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Weather, climate, and farmers: an overview

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Challenges in linking meteorological and climatological information with a wide range of farming decisions are addressed in this paper. In particular, while a considerable amount of weather and climate information is now available for farmers, some types of information under development or already operational, particularly climate forecasting, formation, may be ill-suited for use by farmers for their decision-making. Case studies show it is particularly important for those key farm decisions that are amenable to weather and climate information to be identified clearly so that weather and climate information can be better tailored to suit farming decisions. A participatory approach provides farmers with ownership of the processes associated with development of weather and climate information and facilitates advances in linking climate and weather information and forecasts to farm decisions. Decision-support systems provide useful output when used with farmer discussion groups. Developing appropriate interdisciplinary systems to connect climate, weather, and agronomic information, especially including forecasting systems, with farm management is needed if uptake of weather and climate information by farmers is to be successful. Provision of output of climate change scenario and trend information to aid long-term strategic farm management decisions needs to be considered, especially in regions where more vulnerable farming zones exist.

Keywords: climate and weather forecasting, decision-support systems, participative approaches.

1. Introduction

While there have been major improvements in the ability to provide weather and climate information and forecast systems for farmers, there are arguments that suggest these improvements should not be regarded as a panacea. In terms of forecast information in particular, Stern & Easterling (1999) explain, 'climate and weather forecasts in their current form are often ill-suited for direct use in decision-making and decision-making is often ill-suited for the use of weather and climate information'.

Nevertheless, farmers in developing countries as well as those in countries with a well-integrated market system have the potential to benefit significantly from weather and climate forecasts, those in developing countries as a result of their particularly high vulnerability. Not surprisingly, the greatest benefits may go to those farmers who have the means and resources to take the most advantage of the technology. For smallholder farmers in Africa, and in other developing regions, these would be those farmers who could apply productivity-enhancing technologies such as improved seeds, fertilisers, and labour. Conversely, poor market development limits the demand, especially for farmer-oriented climatic information, since the options available to farmers are limited (Stern & Easterling 1999).

Hansen (2002a) pointed out the prerequisites for potential benefits of meteorological and climatological forecasts if they are to be realised by farmers. Firstly, these types of forecasts have to address a need for farmers that is 'real and perceived'. Climate and weather forecasts have to be a relevant component of the climate or weather system at an appropriate farming spatio-temporal scale. Importantly, Hanson points out that the benefit also depends on the existence of decision options for the farmer which are sensitive to the particular incremental information that the forecasts provide and which are compatible with the farmer's goals. The need for appropriate interpretation is highlighted where farmers require a capacity to interpret correctly relevant forecasts which also have to be made with sufficient lead-time to make an impact on their decisions. Additionally, prediction of the relevant components of weather or climate variability is needed for relevant periods, at an appropriate scale, with sufficient accuracy and lead time, in a form that can be applied to the farmer's decision problems. Yet, the processes needed to provide appropriate climate and weather information for farmers may not be understood by many agencies. The purpose of this paper is to provide an overview of issues and approaches used to supply appropriate climate and weather information, including climate change information, for farmers in order to better meet their decision-making needs across a wide range of timescales.

2. Real-time weather and climate information 'products' for farmers

Motha & Stefanski (2006) provide examples of weather and climate information as data-rich products from many government organisations that provide fundamental ongoing information for farmers, farmer organisations, agricultural consultants, industry, and other agriculturally focussed government or semi-government organisations. In their example, they show the United States Government Joint Agricultural Weather Facility successfully applying weather and climate information in many of its operational applications that are disseminated to farmers and other agricultural users. Specifically, these assessments keep USDA commodity analysts, the Chief Economist, the Secretary of Agriculture, and top staff informed of worldwide weather—their effects on crops and livestock. When integrated with economic analyses and information, these routine and special crop-weather assessments provide critical information to decision makers formulating crop production forecasts and trade policy. These agricultural weather applications or products are grouped into tactical (short-term) and strategic (long-term) products. Examples of tactical products discussed include the long running "Weekly Weather and Crop Bulletin", routine and special crop-weather assessments, and regional weather networks. More strategically focussed products include the U.S. Drought Monitor and the use of weather information in the monthly World Agricultural Supply and Demand Estimates process. Specific products include publications and reports, a drought monitor, crop calendars, as well as international crop and weather information of value to those with interest in commodity prices and similar issues (http://www.usda.gov/oce/weather/pubs/index.htm). In another such example, the Kenyan Meteorological Department (http://www.meteo.go.ke/customer/farmer/resources.html) provides comprehensive and specialised information for farmers that includes rainfall data from over 2000 Kenyan stations country-wide since 1890, other meteorological data (sunshine duration, humidity, radiation, evaporation, soil moisture, temperatures, wind direction and speed) of value to farmers, and specific crop data such as variety of the grown crop, stage of development attained by the crop, general assessment of crop performance, damage by pests, diseases and adverse weather, state of weeding in the farm, plant density and soil moisture together with 10-day summaries of crop and weather advisories. In a further example, from Tanzania, information ranging from Normalised Difference Vegetation Index data to complex weather information of value to farmers is provided (http://www.meteo.go.tz/Bulletin/Apr2002/Apr2002.htm).

Indeed, remarkably comprehensive information similar to that described above now appears as common output products emanating from government meteorological and agricultural departments worldwide that have fundamental value to farmers and farmer-representative organisations. Additional examples include the many examples under World Agrometeorological Information Service (WAMIS). As an example, output products from Germany include monthly agro-weather bulletins, soil temperature information, actual and potential evaporation, grain dampness, forest and grass fire indices, and animal thermal load (http://www.wamis.org). Finally, farmers in drought-prone regions can access climate, drought, and crop prospects using information provided on specialised information sites such as the Australian National Agricultural Monitoring System (NAMS) (http://www.nams.gov.au).

3. Engaging with farmers—the value of a participative approach

In regions where there has been successful uptake of more complex climate and weather information by farmers, it has been important for farmers to participate in the development of appropriate response strategies to climate and weather information, especially in deciding which decisions related to climate forecast information may be suited for them. In this respect, farmers may be suspicious of a forecast (system) if they do not understand or have some ownership of the scientific methods used to develop it, especially if they see the forecast as conflicting with their local traditional indicators (Patt & Gwata 2002).

