Applications of seasonal to interannual climate prediction in agricultural planning and operations

L.A. Ogallo\textsuperscript{a,}\textsuperscript{*}, M.S. Boulahya\textsuperscript{b}, T. Keane\textsuperscript{c}

\textsuperscript{a} Department of Meteorology, University of Nairobi, Nairobi, Kenya
\textsuperscript{b} African Centre for Meteorological Applications for Development (ACMAD), Niamey, Niger
\textsuperscript{c} Research and Applications Met, Éireann, Dublin, Ireland

Received 3 October 1998; received in revised form 29 January 1999; accepted 5 February 1999

Abstract

Climate determines the general adaptation of ecosystems and land use activities at any location. Year to year recurrences of extreme climate events such as drought, flooding, hot/cold spells, etc. often have far reaching consequences in agriculture. Advance warning of such events through climate prediction can minimize various socio-economic problems which are often associated with such events. The severity of the socio-economic impacts of climate related stress varies significantly from one region to another. The impacts are generally more severe in many developing countries where technological adaptations are often very low, and where most of the agricultural systems are rain dependent.

Socio-economic challenges of the next century will include population pressure, industrialization, environmental degradation, and anthropogenic climate change issues, among others. Thus some climate stress in this century may be able to induce far more serious socio-economic disasters in the next century. Advance warning of impending extreme climate events, especially within time scales of months to years, would provide vital information which could be used for sustainable agricultural production. Such early warning information can also form crucial components of national/regional disaster preparedness system which will help to minimise loss of life and property including damage to agricultural investments.

This review has addressed the basic linkages between climate and agricultural systems, the current state of climate prediction science and technology, together with their potential advancements in the next century. The last part of the review highlights the challenges of optimum applications of climate information and prediction products in agricultural planning and operations in the next century. Vital to such an effort are the availability of good databases, skilled multidisciplinary human resources, co-operation between scientists and product users to improve the use of climate prediction products, and to investigate technological and natural adaptations aimed at mitigating the effects of extreme weather. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Climate Information and Prediction Services (CLIPS); National Meteorological and Hydrological Services (NMHSs); Climate Variability and Predictability (CLIVAR); Tropical Oceans and Global Atmosphere (TOGA) Programme; El Niño and Southern Oscillation (ENSO); La Niña

1. Introduction

Climate generally determines natural adaptation of ecosystems at any location. Climate is therefore one of the major factors which often directly or indirectly
influences the space-time distribution of most agricultural systems. Such agricultural systems will therefore be vulnerable to interannual climate variability, especially the extreme events such as excessive precipitation, drought, cyclones, hot/cold spells etc., together with any abrupt changes in the traditional patterns of the local, regional and global climate.

The extreme climate events also often adversely affect land use planning, level of agricultural yield, consistency in yield, cost of production, sowing and harvesting, irrigation needs, transportation, storage, pests and diseases, marketing, farm management, food security and many other socio-economic indicators. They are further known to cause massive loss of life and damage to property, including agricultural investments. Vulnerability of the agricultural systems to interannual climate variability is often higher in many developing countries where most of the agricultural systems are precipitation dependent with very low technical adaptations.

Where greater responsibility is placed on farmers for environmental management they must increasingly rely on climate/forecast information and climate predictions for operational and strategic decisions and planning affecting environmental, agronomic and economic sustainability.

This review has been divided into three major sections in order to adequately address the theme of the paper. The first part will present known linkages between climate and agricultural systems, while part two will review the current state of climate prediction science. The last part presents some key issues which must be addressed in order to enable agricultural planning and operations to take maximum advantage of the current climate prediction methods, together with those which are expected to emerge in the next century.

2. Linkages between climate and agricultural resources

As has been highlighted in the last section, climate has both direct and indirect impacts on many agricultural activities, including adaptation and land use practices, soil and vegetation conditions, nutrient loss, water availability, physiological conditions, environmental degradation such as environmental pollution and desertification, pests and diseases, transportation, marketing and many other agricultural indicators which are crucial to sustainable national development.

