, with its resulting risk of financial loss in poor years, is cited as a key reason for under-investment in soil fertility inputs in rainfed production systems in Africa and elsewhere (e.g. McCown et al., 1991; Vlek et al., 1997; Gadgil et al., 2002: PII: S0308-521X(02)00049-5). Although interventions, such as food aid, at the policy level appropriately focus on adverse conditions, the risk-averse farmer is likely to have greater flexibility and therefore greater opportunity to benefit from reduced downside risk associated with favorable forecasts than from equally skillful forecasts of unfavorable climatic conditions.

Research efforts to foster beneficial agricultural use of seasonal climate prediction often appropriately begin with systematic attempts to answer a range of questions regarding decision makers and their needs and perceptions. For example, who are the appropriate target decision makers? Who are the intended beneficiaries? (Target decision makers may or may not be the primary beneficiaries.) What are their key goals and constraints? How does climatic risk impact them? What climate risk management strategies do they currently employ? Where do they seek information, advice, support? Do they currently receive, understand and act on forecasts? Why or why not? How do they perceive and express the probabilistic nature of climate variability (without or with forecasts)? The choice of appropriate research methods (e.g. rapid rural appraisal, focus groups, designed survey, participatory on-farm research, ethnographic study) depends on the purpose (e.g. exploration, hypothesis testing, monitoring of actual decisions). These social science methods are based in part on the recognition that the answers that one receives can depend on how the question is asked and who does the asking.

Anticipating who will benefit and, more importantly, who might be adversely impacted from climate prediction remains a challenge. Objective methods to characterize both vulnerability of farming populations to impacts of predictable components of climate variability, and their capacity to modify decisions to reduce vulnerability in response to forecasts would help target those who are in a position to benefit (Amissah-Arthur, 2000). However, we know from experience in agricultural development (e.g. Stern and Easterling, 1999, pp. 82–83) and from forecast applications to other sectors (e.g. Pfaff et al., 1999) that actual outcomes from the use of a technological innovation, such as climate prediction, can sometimes be quite different from those intended by advocates or users of the technology. Price effects of large-scale responses to forecasts may either benefit or harm producers, depending on the direction of any shift in the aggregate supply curve and the price elasticity of demand (Mjelde et al., 1998). The potential for social stratification and power relationships among groups to allow some groups to use forecast information to the detriment of other groups is more difficult to predict. For example, Tsikisayi (1998) reported that a probabilistic forecast associated with the 1997–1998 El Niño event, exaggerated by the media to be a prediction of nation-wide drought (Phillips et al.,
2002: PII: S0308-521X(02)00045-8), prompted financial institutions throughout Zimbabwe to withhold agricultural credit, preventing farmers from taking advantage of adequate rains in parts of the country where they were realized. The need to anticipate, or at least monitor, the distribution of benefits and possible negative impacts within populations becomes increasingly important as more institutions support widespread dissemination and advocate widespread application of regional climate forecasts.

4. Viable decision options

Any benefit from climate prediction depends on the existence and understanding of decision options that are sensitive to the incremental information provided by forecasts, and are compatible with decision maker goals, resources and constraints. Researchers have appropriately devoted substantial effort toward identifying and evaluating a range of forecast-sensitive decisions and their technical and socioeconomic constraints, and seeking ways to alleviate those constraints. Much of this effort has focused on field- and farm-scale annual crop production decisions due to their importance to food and livelihood security, and because available forecasts tend to be a good match for the timing of such decisions. Understanding how decision options may benefit from seasonal climate forecasts requires understanding of both the decision makers (as discussed in the previous section) and the systems that they manage. I divide the task into predicting impacts and evaluating decision options.

