Approaches allowing smallholder farmers in India to benefit from seasonal climate forecasting

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Abstract

Climate variability is a major influence on agricultural production in smallholder farming systems of India. Smallholder farmers manage this climate variability only after the negative impacts are realized. The El-Niño/Southern Oscillation (ENSO) phenomenon explains some of this inter-annual rainfall variability. We suggest an integrated, interdisciplinary, participatory systems approach for the application of ENSO-based climate forecasts to vulnerable smallholder agriculture production systems in India. The overall aim of the approach is to demonstrate and deliver the benefits from climate forecasts for farmers and to provide operational support for seasonal climate prediction with in the target region. Our experiences demonstrate improved farm decision-making using climate forecasts combined with cropping system models. Simulated yields and gross margins helped to identify optimal farm decision scenarios conditioned on ENSO forecasts. The most valuable decision responses were associated with crop choice, sowing season and planting density. Although the potential aggregate benefit appears to be substantial, smallholder farmers face several challenges related to the uncertainty of current forecasts and complexity of agricultural systems. We suggest that, to benefit from seasonal climate forecasts, the decision capacity of the smallholder farmers need to be improved and greater emphasis should be placed on farmer involvement and a demand-driven participatory system analysis approach. The climate predictability needs to be improved further for wider application and to exploit potential benefit for smallholder risk management.

Media summary

Seasonal climate forecasting, agricultural systems analysis based on simulation models and a participatory decision making approach has resulted in better-informed decision-making of smallholder farmers in India.

Key Words

Climate forecasts, system analysis, participatory decision-making, smallholder farmers

Introduction

In spite of substantial gains in food grain production in recent decades, 26% of India's population live in poverty. Although poverty levels declined from 51% in 1970 to 26% at present, India continues to face a persistent challenge of feeding a growing population against a background of climatic uncertainties (Shukla et al. 2002). Climate is one of the key components influencing agricultural production in Indian smallholder systems, accounting for two thirds of variation in production. Inter-annual variability of the South Asian monsoon affects more than 60% of the Earth's population (Webster et al. 1998), and has large-scale impacts on food production, power generation, drinking water supply and overall economy (Parthasarathy and Pant 1985). Irrespective of production systems, climate-related events such as droughts, cyclones, floods, hailstorms, frost, high winds and extreme temperature contribute to smallholders' vulnerability and impact on national food security.

Smallholder farming (<2.0 ha per farm) accounts for 78% of the total operational holdings and occupies 32% of total agricultural area. The average size of 84 million small farm holdings in India is <1 ha, with many producing incomes below the poverty threshold. Smallholder dryland farming systems accounts for 70% of the total cultivable area. These systems are characterized by low productivity and widespread, persistent poverty. Improving the profitability of these highly vulnerable smallholder systems is a priority for reducing rural poverty in India (Yadav and Singh 2000). Improved climate risk management based on skillful seasonal forecasts can play an important role in reducing rural poverty.

Growing understanding of ocean-atmosphere interactions and advances in modelling the global climate systems now provide a usable degree of predictability several months in advance for many parts of the world (Goddard et al. 2001). Combined with the ability to systematically quantify agricultural management responses via simulation analysis, this offers an opportunity to improve climate risk management (Meinke and Stone 2004). Integrating seasonal climate forecasting with agricultural system analysis can increase its effectiveness (Hammer et al. 2000; Meinke et al. 2001). The approaches of combining climate forecasts, participatory system analysis and farm decision-making to manage climate risk in smallholder farming are addressed in this paper.

Traditional strategies to manage climatic risk

From historic time, smallholders have adapted their farming systems to climate variability, changing economic conditions, technologies, and resource availability. The experience of centuries has taught the traditional farmer an 'empirical art of practising agriculture' that is in tune with nature's vagrancies (Randhawa et al. 1961). Even prior to the *Vedic* and *Pre-Vedic* period (3500 BC) there had been a system of climate forecast developed by *Idaikkadar Swamigal*, one of the eighteen *Siddhars* who lived in Western Ghats of South India (Subbarayappa 2001). A local folklore in *Marwar* area of Rajasthan describes: *"A century is made up of seven years of famine, twenty-seven years of plenty, sixty-four years of semi-drought, and two years of extreme drought"* (Aparna 2001). Giving these facts, the recent attempts on seasonal climate forecasts are not new but have been dealt in site-specific manner for centuries.

To cope with climate variability, farmers have developed a wide range of management practices such as pre-monsoon dry seeding, stubble mulching, crop rotations and intercropping. Pandey et al (2003) reported on the construction of rainwater harvesting structures across India in response to abrupt climate fluctuations such as drought. Local rules of thumb are used as simple risk management tools. For instance, farmers say *"Any shower below three quarters of an inch is of very little use in tillage and as such heavy falls are at comparatively distant intervals ahead of or at the beginning of the cropping season, the opportunities of cultivation are very limited in number and duration, and must be seized and used on the instant".*

Sir Frederick Nicholson observed in 1887: "In irrigated garden lands the ryot (Indian subsistence farmer) is a past master of his art.… and there cannot be much to teach a man who can produce in one crop from 30 to 80 bushels of grain per acre according to circumstances such as the kind of crop, the season and his means". But current cropping systems are highly vulnerable to climate fluctuations due to over exploitation of resources. Sir Frederick was of the view that empty purses led to poor cultivation and a "full purse in farmers hands could conquer season and soil", indicating a relationship between risk management and farmers' wealth (Randhawa et al. 1961).

