# Final Report

# Management responses to seasonal climate forecasts in cropping systems of South Asia's semi-arid tropics
# APN 2000-017

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**Cover:** Farmers in the Indian village of Thiruchengodu are inspecting their peanut crops (photo: H. Meinke)

# 1) Executive summary

South Asia is home to 40% of the Earth's poor, most of whom depend on agriculture – "the most weather-dependent of all human activities" – for sustenance and livelihood. Vulnerability to year-to-year rainfall fluctuations is particularly severe in smallholder dryland farming systems in the semi-arid regions. Previous experiences in Australia, the USA and South America have shown that the emerging capacity to forecast the likelihood of future rainfall and temperature distributions can contribute to improved agricultural productivity and farmer livelihood, underpinned by more appropriate natural resource management.

By using a systems analytical approach, this CLIMAG South Asia project has demonstrated for developing countries how cropping systems management can be altered by adapting to the underlying climatic variability. In doing so, this pilot study has built a highly effective interdisciplinary network of scientists and organisations spanning three continents (Australia, Asia and USA) that will allow effective applications of seasonal climate forecasting in the target regions.

The project officially commenced in June 2000 when contracts between START and the Department of Primary Industires (DPI), Queensland, Australia, where signed. However, much of the background work was conducted prior to that during the inaugural project team meeting, sponsored by and conducted at the IRI in NY (May 2000).

**The main outcomes from this project are**

- a general process that shows how agricultural systems analysis and climate science and information can be combined with direct linkages to smallholder farmers to positively influence agricultural decisions;
- an agronomic and climatological systems analysis of cropping systems in Southern India and Northern Pakistan, including clear recommendations on where additional research efforts are needed. This includes quantification of strategic management opportunities in these cropping systems and testing of existing analytical models;
- a professional network spanning Pakistan, India, USA and Australia with the subsequent establishment of operational nodes for agricultural systems analysis in Islamabad (Pakistan), Bangalore (India) and Coimbatore (India). The approach uses participatory research methods in conjunction with agricultural simulation models and seasonal climate forecasts;
- new scientific insight into cropping systems in the target regions, including climatic conditions and processes (several scientific publications are currently in preparation);
- substantial awareness of the systems analytical approach across the Asia-Pacific region through the project's considerable input to the 'Training Institute on Climate Variability and Society in the Asia-Pacific Region', an APN sister project.
- resource material, including lectures, tutorials and software that was specifically developed for the teaching and research components of this project. Several CDs have been produced and were distributed to the participants at the Toowoomba and Hawaii workshops.
- a detailed proposal to possible funding providers for a longterm program to develop a blueprint for true 'end-to-end' application of seasonal climate forecasting in agricultural systems in the SAT (currently under development).

Using a participatory research approach, the project team collected baseline data for case study sites in India and in Pakistan. Interactions with farmer groups at project sites indicated that smallholders are, from their own perspective, in a position to benefit from seasonal climate forecasts. They expressed strong enthusiasm for the project, and demonstrated sophisticated awareness of climate variability and the relevance of climate prediction for their decisions. Discussions with the farmers identified a range of relevant, climate-sensitive crop management decisions that formed the basis for subsequent analyses. Results will be discussed with these farmer groups to assess the relevance and feasibility of the findings and their likely adoption.

Agricultural systems analysis for northern Pakistan showed considerable potential to intensify the current wheat – fallow – wheat system by introducing grain legumes into the rotation. Under current prices and production costs, which are regulated by governmental policy, intensification appears profitable in all seasons, regardless of the forecast. However, sensitivity studies showed that a skilful seasonal forecast could become important under different cost/price scenarios. These findings demonstrate the importance of this systems analytical approach for policy decisions. It is therefore imperative for any follow-on program to fully engage the people who inform the policy process.

At the two study sites in Tamil Nadu, India, cotton and peanut crops – currently the two most profitable crops – are sensitive to rainfall shortages in different periods. The study showed considerable potential to increase mean income and to reduce production risk by tailoring farm land allocation among these crops to seasonal forecasts. The methodology developed here allows an objective comparison – on a probabilistic basis – between a range of possible options. For instance, the profitability of peanut and cotton crops differs depending on costs, prices and climatic conditions. The pilot study showed that in positive SOI years peanuts outperformed cotton in 70% years, but income difference can still range from –15,000 to +15,000 Rs/ha. However under falling SOI conditions peanuts had only a minor advantage in 40% of years (up to 3,800 Rs/ha). Such information provides an important basis for well-informed crop choice decisions.

In another example from a neighbouring region, different risk management options for peanut crops were compared. One of these risk mitigation strategies is planting density: high planting densities ensure that a high yield potential can be realised in 'good' years (high rainfall years). However, in 'poor' years such a strategy results in higher than necessary input costs (ie. seed). Simulated results indicated that peanut yield is substantially reduced in years when the SOI phase is falling in April/May. The average yield was highest in positive and rising SOI phase years irrespective of plant population levels. Financial risk can be lowered by reducing plant population by 50%. To estimate the economic consequences of reducing plant population, planting densities in the simulations were halved in years when the SOI phase was either negative, positive or falling (48 out of 99 years). For the remaining 51 years a 'standard' plant population was assumed.

Adopting the tactical approach did not result increased profit every year. However, in many years it was substantially better and in few years it was only moderately worse than the fixed management approach. Overall the tactical approach resulted in higher profits in 35% of the years, in 13% of the years the tactical approach performed worse and in 52 per cent of the years there was no difference.

All these examples demonstrate the importance of using a seasonal climate forecast within the context of real life decision making. This can only be achieved by employing a systems analytical approach that involves participatory research methods in combination with agricultural systems simulation models. The emphasis needs to be on the process of integration.

## 2) Objectives and approaches

As part of the broader CLIMAG program, APN and START supported this multidisciplinary research project to assess the potential for seasonal climate forecasts to reduce vulnerability to climate variability in South Asia. Our approach was to develop a generic process that can be used to optimally combine knowledge and information about cropping and climate systems for better decision making in agriculture. By employing such a process, the specific objectives of this pilot study were to:

- Document current predictability of relevant climate variables as a basis for understanding biological cropping system response to predictable components of climate variability.
- Demonstrate via systems analysis how seasonal climate forecasts could alter management decisions to improve yields, stabilise livelihood, and enhanced sustainability of resources.
- Identify other partners throughout the Asia-Pacific region, including the scientific, farmer and institutional networks necessary to ensure a successful end-to-end delivery program across national boundaries.
- Design and gain additional funding for a comprehensive program.

Information about climate variability and the provision of seasonal climate forecasts has the potential to reduce this vulnerability provided that it is linked to a well-structured, agricultural systems research approach. Using case studies, this project demonstrated how the potential value of such climate information to agricultural producers can be realised. Implementing these research outcomes is expected to reduce vulnerability caused by exposure to climate variability. This exploratory study constitutes a stepping stone towards a well-integrated research and delivery program that will address more comprehensively those aspects of climate risk that impede agricultural production in developing countries.

