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Technical Session I

Vulnerability Assessment of Rainfed Farming to Climate Change

Climate Sensitivity of Indian Agriculture: Role of Technological Development and Information Diffusion

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ABSTRACT

Climate change impact studies on agriculture are broadly divided into agronomic-economic approach and Ricardian approach. The Ricardian approach, similar in principle to the Hedonic pricing approach of environmental valuation, has received significant attention due to its elegance and also some strong assumptions it makes. Broadly, this approach attempts to estimate climate response function using cross-sectional evidence on land values (or, farm level net-revenue as used in the present analysis) and climate, while controlling for all other cross-sectional variations. This paper attempts to extend the existing knowledge in this field by specifically addressing two important issues: (a) extent of change in climate sensitivity of Indian agriculture over time; (b) importance of accounting for spatial features in the assessment of climate sensitivity.

The analysis based on four decades of data suggests that the climate sensitivity of Indian agriculture is increasing over time, particularly in the period from mid-eighties to late nineties. This finding corroborates the growing evidence of weakening agricultural productivity over the similar period in India. The results also show presence of significant positive spatial autocorrelation, necessitating estimation of climate sensitivity while controlling for the same. While many explanations may exist for the presence of spatial autocorrelation, this paper argued that inter-farmer communication could be one of the primary reasons for the spatial dependence. Field studies carried out in Andhra Pradesh and Tamil Nadu through focus group discussions provided limited evidence in this direction.

Key Words: Climate Change; Indian Agriculture; Environmental Valuation; Spatial; Adaptation.

INTRODUCTION

Over the past two decades, the debate on global climate change has moved from scientific circles to policy circles with the world nations more seriously than ever exploring a range of response strategies to deal with this complex phenomenon that is threatening to have significant and far reaching impacts on human society. The Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment report observed that, 'warming of climate system is now unequivocal, as is now evident from observations of increased in global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea level' (Solomon *et al.,* 2007). Policy responses to climate change include mitigation of greenhouse gases (GHG) that contribute to the expected changes in the Earth's climate, and adaptation to potential impacts caused by the changing climate. While GHG mitigation policies have dominated the overall climate policy so far, adaptation strategies are also being emphasized now to form a more comprehensive overall policy response.

The United Nations Framework Convention on Climate Change (UNFCCC) – the international apex body on climate change – refers to adaptation in the context of change in climate only. In other words, without greenhouse gas emissions, there is no climate change and hence no need for adaptation. Going by this widely accepted interpretation, adaptation is necessary only because mitigation of greenhouse gases may not completely halt climate change. Stern Review summarizes this view: 'adaptation is crucial to deal with the unavoidable impacts of climate change to which the world is already committed' (Stern, 2006, emphasis added). However, the reality is that several millions of people world-over are currently at the risk of climate-related impacts. To say that their sufferings are not the concern of climate change policy could make such policies irrelevant from the point of view of developing countries where most victims of climate-related impacts reside. At the same time, it may not be meaningful to attribute every climate related issue to the climate change policy because it would make an already complex policy issue further complicated. Adaptation in the context of climate change should be discussed taking into account these conflicting perspectives.

For both mitigation and adaptation policy formulation, one of the crucial inputs needed is the potential impacts due to climate change on various climate sensitive sectors. For mitigation, such information would provide the required justification for de-carbonizing the energy systems. On the other hand, in the context of adaptation, knowledge on climate change induced impacts will be helpful in prioritizing the adaptation in the most needed sectors and regions. Further, climate change impacts estimated with proper accounting of adaptation will be helpful in identifying the factors that ameliorate the adverse effects of climate change.

Concern about potential adverse impacts of climate change has triggered what could be named as impact assessment research since early 1990s. Over the past two decades, the impact assessment research has gone through a metamorphosis with gradual movement towards vulnerability and adaptation assessment. However, impact assessment studies continue to prosper with interesting innovations in methodology and scope of analysis. Figure 1 shows the conceptual basis for climate change impact assessment studies, with