Indigenous knowledge and tradition still play a role in climate risk management. In Avinashi (a location in Southern India), for instance, if it rains on 10th of Ani (June) or 8th of Adi (July) it is believed that the rainfall in the succeeding season will be good. If the breeze is towards the east during July, the winter monsoon will be good; if towards south, the summer monsoon will be successful. Although some of these beliefs are loosely based on climate phenomena that we are now beginning to understand, indigenous knowledge is slowly losing it's importance and is being replaced by climate forecasts based on our physical understanding of the climate system.

Farmer participatory co-learning for climate application

Perceived need, objectives and decision profiles

In participatory co-learning processes, greater emphasis has been placed on farmer involvement and a demand-driven research approaches. Participatory methods served as a source of information about local practices, problems, impacts, recommendations, policies (Butler and Butler 1987) and facilitate spontaneous responses and high level involvement of farmers. Participatory co-learning processes offer greater scope for identification of cropping system determinants and farmers' real and perceived need. A survey with semi-structured interviews can serve a similar purpose (Nelson et al. 2002). In our example, the farmer interactions identified specific decisions such as sowing time and selection of crops and varieties in response to climate information. Understanding and involving decision makers and their decision profiles are the foundation for effective application of climate forecasts (Hansen 2002).

A survey from two small farmer communities (Avinashi and Salem) in southern India showed monopolization of farm decisions by male farmer and is the most frequent decision-making approach. On average, in our case study locations, male farmers without consultation of others make 40% of all decisions. However, participation of the family (31.7%) and other farmers in-group decisions (14.6%) are still important. Therefore, it is necessary to design ‘climate educational’ programmes that take socio-economic factors such as farmers’ perception, social behaviour, attitude to risk and their knowledge level into account.

Iterative model and evaluating options

The process of incorporating new information into the existing knowledge base is an iterative approach (Pinners and Balasubramanian 1991). Our extensive discussions with the stakeholders provided ample opportunity to document local knowledge on climate prediction. We observed limited, highly location-specific indigenous climate knowledge. Farmers were more inclined to incorporate climate information into their risk management strategies when the traditional wisdom and scientific climate forecasting coincided.

The iterative risk management model involves a cycle of analysis, implementation, testing, modification, evaluation and redesign of risk management strategies and helps to assimilate scientific knowledge with local knowledge (Nelson et al. 2002; Figure 1a).

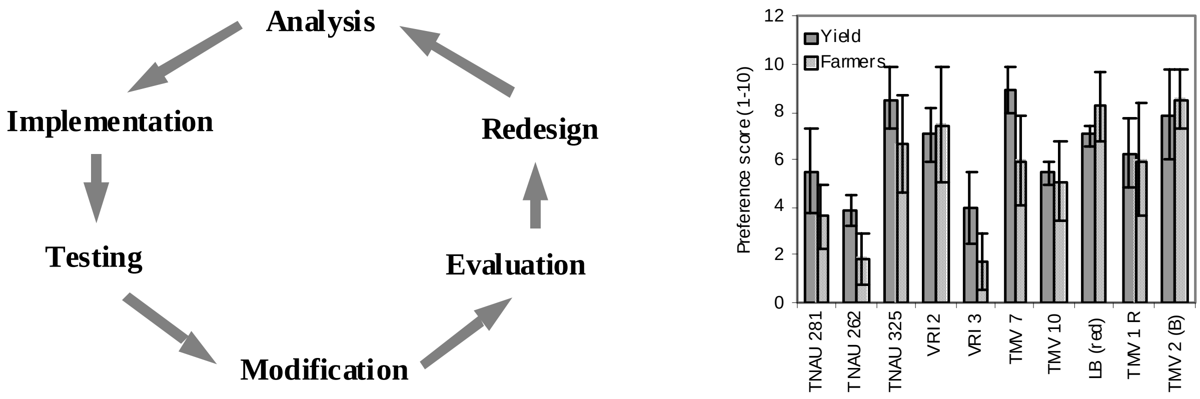

Figure 1. (a) Iterative process of participative climatic risk management (b) on-farm evaluation phase describing peanut variety scores based on observed yields and farmer subjective assessment.

On-farm evaluation of risk management practices fits into the iterative model to redesign the targeted climate applications with farmers’ participation. The on-farm trials are helpful to align the farmers’ preferences with scientists’ understanding of the system in order to device appropriate management options for specific season types. Figure 1b shows the rank of ten varieties in terms of potential yields (researchers’ preference) and farmers’ preference from an on-farm trial at one location (Salem). The data shows similar preference patterns, but also some strong difference among scores and serves as a valuable background for a constructive debate. System analysis via simulation modelling plays a major role to establish varietal differences for different climatic conditions and across locations.