The initial project team brought together scientists and institutions from Australia, USA, India and Pakistan. Initially, the following scientist were nominated as Principal Investigators (PI):

Dr Holger Meinke, DPI, APSRU, Toowoomba, Australia (project coordination)
Dr James Hansen, IRI, New York, USA
Dr R. Selvaraju, Tamil Nadu Agricultural University, Coimbatore, India
Prof. Sulochana Gadgil, Indian Institute of Science, Bangalore, India

After project visits to Pakistan and India (September 2000, for full report see Appendix 2) it became apparent that additional regional expertise in the area of systems agronomy (Pakistan) and climate science and prediction were needed. Hence, two additional PIs were invited to join the project:

Dr Muhammad Aslam, NARC, Islamabad, Pakistan
Dr Krishna Kumar, Indian Institute of Tropical Meteorology, Pune, India

To achieve the projects objectives, the project team selected case study sites in India and Pakistan. At each location we had to

- establish the capacity to conduct agricultural systems simulation
- collect base line data (climatic, agricultural and socio-economic data) to conduct the necessary analyses
- discuss possible management interventions with the decision makers (in this case: farmers)
- quantify the existing rainfall variability and assess the potential to forecast the seasons ahead
- conduct the systems analyses
- and quantify the outcome of the decisions against the status quo.

Participation in planning, conducting and reporting collaborative project research considerably enhanced technical capacity among project scientist. In particular, the training activities at APSRU in Toowoomba (Australia) and at the East-West Center in Hawaii (USA) improved the technical expertise and competence of all team members. Further capacity building was achieved through these targeted training workshops, learning and networking resulting from collaborative project activities. Mr Peter deVoil, APSRU, was specifically employed to provide software support and develop utility programs for data manipulation and teaching purposes.

As a result of the short-term funding the current project had no direct policy implications, although the Pakistan case study clearly demonstrated the importance of such links. However, the proposed follow-on program will have strong policy connections via direct interactions with Meteorological Services, Universities, extension organisations and scientists and farmer networks.

Although the research focused on the application of climate forecasting and variability information at a seasonal time scale, two general issues link it directly to global change. First, population growth and resource degradation (including urbanisation of agricultural land) are expected to increase society's vulnerability to episodic food shortages associated with climate fluctuations in the coming decades. This is particularly true for populations that depend on rainfed production, especially in the SAT. India's rainfed agricultural area is important to global food security by virtue of its size. Second, preparation for the uncertainties associated with global climate change requires an analytical framework and institutional mechanisms for anticipating and adapting to climatic fluctuations. As a CLIMAG demonstration project, the research outcomes contribute directly to the global research programs – START, IGBP, IHDP, WCRP – that sponsor CLIMAG.

## 3) Project coordination

A series of project meetings and field visits facilitated team development and coordination of research activities. These meeting were also used as an avenue to expose the broader research community to the goals and approaches of this pilot study. Additional linkages were formed, for instance, with the participants from the APN sister project (Training Institute on Climate Variability and Society in the Asia-Pacific Region) and with Dr R. Boer, Indonesia. Dr Boer has expressed interest to be involved in follow-on activities and discussions about the development of a further APN project are continuing.

### *Inaugural Project Team Meeting, Palisades, New York, 1-2 May 2000*

The International Research Institute (IRI) for Climate Prediction hosted and funded an inaugural project team meeting to (a) formulate and refine the project action plan, and (b) outline and devise a strategy for funding a more comprehensive follow-on program. Project investigators and advisors present defined a set of “building blocks” that would address the stated objectives of the APN-funded project, and serve as a foundation for an expanded project. These “building blocks” served as a basis for a detailed action plan and time line. The team identified and discussed possible synergistic activities with three complementary projects: a component of an ACIAR-funded climate prediction application project in Tamil Nadu, an ACIAR project on sorghum modelling and improvement in India, and an APN-funded training institute in Hawaii, early 2001.

Key issues related to a more comprehensive follow-up program were discussed, including identification of geographical scope, areas of expertise, scientific partners, potential donors, and institutional linkages. The follow-up program would expand the domain of the current project, integrating more thoroughly the issues of economics, policy, institutional support, communication and links to dynamic climate modelling. Reducing farmer vulnerability, and improving resilience and food security were identified as overarching issues.

### *Project site visits and team meetings, Pakistan and India, September 2000*

Visits to project target locations in Pakistan (Dr. Meinke) and India (Drs. Meinke and Hansen) were designed to (a) provide investigators with project coordination responsibility with a better understanding of production systems, farmer networks, and collaborating institutions at each location, (b) inform and secure long-term support of farmer groups and host institutions, (c) clarify the relevant farmer decisions that would be subjected to systems analysis, and (d) collectively refine plans and responsibilities for the remainder of the project.

In his visit to Pakistan, Dr. Meinke updated Dr. Aslam, who joined the project team after the initial planning meeting and proposal submission, on project objectives, tasks and approaches during this visit. Endorsement of the current project and planned follow up by key national institutions – the Pakistan National Agricultural Research Centre (PARC; Dr N.I. Hashmi, Director General; Dr M. Ashraf, Director; Dr M. Aslam, Senior Scientific Officer), Pakistan Agricultural Research Council (NARC; Dr K.A. Malik, Chairman) and ASIANICS, Agro-Dev. International (Dr Amir Muhammed, Director) – also resulted from the visit.

The visit to India included a project review meeting resulting in further refinement of the work plan and an agenda for the subsequent project workshop in Toowoomba. This was followed by field visits in the case study region bordering Karnataka and Andhra Pradesh, surrounding Pavagada. Meetings and field walks conducted with two different farmer groups (“marginal farmers” and “progressive farmers”) provided a clear picture of some of the key issues facing the farmers, and possible applications of seasonal forecasting under these conditions.

This was followed by meetings at Tamil Nadu Agricultural University, Coimbatore. Dr Selvaraju organized several field trips that provided a wealth of information for the scenario analyses. Based on the information gathered and the contacts made with local farmers, the project team selected as case studies two villages (Naduvacheri and Tiruchengodu) with differing climate patterns, cropping systems and infrastructure development. Important decisions, such as crop and cultivar selection in response to forecast rainfall characteristics, were identified for analysis.

Interactions with farmer groups at each project site indicate that smallholder farmers are, from their own perspective, in a position to benefit from seasonal climate forecasts. They expressed strong enthusiasm for the project, and often demonstrated sophisticated awareness of climate variability and the relevance of climate prediction for their decisions. For example, "marginal" farmers in the Pavagada region debated implications of probabilistic forecasts and prices for viability of alternatives to the dominant peanut crop. Farmers in Naduvacheri, Tamil Nadu, India, requested information about rainfall variability and its decision implications (what to plant, how to control pests and diseases) – a message that we heard consistently from the smallholder farmers. One of the farmers grows both peanut and cotton to reduce risk associated with rainfall variability. In Tiruchengodu, one farmer stressed that he understands the probabilistic nature of seasonal forecasts, and accepts responsibility for decisions based on uncertain forecasts. Our meeting host grows both bunching and runner peanut varieties as a risk management strategy due to their different timing of susceptibility to water stress.

During this trip, Dr. Meinke also visited Dr. R. Ruben at Wageningen University, The Netherlands, and the team of Dr. N. Hamilton from the International Human Dimensions Program (IHDP) of the World Meteorological Program (WMO), Bonn, Germany. Each of those visits resulted in plans for some level of collaboration in the planned follow-up program. A full report of this visit is included in Appendix 2.