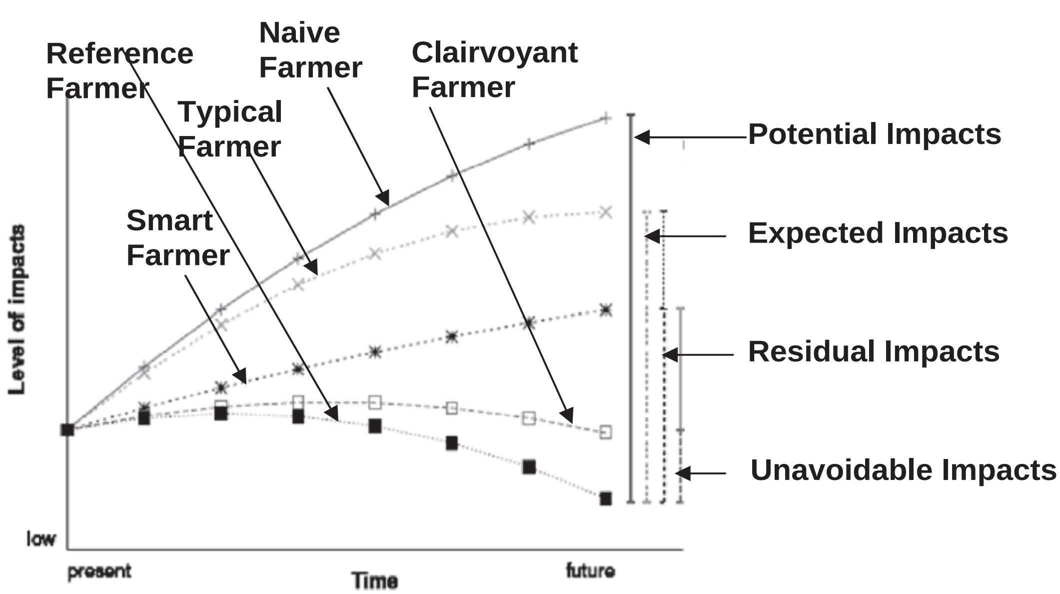

Figure 1. Conceptualization of Climate Change Impacts
(Source: Fussel and Klein, 2006)

focus on agriculture. The reference case illustrates the future without climate change. The naïve farmer allows the adverse impacts of the climate change to manifest without undertaking any adaptation. The impacts under such scenario are referred as potential impacts. A typical farmer is expected to undertake autonomous (or unplanned) adaptation and hence avoid impacts to some extent (resultant impacts are referred as expected impacts). With planned (along with autonomous) adaptation, a smart farmer can further reduce the climate change impacts; the resultant impacts referred as residual impacts. A clairvoyant farmer on the other hand in principle can undertake all theoretically possible adaptations and avoid climate change impacts to the maximum extent. The impacts that even the clairvoyant farmer can not avoid are referred as unavoidable impacts of climate change. In the climate change impacts literature, the residual impacts (or in some cases, the unavoidable impacts) are referred as 'vulnerability'.

Climate change and Indian agriculture

India is a vast country covering 3.28 million km^2, occupying only 2.4 per cent of the world's geographical area but supporting 16.2 per cent of the global human population. It is endowed with varied climate supporting rich biodiversity and highly diverse ecology. More than sixty percent of its population is dependent on climate sensitive activities such as agriculture. Climate change projections made up to 2100 for India, indicate an overall increase in temperature by 2-4^{o}C with no substantial change in precipitation quantity. The expected changes in climate, especially rainfall, are also marked by significant regional variation, with the Western Ghats, the Central Indian and the North Eastern regions projected to receive more rainfall compared to the other parts of India. Further, an increase in intensity and frequency of extreme events such as droughts, floods, and cyclones is also projected. All these changes are likely to have adverse impacts on India's water resources, agriculture, forests and other ecosystems, coastal zones, energy and infrastructure and on human health. Agricultural impacts due to climate change have received considerable attention in India as they are closely linked to the food security and poverty status of a vast majority of population.

Mall *et al.* (2006) provides an excellent review of climate change impact studies on Indian agriculture mainly from physical impacts perspective. The available evidence shows significant drop in yields of important cereal crops like rice and wheat under climate change conditions. However, biophysical impacts on some of the important crops like sugarcane, cotton and sunflower have not yet been studied adequately.

The economic impacts of climate change on agriculture have been studied extensively world over and it continues to be a hotly debated research problem. There are two broad approaches for assessing economic impacts – agronomic-economic approach and Ricardian approach. In the first approach the physical impacts (in the form of yield changes and/or area changes estimated through crop simulation models) are introduced into an economic model exogenously as Hicks neutral technical changes. In the Indian context Kavi Kumar and Parikh (2001a) have estimated the macro level impacts of climate change using such approach. They showed that under doubled carbon dioxide concentration levels in the later half of twenty first century the gross domestic product would decline by 1.4 to 3 percentage points under various climate change scenarios. More significantly they also estimated increase in the proportion of population in the bottom income groups of the society in both rural and urban India under climate change conditions. One of the major limitations of this approach is its treatment of adaptation. Since the physical impacts of agriculture are to be re-estimated under each adaptation strategy, only a limited number of strategies can be analyzed.