Climate knowledge and decision capacity

Climate knowledge is created by raising awareness of climate variability impacts for a range of management options among smallholder farmers. Pre- and post-season climate workshops proved valuable platforms to redesign structure, contents and communication pathways of farmer/scientist interactions. Time series of rainfall, yields and gross margins were essential to understand the climate variability impacts and benefits of climate forecasting. In many areas, the likely outcomes of viable decision options based on crop simulations have become integral to realise benefits of seasonal climate forecasting (Nelson et al. 2002; Meinke et al. 2001).

Climate education programmes for smallholder farmers need to be structured in accordance with the participants background knowledge and skill (Selvaraju and David 2002). Climate education programmes with crop model based scenarios, probabilities and decision games can make the learning process easier and enhance users' understanding of forecast uncertainty and its relevance for decision making (Ingram et al. 2002). Topics covered should address issues related to climate predictability, impact of climate variability and understanding the climate related processes at different scales. Understanding the perceived need of farmers and identification of key decisions responsive to climate forecasts in the system are essential, preliminary steps for successful implementation of climate application programmes. Discussing the management alternatives for the key decisions improves the knowledge level and decision capacity of farmers and scientists alike.

Decision-making ability or decision capacity is defined as the correct interpretation of right information at the right time (Hansen 2002). Understanding decision capacity of farmers helps to achieve effective climate communication. The targeted climate educational programmes must address the importance of every crop management decision and farmer's decision capacity with respect to each decision. If a crop management decision is highly responsive to seasonal climate forecasting and is considered essential for risk management, the decision capacity of the farmers' with respect to that decision needs to be improved (Stephens and McGuckian 1994).

In one of our case study communities (Avinashi), crop choice between cotton and peanut is a responsive decision to climate forecasts and farmers considered it is essential to manage the risk of crop failures. Our survey indicated that about 55% of the farmers considered that decision capacity on optimal crop choice is 'essential', but only 16% are regarded themselves a 'very good' decision makers, indicating need for improvement. The experiences of communication process showed that decision capacity depended heavily on prior climate knowledge. Participatory co-learning approaches lead to well-focused, demand-driven research that incorporates the risk perception of farmers. We found that such decision analysis and participatory option development has stimulated community participation.

Seasonal climate predictability and climate forecasting

The relationship between the El-Niño/Southern Oscillation (ENSO) and variations in Indian summer monsoon rainfall is widely recognized (see, e.g., the review by Webster et al. 1998). For India, a negative (positive) Southern-Oscillation Index (Bhalme and Jadhav 1984) and warmer (cooler) sea-surface temperature (SST) in the central and eastern equatorial Pacific are generally associated with decreased (increased) chance of exceeding median summer monsoon (June-September) rainfall (Parthasarathy and Pant 1985) (Figure 2). The reverse holds for winter monsoon (October – December) rainfall. The spatial pattern of relationship between sub-divisional scale Indian summer monsoon rainfall and SOI phases of Apr/May is relatively coherent (Figure 2).

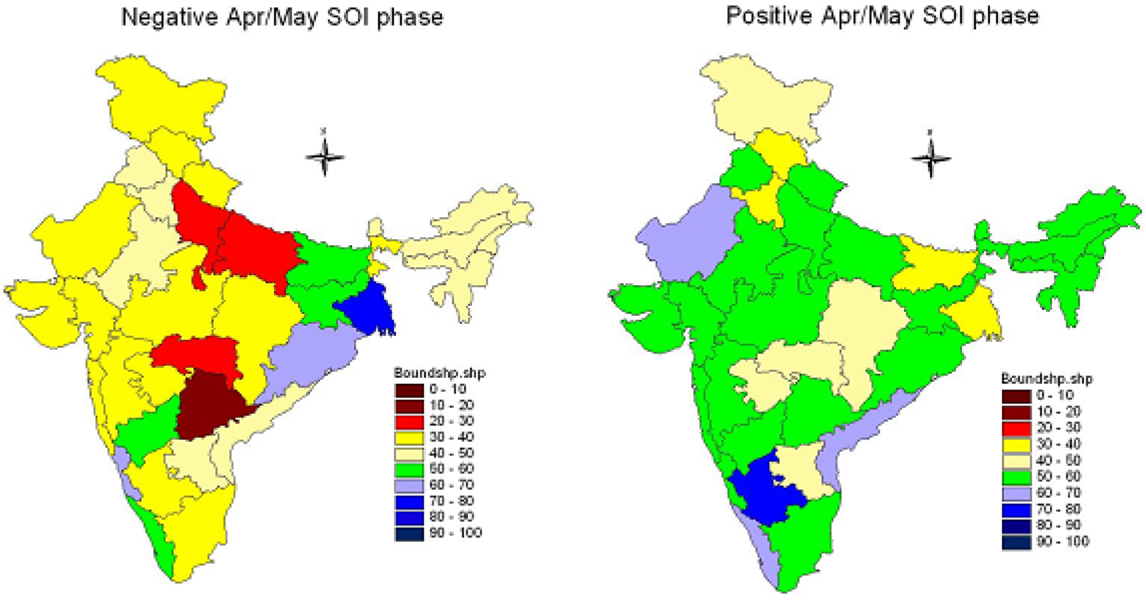

Figure 2. Probability of exceeding long-term (1901-2000) median rainfall during summer monsoon (Jun-Sep) for meteorological subdivisions of India following SOI phases of Apr/May

The influence of ENSO-related climate variability on agricultural production in India (macro-regional scale) has been demonstrated (Selvaraju 2003). The predictability of climate and yield variability associated with ENSO at farm-scale suggests a potential to improve agricultural production decisions to either reduce the negative impacts of adverse conditions or to take advantage of favourable conditions. Successful farm-level application of ENSO based climatic forecast for managing risk have been reported elsewhere (Meinke et al. 1996; Messina et al. 1999; Phillips et al. 2001).