4.1. Predicting impacts

For both the decision maker and the researcher, understanding how decisions may benefit from climate forecasts requires the ability to anticipate outcomes associated with each decision option under different forecast conditions. The complexity of agroecosystem response to the range of combinations of management decisions, initial soil conditions, climatic outcomes, and market conditions—the “curse of dimensionality”—presents difficult methodological challenges. For example, crop production is not a simple function of the 3-month average climatic conditions that are typically forecast, but a response to dynamic interactions between weather, the soil and biotic environment, and physiology and phenology of the crop. The state of the environment prior to the growing season, particularly water stored within the soil profile, can strongly condition crop response to weather during the growing season. Historical production records are useful for assessing and understanding the impacts of predictable components of climate variability (e.g. Carlson et al., 1996; Podestà et al., 1999; Hansen et al., 2001), but cannot reveal response to climate variations under alternative management strategies. Conventional agronomic field experiment methodology is designed to measure average production, profit or resource use efficiency in response to treatment (often management) variables; the primary role of climate variability is to demonstrate stability of results with respect to environmental heterogeneity. Long-term field experiments are not well suited to
addressing management implications of climate fluctuations due to their high cost and the long delay before results are available for a sufficient range of climatic outcomes (e.g. Keating et al., 1991). Importantly, farmers confront the same challenges that researchers face in deciphering the multiple interactions between the set of viable decision strategies and the range of climatic variability.

Appropriate use of systems modeling can overcome some of these difficulties. Regionally adapted and tested crop simulation models allow one to quickly explore the production outcomes of a range of decision alternatives under a wide range of climatic conditions. Appropriate use of systems simulation and analysis, however, requires clear understanding of its capabilities and limitations, and testing at all levels. A number of good examples exist of use of crop model-based systems analyses for understanding crop response to predictable components of climate variability (e.g. Phillips et al., 1999), and for exploring (e.g. Hammer et al., 1996; Meinke et al., 1996; Phillips et al., 1998; Messina et al., 1999; Carberry et al., 2000; Jones et al., 2000b) and communicating (e.g. Meinke and Hochman, 2000; Nelson et al., 2002: PII: S0308-521X(02)00047-1) crop management options that take advantage of seasonal forecasts.

4.2. Evaluating decision options

It is useful to distinguish between descriptive and modeling (also called normative or prescriptive) approaches to evaluating decision responses to a given forecast or forecast system (Stewart, 1997; Stern and Easterling, 1999, pp. 113–117). Descriptive analysis is based on observation of what decision makers actually do, or elicitation of what they would consider doing, in response to predicted climatic conditions (e.g. Phillips et al., 2002: PII: S0308-521X(02)00045-8; Ingram et al., 2002: PII: S0308-521X(02)00044-6). The descriptive approach recognizes the many context-specific determinants of decision making, and farmer knowledge of that context. Farmers are in the best position to evaluate how technological options fit within their own goals, and the constraints imposed by their particular agroecological and socioeconomic environments. Trial-and-error experimentation and shared experience allow farmers to learn something about climate-decision interactions specific to their production systems and, under stable conditions, tend over time to optimize a farming system to its environment.

The modeling approach evaluates options based on some normative rule or assumption, such as maximization of expected profit, utility or producer surplus. The approach lends itself to use with simulation models of crop yields or other biophysical response variables. Retrospective analysis using historic meteorological data with linked climate–crop-decision models provides an assessment of the potential value of the forecast system for the particular decision problem, and has produced insights into the effects of forecast characteristics (e.g. Easterling and Mjelde, 1987; Sonka et al., 1987; Mjelde et al., 1997; Hansen, 2001), and the decision (e.g., Messina et al., 1999; Jones et al., 2000b) and policy environment (e.g. Mjelde et al., 1996) on optimal decisions and potential forecast value. Stern and Easterling (1999, p. 107) submit that the greatest shortcoming of normative firm-
level decision models applied to climate prediction is their tendency to assume indifference to risk (i.e. expected profit maximization). In spite of widespread acknowledgment of the importance of risk implications of farm decisions, relatively few studies have taken advantage of the well-developed framework for risk analysis that has proven useful in agricultural economics (Anderson et al., 1977; Hardaker et al., 1997). Although risk analysis depends on a few simple assumptions (von Neumann and Morgenstern, 1947) that, while intuitively appealing, empirically do not always hold (Tversky and Kahneman, 1981; Musser and Musser, 1984; McFadden, 1999), it makes the tradeoff between profit maximization and risk avoidance tractable, and remains a useful framework for understanding agricultural decisions under climatic uncertainty, and therefore the opportunity to modify decisions in response to probabilistic forecasts. Risk analysis provides an objective basis for recommending incremental management responses that are consistent with forecast uncertainty and decision maker tolerance to risk.