While the value of forecasts to farmers will depend on their accuracy, they will also very much depend on the management options available to the farmer to take advantage of forecasts (Nicholls 1991, 2000). Indeed, the value of climate and weather forecasting to the farmer may never have been demonstrated to the farming community by the institution developing and promoting the forecast information. To the farmer, the cost and benefits of different decision options determine the minimum level of skill for forecast information to have an impact on their decision-making (Katz & Murphy 1987; Hansen 2002a,b; Gadgil et al. 2002). This aspect is reinforced by Sonka et al. (1987) that, for benefits to occur in farming practice, it is necessary to identify those areas where tactical changes can be made either to take advantage of predicted (probabilistic) above-average rainfall or to reduce losses in predicted (probabilistic) below-average situations. In other words, climate and weather forecasts may have absolutely no value unless key management decisions have been identified through close interaction with farmers and the farmers' key management decisions are capable of being changed by incorporation of climate and weather forecasts and information (Nicholls 1991, 2000; Hammer et al. 2001).

Thus, in terms of seasonal climate forecast systems in particular, although several agricultural/climatological agencies now issue seasonal climate forecasts on an operational basis, there may have been a failure by those institutions to engage in suitable participative approaches or to develop a comprehensive profile of users and their key decisions that may be amenable to forecast systems. This failure has resulted in a considerable gap between the information that is likely to be useful to farmers and that provided and disseminated by these agencies. If farmers can use climate forecasts to make better decisions, it is suggested that not only their vulnerability to major climate phenomena such as El Niño events but also their dependence on national and international aid will be less. Furthermore, a common problem leading to confusion of farmers in using climate forecasts and information is the failure to differentiate between the 'skill' of a forecast and its 'value' or 'impact' (Murphy 1993, 1994; Amissah-Arthur 2000; Hammer et al. 1996; Hammer 2000; Weiss et al. 2000; Hammer et al. 2001; Patt and Gwata 2002).

Cash & Buizer (2005) emphasise that effective climate and weather information systems should 'ground the collaborative process of problem definition' in (farmer) perspectives regarding the decision context, the multiple stresses bearing on, in this case, farmers' decisions, and the ultimate goals that the knowledge–action system seeks to advance (Cash & Buizer 2005). In this instance, this would mean shifting the focus towards promotion of broad, *farmer-driven* risk management objectives, rather than necessarily advancing the uptake of particular forecasting or information technologies by the meteorological institution. Hansen (2002b) also identified this point as a core and urgent requirement to bridge the institutional and cultural gap that also exists between meteorological and agricultural support institutions if farmers are to gain from improvements in developments of weather and climate information systems, especially forecasting systems. For example, meteorological institutions tend to regard information systems and forecasts as stand-alone *products*, whereas the farmer—agriculturally orientated profession—in assessing information systems and climate forecasts as an aid to increasing farm productivity, regards these systems as a *process.* To help overcome this problem in ensuring that the objectives are more farmer-driven, it has been suggested that, a *knowledge–action system* needs to be evaluated appropriate to the achievement of the farmers' ultimate goals (e.g., more effective risk management), rather than the goals of the meteorological community (e.g., more or better understanding and use of information and forecasts, with the goal of improving content, format, and distribution in order to increase use and impact (Hansen 2002b; Cash & Buizer 2005).

In a study of seasonal climate forecasting applications for farmers in widely varying regions such as West Africa, India, and Australia, it has been noted that, while farmers were generally interested in receiving seasonal rainfall forecasts that provided the probability of receiving a total rainfall amount in millimetres over their farming season, they were much more interested in receiving forecasts that were more relevant to their actual decisions. This, for instance, could include the timing of commencement and cessation of the wet season, whether there would be interruptions in rains, and whether the time period used as output from the forecast system was relevant. It appears to be the case that once this level of additional detail is provided, especially following use of participative approaches with farmers, they come to regard climate forecasts and weather forecasts as capable of providing useful input into their key management decisions (Gadgil et al. 2002; Everingham et al. 2002; Ingram et al. 2002). Indeed, in an example of sugar farmers in Australia, who became engaged in participative approaches regarding development of more targeted seasonal forecasting, the sugar industry shifted from having the lowest proportion of farmers engaged in uptake of climate forecast information to the highest of all farming groups in Australia applying climate forecasting to their decision-making (CLIMAG 2001).

Sivakumar (2002) stresses the urgent need globally for meteorologists to increase their communication activities with farmers. Cash & Buizer (2005) point out that designing fully 'end-to-end' systems means that climate and weather forecast developers should begin their developmental process by simply going into the field and listening to farmers, learning their perspectives, their problems, and their needs. Everingham et al. (2002) also imply that focused conversations with farmers reveal that climate and weather information are needed as part of a larger suite of information that can help them manage a broad array of risks. Initiating conversations with lead innovators within the farming community appears to be a key factor to success. These farming leaders can lay the groundwork for broader participation of other farmers and improved connection between scientists and farmers (Cash & Buizer 2005).

Participative approaches with farmers may reveal they may have an adaptive management strategy (e.g., planting strategy) in place that is independent of weather and climate information or forecasts. This may be in the form of response strategies to the current soil conditions that have been derived to best manage climatic risk. It is against this type of background that developers of new approaches and aids in risk management such as developing climate and weather forecasts must be prepared to set themselves and compare improvements in risk (Podesta et al. 2002; McCown et al. 1991; Stewart

Table 1. *Agricultural decisions at a range of temporal and spatial scales that could benefit from targeted climate forecasts (Meinke & Stone 2005).*

Farming decision type	Climate system frequency (years)
Logistics (e.g., scheduling of planting/harvest operations)	Intraseasonal (> 0.2)
Tactical crop management (e.g., fertiliser/pesticide use)	Intraseasonal (0.2–0.5)
Crop type (e.g., wheat or chickpeas) or herd management	Seasonal (0.5–1.0)
Crop sequence (e.g., long or short fallows) or stocking rates	Interannual (0.5–2.0)
Crop rotations (e.g., Winter or summer crops)	Annual/bi-annual (1–2)
Crop industry (e.g., grain or cotton; native or improved pastures)	Decadal (~10)
Agricultural industry (e.g., crops or pastures)	Interdecadal (10–20)
Landuse (e.g., agriculture or natural systems)	Multidecadal (>20)
Landuse and adaptation of current systems	Climate change

1991). However, farmers could still be encouraged to plant crops in seasons that may not have even been considered without knowledge gained from climate forecasting (Amissah-Arthur et al. 2002).