Our case studies employed the Southern Oscillation Index (SOI) phase system (Stone et al. 1996) to predict shifts in rainfall (Table 1) and yield distributions (Figure 3). In our example, the chance of exceeding June-September median rainfall was lower following negative (31%) and falling (37%) phases compared to positive (60%) and rising (58%) phases in April-May. The predictability further increases with May-June SOI phase for July-September rainfall. The chance of exceeding the median rainfall (479 mm) during winter monsoon following a negative SOI phase in June-July was 82% compared to 28% following a positive SOI phase (P< 0.01).

Statistical and analogue methods of climate forecasting described above are well suited to connect with existing risk management tools such as crop models. However, they are approaching their limits of predictability (Cane 2001). Although future advances in climate forecasting are likely to be associated with dynamic climate modelling approaches (Goddard et al. 2001; Meinke and Stone 2004), they do not easily and intuitively connect with our risk management tools. This is currently an area of active research (Hansen et al. 2004).

Table 1. Probability (%) of exceeding long-term (1901-2000) median rainfall during summer and winter monsoon seasons at Tamil Nadu following SOI phases of the preceding months

Mthnhs	Negative	Positive	Falling	Rising	Near-zero
Summer monsoon					
JJAS rainfall					
Apr/May	31*	60	37	58	56
JAS rainfall					
Apr/May	25**	60	32	65	56
May/Jun	17*	65*	50	58	41
Winter monsoon					
OND rainfall					
Jun/Jul	82*	28*	46	40*	67
Jul/Aug	79***	29*	50	53	43

*, **, *** Significantly different from 50% at 5,1 and 0.1 per cent probabilities based on the Kolmorogov-Smirnov test

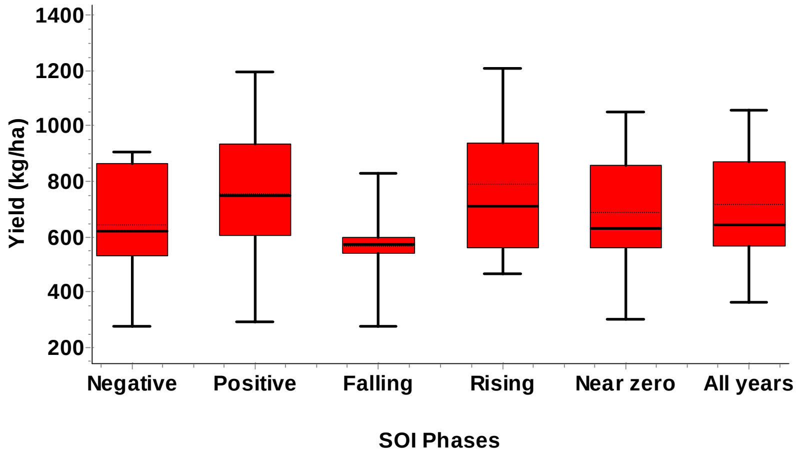

Figure 3. Distributions of simulated cotton yield (kg ha^{-1}) for an early sowing window (June 1- July 31) at Avinashi for years associated with each of the five April-May phases of the SOI and for all years

Use of simulation modelling to inform smallholder's farming decisions

Systems analysis using crop model helps to identify climate sensitive 'leverage points', i.e. key decisions that require climate knowledge. Each of the diverse set of enterprises that characterize smallholder farming requires different information for risk management. Simulation models quantify production uncertainties, and are particularly useful for comparing alternative management options (Meinke and Stone 2004) and assessing the potential value of forecasts (Mjelde et al. 1997). An example for understanding the uncertainty and risk of peanut cropping in a small farmer community (Avinashi) through a crop model is presented in Table 2. Knowing the climate forecasts and associated risks enables a farmer to make better-informed choices for the summer monsoon season. From analysis it is evident that sowing opportunities varied with 20 mm and 25 mm sowing rule. Farmers' thresholds for rainfall to trigger sowing vary by crop and soil characteristics in dryland regions of Indian semi-arid tropics. Considerably more sowing opportunities occurred following a positive SOI phase (76%) compared to a negative phase (60%). Average simulated peanut yields were significantly lower (685 kg/ha) during falling SOI compared to positive SOI phase years (1077 kg/ha).

Table 2. Chance of peanut cropping and mean simulated peanut yield (1901-1999) by SOI phases at Avinashi, Tamil Nadu, India

SOI Category	No. of years	Chance of cropping (%) under sowing rainfall thresholds		Mean yield (kg/ha)*
		20 mm	25 mm	
Negative	15	60	47	713^{b}
Positive	21	76	71	1077^{ab}
Falling	12	67	42	685^{cb}
Rising	26	65	65	1248^{a}
Neutral	25	72	68	1145^{a}

* The Kruskal-Walis H = 9.5* ($p<0.05$). The values with same letter are not significantly different at the 5% probability level using K-S test.