Descriptive and modeling approaches to evaluating decision options each have important limitations. Normative models are too easily applied with inadequate attention to realistic farmer decision criteria and constraints. Furthermore, analysts who use crop simulation understandably tend to focus their attention on the rather small subset of decision variables that are built into available crop models, potentially overlooking important decisions such as crop selection, pest management or marketing. The major weakness of the descriptive approach is the demand it places on farmers’ knowledge (Bebbington, 1994; Martin and Sherington, 1997). Many research efforts focus on decision makers with little or no prior access to relevant seasonal forecasts. We have no reason to assume a priori that farmers will know how to interpret the management implications of seasonal climate forecasts in the absence of prolonged learning and experimentation. Furthermore, most farming systems face rapid changes (e.g. environmental, demographic, market or technological) that impose a moving target, potentially rendering forecast-based decision strategies obsolete by the time farmers develop them. Due to the complexity of human behavior and inherent limitations of human cognition, the modeling approach will never perfectly predict what decision makers will do, and the descriptive approach will never perfectly identify what decision makers could do, with climate forecast information.

It is possible to combine the best elements of descriptive and modeling approaches to evaluating decision options (e.g. Sonka et al., 1988; Jochee et al., 2002; see also discussion by McCown et al., 1994; Meinke et al., 2001; Thornton and Herrero, 2001). An appropriate hybrid approach might include one or more iterations of participatory identification of decision criteria and promising decision options, model-based analysis of the elicited decision options including their associated risk, then participatory evaluation and refinement of results. When realistic decision criteria elicited from decision makers are integrated with process models of agroecosystem response into quantitative retrospective analysis of decisions, the distinction between the descriptive and modeling approaches seems to lose its relevance. Since farmers and researchers each offer information and perspective that the other lacks, the resulting participatory, co-learning approach to understanding decision options promises to produce insights that neither group has alone.
We must face the challenge of giving balanced attention to the range of relevant decisions if agriculture is to benefit fully from climate prediction. Agriculture is a complex, hierarchical system with decision makers ranging from individual farmers to agribusiness and natural resource managers to government policy makers, managing systems whose spatial scales range from fields to nations or regions (Hammer, 2000; Jones et al., 2000b). So far, the decisions that have received the most attention relate to planning or management of annual field crops. Furthermore, analyses of crop management decisions tailored to climate forecasts have tended to ignore relevant decisions that current crop models do not adequately address. We can expect that advances in our understanding of a broader range of climate-sensitive agricultural decisions, such as pest management, irrigation water management and allocation, input supply, marketing, food aid and government policy, will eventually yield substantial benefits.

5. Climate prediction

The third prerequisite for using climate forecasts to improve agricultural decisions is prediction of relevant components of climate variability in relevant periods, at an appropriate scale, with sufficient accuracy and lead time for relevant decisions. Climate prediction science and forecast product development are advancing independently of their application. Current effort focuses largely on dynamic models of the atmosphere and its interactions with ocean and land surfaces. Although resulting dynamic forecasts are not, in general, more skillful than simpler statistical prediction schemes (Barnston et al., 1994, 1999; Anderson et al., 1999; Cane, 2001), future improvements are expected to come largely through improved dynamic climate models (Cane, 2001; Goddard et al., 2001).