For farmers, most management decisions have to fit within a whole-farm strategic plan such that many decisions are planned months ahead and their consequences seen months afterwards. The requirement for a certain lead-time between deciding on a course of action and realising its results is a characteristic of managing and farming cropping and grazing systems (Carberry et al. 2000; Carter et al. 2000). Pannell et al. (2000) stress the importance of getting the 'big (strategic) decisions' right, such as land purchase, machinery investment and resource improvement. Farmers are usually better off if they solve the whole problem roughly, rather than to attempt to solve part of the problem extremely well (Meinke & Stone 2005). Alternatively, 'in farming it is better to be roughly right than precisely wrong' (P. Hayman, South Australian Research and Development Institute, personal communication).

4. Integrated systems approaches to application of climate and weather information

At the broader industry level, application of seasonal climate forecasting, and similar systems at a whole farming system scale and across industry value chains, improves the overall benefit of application and integration of information and forecasting with farm management strategies. This approach has the potential to benefit industries in many areas. In an example for sugar farming, that could also have application in a general sense to other industries, these strategies include:

- improved on-farm profitability by better using scarce water resources, increasing water use efficiency, and enabling higher production with consequent minimal movement of nutrients and pesticides off-farm,
- improved planning for wet weather harvest disruption and early season supply and better scheduling of milling operations leading to more effective use of resources (e.g., milling capacity, haulage capacity, haulage equipment, shipping, together with enhanced on-farm profitability),
- enhanced industry competitiveness through more effective forward selling of the commodity based on enhanced knowledge of the amount of supply and improved efficiency of commodity shipments.

The value of integrated climate/crop modelling efforts can also be seen when probability distributions of a large number of simulated yields and gross margins can be produced and incorporated into risk assessment tools. Furthermore, the large number of simulations using the modelling approach allows the exploration of climate influences such as ENSO on extreme outcomes, a difficult approach with purely historical series that are typically short in duration (Sivakumar 2002; Podesta et al. 2002; Meinke & Stone 2005).

Decisions that could benefit from more integrated and targeted forecasts are also made at a range of temporal and spatial scales. These range from tactical decisions regarding the scheduling of planting or harvest operations to policy decisions regarding land use allocation (e.g., grazing systems vs. cropping systems). Table 1 provides some examples of these types of decisions at similar time scales to those seen in major modes of climatic variability. Hammer et al. (2001) stress the most useful lessons lie in the value of an interdisciplinary *systems* approach in connecting knowledge from particular disciplines in a manner most suited to farming decision makers. It may be especially useful to think about linking all aspects of climate/weather/farming systems research and farmer decision-making from a systems perspective. The RES AGRICOLA project is an evolution of the 'end-to-end' concept proposed by Manton et al. (2000). Importantly, it distinguishes three discipline groups that need to interact closely if farmers are going to benefit. These (fundamentally important) discipline groups are (i) climate sciences, (ii) agricultural systems science (including economics), and (iii) rural sociology (Meinke & Stone 2005).

Improved pay-offs for farmers are significantly facilitated when such an integrated systems approach is employed that includes farmers, other decision makers, and scientists (climate/meteorology/biophysical) across various disciplines which ensures that the issues that are addressed are relevant to the farmer (Meinke et al. 2001). Hansen (2002a) stressed that the sustained use of such a framework requires institutional commitment and favourable policies. An example where links could be strengthened is in the area of connecting agricultural simulation with both whole farm economic analyses and broader government policy analyses. Using a case study, Ruben et al. (2000) reviewed the available options for adapting land use systems and labour allocation for typical households in a region in Mali. They showed that compensatory policy devices could, at least, partially offset consequences of climatic patterns, largely through better-informed price policies which would enable welfare-enhancing adjustments for better-endowed farm households, while poor farmers would benefit from reductions in transaction costs.

5. The value of case studies in the use of scenario analyses

There are some general lessons that may be learnt from case study analyses from a number of regions where integration or dissemination of climate and weather information with farming decisions has been trialled. Case studies may represent a wide diversity of agricultural systems and various scales of farm operation. To facilitate case study development, a useful approach over recent years has been to provide scenario analyses based on simulation with credible agricultural models as a valuable aspect of the learning process for farmers and industry. These include use of crop simulation models such as 'APSIM' (McCown et al. 1996; Keating et al. 2003), or its derivative 'Whopper Cropper' (Nelson et al. 2002).

Decision-support systems have often been cited as an effective means of providing output of integrated climate-agronomic information in the form of scenario analyses that can be valuable to farmers. However, there is also a perception that these systems have been less than ideal in their overall effectiveness (Stone & Meinke 2005). However, when used in the manner of '*discussion-support*' systems, farmers can engage in discussions with advisors regarding weather, climate, and crop management scenarios and maintain ownership of the overall processes and final decision-making. In this way, discussion-support systems move beyond traditional notions of supply-driven decision-support systems and can compliment the participative action research described earlier. The critical role of interaction and dialogue among the key participants—farmers, advisors, crop modellers, and climate or meteorological scientists—is paramount (Podesta et al. 2002; Plant 2000; Nelson et al. 2002).

In an example of a particular case study, the value of development of scenario analyses associated with climate forecasting systems that have been targeted to a particular cropping regime has been demonstrated with detailed analyses for locations in India. In this study, case studies at farm and village scale included farm-scale cash flow to identify benefits for farmers in applying climate forecast systems. The results from these analyses indicated that farmers can benefit from modifying a range of crop management decisions in response to Southern Oscillation Index (SOI)-based climate forecasts.