Agricultural systems models can link climate forecasts and farmers local rules of thumb. The models are discussion and action support tool that translate generic climate information into actionable knowledge within the smallholder's system. Although agricultural production in variable climate can be improved by combining targeted climate information with well-focused system modelling (Hammer et al. 2000), differed types of models are necessary depending on information needs and scale (Meinke and Stone 2004). For instance, participatory system analysis was helpful to decide the crop area decisions by the dryland small farmers based on the climate forecasts and risk preferences (Selvaraju et al. 2001). The system analysis and simulations take account of starting soil moisture conditions, regional soil types and an SOI-based climate forecasts. For peanut, yields differed depending on planting dates, soil types and seasonal climate forecasts (Figure 4a,b).

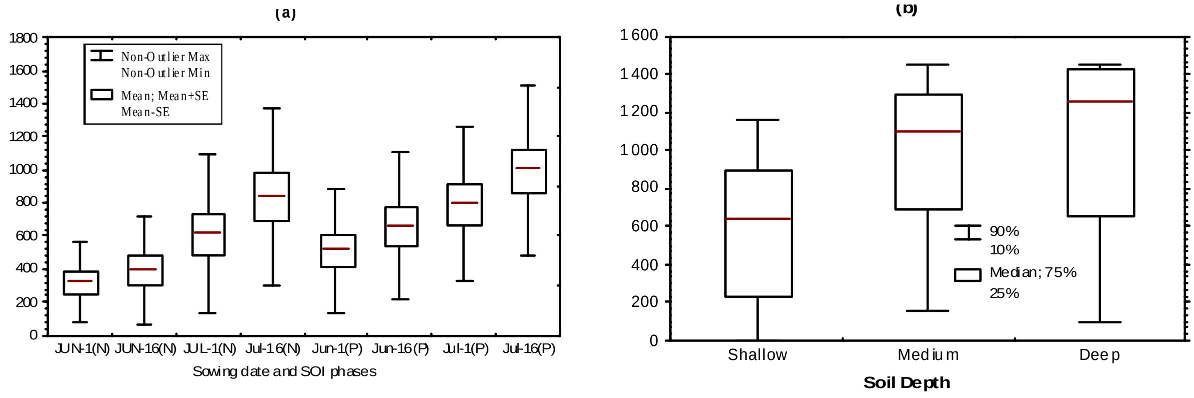

Figure 4. Simulated peanut yields for (a) different sowing dates with in a sowing window under Apr/May negative (N) and positive (P) SOI phases and (b) different soil types for July 1 sowing date

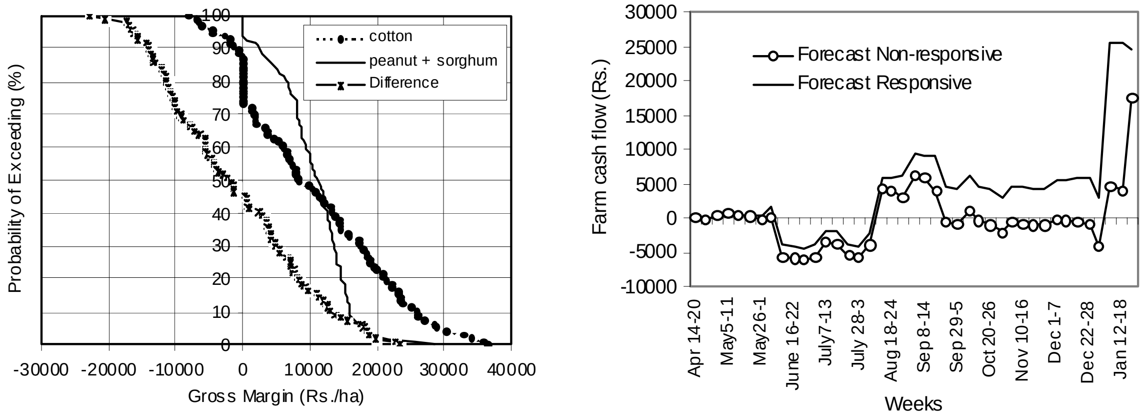

Figure 5. (a) Cumulative probability of gross margin difference between the peanut – sorghum and cotton based cropping systems (positive differences indicate the advantage of cotton over peanut – sorghum based system) (b) cash flow of a representative farm with forecast responsive and non-responsive strategies.

The simulation models are effective tools to derive optimal management strategies in small farmer cropping systems overlapping into seasons with contrasting response to ENSO. During El Niño type years, the probabilities for above normal summer monsoon rainfall in Tamil Nadu (India) are lower, whereas chances of above average winter monsoon rainfall are higher, with potential benefits for winter crops. In our example (Figure 5a), comparing the gross margin between the two cropping systems, peanut (summer)-sorghum (winter) is performing better than cotton (overlapping into summer and winter) in 65% of the occasions with 10% risk of negative monetary return or no return. The cotton-based system was able to maintain positive gross margin in 72% of years. In 22% of years there is risk of negative gross margin with a maximum loss of Rs.10000/ha. The overall comparison showed that cotton is optimal in falling phase years and peanut could be considered during positive, rising and near zero phase years. Similarly a preliminary whole-farm modelling considering all the farm enterprises showed increased farm income by using climate forecasts (Figure 5b).