The opportunity to leverage the considerable investment in climate research, ocean and atmospheric monitoring, and climate model development is one reason for the current interest in agricultural use of seasonal climate prediction. However, the ability of climate prediction to advance independently of its application has also contributed to mismatches between forecast characteristics and user needs. Forecast quality tends to be measured in terms of accuracy or skill (an expression of accuracy relative to some baseline such as the mean or distribution of the historic climatological record), at the expense of other important determinants of utility. In particular, forecasts over large regions or the grid cells of a general circulation model (GCM; currently on the order of 8000 km²) are a poor match for the spatial scale of farm impacts and farmer decisions. The temporal resolution of seasonal forecasts is a related concern. Climate forecasts often focus on means over 3-month seasons in order to reduce the “noise” from day-to-day weather variability that can mask the more predictable seasonal climatic variations. However, crop production and appropriate crop management are likely to depend as much on the distribution of precipitation within a season as on the season total. Rainfall onset, probability of water deficit during critical periods for yield determination, and conditions during ripening, harvest and drying are often particularly important. Agricultural decision
makers clearly need forecast information at the spatial and temporal scale of impacts and decisions, not at the scale that maximizes prediction skill.

Researchers working with agricultural decision makers generally recognize the importance of the scale of forecast information. For those who use dynamic crop simulation models to understand, evaluate and communicate management implications of forecasts, the point spatial scale and daily time step of the models dictates forecast information requirements. Several research groups use sets of analog years based on categorical indices of the observed state of the ocean-atmosphere system (e.g., ENSO phases) as their operational forecast system (e.g. Jagtap et al., 2002, this issue; Podestá et al., 2002; PII: S0308-521X(02)00046-X; Everingham et al., 2002; PII: S0308-521X(02)00050-1). Analog years provide daily weather series at individual stations for driving crop simulation models. Distributions derived from climatic realizations, or simulated yield or economic outcomes, for the set of analog years associated with each category, facilitate probabilistic interpretation and presentation to users. Interest in evaluating and applying forecasts based on dynamic atmospheric models is strong within these research groups, but has so far been hampered largely by mismatch of spatial and temporal scale between climate model output and requirements of both crop models and target decision makers (IRI, 2000). Fortunately, a growing number of researchers recognize and are responding to the challenge of connecting output from dynamic climate prediction models to the spatial and temporal scales of agricultural impacts and decisions. Promising avenues of research include downscaling in space and time using either statistical transformations or high-resolution regional dynamic models (Wilby and Wigley, 2000), and efforts to predict within-season characteristics such as rainfall onset and distribution of dry spells in critical periods for crop growth. In several instances, collaborative projects and innovative institutions, such as the International Research Institute for Climate Prediction, are providing the two-way interaction between forecast development and its application that is required to influence climate prediction research priorities and forecast information products.

6. Communication

The effective use of seasonal climate prediction requires that the right audience receives and correctly interprets the right information at the right time, in a form that is relevant to the decision problem(s) and compatible with the decision process. Attention must therefore be given both to information content and to the multiple facets of the communication process.

6.1. Information content

Chavas and Pope (1984) define information as a message that alters probabilistic perceptions of stochastic events. This definition fits skillful but imperfect climate forecasts, which are appropriately interpreted as shifts in the distributions of outcomes (climatological or impacts). However, for the information to have value,
altered perceptions must also alter actions in a way that improves outcomes (Mjelde et al., 1997; Barrett, 1998; Stern and Easterling, 1999). Any value associated with forecast information is therefore tied to its relevance to viable decisions. Understanding the interactions between climate and agroecosystems, and the nature and timing of relevant climate-sensitive decisions, can clarify what forecast information is most relevant to the decision problem in a particular context.

One approach to identifying appropriate content is to elicit forecast information that agricultural decision makers desire. This is often done in the context of exploratory surveys designed to characterize perceptions and perspectives on a range of related issues. While these studies have yielded valuable insights in particular contexts, their results are too infrequently reported in broadly available scientific literature. A systematic effort to synthesize and interpret results of such studies seems overdue. When using elicitation to prioritize information needs, it is important to distinguish between information that is desired and information that will influence viable decisions. Where system processes and key decisions are understood sufficiently well to analyze with system models, a complementary approach is to evaluate the importance of alternative forecast characteristics, such as skill, lead time, forecast period, and spatial and temporal resolution for potential decisions, to forecast value estimated through retrospective analysis using a normative decision model (e.g. Sonka et al., 1987; Mjelde et al., 1988, 1997).