The estimated benefit of changing crop management practices in response to SOI-based forecasts ranged from Rs. 35 to 665 ha^{-1} $year^{-1}$ averaged across all years (Selvaraju et al. 2004; Meinke et al. 2006). In particular, Meinke et al. (2006) argue that the use of appropriate crop modelling, integrated with a seasonal climate rainfall forecast system, can provide appropriate probabilistic information in a manner relevant to decision-making at the farm scale.

Figure 1 provides an example of resultant probability distributions of gross margins associated with each of the five SOI patterns ('SOI phases') (Stone et al. 1996; Meinke et al. 2006) for simulated groundnut yields at Avinashi, India. It is argued that this type of simulated output, made available before the farmer plants their crop, will significantly affect their decisions. For example, anticipated income from planting groundnut in a particular year may influence a farmer's decision on whether to plant at all or whether to reduce inputs that year. Not surprisingly, potential gross margins for farmers associated with likely (simulated) yields showed considerable differences between season types associated with the SOI phases. The average gross margin was Rs. 4139 ha^{-1} $year^{-1}$ lower following a 'consistently negative' SOI phase in April/May and Rs. 4525 ha^{-1} $year^{-1}$ lower following a 'rapid fall' SOI phase than the 'all-years' average. Conversely, average gross margins were likely to increase following either a 'consistently positive' (Rs. 117 ha^{-1} $year^{-1}$) or 'rapid rise' (Rs. 2168 ha^{-1} $year^{-1}$) SOI phase year pattern in April/May. In their analyses, Meinke et al. (2006) revealed an increased risk of low farm yields associated with reduced or negative gross margin (compared to an all-year average) following either a 'consistently negative' or 'rapid fall' SOI phase, which is often associated with development of an El Niño event. Additionally, the gross margin deviation from the 'all-year' average during a La Niño event was less than during an El Niño event. Thus, the opportunity for gain for farmers who make decisions with knowledge of a 'consistently positive' or 'rapid rise' SOI phase before planting was less than the risk of loss when making a decision at planting following a 'consistently negative' or 'rapid fall' SOI phase through April/May. Similar types of analyses may be conducted for a wide range of soil types and climatic environments in any region. Application of the relationships of potential yields with 'SOI phases' as part of this type of analysis also largely

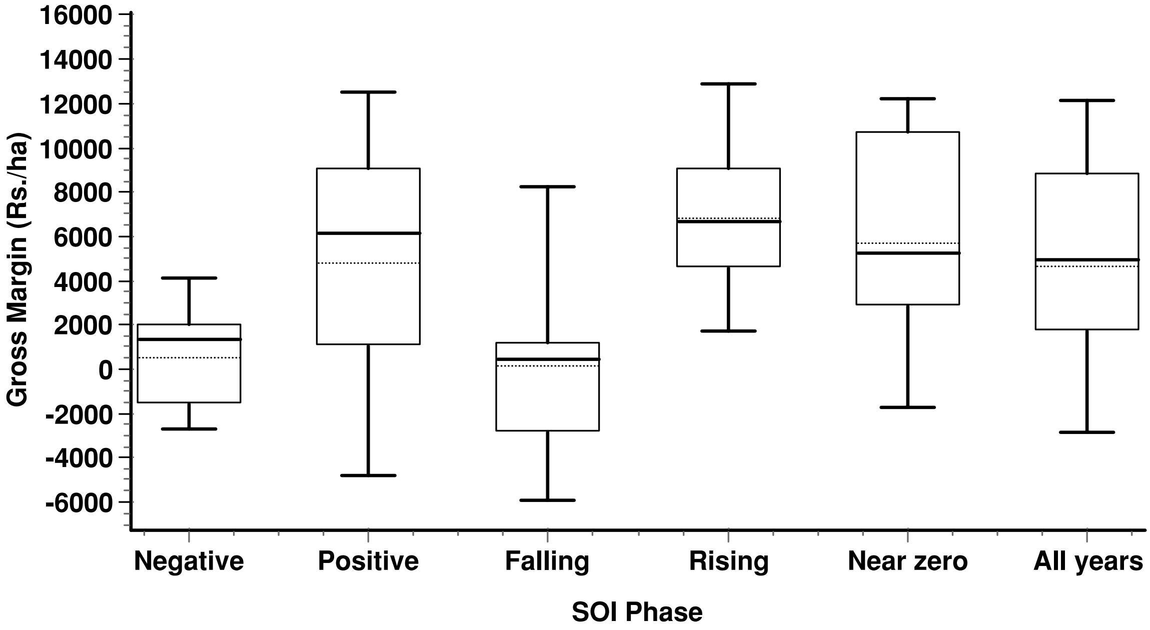

Figure 1. *Distributions of simulated groundnut gross margins at Avinashi, India, associated with each of the five SOI phases in April/May together with the distribution for 'all years'. The boundaries of the box-plot denote the 20th and 80th percentiles, respectively while the 'whiskers' associated with the box-plot denote the 10th and 90th percentiles (from Meinke et al. 2006).*

depends on the influence of ENSO in a particular region (Meinke et al. 2006).

'Real-world' case studies of the use of seasonal forecast systems by farmers in terms of the decisions that have already been made over a number of years as part of their normal farming management can also highlight the complexity of the types of weather, climate, and crop modelling information gathered by farmers in order to aid significantly their decisions. One such example is from a successful group of farmers in New South Wales, Australia, who integrate climate, weather, and agronomic information into their operational decision-making through:

- continual monitoring of long-term predictions of La Niño and El Niño using preferred web-sites, e.g., United States Climate Prediction Centre – National Oceanic and Atmospheric Association (NOAA) weekly updates and coupled model outputs (http://www.cpc.ncep.noaa.gov/products/); Australian Bureau of Meteorology web site, including experimental output from the 'POAMA' model (http://www.bom.gov.au/climate/coupled_model/poama.shtml/); ECMWF model forecast output (http://www.ecmwf.int/products/forecasts/d/charts/seasonal/forecast/plumes/);
- understanding the potential impacts of La Niño and El Niño on their farms by using 100-year crop simulations supplied by the Agricultural Production Systems Research Unit (APSRU) and the 'APSIM' crop simulation model that has the capability of integrating crop simulation modelling with climate forecasting systems (Keating et al. 2003).