In an effort to apply the dynamic forecasting techniques to smallholder risk management, GCM-based climate forecasts were linked with crop models for yield prediction (Figure 6). A statistical transformation of seasonal rainfall output fields from ECHAM4 to identify optimal predictors was carried out. Simulated peanut yield results are based on monthly rainfall hindcasts that were disaggregated to daily values using a stochastic weather generator (Hansen and Indeje 2004). The results showed a promising level of predictability and the approach should be further investigated.

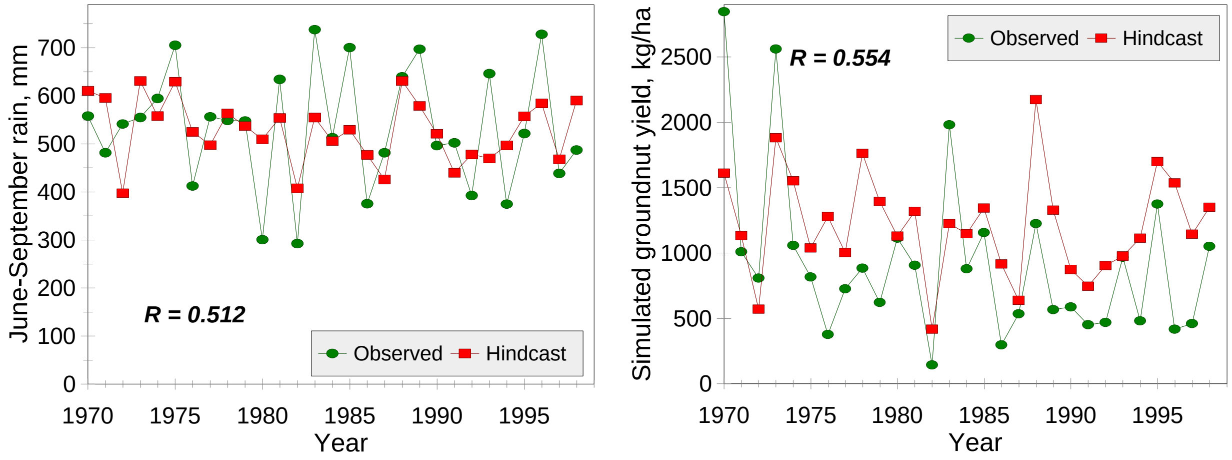

Figure 6. Observed and hindcast station rainfall and simulated peanut yields based on transformed, cross-validated ECHAM 4.5 predictions.

Value of climate forecasts in smallholder farms

The value of climate forecasts varies with type of decisions. Table 3 summarizes the value of climate forecasts for different management decisions and SOI phase. The value of forecasts in smallholder systems depends on prediction skill, SOI phase types, and types of decisions and their responsiveness to climate forecasts. Though the forecast skill for summer monsoon is concurrent and moderate, the value is greater for peanut and cotton management. Winter monsoon rainfall forecasts are reasonably ‘skilful’ (i.e. they show a fair degree of separation between forecast categories) with sufficient lead-time but have low value for sorghum management.

The average value of forecasts across all years ranged from Rs.34 ha^{-1} for peanut fertilizer management to Rs.504 ha^{-1} for peanut stand density adjustment. The crop choice decisions following negative and falling April/May SOI phases would improve the average annual net income to a greater magnitude. The plant density decision would also improve the gross margin but to a lesser extend than altering crop choice decision. Though the value of crop choice decision was greater for negative and falling SOI phases, the all year average value was lesser than the stand density adjustment.

Table 3. Economic value (Rs.ha^{-1} year^{-1}) of small farm crop management practices tailored for SOI phase based seasonal climate forecasts (Avinashi, Tamil Nadu, India)

Crop / season	Decision	Economic value (Rs. ha^{-1} year^{-1})					
		Negative	Positive	Falling	Rising	Neutral	Total (all years)
Peanut (Summer)	Stand density	2546	0	2049	0	0	504
	N Fertiliser	17	79	115	0	0	34
	Crop choice (Peanut/sorghum)	4128	0	4059	0	0	287
Cotton (Summer)	Sowing window	0	751	78	0	580	282
	N fertilizer	600	290	548	0	0	288
Sorghum (winter)	Stand density	43	0	272	83	0	80

Community impact of applying seasonal climate forecasts

Our experiences in two regions (Avinashi and Salem) in Southern India suggest that discussing the simulation model results to derive better options for on-farm risk management can lead to community level impact at village scale. The forecast of a greater chance of below normal summer monsoon rainfall (June-Sept, 2002) based on the Apr/May (falling) and May/Jun (negative) SOI phases was discussed with 2 sample farmers individually and with nearly 30 farmers in group sessions near Avinashi (Thamaraikulam) in Tamil Nadu, India. Simulation model output was used to discuss options to reduce risk (eg. crop choice, planting density; simulations indicated high chances of reduced peanut yield that could be mitigated by reducing plant populations; model output also suggested sorghum as a viable alternative under very dry conditions). These discussions had a significant impact. The options derived through discussion support tools have demonstrably changed the cropping area in our case study village. Many farmers changed from growing cotton in June to early sorghum during 2002 (72 hectares planted, Figure 7). Farmers also reduced population densities, harvesting at least 0.8 t/ha of peanut. However, crop choice decision was key with more that 70% of farmers growing some sorghum. The 20% of farmers, who took the risk and planted cotton had to abandon their crops by August, loosing all their input costs.