## *Toowoomba Training and Analysis Workshop, 6-17 November 2000*

The objectives of the workshop were to (a) familiarise team members with systems analytical tools and approaches, (b) equip participants to conduct analyses for their study regions, and (c) initiate the necessary simulations and analyses for the case studies outlined in the action plan. The first week was devoted primarily to teaching via lectures, training in the use of APSIM crop simulation tools, and identification and prioritisation of specific decision scenarios for analysis at each project site. Based on the information collected at the project sites, team members finalised input data, conducted preliminary crop simulations, and planned details of analyses including use of alternative forms of climate forecast during the second week.

Results of analyses initiated during the workshop are presented in chapters 4 to 7. Several challenges had to be addressed. Firstly, the lack of adequate, long-term climate records for simulation purposes had to be overcome. Secondly, the project team needed to become proficient in the use of the simulation platform APSIM. Often parameterisation provided a challenge due to the lack of experimental data. Training of project staff in the appropriate use of the simulation model was considerably more time consuming than initially estimated. All the resource material, including the lecture notes have been distributed to course participants on CD. Additional details regarding the workshop are provided in Appendix 2.

## *Training Institute on Climate Variability and Society in the Asia-Pacific Region, Honolulu, Hawaii, and Final Project Meeting, February 2001*

The project team presented the approach and exercises from project case studies to a group of twenty young scientists during the latter portion of the training institute led by Dr. E.L. Shea (sister project; APN 2000-003). This was an opportunity to showcase results from the

CLIMAG project, extend relevant skills and lessons to trainees, and discuss with a broad audience the future direction of the initial effort. Lectures, role-playing and analytical exercises were received with enthusiasm. Trainees generally felt that aspects of the approach used in this project could be adapted to other regions and sectors. A final project meeting coinciding with the Training Institute focused on strategy for completing, reporting and publishing case studies, and on design and strategy for advancing toward the more comprehensive program.

## *Publications related or arising from this project*

Results from each case study region are currently being prepared for publication in international scientific journals. We expect that his will result in at least four (and possibly more) journal articles based on chapters 4 to 7. In addition to these articles in preparation, the following publications are directly related to this project:


Hammer, G. and Meinke, H., 2000. Linking climate, agriculture, and decision-making – experiences and lessons for improving applications of climate forecasts in agriculture. Proceedings of the International Forum on Climate Prediction, Agriculture and Development. IRI-CW/00/1. International Research Institute for Climate Prediction, April 26-28, 2000, Palisades, New York, 72-76.

Hansen, J.W. 2000. IRI Strategy for agricultural applications. Proceedings of the International Forum on Climate Prediction, Agriculture and Development. IRI-CW/00/1. International Research Institute for Climate Prediction, April 26-28, 2000, Palisades, New York, 67-71.

Meinke, H. and Hammer, G., 2000. Experiences in Agricultural Applications of Climate Predictions: Australasia. Proceedings of the International Forum on Climate Prediction, Agriculture and Development. IRI-CW/00/1. International Research Institute for Climate Prediction, April 26-28, 2000, Palisades, New York, 52-58.

Meinke, H., Baethgen, W., Carberry, P.S., Donatelli, M., Hammer, G.L., Selvaraju, R. and Stöckle, C., 2001. Increasing profits and reducing risks in crop production using participatory systems simulation approaches. Ag Systems, in press.

Meinke, H., Hammer, G., Phillips, J. and Baethgen, W., 2000. Using climate forecasts to improve global agro-ecosystems. Book of Abstracts, 3rd International Crop Science Congress (ICSC), August 17-22, 2000, Hamburg, Germany, p. 13.

Meinke, H., Hammer, G., Power, S. and Allan, R., 2000. Multidecadal climate variability: world rainfall and impact on Australian wheat crops. Book of Abstracts, 3rd International Crop Science Congress (ICSC), August 17-22, 2000, Hamburg, Germany, p. 43.

Meinke, H., Hammer, G.L. and Selvaraju, R., 2000. Using Seasonal Climate Forecasts in Agriculture - The Australian Experience. ‘Proof of Concept’ or ‘Taking The Next Step: Concept Adaptation’? In: Sivakumar, M.V.K. (ed.), Climate prediction and agriculture. Proceedings of the START/WMO International Workshop, Geneva, Switzerland, 27-29 September 1999. Washington DC, USA, International START Secretariat, p. 195-213.

Meinke, H., Pollock, K., Hammer, G.L., Wang, E., Stone, R.C., Potgieter, A. and Howden, M., 2001. Understanding climate variability to improve agricultural decision making. Tenths Australian Agronomy Conference. Australian Society of Agronomy (eds.), 2001, Hobart, Australia.

## 4) Climate Variability and Seasonal Climate Forecasts

As part of this one-year pilot study we did not attempt to develop, test or implement new or improved forecasting schemes for this region. Instead the project team agreed to use the best available current information based on ENSO to demonstrate the potential of such information in on-farm decision making. However, the consistency of the ENSO signal in terms of its impact on the monsoon has recently been questioned and it is therefore important to look towards scientific advances in our understand of climate variability in this region. Hence, we took a two-tier approach to seasonal climate forecasting as part of this pilot study: In the first instance we used SOI phases based on the research by Stone et al., 1996 (Prediction of global rainfall probabilities using phases of the Southern Oscillation Index. Nature 384, 252-55) as an example of our current ability of seasonal climate forecasting in this region. As a second step, Dr K. Kumar conducted a detailed regional analysis of rainfall, including suggestions on how to advance seasonal forecasting for this region in the future.

### *General description of climatic features and issues for the future*

South Asia, where our target countries of India and Pakistan are situated, is dominated physically, culturally and economically by the most important monsoon systems of the world. The southwest or summer monsoon is the principal source of water for most of the country, the northeast or winter monsoon is particularly important for the southern peninsular regions of India. The whole year's supply of water over a major part of the area is realised in just 3 to 4 months in the summer monsoon season, which makes the people critically dependent on the monsoon activity. The rainfall over these two countries is subject to a high degree of spatial and temporal variability, leading to a variety of climatic zones, ranging from arid to moist tropical rain-forest, and the occurrence of devastating droughts and floods. The striking regional contrasts in rainfall can be understood from Cherrapunji's (Northeast India) annual average of 10.8 m (the world's highest, with a record of 24.0 m) to almost rainless years in Sind (Pakistan). Apart from these large spatial variations, the year-to-year variability of monsoon rainfall in these countries occasionally leads to large scale floods and droughts over different parts resulting in serious reduction in agricultural output affecting the regional and national economies. In view of the critical influence of such variability on agricultural and industrial production, forecasting of monsoon rainfall, at least a season in advance, assumes profound importance for policy making and planning mitigatory efforts.

The mechanisms responsible for inter-annual variability of seasonal mean climate can be thought of as a consequence of internal dynamics and boundary forcing. There is considerable evidence that the internal dynamics, which are a manifestation of non-linear chaotic dynamics of the atmosphere, is relatively weak in the tropics. It is also generally known that the inter-annual variability in the summer monsoon rainfall is largely determined by the slowly varying boundary forcing factors such as sea surface temperature, sea ice cover, land surface temperature, albedo, soil moisture and snow cover, although not all of them are equally important. Variations in lower boundary conditions result from the coupling of the dynamics of the atmosphere to the dynamics of the oceans and to the hydrology of the land masses. The most dominant mode of variability of the tropical ocean-atmosphere system associated with El Ni™o/Southern Oscillation (ENSO) has its origin in the tropical Pacific and extends to influence much of the globe. ENSO accounts for a significant part of variability in the Indian summer monsoon rainfall.