In this way, different types of crop rotations for both winter and summer cropping regimes have been investigated to identify the types of regimes that would produce the best yields in La Niña and El Niño years, including the important knowledge of the role that soil moisture, already stored in the ground in this region, can make when these climate patterns are developing. Developing crop rotation strategies, sowing rates, fertiliser rates, and row configurations that are adjusted according to the levels of stored soil moisture, and then, also according to the more quantitative seasonal climate forecasts valid for the particular season ahead. The above approach allows these farmers to concentrate on 'fine-tuning' their crops with the result they have been able to double their yields and double their profits over a recent eight-year period (Clark 2002).

The 'case-study farmers' described above make constant use of available information throughout the season, and also before a particular season of relevance commences. Weather information and forecasts are monitored each day and climate forecast information relevant to the region is monitored monthly. In addition, between February and June, these farmers closely monitor progress of the global climate system throughout the so-called (austral) 'autumn predicability gap' (Drosdowsky & Allan 2000) when climate systems closely linked to the equatorial Pacific Ocean are known to change phase, with the knowledge that patterns established during this period can have important ramifications for ensuing climate patterns over the next 10–12 months (Clark 2002).

The value of 'discussion-support' systems and similar workshop environment activity in some areas has been demonstrated through recognising the value of clearly

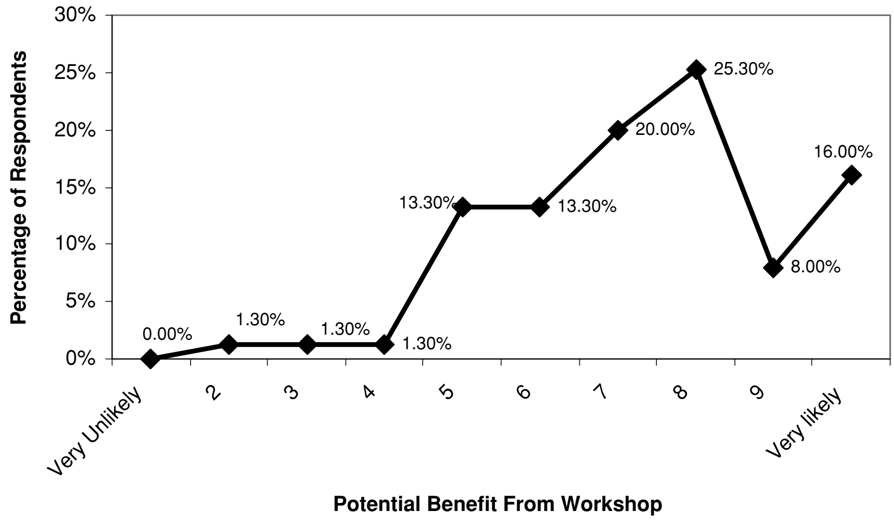

Figure 2. *Results of 'Managing for Climate and Weather' workshop evaluation in Queensland, Australia, in terms of farmers' opinions regarding the likelihood information obtained at the workshops would be of potential benefit in their future primary production decisions (N. Cliffe, personal communication).*

identifying farmer decisions that may be amenable to weather and climate variability, and then, through a participative approach, identifying clear opportunities for use of weather and climate information and forecasts by farmers.

In a further case study example of workshop results (in Australia) (Figure 2), participants were shown to respond highly to the concept of placing climate and weather information and forecast systems within the framework of their own decision-making within a slightly formal discussion environment. Figure 2 shows 70% of primary producers in one study believe their involvement in a participative approach regarding use of weather and climate forecast systems in their management has been beneficial. This type of workshop environment allows farmers to listen to 'guest lecturers' in the fields of meteorological and climatological forecasting and science and to determine for themselves the levels of merit and uncertainty peculiar to each type of forecast system and output. Importantly, the probabilistic framework associated with climate forecasting is made distinctive from the more deterministic framework of weather forecasting. Similarly, farmers' decision-making processes and their 'decision-points' are discussed in terms of both tactical decisions (that could be related to weather forecasts) and strategic decisions (that could be related to climate forecasts). Some 16,000 farmers have, so far, participated in these one-day 'discussion-support' workshops in Queensland, Australia, which also include aspects of integrated crop and pasture simulation model output and which are facilitated by professional extension personnel. Through this process, it is now estimated that ~50% of farmers, in this region, now utilise climate and weather forecasts in their on-farm decision-making (N. Cliffe, Queensland Department of Primary Industries and Fisheries, personal communication). Similar processes, in which trained extension personnel 'drive' the interactive processes between scientists and farmers have been introduced in Florida with considerable success in bridging the gap between current climate forecast capabilities and outputs and the information needs of farmers (Jagtap et al. 2003).

In order to aid the decision-making process, the use of crop and other models must reduce decision complexity rather than unnecessarily proliferate choices for the farmer or farmer's advisor. In this respect, in spite of the questionable track-record of decision-support systems that encompass climate forecasting systems, they are still likely to have a role when properly integrated into group processes, especially if a tandem approach is used whereby the participatory approach becomes an essential component of the early stages of integrated model application for farmers (Hammer et al. 2001; Meinke et al. 2001). Cox (1996) and McCown et al. (2002) argued that these types of agricultural correspond poorly to the decision style of farmers and the context in which they operate. However, the research, development, and extension programs associated with delivering these programs have facilitated social interaction between researchers, extension officers, and farmers so that simulation-aided *discussions* about crop or grazing management has underpinned advances in farming systems analysis as a vehicle for improved farmer management (Keating & McCown 2001; Nelson et al. 2002).

Forecast systems that are able to provide analogue years or seasons, and thus provide a forecast distribution, have become increasingly utilised in agricultural and farming systems. The concept of analogues is important as this approach allows pertinent information relevant to crop growth production to be extracted for further analysis. Thus, once a forecast is issued in 'real-time', its derived parameters can be associated with past seasons or years and a suitable set of analogues can be provided and crop or pasture production scenarios can be produced. These scenarios can take into account the amount of stored soil moisture, relative advantages of planting early or late, of applying extra fertiliser, of using single or 'skip- row' planting, altering planting densities, and so on, of direct relevance to the farmer's decisions. Additionally, the set of hindcast analogues has the further benefit of allowing farmers to recall those sets of years when the relevant climate pattern prevailed and what impacts associated with that climate pattern were produced on their farm, thereby facilitating ownership of the forecast output by the farmer (Cliffe et al. 1999; Everingham et al. 2003).