The impacts of interannual climate variability, especially the extreme events, are often very devastating, especially in developing countries where technological adaptations are still minimal. In developed countries, the changing role and characteristics of farming, which include improved quality and decreased use of chemicals has also emphasised the needs of farmers for information on practices based on current and forecast weather and longer-term climate predictions.

Advance warning of hazards and extreme climate anomalies at time scales of months to years would therefore be extremely important in agricultural planning and operations. Apart from the traditional weather information, agricultural systems would benefit from advance information regarding future expectations of the following, among many others:

- For scales of less than a month, daily/weekly/10-day precipitation amount, intensity, number of rainy days, distribution of the wet/dry spells; temperature information on heat waves, cold spells and frosts.
- Seasonal climate information, such as time of onset of rainfall or drought, or any extreme climate event, its duration and extent.
- On an inter-annual time scale, the probability of persistence of an extreme, the probability of switching to another state, e.g. from drought to flood, within the period of the forecast.
- Climate change resulting into significant shifts of the traditional patterns of weather and climate.

The next section will address the current state of seasonal prediction science and technology which could be used to provide relevant advance climate information for agricultural planning and operation.

3. Current state regarding seasonal to interannual climate prediction

It was noted in Section 2 that advance warning of future expectations of extreme weather/climate events is extremely useful in agricultural planning and operations. In general, climate information and prediction
products required in agricultural applications can be classified into the following categories:

- Historical and past climate records;
- Real-time and near real-time information;
- Short-range weather forecasts of up to about 1 week;
- Medium-range weather forecasts of time scales beyond the short-range and up to about 2 weeks;
- Long-range weather forecasts and climate prediction of monthly, seasonal and interannual time scales;
- Climate change information.

This section is expected to highlight the major recent advancements regarding monthly, seasonal and interannual climate predictions. It would, however, be futile to address issues related to climate prediction science and technology without a brief discussion of the other time scales since they are directly or indirectly, fundamental to climate prediction.

3.1. Historical and past climate records

All relationships between climate and agricultural systems are derived from historical and past records of both climate and agriculture. Such records are also used in deriving the basic statistics and risks that may be associated with any climate based planning and operational decisions.

Availability of long period, high quality climate and agricultural records are therefore crucial for maximum application of climate information and prediction services in agricultural planning and operations. Such records are not available in many countries. Even when they are available, locations, exposure and types of instruments may have changed. Changes have also occurred in observation routines, types of sensors, etc due to the fast development in science and technology. Such changes can make observations taken before and after such changes not too strictly comparable. These can mask the typical linkages between climate and agricultural systems. The length and quality of the climate and agricultural records are key issues that must be addressed as they provide the information base in any efforts to optimize applications of climate prediction products in agricultural planning and management in the next century. This requires user specific computerised databases, and improved agrometeorological networks.

3.2. Real and near real time climate information

Some agricultural operations require real-time information. Land use activities, however, vary from one location to another. The network of the agrometeorological observations must be able to adequately represent large variations in the needs of the users. Real-time and near real-time users require timely availability of the agrometeorological information on a daily or weekly/10-day basis. Information dissemination and the network of agrometeorological stations are very poor in many regions, especially in the developing countries. The locations of many weather stations rarely follow the pattern of agro-ecological zones and major areas of food production (Gommes et al., 1996). Even in developed countries many weather stations are located near towns and cities, and at airports where exposure is not representative of the agricultural region. Recently, attempts have been made to enhance the use of remote sensing techniques to provide real and near real-time agrometeorological information. Calibration of such methods for user specific applications has not been carried out in many regions, especially in many developing countries. In the early warning systems operated by FAO, agrometeorology and remote sensing already play an important role in monitoring and forecasting in a qualitative manner (Gommes et al., 1996).