Apart from ENSO, the areal extent and thickness of Eurasian/Himalayan snow in preceding winter and spring seasons is also known to have a profound influence on the strength of ensuing monsoon, via enhancement or reduction of the land-sea thermal gradient. This suggests considerable potential predictability of the inter-annual variability of the monsoon system on seasonal time scales. However, significant inter-decadal changes occur in the strength of relationship between monsoon rainfall and various precursors/predictors. Of particular interest and relevance to the target region is the recent weakening of monsoon-ENSO relationship attributed generally to (1) a southeast-ward shift in the ENSO induced anomalous Walker circulation leading to reduced suppression of convection over the Indian sub-continent, thus favouring normal monsoon conditions, and (2) increased surface temperatures over Eurasia in winter and spring as a consequence of recent mid-latitude continental warming trend, resulting in enhanced land-ocean thermal gradient conducive for a strong monsoon.

Diagnostic studies, involving both regional and global meteorological data sets, carried out to identify precursors of seasonal rainfall on an all-India scale and also at individual project sites, indicate that the reduction in predictive skill due to the weakening monsoon-ENSO links in recent decades appears to be compensated to a large extent by the increased role of Eurasian winter surface temperatures (taken as a proxy for snow conditions) and sea surface temperatures over the north Indian Ocean. These provide apparent predictability at long (6 to 9 months prior to the monsoon season) lead times. Several experiments using Max-Planck Institute's (MPI) atmospheric general circulation model (AGCM) have been conducted to study the sensitivity of monsoon rainfall over the Indian sub-continent to different El Niño related sea surface temperature patterns over the Indo-Pacific basins, with and with out continental warming. These experiments corroborate the general role of recent Eurasian continental warming in counteracting the negative impacts of El Niño events on monsoon rainfall.  Based on these diagnostic studies, prediction schemes (empirical at this stage) have been developed following a step-wise regression algorithm by initially screening more than 40 different precursors covering various facets of ocean-land-atmosphere system for all the target stations of the present project. For reasons discussed above, predictors representing the ENSO conditions (both sea surface temperature and sea level pressure indices) prior to monsoon season; winter Eurasian surface air temperature; previous summer and autumn sea surface temperatures over the north Indian Ocean (particularly Arabian Sea) and those indicating the pre-monsoon thermal conditions over the Indian region have been included in the prediction schemes. The prediction schemes, in general, yielded respectable skills in both hindcast and independent modes of verification for most of the target stations.

Time constraints restricted us to develop seasonal forecast schemes using only empirical methods. For the expanded project, we propose to develop statistically- or dynamically-downscaled seasonal climate forecast products from general circulation model projections for the target regions in order to provide forecasts at spatial and temporal resolutions appropriate for agricultural decision making. Detailed climate characterization and description of prediction schemes at all the sites of the project will be included in the Final Project Report.

Climatically, a large part of Pakistan is arid to semi-arid, with large spatial and temporal variability in many climatic parameters. The orographic features of Pakistan have a great influence on its climate, and there are peculiarities resulting from its geographical location. The western fringes of active monsoon disturbances during the southwest monsoon season contribute considerably to the rainfall over the eastern plains (the target sites are located here), while the western disturbances and other circulation systems, mostly active in the winter and in the transition period of the pre-monsoon, are the main source of precipitation over the western parts. The target sites in Pakistan receive nearly 70% of their annual rainfall in summer monsoon season.

### *Current skill of seasonal forecasting based on SOI phases*

Significant, physically based lag-relationships exist between the Southern Oscillation Index (SOI) -- an index of the El Niño/Southern Oscillation (ENSO) -- and future rainfall amount and temporal distribution in eastern Australia and many other areas across the globe (Stone et al., 1996). An El Niño event, which generally corresponds to negative Southern Oscillation Index (SOI) values, usually lasts for about one year, beginning its cycle in the austral autumn period of one year and terminating in the autumn period of the following year.  During the termination of an El Niño event the SOI may rise sharply. Stone et al. (1996) have shown how phases of the SOI are related to rainfall variability and are useful for rainfall forecasting for a range of locations in Australia and around the world. As the SOI pattern tends to be 'phase-locked' into the annual cycle (from autumn to autumn), the SOI phase analysis provides skill in assessing future rainfall probabilities for the season ahead.

We have employed this system and showed skill in forecasting rainfall distributions for sub-divisions of Indian rainfall districts. Figure 4.1 illustrates the different effects ENSO has on the peak rainfall seasons in Sub-Himalayan West Bengal (June to September, Fig. 4.1 left) and the Tamil Nadu region (September to December, Fig. 4.1 right). The diagram shows the probability of exceeding a certain rainfall amount for each of the 5 SOI phases. The analysis clearly shows the contrasting effects of ENSO on these two different regions: In West Bengal a consistently positive SOI phase (often associated with La Niña conditions) preceding the rainy season (JJAS) results in higher rainfall probabilities, particularly when compared to a consistently negative SOI phase (often associated with El Niño conditions). The reverse is evident in Tamil Nadu for the SOND rainfall period.

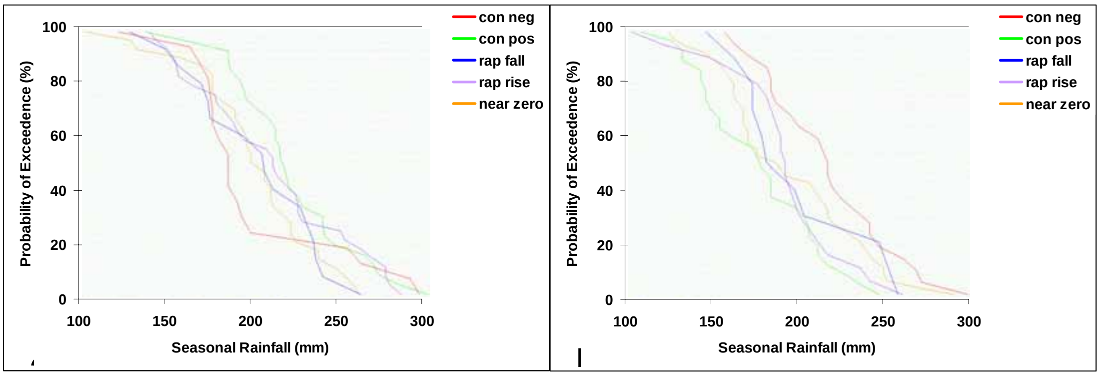


**Fig. 4.1** Probability of exceedence of (left) JJAS rainfall for Sub-Himalayan West Bengal Region based on April/May SOI phases and (right) SOND rainfall for Tamil Nadu based on July/August SOI phases. The phases are classified as consistently negative, consistently positive, rapidly falling, rapidly rising and near zero.

*Tamil Nadu*

This region frequently experiences problems due to erratic monsoon seasons, crop failures and often inappropriate resource management. The variability even within the sub-division (Fig. 4.1, right) is high and ENSO effects differ markedly depending on the distance from the Western Guards. In the main cropping regions there is a stronger ENSO signal during the Northeast monsoon (Table 1). In both seasons variability is less in negative SOI phases with chances of getting at least median rainfall considerably higher than in other years.