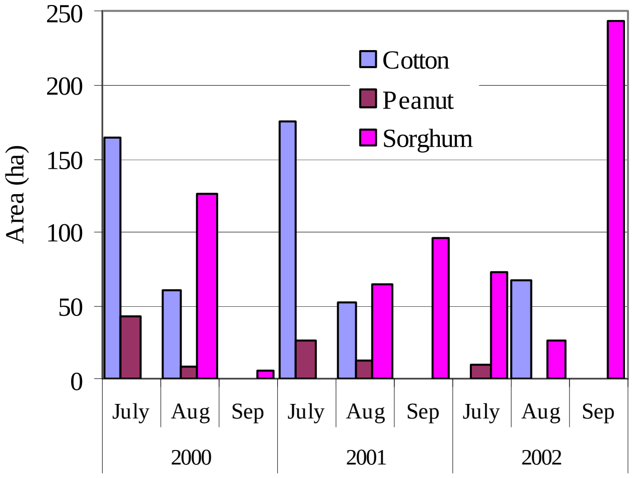

Figure 7. Shift in crop area during the 2002 summer monsoon compared to previous years at Thamaraikulam, Avinashi, Tamil Nadu, India.

The value of changing decision based on our discussion was analysed for a single farmer having 2.8 hectares of land. Our pre-season contact with the farmer revealed that the farmer planned to grow 1.6

hectares of cotton, 0.8 hectares of sorghum and 0.4 hectare of peanut. The forecast based on Apr-May SOI phase (falling) during 2002 indicated only 37% probability of exceeding the longterm, median rainfall. The model-based analysis indicated relatively low risk with allotting part of the land intended for peanut and cotton to sorghum. Accordingly, the farmer decided to allot 0.8 additional hectares of land to sorghum. The economic benefit of the decision was analyzed through partial budgeting. The added cost of growing sorghum in additional 0.8 hectare was Rs.5500. The amount gained from additional sorghum was Rs. 8800. The reduced cost that might have been spent on cotton was estimated at Rs. 4299. Estimated change in net income due to change in decision based on use of climate information and model based cropping options were Rs. 7049 at farm scale.