Interactions with agricultural decision makers consistently highlight a few characteristics of forecast information that are generally important to farmer decisions (Stern and Easterling, 1999; Jones et al., 2000a,b; Letson et al., 2001; Ingram et al., 2002; PII: S0308-521X(02)00044-6; O’Brien et al., 2000). The first is site specificity. Farmers are aware of spatial variability, can recognize scale mismatches between forecasts and decisions, and want to know what to expect on their own fields. Interestingly, they often also ask about price implications of conditions predicted in competitors’ regions. Second, temporal specificity includes timing relative to decisions and impacts, and intra-season characteristics such as rainy season onset, dry spell distributions and harvest conditions. Third, farmers are concerned with forecast skill (often in terms quite different from those that forecasters use). For farmers who are concerned with managing risk, modest but well-characterized skill may be more valuable than high but uncharacterized skill.

An important and controversial question is whether forecast information should be provided alone to decision makers, or supplemented with interpretation of agricultural impacts and management implications. Are farmers able to translate probabilistic seasonal climate forecasts into predictions of impacts and improved management strategies? The evidence, or at least its interpretation, appears to be mixed. Use of indigenous forecasts, prior relevant research, providers’ capabilities and reputation, and perceived flexibility may influence both farmers’ ability to translate climate forecast information into improved management strategies, and their willingness to try the recommendations of agricultural advisors. Arguments in favor of providing forecast information alone include examples of inappropriate top-down recommendations, appropriate recognition of farmer knowledge and ingenuity, and the costs and practical difficulties of providing more targeted infor-
mation. In some cases, reluctance to suggest management responses to forecasts seems to reflect the traditional focus of the meteorological profession on information products.

I would argue that, in most cases, agricultural decision makers will realize the potential benefits of climate prediction only if we go beyond providing climate information alone. The information most relevant to decision making is the likely outcome (e.g. production or income) of viable decision options within the system being managed, not the climatic influences on those outcomes (Hammer et al., 2001). As discussed earlier (Section 4.1), translating seasonal climate forecasts into production or economic outcomes is not a straightforward task. Application of seasonal forecasts is a new technology. Because it is implemented through adjustments of possibly many interrelated decisions, effective forecast application imposes intensive demands on management skill. In general, sound agricultural research reduces the uncertainties and learning time associated with adopting new technology. I expect that supporting forecast information with information about impacts and management implications, based on sound research and underpinned with effective extension, will likewise enhance adoption of appropriate use of climate forecast information. Researchers in Queensland, Australia, have demonstrated the feasibility and benefits of translating probabilistic forecasts into likely impacts and viable decision responses, using crop simulation within a farmer participatory approach (Meinke and Hochman, 2000; Nelson et al., 2002; PII: S0308-521X(02)00047-1).

6.2. The communication process

As with any new technology, adoption and effective use of seasonal climate forecasts requires a period of exposure and learning. Although the use of climate prediction is analogous in many respects to other agricultural technology, its dynamic nature and potential interactions with a range of agricultural decisions present particular challenges to management capability. Appropriate training may reduce the time required and costs to the decision maker of learning. Artificial experience, in the form of crop simulation based on historical weather data, and probability and decision games such as the “chocolate wheel” used with farmer groups in eastern Australia (Hayman, 2000), appears to enhance users’ understanding of forecast uncertainty and its decision implications (Hammer et al., 2001; Ingram et al., 2002; PII: S0308-521X(02)00044-6; Nelson et al., 2002; PII: S0308-521X(02)00047-1).

In many cases, farmers evaluate the credibility of information and advice based on its source (e.g. Jones et al., 2000a,b; Ingram et al., 2002; PII: S0308-521X(02)00044-6). They are most likely to act on information when it comes from sources that they already know and trust. Experience in Florida taught us that involving trusted agricultural advisors in early stages of planning can be a precondition to gaining entree to agricultural communities, and that a sense of ownership on the part of the same advisors can be crucial to long-term success (Jagtap et al., 2002; PII: S0308-521X(02)00048-3).