**Table 1:** Probability of exceeding the long-term median rainfall during either the south-west monsoon (SWM) or the north-east monsoon (NEM) in relation to the five SOI phases preceding these seasons.

| *SOI Phase* | *SWM (%)* | *NEM (%)* |
|---|---|---|
| Negative | 80 | 75 |
| Positive | 55 | 47 |
| Falling | 42 | 46 |
| Rising | 35 | 30 |
| Near Zero | 30 | 58 |

## 5) Case study Pakistan

For Pakistan two sites were selected as a case study for the CLIMAG demonstration project. The aim was to explore the productivity of the given cropping system and to make more effective management decisions through systems analysis, seasonal climate forecasting and climate variability information. For both locations we collected data on current cropping systems, key decision points faced by farmers, soil, climate and socio-economic circumstances. These results were summarised in two comprehensive reports and presented at the Toowoomba workshop held during November 2000 (Appendix 1).

### *Islamabad Zone*

Agricultural production around Islamabad is based on dryland cropping and hence wholly dependent on either in-season rainfall or stored soil moisture. It centres on the Pothwar Plateau comprising 6 districts. The Pothwar Plateau has three distinct rainfall zones ie. high (>750 mm), medium (500 to 750 mm) and low annual rainfall (<500 mm). During winter (Rabi season), wheat, the staple food, is sown on 90% of the area. Cropping intensity tends to be relatively low with large areas left fallow for a whole year to conserve soil moisture. While this appears to be a sensible risk mitigation strategy under low rainfall conditions, there may be scope for intensification of this productions system. We therefore addressed these questions:

1. Are there opportunities to increase cropping intensity particularly in high to medium rainfall areas?
2. Can mungbean be introduced as an opportunity crop to increase fallow water use efficiency?
3. What are the likely consequences of a mungbean crop for the subsequent wheat crop in terms of yield and production stability?

*Use and parameterisation of the APSIM model*
To answer these questions, the cropping systems simulation model APSIM was parameterised and tested for Islamabad zone using local data of soil, climate and crop management for wheat and mungbean crops. For this purpose experiments conducted at NARC, Islamabad, from 1992 to 1994 were used to test the model's performance. This showed that the model was capable of reproducing realistic mungbean and wheat yields under a range of climatic and soil moisture conditions. This allowed us to use the model analytically to investigate the effect of mungbean opportunity cropping against the background of local climate variability. Using 30 years of historical daily weather data (1961 to 1990) APSIM simulations were perform for wheat and mungbean crops separately and then for a mungbean – wheat rotation. A soil with a plant available soil water holding capacity of 280mm was assumed for the preliminary results presented here. Simulated yields were used to calculate gross margins for both the traditional wheat – fallow – wheat systems and for mungbean as an opportunity crop within a wheat dominated cropping system. An SOI-based forecasting system (SOI phases, Stone et al., 1996, Nature 384: 252-55; see also chapter 4) shows some skill in predicting future rainfall distributions for both the Kharif and Rabi seasons in this region. This allowed an assessment of the potential value of seasonal forecasting for cropping decisions.

*Results*
For the gross margin (GM) analyses, current prices and production costs were assumed. For mungbean (wheat) the prices were 12 (10) Rs/kg and production costs 1200 (4500) Rs/ha. Fig. 5.1 shows the probability of exceedence for the annual difference between the mungbean – wheat rotation and the wheat monoculture. A negative difference indicates that for the year in question the wheat monoculture would have resulted in a higher GM; conversely a positive difference indicates advantage of the mungbean – wheat rotation over the wheat monoculture that year. Under the given costs and prices, location and soil type, the results show that a mungbean – wheat rotation would have be advantageous in 86% of years (Fig. 5.1, left).

When these results were stratified by May/June SOI phases, we found that when the SOI phase was either negative or falling – a pattern frequently associated with El Niño conditions – 80% of all years resulted in advantages from the mungbean – wheat rotation with an average advantage of 6322 Rs/ha (Fig. 5.1, right). When the SOI phase was either positive or rising in May/June (typical for La Niña conditions), 90% of years favoured the rotation and the average advantage nearly doubled to 10616 Rs/ha. All seven years when the SOI was in a 'near zero' phase resulted in an advantage for the mungbean – wheat rotation (average = 11819 Rs/ha).

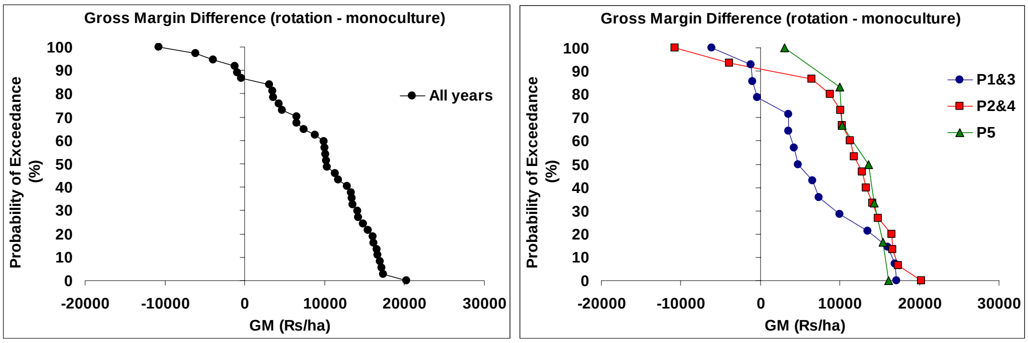


**Fig. 5.1** Probability of exceeding annual difference of GM between the wheat monoculture (traditional system) or the mungbean - wheat rotation. A negative outcome indicates advantages of the monoculture, a positve outcome advantages of the mungbean – wheat rotation. The diagram on the left shows the results regardless of seaonal outlook (all years), on the right these years were split into 3 categories based on the May/June SOI phase (known prior to sowing).

Based on this preliminary analysis, the introduction of mungbean into the wheat - fallow-wheat system appears economically beneficial in most years, regardless of the SOI-based seasonal forecast. Advantages were considerably lower in years when the May/June SOI was either negative or falling. A changed cost / price structure or a different soil water holding capacity could significantly change these findings. In a region where commodity prices and input costs are regulated, this type of analysis could become a powerful tool to assess the likely effect of policy intervention. These results are currently being discussed with farmers in the region. Some small scale experimental planting of mungbean is expected for the next seasons.

### *Lahore Zone*

In this region, rice is the dominant summer crop (Kharif season, 74% of area sown) and wheat is the dominant winter crop (Rabi season, 77% of area sown). Currently, the dominant cropping system is rice - wheat with 94% of the farmers follow this cropping system. Wheat should be planted as soon as possible after the harvest of the rice crop to ensure a high yield potential. This yield potential is estimated to be reduced by 1% with every day sowing is delayed after 20 November. Changing surface management practices from conventional tillage to zero tillage considerably reduces the time needed before wheat can be planted. However, it also requires better weed management practices and chemical weed control. Hence, APSIM-Wheat is used to assess and quantify the possible advantages of zero tillage. The model was tested using local data from on-farm experiments conducted on zero tillage and conventional system by PARC's Wheat Program from 1984 to 1990. The model predicted the experimental results well. Long term simulations were performed using climatic data from 1961 to 1999. Although results are still being analysed, preliminary findings indicate that based on October/November SOI phases the conventional system is more vulnerable to the climatic variability than the zero tillage system.