Applications of remote sensing techniques hold the key to many future applications, but they will not be able, in the near future, to provide specific agrometeorological information at the farm level. Neither will they able to replace traditional farm level agrometeorological measurements in the near future. At present the advantage to be gained from remote sensing is primarily in the complete areal coverage of information it provides. The data derived from current satellites are qualitative or at best semi-quantitative indices relating to the dominant crop on a pixel or multi-pixel basis. In the longer term, advances in next generation satellite sensors will enable finer resolution and more quantitative detail to be provided at the local scale.

3.3. Short and medium-term weather forecasts

Some agricultural systems and operations require not only daily climate records, but also cumulative weather information over several days or weeks. The
science and technology of short and medium range weather forecasting with computer models of the global climate processes, are now quite advanced. Operational short to medium range weather forecast products are now available in many climate centres world-wide.

For such products to be useful in agricultural applications, they have to be downscaled, not only to national and regional levels, and ultimately to specific farm levels. Many downscaling techniques have been developed in recent years. These have ranged from the use of complex downscaling statistical methods, to the nesting of a meso-scale models within a general circulation model of the global climate system (Von Storch et al., 1993; Hughes and Guttorp, 1994; Zorita et al., 1995; Kidson and Thomson, 1998).

Although most of the short and medium-range weather forecast products are readily available to all National Meteorological and Hydrological Services (NMHSs) world-wide through the efforts of WMO and other institutional linkages, many developing countries still do not have adequate capacity to make use of the available products through further adaptation and post processing.

Furthermore, most of the regional/local scale downscaling techniques require good knowledge of the local/regional climate processes which are still lacking in many developing countries due to the serious limitations of the basic local meteorological research. The downscaling to specific farm level appears to be unrealistic in the foreseeable future as most of the techniques will at best only incorporate generalised regional characteristics.

3.4. Seasonal to interannual climate prediction

The science and technology of climate prediction within monthly, seasonal to interannual time scales is still very young, and is currently under intensive investigation world-wide. The last 10 years, however, have witnessed a major advance in understanding the predictability of the atmosphere at seasonal to inter-annual time-scale (Palmer and Anderson, 1993; NRC, 1996; Carson, 1998). The major impetus in current seasonal to interannual time scale prediction efforts was provided by the Tropical Ocean and Global Atmosphere (TOGA) Programme, which was carried out by WMO, ICSU and several other co-operating institutions between 1985–1994. Results from TOGA demonstrated that it is possible to predict Pacific ocean El Niño and Southern Oscillation (ENSO) related Sea Surface Temperatures (SST) over time scales extending from a few months to over 1 year.

El Niño and Southern Oscillation, which are collectively known as ENSO, are some of the known key drivers to interannual variability, and have been associated with world-wide extreme climate anomalies, including changes in the space-time patterns of floods, droughts, cyclone/severe storms activity, cold/hot spells, etc. (Rasmusson and Wallace, 1983; Cane et al., 1986; Ogallo, 1988; Ropelewski and Halpert, 1989; NRC, 1996).

The ability to forecast some aspects of ENSO signals for time scales of months to over one year are currently being used to extrapolate the potential occurrences ENSO related extreme weather/climate events for specific seasons and regions of the world which have strong ENSO signals. Such information now forms crucial components of early warning systems, including the planning, management and operations of agricultural activities in some parts of the tropical regions. For some of these agricultural applications have developed models which transfer projected ENSO signals directly into agricultural stress indices (Nicholls, 1985; Cane et al., 1994; Glantz, 1994; Keplinger and Mjelde, 1995; Hammer et al., 1996; Mjelde, 1998).

While the association with ENSO signals are known to be strong in interannual climate variability over parts of US and many parts of the tropics, empirical studies have shown weak ENSO climate linkages over Europe. However, the recent rate of fast development in computer hardware/software, together with the general advancement in communication and climate prediction science and technology seem to suggest that useful model-based seasonal forecasts are possible in future years. When strong perturbations are present, the possibility of a model signal being real is relatively high even in middle latitudes. It should, however, be noted that even in regions with strong ENSO signals, not all inter annual climate anomalies are caused by ENSO. Neither are all ENSOs similar in terms of their associated space-time climate anomalies.