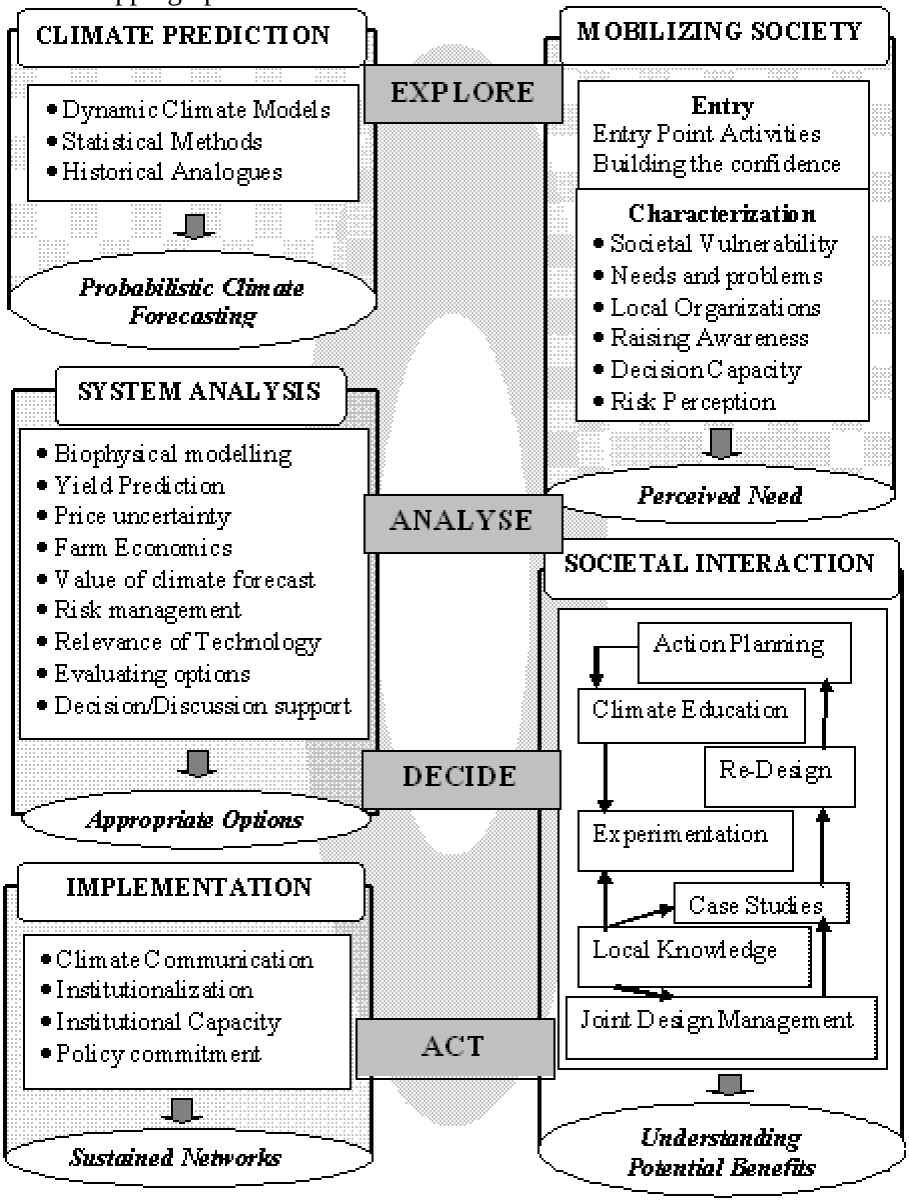

Figure 8. Evolutionary, participatory research and implementation framework for climate applications in smallholder systems

A cross-cutting, integrated approach to benefit from climate forecasting

The approaches of applying seasonal climate forecast in smallholder farms needs to ensure two important components viz., (i) well focused and targeted participatory research to demonstrate the value of climate information at different spatial scales (ii) efficient and sustained use of forecasts beyond the research period through existing technology delivery (extension) systems. The first component highlights the need for effective collaboration, cross-disciplinary research and communication among the research institutions, disciplines and people. The second component ensures institutionalization of climate and agricultural programmes. Equal emphasis on social mobilization and societal interaction are required for both research and effective delivery. Further, it is essential to identify and involve existing technology delivery systems (local extension) and policy instruments for cost effective implementation. In the entire process, considerable efforts and investment is required to improve the knowledge and skill of the planners, intermediaries and end users through climate education.

The approach can address the key issues relevant to researchers and decision makers in the areas of climate prediction, developing management options, climate communication, and institutional and policy environment (Figure 8). The framework integrates the major determinants of successful climate application viz., (i) climate predictability, (ii) human vulnerability and (iii) decision capacity and encompasses three evolutionary strategies viz., (i) exploratory (ii) pilot and (iii) an operational phases outlined by Hansen (2002). Our experience strongly suggests the need for interaction among the participants and evenly combines 'top-down' and 'bottom-up' approaches for successful use of seasonal climate forecasts.

Challenges to benefit from seasonal climate forecasts

Despite significant opportunities for forecast application, several obstacles limit the use of climate forecasts in smallholder systems (Table 4). Communicating forecasts uncertainty in probabilistic terms without distortion is now widely recognized as a difficult but crucial challenge (Glantz 1996; Podesta et al. 2002), and hence effective forecast use requires a period of exposure and learning (Hansen, 2002). Our communication exercise in our case study region targeted farmers' needs. Farmers were asked about their objectives (eg. rainfall/yield/gross margin) and decision options for the coming season. The probabilities associated with the required quantities (eg. rainfall, yield levels and returns) to meet the objectives were discussed. Use of pie charts and probability of exceedence graphs were helpful to communicate the uncertainty. Stressing the uncertainty, gambling analogies can provide useful lessen to understand the intricacies of forecasts (Nelson et al. 2002).

Although all India summer monsoon rainfall forecast was issued through mass media from 1988, explaining science of ENSO and seasonal outlooks is new to smallholder communities. The country scale forecast is based on a 16-parameter power regression model (Rajeevan 2001) and, until recently, ignored spatial resolution and probabilities. In our efforts to achieve effective climate communication of probabilistic forecasts, we emphasised issues relating to predictability, agricultural systems and socio-economic features through participatory approaches. Such participative learning allows the scientists to find out about stakeholders' needs, and stakeholders to learn about capabilities and limitations of climate prediction (Hammer et al. 2001).

Table 4. Challenges of using seasonal climate forecasts in smallholder farms

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

Conclusions

Climate sensitive, agricultural risk management requires more rigorous and systematic approaches than normal agricultural extension. It appears that there are substantial opportunities for resource-limited smallholder farmers in developing countries to better manage production through use of climate forecasts. However, communicating the risk/opportunities of alternative management options is a major challenge. Transferring simple rules of thumb into a comprehensive modelling framework may answer some of the ‘what if’ questions faced by the farmers. This also facilitates translating climate information into diverse outcomes, a fact particularly relevant for the smallholder farms. Participatory approaches help us to understand the cropping system determinants and farmer ‘rules of thumb’ for crop management.

The communication efforts need to be focused on the probabilistic nature of climate prediction and management alternatives, because the final decisions will always rest with the farmers. Such empowerment and ownership can give clear understanding of the strength and limitation of climate forecast and the consequent outcome and risks. To conclude, seasonal climate forecasting, agricultural systems analysis based on simulation models and a participatory approach involving decision makers, extension workers and researchers has resulted in better informed decision-making of small holder farmers in India.

Acknowledgement

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