## 6) Case study Tamil Nadu, India

### *Background*

About 70% of the population in Southern Indian state of Tamil Nadu depends on agriculture for their livelihood. The vulnerability of rainfed production systems to climate variability is enhanced by the high water use of nearby intensively irrigated cropping systems. The mean annual rainfall in the study region is 640 mm, while the mean annual potential evaporation is 1620 mm indicating typical semi-arid conditions. The region consists of mainly red (Alfisols) and black (vertisols) soils. The red soils are shallow with low water retention capacity and the black soils are moderately deep with water stagnation during heavy rains and cracking during droughts. Both the soils are low in major nutrients combined with climate related constraints.

Peanut, cotton and sorghum are the principal dryland crops of this region, with most of the crops produced during the summer (June-September) and winter (October-December) monsoon seasons. The major cropping systems in the rainfed regions are peanut - sorghum, peanut – pulses, cotton – fallow on the red soils and cotton – fallow, pulses – sorghum, cotton/sorghum/chickpea (response system based on rainfall) on the black soils. These systems evolved decades ago for several economic and subsistence farming reasons. A skilful forecasting system can potentially reduce the risk during bad years and utilise the opportunities in good years.

To evaluate the likely performance of alternative crops such as peanut, cotton and sorghum we used the cropping systems model APSIM in conjunction with long-term, daily weather records. The model requires daily meteorological data as inputs. Two locations, namely Avinashi and Thiruchengodu, were considered. Long-term daily meteorological data were available from 1901 to 1999 for both the places. The model was parametrised using the observed soil physical and chemical parameters. Soils for both locations are characterised as shallow Alfisol. The bunch type peanut variety (TMV-2), medium duration dryland cotton (LRA5166) and a tall growing sorghum variety (M35-1) were used for the simulations in accordance with local practise.

### *Farm surveys*

Farm surveys were conducted at the selected case study locations (Avinashi and Thiruchengodu), which are both dominated by red soils with groundnut based cropping systems. Thirty farmers, randomly selected from the two locations, were surveyed for description of the physical environment, socio-economic environment, agricultural systems and cropping systems. The category of the farmers included for the survey are marginal farmers (<1 ha), small farmers (1-2 ha), semi-medium farmers (2 – 4 ha), medium farmers (4-10 ha) and large farmers (>10 ha).

Focus group meetings were conducted at two case study locations (Avinashi and Thiruchengodu) to identify the cropping system determinants and to develop effective educational programs to communicate the seasonal climate forecasts. The primary aim also included identification of the major decision rules used by farmers (eg. sowing rain, sowing window, harvesting time, initial soil moisture). Farmers selection was based on previous interaction with the State Department of Agriculture extension officers and farmers in the region. These dryland producers were asked to discuss observed changes in the cropping systems over the years and provide possible reasons for the change. The farmers were also asked to discuss the most important factors affecting their decision and to identify the leverage points where seasonal forecasts could influence decisions. The most important issues identified through survey and focus group meetings were crop choice, plant population (seeding rate), nitrogen management, commodity prices and input costs.

### *Avinashi*

The long term annual average rainfall of the region is 718 mm. This region is dominated by the winter monsoon rainfall between October and December. Farmers are sowing either peanut or cotton during the summer monsoon season (June-September). If cotton is planted, the crop overlaps into the subsequent winter monsoon season as well. If peanut is sown, short duration pulses or sorghum follow. The sowing decision for both peanut and cotton are based on the receipt of 20 mm of rainfall in 4 consecutive days. The sowing window for peanut is June 1-July 31. The question remains: which is the more profitable crop in any given season?

Results show that the chance of achieving at least 1000 kg of peanut yield / ha when the SOI phase is positive for April/May is 65%. Conversely, there is only 32% chance of achieving such a yield in years when the SOI phase is falling. Similar analyses were conducted for cotton and the economic performance of both systems was compared on a gross margin basis (Fig. 6.1). Results are presented as the probability of exceeding annual difference in gross margin (peanut – cotton). It clearly shows that in positive SOI years peanuts outperformed cotton in 70% years, but income difference can still range from –15,000 to +15,000 Rs / ha. However under falling SOI conditions peanuts only had an minor advantage in 40% of years (up to 3,800 Rs / ha). Consequences of such crop choices based on seasonal forecasts for the following rotations have also been evaluated and will be presented in the final report.

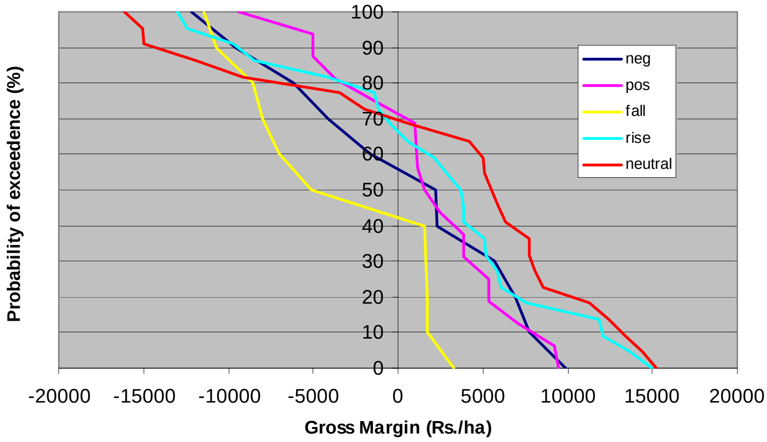


**Fig. 6.1** Cumulative probability of difference in gross margin (GM) for various SOI phases (positive difference indicate the advantage of peanut over cotton).

### *Thiruchengodu*

This region is dominated by both summer and winter monsoon seasons with an annual longterm average rainfall of 789 mm. Farmers are growing peanut during the summer monsoon season, followed by sorghum. Both peanut and sorghum have dominant places in the system without any other crop choices under rainfed conditions. Sowing decision for peanut is any rainfall event of >25 mm in 4 days between June 1 and August 10.

Comparing the simulated peanut yields over the 99-year record showed that the peanut yield is substantially reduced in years when the SOI phase is falling in April/May (Table 6.1). The average yield was highest in positive and rising phase years irrespective of plant population levels. Financial risk can be lowered by reducing plant population by 50%. The main consideration for reduced population is to minimise the cost of seed, which accounts for almost 40% of the total cost of cultivation.

**Table 6.1** Mean yield, median yield and standard deviation of simulated peanut yield (kg/ha) for two plant population by SOI phases at Thiruchengodu, Tamil Nadu, India.

| SOI phases | Higher plant population (30 plants/$m^2$) | | | Reduced plant population (15 plants/$m^2$) | | |
|---|---|---|---|---|---|---|
| | *Mean* | *Median* | *SD* | *Mean* | *Median* | *SD* |
| **Negative** | 1828 | 1865 | 532 | 1836 | 1913 | 443 |
| **Positive** | 2058 | 2111 | 452 | 2046 | 2166 | 409 |
| **Falling** | 1625 | 1516 | 733 | 1617 | 1629 | 647 |
| **Rising** | 2061 | 1922 | 539 | 2048 | 2026 | 434 |
| **Neutral** | 1845 | 1922 | 547 | 1819 | 1893 | 524 |
| **All** | 1917 | 1922 | 559 | 1904 | 1959 | 497 |

To estimate the economic consequences of reducing plant population, the planting density was halved in years when the SOI phase was either negative, positive or falling (48 out of 99 years). For the remaining 51 years a 'standard' plant population was assumed. The average increase found for the tactical approach is derived from a distribution of differences between the two approaches (using or not using the forecast information) on a year-by-year basis. Adopting the tactical approach did not result increased profit every year. However, in many years it was substantially better and in few years it was only moderately worse (Fig. 6.2). Overall the tactical approach resulted in higher profits in 35% of the years, in 13% of the years the tactical approach performed worse and in 52 per cent of the years there was no difference.