Since the scope for incorporating adaptation into the agronomic-economic approach is rather limited, an alternative approach was proposed by Mendeloshn *et al.* (1994). This approach, called Ricardian approach, is similar to Hedonic pricing approach of environmental valuation. The approach is based on the argument that, 'by examining two agricultural areas that are similar in all respects except that one has a climate on average (say) 3^{o}C warmer than the other, one would be able to infer the *willingness to pay* in agriculture to avoid a 3^{o}C temperature rise' (Kolstad, 2000). While all possible adaptations are accounted for in the impact estimation using this approach, the constant relative prices assumption could lead to biased results of this approach. For India, Kumar and Parikh (2001b) have used a variant of this approach and showed that a 2^{o}C temperature rise in and seven percent increase in rainfall would lead to almost 9 percent loss in farm level net revenue (1990 net-revenue expressed in 1999-2000 prices). The regional differences are significantly large with northern and central Indian districts along with coastal districts bearing relatively large impact. Mendelsohn *et al.* (2001) have compared climate sensitivity of the US, Brazilian and Indian agriculture using the estimates based on the Ricardian approach and have argued that using the US estimates for assessing climate change impacts on Indian agriculture would provide biased results.

The results of the two broad approaches outlined above correspond to what could be termed as 'typical' and 'clairvoyant' farmer, respectively (Fig.1). While the estimates from agronomic-economic approach account for adaptation only in partial manner, the Ricardian approach treats farmer as though she has perfect foresight. In the Ricardian approach, farmers are assumed to identify instantaneously and perfectly any change in climate, evaluate all associated changes in market conditions and then modify their actions to maximize profits. These assumptions also imply that agricultural system is ergodic i.e., space and time are substitutable. Ergodic assumption implies, for example, that skills, institutional and financial endowments for responding to say, drought (that are typically refined in arid places) are assumed to be available for use by people in humid areas (where such resources are under-developed) immediately and in essentially cost-less manner. Further, there is scope for inter-farmer communication and information diffusion. Both these factors motivate incorporation of spatial features in the Ricaridan analysis. There are other motivations for accounting for spatial autocorrelation in the Ricardian analysis. For instance, Schlenker *et al.* (2006) bring in spatial features to arrive at efficient estimators of regression parameters. Recent studies in the US have demonstrated that such refinements are essential to get accurate estimates of climate sensitivity (Polsky, 2004; Schlenker *et al.,* 2006).

Similarly, careful analysis of the changing nature of climate sensitivity of Indian agriculture is important to understand the role of technology in ameliorating the climate change impacts. This paper attempts to incorporate these features into the Ricardian approach to assess the climate change impacts on Indian agriculture.

Any study dealing with climate change impact assessment should be wary about the potential uncertainties associated with the analysis. Uncertainties exist at each step of the impact assessment starting with the climate predictions. The degree of uncertainty increases as the analysis moves towards economic impact assessment. Among the various sources of uncertainties, the uncertainty associated with climate predictions perhaps is the most crucial and difficult to deal with. Most studies in the literature have adopted scenario approach to handle the climate uncertainty. Thus, there is no single climate prediction for which the impacts would be assessed, but they are estimated for a range of likely temperature/precipitation combinations. The present study also follows similar approach and as explained at the beginning of section 3, predictions from a number of climate models have been considered while developing India specific climate change scenario. Based on this suite of climate models, by 2070-2099, the average temperatures across seasons are likely to range between 2.5 to 5°C over different regions of India. Winter temperatures are likely to be significantly higher ranging between 3.75 to 4.95°C across the regions. The uncertainty is much higher with regard to the precipitation prediction and by 2070-2099 the South-West monsoon precipitation is likely to increase between 9 to 27% across the regions.

The rest of the paper is structured as follows: The next section explains the model structure and data. The third section presents results and discusses the distributional issues of climate change impacts on Indian agriculture. The fourth section briefly discusses the lessons learnt about inter-farmer communication through focus group meetings in Andhra Pradesh and Tamil Nadu. The last section provides policy discussion and concludes the paper.