Additionally, it is becoming clear that skill in climate forecasting offers considerable opportunity to agricultural systems managers, especially, it seems via its potential to realise improvements throughout an entire system such as increased food production or increased profitability and improved food security policy (Hammer et al. 2001).

Applying climate forecasting to a resource-rich but poor farming region, such as Zimbabwe, has demonstrated that there is a number of opportunities for resource-limited farmers provided quality information is available. However, access to 'safety-nets' such as insurance or personal savings may be limited, suggesting that the potential risks associated with applying climate forecasts need to be considered in defining what is meant by 'quality' information. In this respect, it has been suggested that climate applications by farmers in this context should be limited to safe strategies such as shifts in area planted, with the degree of alteration being defined by the degree of certainty in the forecast (Hammer et al. 2001). While farmers and producers of integrated climate-crop forecasts tend to focus on the potential value to agronomic decisions, farmers may also be aware of financial strategies (futures, options, derivatives, crop insurance) as part of the spectrum of alternative approaches to responding to the expected climate (Podesta et al. 2002).

6. Linking climate and meteorological information to farmer action

Cash & Buizer (2005) argue that linking climate and meteorological knowledge to farmer action is more likely to be effective if it is perceived by farmers to be simultaneously *salient*, *credible*, and *legitimate*. These terms are described as follows (Cash & Buizer 2005):

- *Salience* relates to the perceived relevance of climate and weather information: does the system provide information that farmers think they need, in a form and at a time that they can use it?
- *Credibility* addresses the perceived technical quality of information: does the system provide information that is perceived to be valid, accurate, tested, or more generally, at least as likely as alternative views to be "true".
- *Legitimacy* concerns the perception that the system has the interests of the farmer in mind and is not simply a vehicle for pushing the agendas and interests of other actors.

Patt & Gwata (2002) have proposed six factors limiting farmers' use of climate forecasts together with suggestions for corrective action (Table 2).

Additionally, there may be certain additional important factors that significantly inhibit uptake of climate information and forecasts by farmers. Selvaraju et al. (2004) identified these as 'obstacles' that could be classified as (i) being associated with inherent underlying issues related to the forecast system itself, (ii) related to the nature of smallholder cropping or farming systems to which the forecast systems were to be employed, (iii) related to inherent underlying aspects associated with the socio-economic characteristics of the farmers, (iv) related to issues associated with the information delivery systems, and (v) related to external policy and external institutional factors. These are elucidated in Table 3.

Global crop production may considerably alter in the presence of seasonal climate forecasts. In modelled analyses, the decrease in farm production in potentially less favourable years was shown to be less substantial than in an analysis of actual actions of resource-poor farmers in Zimbabwe in response to climate forecasts of a poor year. It is suggested that in the case of resource-poor farmers with few production options, decreases in area planted in potentially poor rainfall seasons, together with the resulting increase in production volatility may be a common occurrence when forecasts become more widely available. The end result may be subsequently reduced production by small farmers in years when the crop investment is expected to be more costly. Importantly, how farmers perceive and react to the climate forecasts will determine whether aspects of increased uncertainty with regards to farming production will result in avoided costs or missed opportunities (Hill et al. 2001; Phillips et al. 2002).

It is suggested that a decrease in total farm production in years in which climate forecasts suggest increased chance of below-normal rainfall needs further investigation as a rational response (Phillips et al. 2002). Off-farm employment and income in potentially poor years may provide an attractive alternative for farmers instead of planting 'risky' crops in a potentially poor season. Additionally, for poor farmers, it may be difficult to turn short-term gain into savings for the poor production years in the future (Phillips et al. 2002).

Hammer (2000) demonstrated the basis for effective application of seasonal climate forecasting on-farm using a simple example of tactical management of

Table 2. *Factors limiting farmers' use of climate and weather forecasts (after Patt & Gwata 2002).*

	Causes	Effects	Corrective action
Credibility	Previous forecasts are perceived as being 'wrong' and the communicator is not generally trusted	Farmers will ignore the forecasts	Give probabilistic forecasts and rely on trusted communicators
Legitimacy	Forecasts are perceived as superseding farmers' local knowledge	Farmers will ignore the forecasts and reject any associated advice	Attempt to incorporate local knowledge into the forecast and important to involve farmers in developing the advice information
Scale	Forecasts provide no information about events in their local area	Farmers will not incorporate forecasts into their decision-making processes	Need to work with farmers to analyse the implications for the local area. Attempt to provide regional or local scale forecast information, in probabilistic format
Procedures	Forecasts produced at the wrong time, to the wrong people, or is unexpected	Farmers will not incorporate forecasts	Repeat communication to resolve the timing, involvement of relevant key players
Choices	Forecast information does not contain enough information to alter any specific decision	Farmers will not change decisions in response to a forecast	Need to improve forecast skill and encourage farmers to make incremental decisions ('lean' rather than 'jump')
Cognition	Forecasts are new in format, confusing, and different.	Farmers will either not incorporate forecasts or they will do so in a way that is counter-productive	Need to work repetitively with farmers to decipher the meaning of forecasts for their region and to correct mistakes

Table 3. *Challenges in using seasonal climate forecasts in smallholder farms (after Selvaraju et al. 2004).*