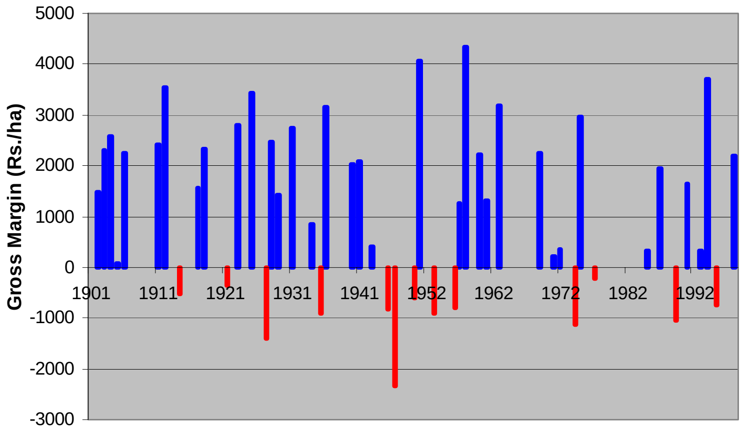


**Fig. 6.2** Difference in gross margin between tactical (forecast responsive) and fixed (non-responsive) plant population management for rainfed peanut at Thiruchengodu.

# 7) Case study Bangalore, India

## *1. Socio economic environment*

*1.1 Social structure land holding distribution*
The study area is in Pavgada taluk (near Ananthapur). Here the habitations are mostly villages and hamlets. Villages typically consist of about 300 households belonging to different endogamous groups (castes). Hamlets are much smaller in size consisting of about 60 households all of them often belonging to the same caste group. For all caste groups, peanut is an important crop. Large farmers (land holding of > 12 ha) generally own lands with soils that are relatively deep, fertile and often located next to the village. These farmers belong to high and medium social status caste groups. Small and marginal farmers (with land holdings of 2 - 12 ha and < 2ha, respectively) usually belong to low and middle status caste groups, characterized by shallow soils with low fertility, located further away in the upper parts of the watershed. In the region, more than half the peanut farmers are marginal farmers and a considerable number are small farmers. In Pavgada taluk (about 1350 $km^2$) 54% are marginal farmers (with about 36% of the land holding), 39% small farmers (with about 49% of the land holding) and only 7% are large farmers (with about 14% of the land holding).

The changes that led to the evolution of the current cropping system also led to the transformation of the structure of the farming community. Prior to the sixties, almost all of the rain-fed lands belonged to the large farmers. The cultivation on these lands was done by share croppers. At that time, a large fraction of the land was also under natural vegetation, which supported livestock and a large number of people who depended on the livestock. In addition, there were people with specialised skills such as tanning of leather, manufacturing cloth using handlooms and dyeing of cloth. From the early sixties, land reform legislation led to major changes in land-holdings and a large number of share croppers became marginal / small farmers. Also, much of the land under natural vegetation was cleared for agriculture and the erstwhile cowherds and shepherds also became small / marginal farmers. With development of roads and competition from the large factories in the towns, the local production of leather and textiles became unprofitable and those skilled in these crafts also took to agriculture. Thus the diversity of occupations decreased markedly and a farming community with large disparities in land-holding and resources, cultivating mainly peanut on their rainfed lands, was created.

It is important to note that although there is considerable disparity in the land-holding and availability of resources, there is hardly any difference in the know-how of the different types of farmers. There is considerable rapport between the different types of farmers in the same locality. The large farmers often seek advice of the marginal farmers before making decisions about the timing of ploughing, sowing etc.

*1.2 Farm economics*
The yield of rainfed peanut varies considerably from year to year, largely in accordance with associated rainfall variability. In the best year (1998) the highest yield obtained by the marginal farmers is about 1.1 t/ha. The yields of large farmers are much higher, presumably due to higher use of fertilisers and other inputs. The typical cost of cultivation is Rs 6000 per ha and market price for peanut is Rs 12,000 per t. This implies that for yields below 0.5 t/ha the cost of cultivation exceeds the income. In 1997, the yields were below this level in many of the cases. It is intriguing that despite such low yields in some years, farmers continue to grow peanut in the rainfed areas. The commonly held view is that no better options are available. Further, the perception of what is reasonable or economical is interesting. Marginal farmers use largely family labour and do not count it as component of the cost of cultivation. Hence they have a somewhat biased perception of profits. For example, typically 50% of the contribution for labour + bullock (ie. about the equivalent of 0.17 t/ha) is discounted in their investment and hence a yield below 0.33 t/ha (instead of 0.5t/ha) is considered as a crop failure.

Whereas marginal farmers do not take into account family labour, large farmers also underestimate the cost of farming operations by not taking into account maintenance of tractors and other machinery. Peanut prices fluctuate strongly and it is questionable whether on time-scales of 10 years or more peanut production is indeed economically viable. Hence, alternative crops need to be considered urgently.

*1.3. Access to credit*

For many large farmers and some of the small farmers money lending and trade are important additional sources of income. The annual interest rates for loans range from 24 to 60%. However high percentage of recovery is dependent on good yield of peanut – the only crop for which credit is readily available. Trade by large farmers often involves marketing decisions. They purchases commodities at low market prices during harvest (mostly peanut) and sell them when prices improve. Many of the large and small farmers are actively involved in politics. For them a significant fraction of income is derived from execution of government contracts, subsidies, and other government programs. Generally, however, the contributions from off-farm employment to the family income is rather small.

*1.4 Vulnerability and coping strategies*

Marginal farmers have several strategies to cope with low yields. In case of a moderately low yield, the marginal farmers sell the manure (FYM), peanut seeds, peanut haulm as fodder and if necessary, livestock. If the yield is extremely low or moderately low in two or three consecutive years, they have to resort to what they consider extreme measures for survival. These involve leasing out the land and adults in the family move to other regions seeking employment. Although government-sponsored drought relief programs exist, farmers often need to borrow more money from the local money lenders in such years. These farmers seem to be almost continuously in a debt trap. If they do not have seeds (as it often happens in a year following one with low yield), they take these from the money-lenders for sowing and have to return 150% after harvest. The interest charged for money borrowed from these local money-lenders is also high. However, they prefer the local money lenders to the banks since they are more responsive to the needs and give the loan whenever needed. In fact, most of these farmers avoid the bank because many of them have defaulted before.

The small farmers borrow money from money lenders as well as banks in years of low yield. They also sell cattle, sheep, goat, farm trees and crop lands. In the year following one with poor yields they reduce the fraction of peanut in intercropping. The large farmers borrow money from banks and sell farm trees and also land, if necessary. Prior to 1997 large increase in price of peanut during off season were common. This generated large profit for farmers involved in trade. Recently, changes in import/export policies and lowering import duties has caused changes in the pattern of domestic price fluctuations of peanut and other important commodities of trade in the region.

Most of the large farmers are engaged in money lending business to some extent though only some of them operate on a large scale. In this business no formal records or legal agreements are involved and the recovery of the loans depend on mutual trust and social pressure. In recent years, the influence of leftist-radical revolutionaries has extended to several parts of study area. Under the rapid spread of this movement, money lenders are often targeted for extortion. There is also a steady erosion of social values on which recovery of the loans given by money lenders depends.