Model specification and data

The Ricardian approach suggests that under certain assumptions, the value of the change in the environment is captured exactly by the change in aggregate land values (Mendelsohn *et al.*, 1994). Due to non-existent and/or absence of well functioning land markets in the developing countries, a variant of Ricardian approach has been used in the earlier Indian studies. In place of land values, farm level net-revenue is used as welfare indicator and the value of the change in the environment is assessed through change in farm level net revenue. The Ricardian model is specified as follows:

$$R = f(T_j, T^2_j, P_j, P^2_j, T_j, P_j, SOIL, BULLOCK, TRACTOR, POPDEN, LITPROP, CULTIV, HYV\ IRR, ALT) \quad (1)$$

where, R represents farm level net revenue per hectare in constant rupees; T and P represent temperature and rainfall respectively. It may be noted that based on the existing literature a quadratic functional specification is adopted and the model includes climate interaction terms also. The control variables include soil (captured through dummies representing several soil texture classes and top-soil depth classes), extent of mechanization (captured through number of bullocks and tractors per hectare), percentage of literate population, population density, altitude (to account for solar radiation received), number of cultivators (since the cost of labor could not be accounted for while calculating the dependent variable), fraction of area under irrigation and fraction of area under high-yielding variety seeds.

Cross-sectional data is used for estimating the above model. Districts are the lowest administrative unit at which reliable agricultural data is available. A comprehensive district level dataset of the period 1956 to 1999 is developed for the purpose of analysis. Agricultural data at district level is assembled in the dataset along with relevant demographic and macro economic data. This dataset expands an earlier dataset developed by the author along with two other researchers for the period 1956 to 1986. The dataset covers districts defined as per 1961 census across thirteen major states of India (Andhra Pradesh, Haryana, Madhya Pradesh, Maharashtra, Karnataka, Punjab, Tamil Nadu, Uttar Pradesh, Bihar, Gujarat, Rajasthan, Orissa and West Bengal). In all the dataset includes 271 districts. For the purpose of analysis, the dataset is divided into three distinct periods: 1956-1970; 1971-1985; 1986-1999. Analysis over these three periods will provide insight on changing nature of climate sensitivity of Indian agriculture over time.

The variables covered in the dataset include, gross and net cropped area; gross and net irrigated area; cultivators; agricultural laborers; cropped area under high-yielding variety seeds; total cropped area under five major crops (rice, wheat, maize, bajra and jowar) and fifteen minor crops (barley, gram, ragi, tur, potato, ground nut, tobacco, sesamum, ramseed, sugarcane, cotton, other pulses, jute, soybean, and sunflower); bullocks; tractors; literacy rate; population density; fertilizer consumption (N, P, K) and prices; agricultural wages; crop produce; farm harvest prices; soil texture and top soil depth. For the purpose of analysis, farm level net revenue per hectare is defined as follows:

$$\textit{Net}\ \text{Revenue}\ \textit{per ha} = \frac{((\textit{Gross}\ \text{Revenue}) - (\text{Fertilizer and Labor Costs}))}{\textit{Total Area}}$$

where, gross revenue is calculated over twenty crops mentioned above, total area is the cropped area under the twenty crops, fertilizer costs are total yearly costs incurred towards use of fertilizer for all the crops and labor costs are yearly expenses towards hiring agricultural laborers. It may be noted that costs attributable to cultivators, irrigation, bullocks and tractors are not included in the net revenue calculations as appropriate prices are difficult to identify. However, these variables are used as control variables in the model as specified in equation (1).

Unfortunately, there is no ‘clean’ climate data available for the analysis. Meteorological data is typically collected at meteorological stations and any district may have one or many stations with in its boundary. Since all other data is attributable to a hypothetical centre of the district, the climate data should also be worked out at the centre of the district. For this purpose meteorological station data is interpolated to arrive at district specific climate (Kavi Kumar and Parikh, 2001b; Kavi Kumar 2003 for more details on the surface interpolation employed for generate district level climate data). Climate data corresponding to about 391 meteorological stations spread across India is used for the purpose of developing district level climate. The data on climate – at the meteorological stations and hence at the districts – correspond to the period 1951-1980 and is sourced from a recent publication of India Meteorological Department. All the climatic variables are represented for four months – January, April, July and October. The climatic variables include daily mean temperature and monthly total rainfall.