Improvement in the seasonal to interannual climate prediction is one crucial factor that could reduce the vulnerability of the agricultural systems to severe
impacts of extreme interannual climate anomalies. The challenge to improve climate predictions for seasonal to interannual scales has been taken by the new WMO/ICSU programme known as the Study of Climate Variability and Predictability (CLIVAR) (e.g. WMO, 1997a) and in the implementation of the project on Climate Information and Predictions Services (CLIPS) (e.g. WMO, 1997b). It is also a priority research area in many climate centres world-wide.

3.5. Climate change information

It was noted in Section 1 that climate determines natural adaptation of ecosystems and specific land use activities at any given location. Any change in the traditional patterns of climate resulting in significant changes in the space-time patterns of climate parameters can have far reaching implications in agriculture. Such changes may be reflected in the mean rainfall patterns or changes in the frequency, intensity, duration, seasonal distribution, year to year persistence of the extreme climate events such as droughts, floods, cyclones.

Climate change is one of the current key scientific and policy issues which are of great concern to mankind due to the recent scientific studies which have confirmed that human activities can interfere and change the traditional patterns of the global climate systems which drive most of the global agricultural systems. Such human activities include agricultural practices, deforestation, desertification, overgrazing, intensive cultivation resulting in erosion, and many other activities of mankind arising from the fast increasing population (IPCC, 1995b).

The science of climate change, its impacts, and the optimum adaptation and response strategies are currently being addressed by the UN wide system through the WMO/UNEP Co-ordinated Intergovernmental Panel on Climate Change (IPCC). Several climate change assessments have been provided since the establishment of IPCC in 1988 (IPCC, 1995a, b, c). An effort has been initiated to provide another global climate change assessment by the beginning of the next century. The IPCC assessments have played crucial roles in the recent climate change debates, including the negotiations of the three recent UN environmental related conventions namely, conventions on climate change, desertification and biodiversity. The provision of climate change information, useful to those managing agricultural systems will be a key challenge of the next century.

Realistic local/regional climate change scenarios, required for studies of agricultural impacts and adaptation assessments are still not available due to the current limitations of the available prediction science and technology. However, now available are some techniques which can be used to assess the impacts of particular agricultural practices under a fixed set of climate change scenarios (IPCC, 1995a, b, c).

4. Challenges to optimum utilization of climate information and prediction products in agriculture in the next century

This section discusses the key agrometeorological factors that should be addressed in order to optimize the use of climate information and prediction services in agricultural planning and operation in the next century. The task of future agriculture is to produce sufficient quality food, efficiently and to high environmental standards.

4.1. Agrometeorological observation network

The network of the agrometeorological observations is often poor in many countries. The situation is worst in many developing countries which have yet to study the basic linkages between local climate and agricultural systems. The adoption of WMO recommended standards and practices of observation and the use of more reliable observing systems, both manual and automated, should be universally accepted and priority given to their implementation.

4.2. Historical agrometeorological database

Many countries do not have a good historical agrometeorological database that forms the backbone of all agrometeorological applications. The spatial and temporal resolutions at which meteorological data are available are often insufficient to meet the needs of agriculture and represent the main constraint in operational applications. Daily and at most 10-day values of the main parameters should be available in real
time from a representative distribution of weather stations. Timely accessibility of the basic agrometeoro-
logical statistics is crucial in many agrometeorological analyses and applications. Also, agrometeorological data bases should include other relevant information, e.g. phenological data, distinguishing station features, soils, topographical and supporting environmental data.

4.3. Skilled human resources

Skilled multidisciplinary human resources for integrated agrometeorological applications are relatively limited, especially in many developing countries. Even in developed countries research and applications at national/regional level are often fragmented and un-coordinated. Commercial pressures on many NMHSs have helped weaken this collaboration in agrometeoro-
logical research. There is, therefore, a great need to strengthen the capacity of the national/regional climate and agrometeorological institutions to pursue the development of such a multidisciplinary resource.