Depending on the design of a project, researchers may exert considerable control over information communicated to small, targeted groups of decision makers.
However, broad distribution and operational use of forecasts beyond the life of a project must be supported by appropriate institutional dissemination channels, with safeguards to ensure quality, accessibility and timeliness of the information. Equitable access is a particular concern in remote regions of less developed countries (Stern and Easterling, 1999). While national meteorological services and international climate institutions are charged with broad dissemination of climate forecast information, it is essential to link these institutional forecast providers with the institutions that agricultural decision makers rely on for other forms of information, advice and support. In some cases, government agricultural extension services are the most effective communication channel (Jones et al., 2000a, Jagtap et al., 2002; PII: S0308-521X(02)00048-3). In other cases, farmer associations, non-governmental development organizations, input suppliers, influential farmers or village leaders may be more effective. The media generally provides the broadest dissemination at the lowest cost, but with the fewest safeguards for the quality and relevance of the information.

Communicating forecast uncertainty in probabilistic terms without distortion is now widely recognized as a difficult but crucial challenge (Barrett, 1998; Mjelde et al., 1998; Dilley, 2000; Jones et al., 2000b; Phillips et al., 2001; Hammer et al., 2001). Distortion can easily occur anywhere in the forecast generation, distribution, interpretation and application process, and can lead to inappropriate actions that expose decision makers to unwarranted risk (Dilley, 2000; Hansen, 2001) and damage the credibility of forecast providers (Orlove and Tosteson, 1999; Stern and Easterling, 1999). Predicted impacts or management recommendations will tend to add to the uncertainty of an associated climate forecast. Vulnerable farmers inevitably understand something about climatic risk and resulting production variability, but may use very different language than researchers or forecast providers to think about and express it. Better understanding of how target decision makers perceive and communicate probabilistic information is needed for designing information products and training to move farmers, researchers and various intermediaries in the communication process toward a common probabilistic language. Training intermediaries in the communication process should reduce the likelihood of distortion as information changes hands. This seems to be a particular concern for forecast information disseminated via the media (Nicholls and Kestin, 1998; Dilley, 2000).

7. Institutions and policy

Sustained operational use of forecasts beyond the life of a research project requires the commitment of relevant institutions to provide forecast information and a range of other forms of support, and policies that foster provision and use of climate forecasts.

Engaging relevant institutions in all phases of the research process is crucial for long-term success. It is useful to distinguish research efforts initiated within the relevant institutional systems (e.g. Jagtap et al., 2002; PII: S0308-521X(02)00048-3) from outside initiatives for whom the institutional environment may not be well understood (e.g. Ingram et al., 2002; PII: S0308-521X(02)00044-6). In the former
case, researchers already within Florida’s agricultural research–education–extension system were in a position to influence institutional extension support for farmer use of climate information and prediction. The latter case benefitted from a systematic effort to characterize the missions, functions, products and patterns of information flow and cooperation among institutions currently and potentially responsible for providing forecast information and supporting farmers (Kirshen and Flitcroft, 2000). Such analyses may identify gaps in effective flow of information, identify key institutional partners and inform strategy for improving institutional support for agricultural use of climate prediction.