In each case the panel data is analyzed with year fixed effects and it may be noted that district effects are not considered as the climate (and soil) data is invariant over time. Fixed and random year effects specification is tested through Hausman test in each case. In each time period, fixed effects specification could not be rejected in favor of random effects model. Further, since the units of analysis (i.e., districts) differ significantly in size and agricultural activities, the measurement errors might also substantially differ across districts. Hence, the data for each unit of analysis is weighted by the total area under the twenty crops.

Climate sensitivity and spatial autocorrelation

As argued in the first section presence of spatial autocorrelation necessitates re-specification of model either as spatial lag or spatial error model as shown below:

Spatial error model: $y = X\beta + \eta$, where $\eta = \rho W\eta + \varepsilon$ *(2a)*

Spatial lag model: $y = \rho Wy + X\beta + \varepsilon$ *(2b)*

where, y is (nx1) vector of dependent variable observations, X is (nxm) matrix of observations on independent variables, β is (mx1) regression coefficient vector, η is (nx1) vector of spatially correlated error terms, ρ is

(1x1) the spatial autoregressive parameter, W is (nxn) spatial weights matrix, ε is (nx1) vector of random error terms. Note that y and X are respectively, the left hand and right hand side variables specified in equation (1) above. The period 1966-1986 is considered for the spatial analysis.

One of the crucial inputs needed for spatial analysis is the weight matrix W. While there are several ways to generate the weight matrix, the present analysis used Rook contiguity based weight matrix generated for the Indian districts in GeoDa software. Since it is not feasible to estimate the spatial fixed effects model in GeoDa, the weight matrix is transferred via R-software to ASCII data format. The spatial panel model is estimated using MATLAB software as it provides scope for reading sparse matrices. Table 1 shows details of various analyses carried out.

Table 1. Details of various analyses

Sl. No.	Aim of the Analysis	Period(s) of Analysis	Model Specification	Estimation Procedure and Software Used
1	Explore changing nature of climate sensitivity over time	1956-1999 with sub-periods:1956-1970; 1971-1985; 1986-1999	Equation (1)	Panel fixed (year) effects by weighting the observations; STATA
2	Explore influence of spatial autocorrelation on climate sensitivity	1966-1986	Equation (2a) and (2b)	Panel fixed (year) effects with correction for spatial autocorrelation; GeoDA; R; MATLAB

Results

The results are reported in three sub-sections: in the first sub-section the changing nature of climate response function over time is presented along with estimates of climate change impacts. The second sub-section reports the results based on spatial analysis along with the estimates of climate change impacts with and without the correction for spatial autocorrelation.

The climate change projections for India used for the analysis are those reported in Cline (2007). The climate change projections are average of predictions of six general circulation models including HadCM3, CSIRO-Mk2, CGCM2, GFDL-R30, CCSR/NIES, and ECHAM4/OPYC3. Table 2 shows the region-wise and season-wise temperature and rainfall changes for the period 2070-2099 with reference to the base period 1960-1990. From these regional projections, state-wise climate change predictions are assessed by comparing the latitude-longitude ranges of the regions with those of the states. Besides this, India specific climate change scenario, the impacts are also assessed for two illustrative uniform climate change scenarios that embrace the aggregate changes outlined in the fourth assessment report of IPCC (Solomon, 2007).

Table 2. Projected changes in climate in India : 2070-2099

	Jan.-March	April-June	July-Sep.	Oct.-Dec.
Temperature Change (ºC)				
Northeast	4.95	4.11	2.88	4.05
Northwest	4.53	4.25	2.96	4.16
Southeast	4.16	3.21	2.53	3.29
Southwest	3.74	3.07	2.52	3.04
Precipitation Change (%)				
Northeast	-9.3	20.3	21.0	7.5
Northwest	7.2	7.1	27.2	57.0
Southeast	-32.9	29.7	10.9	0.7
Southwest	22.3	32.3	8.8	8.5

Changing nature of climate sensitivity of Indian agriculture over time

Equation (1) is estimated using the pooled data over the period 1956-1999 by separating out climate coefficients for three distinct periods: 1956-1970, 1971-1985, and 1986-1999. Year effects are included in the estimation. Hausman test favored fixed effects specification against the random effects. Table 3 shows the estimates of climate coefficients along with important control variables for the three time periods. The dependent variable in each case is net revenue per hectare expressed in constant 1999-2000 prices. The control variables are all significant in all the three periods and have expected sign. Barring a very few exceptions, in all the three periods, the climate coefficients are all significant and the F-tests for joint significance of climate coefficients in each period rejected the null-hypothesis.