4.4. Climate prediction services and users interface

The need to address the climate needs of the specific sectoral agricultural users is necessary in order to enable the customer tailored climate prediction products to be developed by the climate prediction centres. There is an over expectation of forecast accuracy among users. The difficulty is to associate what is ade-
quate with what is attainable. It is crucial that the agricultural users have good knowledge of the skill and limitations of any climate prediction products. It is therefore necessary to educate the users of agro-
meteorological products.

4.5. Technological adaptation

Science and technology have been successfully used in the sustainable management and adapta-
tion of agricultural systems to local/regional climate variability in many advanced countries. Technologi-
cal adaptation of agricultural systems to interannual climate variability is, however, still relatively low es-
specially in many developing countries. Technological advances will play a major role in the minimization of the environmental degradation and the severe impacts of extreme interannual climate variability in the next century.

4.6. Research

The current status of seasonal to inter-annual fore-
casting allows predictions of spatial averages, which may not account for all the critical factors that in-
fuences regional and national climate variability. En-
semble predictions (made up of forecasts initialized during a period of a month, for example, centred on the forecast reference data) also provide probability plots. The higher moments of the ensemble distribu-
tion may suggest the more extreme statistical proper-
ties of weather activity, e.g. extreme weather events, blocking, cyclonic spells.

Optimum utilization of any climate prediction products in agriculture will require basic and applied agrometeorological research, including understanding of the local climate/agricultural systems and the as-
associated linkages, especially with respect to extreme events, climate and pests/diseases linkages, adaptation of agricultural systems to the local climate variability through the development of drought resistant vari-
ties, etc. Enhanced agrometeorological research is required in facing the agrometeorological challenges of the next century. Improved and integrated data sources and interpolation methods, locally validated crop models, and down-scaled meso-scale numerical forecast models are realistic and attainable goals for agrometeorology early in the new millennium.

4.7. Agrometeorological information system

An efficient integrated agrometeorological informa-
tion system is required for timely decision making regarding food quality and security production. Such agrometeorological watch requires the close collabora-
tion between the various multidisciplinary organiza-
tions.

4.8. Disaster preparedness

Climate prediction products can be used to provide early warning and minimize the damage and loss of property and life. Clear local/regional/global scale
disaster preparedness policies are required in order to optimize the benefits of climate prediction products.

5. Conclusions

Most skill in seasonal forecasting is achieved in the tropics and sub tropics, and is especially strong in El Niño years. Useful skill has also been reported at the higher latitudes in the US but less satisfactory skill has been found in Europe. The models are not yet sufficient to account for all the factors that influence regional and national climate variability. Nevertheless results have shown some promise and a number of climate centres now undertake seasonal forecasting on an operational basis, e.g. the ECMWF (European Centre for Medium Range Forecasting) (Anderson et al., 1997), Hadley Centre (Carson, 1998), IRI, etc.

Seasonal forecasting creates the possibility of tailoring crop management to anticipated weather conditions either to take advantage of favourable conditions or to reduce the effects of adverse conditions (Mjelde et al., 1997). Reducing the risk associated with increased climate variability has a high potential for increasing productivity and quality while protecting the environment. Advance warning of impending extreme climate events would provide important information which could be used for sustainable agricultural production. Much research needs to be done on the determination of the scale and time at which seasonal predictions are suitable for application to agriculture and environment and on the connection between the past and present weather and the upcoming predicted season. The recommendations of the first Forum on Seasonal Forecasts and its Applications to Early Warning Systems for Food Security in West Africa (PRESAO-1, 1998), that a unified climate forecast be put in place in each meteorological service and the creation of Multi-disciplinary Work Groups (MGP) for interpretation and diffusion of climate information, are worthy of further discussion.

References


WMO, K., 1997b. CLIPS: Stepping Forward — Implementation of the WMO CLIPS Project. WMO No. 864 (see also WMO No. 832, 1995).