The potential for seasonal climate prediction to benefit agriculture and the rural poor has caught the attention of both the meteorological and agricultural (and associated natural resource management) research communities. Realizing that potential would seem to require close cooperation between meteorological and agricultural support institutions. Bridging the institutional and cultural gap that exists between them stands out to me as a crucial ongoing challenge. Meteorological services are mandated with the production and broad dissemination of forecast information products that increasingly include the seasonal time scale. Effective agricultural research and extension services are often (but not always) more connected with agricultural decision makers, and are in a position to address the broad range of technology, resource availability and policy issues that often determine the ability of agricultural decision makers to act on forecasts. Unfortunately, climate- and agriculture-oriented institutions are typically separated at the highest levels of national government. Rather fundamental differences in disciplinary culture and perspective tend to reenforce this institutional separation. At the risk of over-generalization, the meteorology profession tends to regard forecasts as a stand-alone product, whereas the agricultural profession, where it has embraced climate prediction, has generally regarded it as part of a process. Consistent with their product emphasis, research to foster forecast application initiated within the meteorological community has focused largely on reasons for use or non-use, with the goal of improving content, format and distribution in order to increase use and impact. Decisions regarding use are the responsibility of users, and outside of the traditional domain of meteorological services. In contrast, agricultural support services traditionally take an active role in influencing decisions by developing, evaluating and promoting technology and policy. These differences of institutional mandate and disciplinary perspective result in complementarity that clearly justifies cooperation. Yet the result is often competition and costly redundancy when, for example, agricultural services produce their own forecasts and meteorological services issue forecast-based agricultural recommendations.

Although policy can be viewed as one level of a continuum of decisions for which climate prediction information is relevant, I treat it separately because it forms an important part of the broader decision environment that constrains or empowers agricultural decision makers. Because institutional mandate derives from policy, policy makers are in a position to direct institutions that provide forecast information and support its use. At a more basic level, however, allocation of public resources to research, education and development can either constrain or enhance
the effectiveness of such institutions. Market policy and infrastructure strongly influence the range of economically viable options available to decision makers by controlling commodity prices, production input costs and transaction (e.g. marketing) costs, as Eakin (2000) illustrates for smallholder farmers in Tlaxcala, Mexico. Risk spreading mechanisms such as crop insurance and subsidized foods, and tactical disaster response measures such as food aid are designed to reduce vulnerability of rural populations to the impacts of climatic extremes. Such policies could reduce incentives for agricultural producers to use forecast information to manage their own risk (Mjelde et al., 1996), but might, under particular circumstances, yield greater societal benefits than use of forecasts by individual farmers. Understanding how forecasts and policy can interact to bring the greatest societal benefit remains a challenge.

8. An evolutionary strategy

Efforts to improve agricultural decision making through climate prediction range from exploratory studies of particular issues, to the provision of forecast information to large populations on an operational basis. It seems useful to consider three possible phases of development: exploratory, pilot and operational. Although not all efforts do, nor should, proceed sequentially through these phases, the distinction does account for some observed differences of emphasis and approach. Furthermore, the lessons and credibility obtained from exploratory and pilot research provide a valuable and sometimes essential foundation for operational climate prediction information and support services.

An exploratory phase allows researchers to gain understanding of the system (climatic, agroecological and human) and assess the potential to benefit from seasonal climate prediction before mobilizing substantial human and financial resources, or asking farmers to put their livelihoods on the line. Our experience with the Florida Agricultural Extension Service (Jones et al., 2000a) demonstrates that relevant operational institutions may require credible preliminary assessment of potential benefits in order to justify an extensive operational effort.

A pilot phase is characterized by co-learning through intensive interaction between researchers and targeted groups of decision makers. Although objectives of this phase will generally include understanding and benefitting groups of cooperators, the ultimate goal (if results are favorable) is to provide the understanding, credibility and networks that are foundational to the mobilization of large-scale institutional support of climate prediction applications on an operational basis. Pilot phase research tasks might include participatory identification and evaluation of decision options tailored to climate forecasts, distribution and evaluation of forecast information products, training in their interpretation and use, monitoring of actual use of forecast information, and exploration of new ideas or opportunities posed by target decision makers.

A focused pilot project might initiate use of seasonal climate prediction to the benefit of a small target group of decision makers. However, continued benefits beyond the life and scope of a project clearly depend on the capacity and commitment of relevant institutions. The operational phase focuses on engaging, equipping
and transferring ownership to those institutions that will provide to a larger target audience, on a sustained basis, the types of support identified in the pilot phase.