Inclusion of interaction terms makes it difficult to interpret the marginal effects of temperature and precipitation. To gain insight about the effect of climate variation terms in the model the climate change induced impacts are estimated for the climate change scenarios described above. The climate change induced impacts are measured through changes in net revenue triggered by expected changes in the climate variables. The impacts are estimated for each year at individual district level and are then aggregated to derive the national level impacts. Average impacts over all the years are reported in Table 4. The table reports the all India level impacts estimated in each time period as percentage of 1990 all India net revenue expressed in 1999-2000 prices. Comparison with 1990 net revenue is considered mainly to accommodate comparison with previous results reported in the literature. The impacts are interpreted as change in 1990 net-revenue if the future climate changes were to be imposed on 1990 economy. As could be seen the impacts (based on the illustrative uniform scenarios) are increasing over time indicating increasing climate sensitivity of Indian agriculture. This is despite the possible advances made through technology adoption and overall development. Significantly higher impacts reported in the period from mid-eighties to late nineties. This finding corroborates the growing evidence of weakening agricultural productivity over the similar period in India. The impacts estimated using India specific climate projections show that impacts decline in period 1971-1985 and again increase in the last period. The decline in the middle period could possibly be due to improved resilience of Indian agriculture during this period and also due to the regional variation in the climate projections.

Table 3. Climate response function over time

Variable	1956-1970		1971-1985		1986-1999	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Climate Variables						
Jan-T	-449.8602	0.000	-327.4542	0.001	-399.9256	0.000
Apr-T	-26.2412	0.809	-855.2145	0.000	-985.8106	0.000
Jul-T	-737.5402	0.000	-838.6752	0.000	-763.3346	0.000
Oct-T	1603.5600	0.000	2158.3240	0.000	2624.1480	0.000
Jan-P	17.0548	0.189	39.9249	0.001	122.5294	0.000
Apr-P	-8.0753	0.038	-19.5432	0.000	-16.7260	0.000
Jul-P	-0.2700	0.755	-2.9057	0.000	1.0216	0.194
Oct-P	25.8997	0.000	26.7250	0.000	12.4678	0.002
Jan-T-sq	-6.2100	0.702	-49.9343	0.001	26.6250	0.111
Apr-T-sq	-15.1834	0.605	150.2279	0.000	50.1199	0.049
Jul-T-sq	-157.3086	0.007	-88.3555	0.109	-350.6405	0.000
Oct-T-sq	-154.4181	0.000	-269.8104	0.000	-321.1355	0.000
Jan-P-sq	-0.7280	0.069	-2.9675	0.000	-3.0880	0.000
Apr-P-sq	0.1024	0.003	0.1896	0.000	0.2141	0.000
Jul-P-sq	0.0039	0.016	0.0016	0.276	0.0030	0.034
Oct-P-sq	-0.0142	0.686	0.0459	0.161	-0.0654	0.049
Jan-TP	-21.7075	0.000	-34.5983	0.000	-20.2050	0.000
Apr-TP	7.9786	0.000	16.5937	0.000	15.8305	0.000
Jul-TP	-1.2940	0.022	-1.8498	0.000	-2.0714	0.000
Oct-TP	1.1694	0.546	-3.1449	0.074	-6.1247	0.001
Control Variables						
Cultivators/ha	336.7072	0.263	435.8161	0.068	587.3252	0.009
Bullocks/ha	958.3203	0.009	-200.0078	0.484	-727.1433	0.006
Tractors/ha	676432.5000	0.000	152806.9000	0.000	88268.4800	0.000
Literacy	123.9629	0.873	2829.1690	0.000	3326.1930	0.000
Pop. Density	376.6634	0.000	217.0976	0.000	47.3803	0.019
Irrigation %	4442.7910	0.000	2178.5120	0.000	2091.4530	0.000
No. of Obs.	11924					
Adj R2	0.5398					

Table 4. Climate change impacts over time

Scenario	1956-1970		1971-1985		1986-1999	
	Impacts	% of 1990 Net Revenue	Impacts	% of 1990 Net Revenue	Impacts	% of 1990 Net Revenue
+2°C/7%	-53.7	-6.1	-76.8	-8.7	-188.7	-21.3
+3.5°C/14%	-297.4	-33.6	-303.4	-34.3	-754.9	-85.3
India Specific CC Scenario	-219.6	-24.8	-153.6	-17.4	-544.4	-61.5

Note: Impacts are in billion rupees, 1999-2000 prices; 1990 net revenue is also expressed in 1999-2000 prices.