No.	Obstacles in regards to farmer uptake of climate information and forecasts
	I. Climate prediction and information system
1.	Same climate information, but diverse needs on-farm (manpower, technical capacity) (climate forecast system too general in nature to suit diverse on-farm needs)
2.	Low level of predictability of climate forecast system or need for longer lead times
3.	Motivated scepticism of farmers due to high spatial variability (heterogeneity of ENSO impacts)
	II. Smallholder cropping systems
4.	Diverse cropping systems resulting in different needs (>10 systems in a smaller region)
5.	Overlapping cropping seasons, which respond differently to ENSO indices
6.	Farmer strategies are already triggered by local rules of thumb
7.	Non-responsive decisions due to shortage of labour and inputs (unable to respond to forecasts and information)
	III. Farmers' socio-economic characteristics
8.	Conflicting objectives of the farmers (profit maximisation vs. sustainable technologies)
9.	Migration of young educated mass to neighbouring towns seeking off-farm employment
10.	Complex decision capacity, risk perception and heterogeneity in literacy levels
	IV. Information delivery
11.	Multiple tasks of the information brokers (input distribution, acreage estimation, meetings, etc.)
12.	Confusion of climate forecasts with weather forecasts and problems of understanding probabilities
	V. Policy and financial institutions
13.	Limited access to credit and non-cooperation of financial institutions during distress
14.	Limited market facilities and high price fluctuation limit optimal choices (e.g., cotton and vegetables)

row configuration in a cotton crop. The key decision-point for the farmer in this example is 'what row spacing to apply during October planting'. Hammer (2000) also showed that it was possible to improve farm profitability by tactically manipulating row configuration in dryland cotton in response to seasonal climate forecasting. To do this, Hammer (2000) used an integrated climate forecasting/crop simulation approach and 100 years of historical rainfall data and determined the most profitable option for row configuration (solid, single skip, or double skip) for either 'all years' or those years associated with each phase of the Southern Oscillation Index (SOI) prior to sowing. The results are shown to be in increasingly more profitable options for cotton farmers. Comparing the tactical and fixed management approaches in cotton management over the complete historical climate record gave an average gross margin increase for the farmer of about 6% (or 11% in profit, calculated by deducting fixed costs) when using appropriate tactical management and climate forecast systems. However, while the overall result over the course of the study period was positive, there was a number of specific years in which responsive farm management associated with climate forecasting was inferior. For a farmer, demonstrating that each decision can be potentially costly is important; the decision-making 'calculus' hinges on a variety of economic, social, and geographic factors in addition to the expectation about above or below normal rainfall or other aspect associated with the climate and weather forecast (Hammer 2000; Hammer et al. 2001). For crops likely to be adversely affected by overly dry conditions, it is suggested by some that forecasts may be more useful for farmers when the prediction is for a low probability of drought (that is prediction of a 'good year'). In these years, farmers may risk planting higher yield varieties and investing in additional inputs such as fertiliser (Patt & Gwata 2002). However, it is important to point out to farmers that the higher rainfall probability values can also be associated with overly high amounts in some of these types of years resulting in potential downgrading of grain quality, waterlogging of the crop, and increases in disease outbreak, resulting in overall poorer yields than that expected given the high rainfall forecast (probability) and high expectations resulting from such a forecast. In this case, suitable management strategies for such a forecast have to be developed well before planting (e.g., Stone & Meinke 1999).

Finally, to induce large behavioural change for farmers, it has been argued that climate or weather forecast information must disrupt a farmer's expectation so much that the outcome of the normal choices appears not simply sub-optimal, but inadequate to meet their basic requirements. Patt & Gwata (2002) believe that given current limitations in forecasting skill in some regions that it is unlikely that a seasonal forecast, even if communicated appropriately to farmers, would induce such a large change. In this respect, Hayman and others' (P. Hayman, personal communication) survey results with accuracy levels of '70–75%' provide the benchmark value to which developers of forecast systems are supposed to aspire. However, once clear linkages are made to key decision-points in farming, farmers may become enthusiastic adopters of weather and climate information. If they become what Hayman and others call 'mature adopters', they will use forecast information 'to lean rather than jump into new decision systems' (P. Hayman, personal communication).

7. Dissemination of climate and weather forecasts and information to farmers

Considering the complexity of climate and weather forecast information, it may not be surprising that the effectiveness of forecast information depends strongly on the systems that distribute the information, the channels of distribution, farmers' modes of understanding and judgement about information sources, and the ways in which the information is presented (Stern & Easterling 1999). Some farmers may have trouble correctly understanding a probabilistic forecast, and therefore, erroneously attempt to obtain and translate this information into a deterministic version. Some rural belief systems do not incorporate the idea of chance or luck but rather that a poor season or similar must be because of some previous action. Additionally, policy makers may prefer to communicate forecasts to farmers deterministically, thereby further confounding the nature of the climate forecast information. Despite the fact that communication-related issues have been repeatedly identified as important barriers or impediments to the use of climate information, the communication process as an integral component of an effective climate information system has not received much attention by the producers of climate forecasts (Changnon 2000; Patt & Gwata 2002; Podesta et al. 2002).

In locations such as Zimbabwe, forecast output management practices can constrain forecast use. For example, the Southern African Regional Climate Outlook Forum (SARCOF) meeting in southern Africa occurs in late September but it can take some weeks before 'downscaling' meetings occur in Zimbabwe and more weeks or months can pass before the extension systems are able to translate the information into agricultural decision-making for farmers, often too late for effective decisions to be made (Patt & Gwata 2002). These types of arguments reinforce the compelling need for climate forecast information to be prepared and disseminated in a very timely manner in order to link with key decision times in a farmer's planning schedule. There may be just one occasion in a year when a farmer would apply management information that would be significantly aided by weather or climate forecast information. Issuing climate forecast information too late for effective management systems to be put into place can completely negate the efforts needed to compile that forecast information in the first place. It is stressed that it is only through repetitive communication that developers of climate forecast systems and farmers learn about each others methods such as who makes the decisions, what decisions they make, and through what channels information arrives (Patt & Gwata 2002).

Plant (2000) emphasises that some farmers hold great pride in their learnt farm management capabilities, especially with regards to links to weather and climate patterns. However, these same more experienced and knowledgeable farmers can provide useful extension roles in further translating publicly available climate and weather information into terminologies more readily understood by less experienced or less knowledgeable farmers in the region (Plant 2000).