9. Where are we now?

Agricultural use of seasonal climate prediction is still a new and developing technology. Seasonal forecasts have been distributed to farmers on an operational basis for up to about a decade in only a few places, including northeast Brazil, Ethiopia and Australia. The 1997/1998 El Niño event prompted widespread awareness of ENSO and a great deal of activity directed toward applying climate forecasts to real-world problems, particularly related to agriculture. A number of exploratory and pilot studies are now in place due, in large part, to funding from meteorological and global change organizations seeking to add value to investment in climate prediction research and infrastructure. The relatively small number of well-documented successes arising from such studies has led some to question the potential for farmers, particularly resource-poor smallholder farmers, to benefit from climate prediction. In some cases, however, the duration and scope of these studies have not been sufficient to allow necessary learning on the part of both farmers and support institutions, or to address apparent barriers to forecast use. In other cases, opportunities associated with favorable forecasts have not been considered due to an exclusive or disproportionate focus on adverse climatic extremes.

We know that agricultural decision makers are incorporating climate forecasts into their decisions. For example, potato farmers in Florida saved their 1997 winter crop by contouring their fields and clearing state-owned drainage canals in anticipation of excess rain associated with El Niño (Jagtap et al., 2002; PII: S0308-521X(02)00048-3). The highly visible success of grain crop farmers in the Pampas of Argentina who increased their income substantially by planting more maize in anticipation of favorable rainfall associated with the 1997–1998 El Niño, led to more widespread efforts to devise management responses to forecast conditions (F. Royce, personal communication); 42% of surveyed farmers altered decisions based on forecasts of the 1998–1999 La Niña (Letson et al., 2001). Gadgil et al. (2002; PII: S0308-521X(02)00049-5) present a letter in which a group of “marginal” farmers in south-central India detailed previous and planned management responses to monsoon rainfall forecasts. Farmer survey data indicate that rather large changes in areas planted by communal farmers in Zimbabwe during the 1997/1998 El Niño and the 1998/1999 La Niña were at least partially a response to seasonal forecasts that were widely-publicized these 2 years (Phillips et al., 2002; PII: S0308-521X(02)00045-8). An Africa-wide agricultural input supplier markets seeds of cultivars based on their appropriateness to seasonal rainfall forecasts, and uses forecasts in planning their distribution among regions (Malusalila, 2000). In other cases, agricultural decision makers have identified viable decision options that they believe will benefit from seasonal forecasts once their reliability is demonstrated and availability assured (e.g. Ingram et al., 2002; PII: S0308-521X(02)00044-6; Everingham et al., 2002; PII: S0308-521X(02)00050-1; Jagtap et al., 2002; PII: S0308-521X(02)00048-3).
Innovative institutional mechanisms are strengthening the foundation for operational dissemination and support of agricultural use of climate forecasts into the future. Periodic regional climate outlook forums in Africa and Latin America bring forecast providers and stakeholders together regularly to develop consensus forecasts and explore opportunities for their use (Buizer et al., 2000). Agricultural support institutions in Australia, Zimbabwe and the southeast USA, have incorporated seasonal climate forecasts into their operational programs for advising farmers.

Research to foster appropriate use of forecasts for improved agricultural decision making is advancing well, but is still new enough to warrant a degree of caution about making strong generalizations about the value of climate forecasts. However, based on the evidence I have seen and the research efforts of which I am aware or involved, including those reported in this issue, I expect that continued appropriate, holistic research will yield substantial benefits in those contexts where the necessary conditions either are, or could potentially be put, in place.

Acknowledgements

I gratefully acknowledge helpful comments from S. Agrawala, A. Barnston, R. Basher, K. Broad, L. Goddard, P. Hayman, K. Ingram, U. Lall, D. Letson, H. Meinke, G. Podestá, C. Roncoli and L. Zubair, and from referees J. Jones and D. Liverman. Any errors or omissions are mine. This work was supported by a grant/cooperative agreement number NA67GP0299 from the National Oceanic and Atmospheric Administration. The views expressed herein are those of the author and do not necessarily reflect the views of NOAA or any of its sub-agencies.

References


Blench, R., 1999. Seasonal climate forecasting: who can use it and how should it be disseminated. Natural Resource Perspectives No. 47. Overseas Development Institute, London.