Effect of spatial autocorrelation on climate sensitivity

The spatial clustering of the dependent variable (i.e., net revenue per hectare) is analyzed by constructing Moran scatter plots for several time points in the period 1956-1999. Figure 2 shows the scatter plots along with the Moran's I value. The scatter plot is graph of Wy versus y, where W is a row-standardized spatial weight matrix and y = [(net revenue – mean net revenue)/standard deviation of net revenue]. Clustering of values in the upper right quadrant and lower left quadrant represents significant positive spatial autocorrelation. As could be seen from Figure 2 in all the six periods for which the scatter plots are reported, the dependent variable exhibited significant positive spatial autocorrelation.

Indication of significant pattern of spatial clustering given by the spatial autocorrelation statistic represents only the first step in the analysis of spatial data. Two typically considered specifications for modeling spatial dependence are: spatial error and spatial lag model. These models specified in equations (2a) and (2b) are estimated for the period 1966-1986. Table 5 shows the climate response functions estimated with and without consideration of spatial autocorrelation. All the estimates are based on fixed (year) effects specification in the pooled data and observations are weighted by the total area under all the crops considered in the analysis. Barring a few exceptions, the climate coefficients in the models that accounts for spatial autocorrelation (either through spatial lag or spatial error models) are uniformly lower than that ignores the presence of spatial autocorrelation indicating the true climate change impacts to be lower. This is confirmed by the climate change impacts reported in Table 6. The overall impacts estimated (for same climate change scenario) using climate coefficients obtained from model that accounts for spatial autocorrelation are significantly lower than those obtained from model that ignores the spatial effects. Figures 3 and 4 compare the distribution of climate change impacts at the state and district level between the model accounts for spatial autocorrelation and that does not. As could be observed, consideration of spatial effects has contributed to positive spin-offs, possibly among other factors due to the inter-farmer communication. The following section explores this issue further.