8. Farmers' needs for decision-systems related to climate change

Managing future farming risks associated with long-term climate change could be regarded as managing low-frequency components of climate variability with the important point that the same quantitative approaches currently being developed for strategic planning issues in farming associated with climate variability could also be applied to the complex farming issues likely to be encountered under climate change (Meinke & Stone 2005). Moreover, despite there being likely complex issues associated with climate change such as changes in land cover and changes in runoff associated with altered precipitation and temperature patterns, many believe farmers are likely to cope and adapt to climate change. Indeed, there appears to be a surprising belief, especially in some studies assessing future economic impacts of climate change on agriculture, that farmers will continue to produce the same commodities on the same land using the same management tools (Abler & Shortle 2000; Abler et al. 2000; Rogers & McCarty 2000).

However, extreme weather events over the past 30 years have already caused severe crop damage and induced significant economic toll for United States' farmers alone. This has occurred against a back-drop of greater variability in crop yields, price and farmer income, part of which can be related to long-term climate change (Rosenzweig et al. 2000). Additionally, it is the authors' experience that farmer needs and requests in eastern Australia for climate-related information (while engaging in participative workshops) have shifted markedly over recent years from the need for issues only associated with managing risks due to climate variability on a 3- to 7-year time scale to be addressed to the needs for longer term, high-level strategic issues associated with climate change to be addressed. These types of practical issues range from the need to find ways of coping with perceived more extreme weather events in tactical day-to-day farm management to more complex whole-farm economic issues associated with 5- to 20-year planning horizons. Typical management examples often cited relate to long-term reduction of cattle stocking rates on available land because of perceived long-term decline in rainfall and pasture availability (with some expectation, these conditions will, more or less, continue) or to otherwise make the high-risk decision to purchase an adjoining property in order to maintain constant stocking rates under potentially increasing drying and warming conditions.

Many impact assessments regarding climate change on agriculture are typically based on smoothly varying climatic change trends, whereas Schneider et al. (2000) note 'farmers in the real world will need to adapt to climate change trends embedded in a very noisy background of natural climatic variability'. They argue this variability can mask slow trends and delay necessary adaptive responses by farmers. Additionally, incorrectly perceived trends by farmers may also prompt false starts leading to maladaptation. To add to this complexity, farmers need climate change information to anticipate and plan in a dynamic world in which many factors are changing both simultaneously, and not necessarily independently. These factors include degrees of belief that the climate is actually changing in their region, knowledge of how it will change, foresight on how technology is changing, estimation of what will happen in competitive farming systems, and assumptions about future government policy changes. Thus, adaptive behaviour by farmers to climate change will also need information on shifting market and social conditions which may render adaptive behaviour for climate change much more multi-faceted that may be assumed (Risby et al. 1999; Schneider et al. 2000). It is, therefore, not surprising there has been some debate between those who assert that farmers could overcome most plausible climate change scenarios and those who assert that such a complete response would require farmers to be aware of the probability distributions of plausible climate, technological, and market conditions and to be financially and intellectually capable of instant response strategies. While research and development agencies, in some developed countries, continually monitor environmental trends and may be able to develop adaptive strategies for farmers, in developing countries, problems with agricultural pests, extreme weather events, and lack of capital to invest in adaptive strategies and infrastructure will be a serious impediment to reducing climatic impacts for agriculture, even for the 'best' farmers (Schneider et al. 2000).

Nevertheless, it is suggested that activities that could already be put into place could include provision of advice relating to seasonal climate forecasts in order to improve farmers' capabilities of changing farming practice to better suit the forthcoming season, careful provision of current local trends, not only of precipitation and temperature but changes in selected indicators such as flowering dates and flood heights, as well as long-term climate change forecast output, if available. It has also been argued that information dissemination networks, such as agricultural extension services, should now start to carefully provide data on trends and observed weather in local regions (Fankhauser et al. 1999). It is suggested that a more focussed and urgent effort be made worldwide to provide enhanced and targeted climate trend and scenario information that is of direct relevance and value to farmers, their advisors, and their governments. This may, especially, be the case in developing countries where climate change may shift farming regions into increasingly more vulnerable farming zones (Rosenzweig & Parry 1994).

9. Conclusions

Climate and weather information and forecasts in their current form have the potential to provide improved farm management and profitability worldwide. However, these forecasts and information systems may, in some instances, be ill-suited for direct use by farmers in their decision-making. To overcome this problem, it is very important for key farm decisions to be identified that would be sensitive to the information which forecasts provide and which are also compatible with the farmer's goals. Climate and weather forecast information, then, has to be tailored in a form that is suited to influencing those key decisions. Indeed, climate and weather forecasts may have absolutely no value unless they can change these key management decisions.

However, through an emphasis on participatory approaches with farmers, considerable gains can be made in linking climate and weather forecasts and information to farm decisions. Farm management decision-support systems, while having less than anticipated uptake with farmers in many regions so far, can provide particularly useful information for discussion groups that meet to address key farm management options, 'grounding the collaborative process of problem definition in the farmer's perspectives' and shifting the focus towards broad, farmer-driven risk management objectives rather than advancing the uptake of particular forecasting techniques. The short case study report from Clark (2002) provides particularly valuable insight into farmers' 'real-world' decision-making processes when needing to assimilate many aspects of complex climate, weather, and agronomic information. In this respect, interdisciplinary systems approaches are especially useful in connecting the knowledge from particular disciplines in a manner most suited to farmers. Applying this approach is well aided by developing case studies that can represent the wide diversity of farming systems and the varying scales of farm operation. Developing appropriate interdisciplinary systems in order to connect climate and weather forecasting with farm management may be a more complex task than initially envisaged when new forecast systems were first developed.

Once undertaken, it appears from evidence in some countries that participatory interaction involving farmers, climate, and agricultural scientists promises particularly large benefits, particularly in regions subject to high levels of climate variability. Successful farm management decision-making undertaken through appropriate targeting of forecast information is already providing substantial benefit in some countries and regions, especially in Australia, India, parts of the United States of America, southern Africa, Argentina, and Brazil. The challenge remains in linking the science of meteorological and climatological forecasting to the wide range of farming industries and regions not yet addressed. It could well be the case that applying forecasts at the level of the individual farmer offers the greatest challenges and the greatest rewards. Finally, provision of information on climate change trends and scenarios of direct relevance to farmers in terms of the complexity of their medium to long-term strategic management decisions must be addressed urgently, especially in developing countries where climate change may shift more farming regions into particularly vulnerable farming zones.

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