## *2. Simulation of peanut yield and biomass with APSIM*

For this region a systems simulation capability is required in order to evaluate possible alternatives to peanut. This requires detailed model parameterisation, including access to experimental data. This is a time consuming process that cannot be achieved within the time frame of a one-year pilot study. The modelling framework APSIM contains crop modules for most of the key crops (eg. peanut, pigeonpea and other legumes). Preliminary results indicate that APSIM can simulate climate induced variability of biomass and yield of rainfed peanuts (TMV-2 variety) for the study region near Anantapur. Parameterisation provided a challenge, because genetic coefficients for TMV-2 (a short duration Virginia bunch variety) were not readily available. During the Toowoomba workshop, the APSIM team suggested the appropriate cultivar parameters for this variety. Simulation from 1970-98 show that APSIM is, with a couple of exceptions such as 1985 and 1987) able to capture the year to year variations in both biomass and yield. However, possible cultivar difference as suggested by local farmers can only be simulated once the necessary experimental data to derive the necessary parameter values have been conducted and analysed. Work is now under way to parameterise alternative crops so that comparisons similar to those conducted for Pakistan and Tamil Nadu can be conducted.

## 8) Lessons learned and recommendations – the next phase

Based on the encouraging results of this feasibility study we propose the funding and implementation of a larger program that comprehensively addresses all the components outlined in Fig. 8.1. The project team believes to have clearly demonstrated that via a systems analytical approach effective networks can be put in place that can considerable reduce climate related vulnerability in agricultural systems. Once implemented, such an interdisciplinary network would be self sustaining by (i) attracting systems thinkers across the disciplines and (ii) through the provision of objective methodologies for decision making at farm, marketing or policy level. The emphasis will be on relevant knowledge acquisition and dissemination with a clear intention to intervene in order to achieve better outcomes. It will provide objective tools that allow the assessment of the economic, social and environmental consequences of alternative decisions.

### *Climate And Agriculture: From Vulnerable To Resilient Farming Systems*

The proposed follow-on program needs to be global in its outlook. It will result in the development of resilient farming systems that are in tune with current climatic conditions and adaptable to climate variability and change. It will refine and deliver a general methodology/process for reducing vulnerability in agricultural systems operating under climatic risk. The process will be applicable globally and builds largely on approaches that have proven successful in this pilot study, where the CLIMAG team has demonstrated that climate information and climate forecasting can be value added via a systems analytical, participatory research approach. The program will cover the dimensions of climate science and information, agricultural systems and socio-economic systems with a focus on farmers in risky environments. It will provide a means to reduce vulnerability caused by exposure to climate variability at the field, farm household and village level. Analysis of policy options, constraints and their feedbacks on on-farm management will form an important part of this research network.

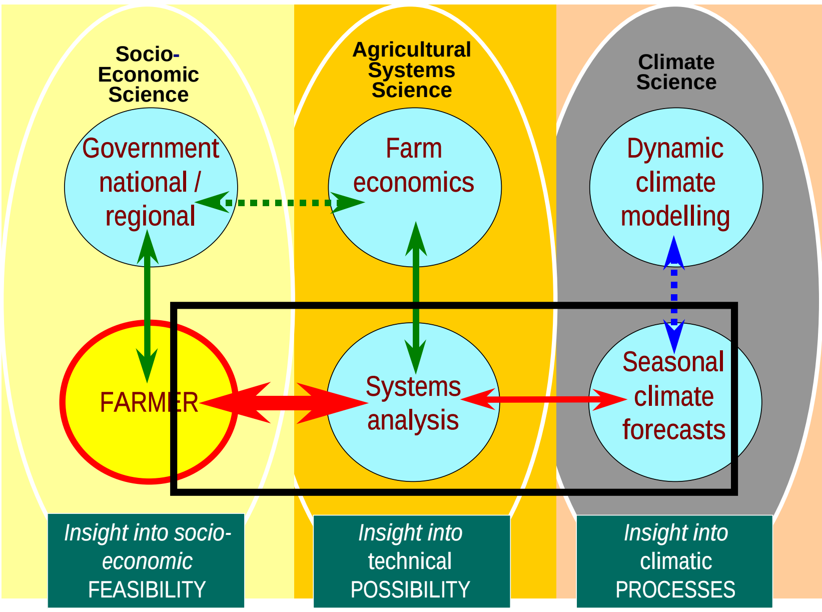


**Fig. 8.1** Program concept – disciplines, relationships and linkages for effective delivery of climate information for decision making. The boxed area indicates the realm of this CLIMAG Demonstration Project. Operational links are indicated by the solid arrows. Dashed arrows indicate areas where an operational connection are still weak or do not exist and where the larger program needs to develop components for true 'end-to-end' applications. Solid arrows indicate links that have proven useful in the more developed parts of the SAT (ie., Australia, USA and South America).

The program will take a large step beyond climate impact assessments by evaluating and quantifying potential short, medium and long term adaptive responses within farming systems. It will draw on the collective expertise of the global research community to develop 'resilient' cropping systems, ie. cropping systems that are to a large extent 'climate proof' by allowing farmers to draw on systems resources (eg. water, nutrients, reserves) at times of need, with these debts being repaid once climatic conditions improve.

Climate variability generates risks for management decision-making on both short and long time horizons because outcomes of decisions cannot be predicted with certainty, be they decisions on crop management, stocking rate, water allocation, or insect population management. Risk, or the chance of making a financial or environmental loss, is a key factor pervading decision-making in management of agricultural and natural ecosystems. A systems approach in a problem-solving context requires on-going connections between decision-makers, advisors, modellers and researchers for effective outcomes. This integration of skills is required to achieve the balance needed between practicalities of system management, needs of decision-makers, and development and use of system simulation or expert knowledge to evaluate options.

A participatory research approach that includes all players will link individual partners and institutions within the network. This is required to ensure adoption by the users and beneficiaries of the approach and to facilitated communication and tool development across all disciplines. Production and conservation issues in these agricultural systems provide the major focus for management intervention. This fully interdisciplinary program will integrate our scientific understanding and provide insights into climatic and agricultural processes (Fig. 8.1). This must be accompanied by a rigorous assessment of the technical possibilities that demonstrates where climate information and seasonal climate forecasting can positively influence systems performance. These technical possibilities must be evaluated for their socio-economic feasibility. This is an iterative process that can only be achieved via a participatory research approach that involves all players.

To be successful, such a program will require a long-term financial commitment with dedicated staff working on specific issues at various research centres around the world. Equally important will be an effective program management that ensures that component research is focused on the target system and provides the types of output that can be used by other program partners as either input for further analyses or as base line data for necessary assumptions. At a minimum following major program areas need to be resourced at a range of research centres:

- Project coordination and communication
- Climate science (from climate models to agricultural models)
- Agricultural systems modelling and field scale modelling
- Socioeconomic analysis, farm/village/regional level modelling
- Institutional analysis and guidance
- Communication / Training
- Training and capacity building

## Appendix I (details relating to chapters 4-7)

The results form the individual case studies (ie. chapters 4-7) will be published as journal papers. The manuscripts are currently in preparation and it is expected that final drafts will be available by mid 2001.

## Appendix II (additional documentation; materials developed during the project; details from initial planning meeting)

Details will be provided with the official final report.