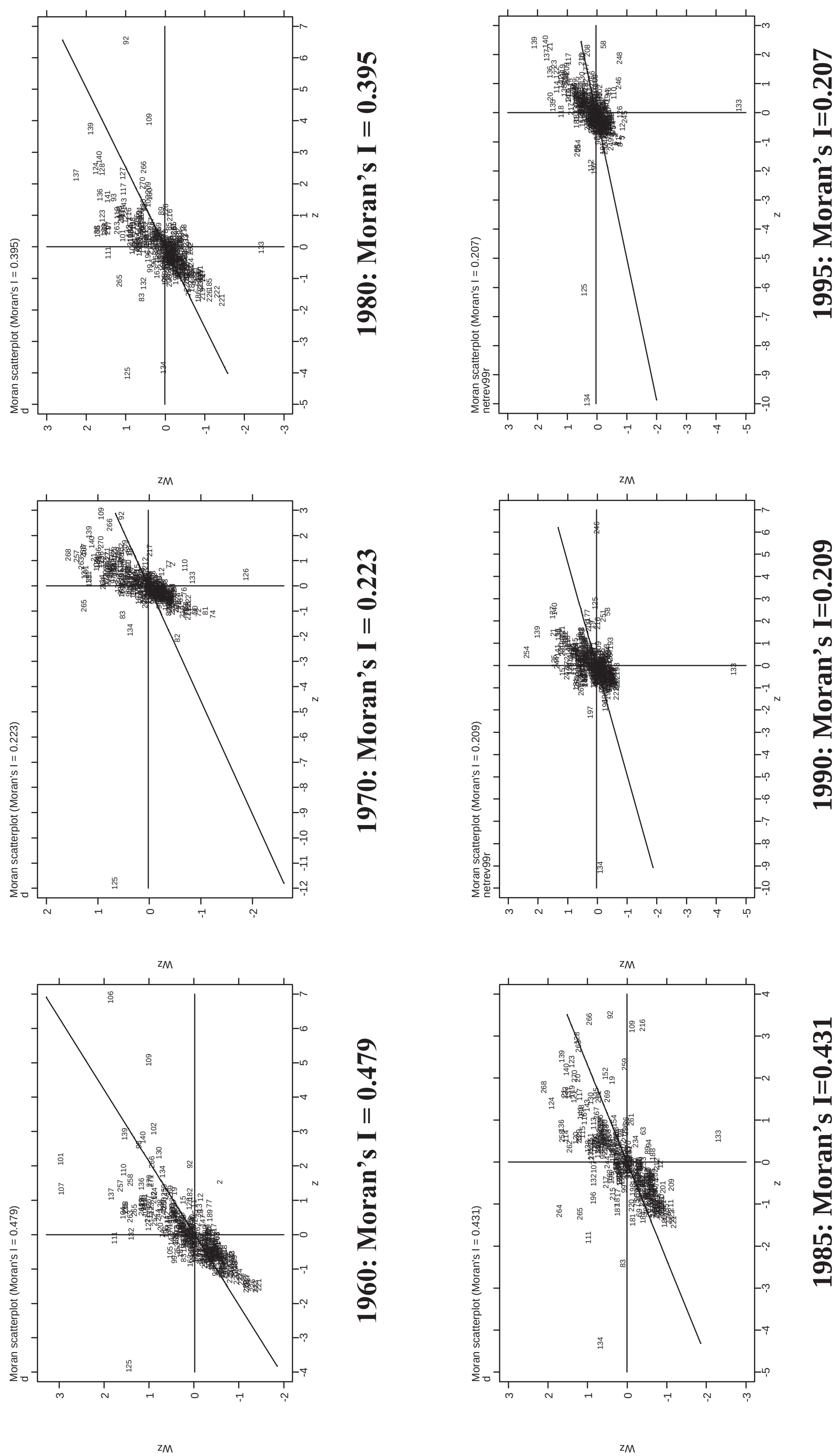

Figure 2. Spatial Autocorrelation - Moran Scatter Plots

Table 5. Effect of spatial autocorrelation on climate sensitivity: 1966-1986

Variable	Without Spatial Autocorrelation		With Spatial Autocorrelation			
			Spatial Lag Model		Spatial Error Model	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Climate Variables						
Jan-T	-443.3306	0.000	-394.8037	0.000	-395.3314	0.000
Apr-T	-695.5482	0.000	-537.1341	0.000	-668.5077	0.000
Jul-T	-817.8726	0.000	-575.3063	0.000	-809.3126	0.000
Oct-T	2160.3500	0.000	1833.0273	0.000	1709.0474	0.000
Jan-P	38.5183	0.000	13.5505	0.106	-7.2706	0.448
Apr-P	-17.2423	0.000	-14.5812	0.000	-7.8016	0.004
Jul-P	-2.1913	0.000	-1.2732	0.027	-2.5012	0.000
Oct-P	29.5283	0.000	20.7544	0.000	18.3900	0.000
Jan-T-sq	-43.8116	0.000	-24.1114	0.033	-11.4262	0.332
Apr-T-sq	118.3944	0.000	101.9399	0.000	138.9808	0.000
Jul-T-sq	-96.9162	0.014	-25.5708	0.524	117.6600	0.006
Oct-T-sq	-264.0382	0.000	-233.9736	0.000	-236.2654	0.000
Jan-P-sq	-2.7809	0.000	-2.5723	0.000	-1.8918	0.000
Apr-P-sq	0.1738	0.000	0.1530	0.000	0.0967	0.000
Jul-P-sq	0.0037	0.001	0.0049	0.000	0.0022	0.039
Oct-P-sq	0.0281	0.232	0.0885	0.000	0.0566	0.019
Jan-TP	-36.3116	0.000	-38.5205	0.000	-26.7720	0.000
Apr-TP	15.8434	0.000	15.2391	0.000	10.3268	0.000
Jul-TP	-1.4774	0.000	-0.6823	0.071	-0.3687	0.346
Oct-TP	-2.8658	0.024	-4.1127	0.001	1.8310	0.192
Control Variables						
Cultivators/ha	253.3993	0.119	163.0752	0.331	758.4805	0.000
Bullocks/ha	103.0263	0.615	558.4283	0.009	1105.5576	0.000
Tractors/ha	147348.6918	0.000	63282.7868	0.000	67538.9637	0.000
Literacy	2429.2926	0.000	4039.0490	0.000	3160.1950	0.000
Pop. Density	178.9486	0.000	174.4978	0.000	182.0459	0.000
Irrigation %	2669.4620	0.000	2648.3836	0.000	3538.1377	0.000
Spatial Lag/Spat. Auto.			0.0649	0.000	0.5719	0.000
No. of Obs.	5691	5691	5691			
Adj. R2	0.6791	0.6517	0.7233			

Table 6. Climate change impacts – without and with accounting for spatial autocorrelation : 1966-1986

Scenario	Without Spatial Autocorrelation		With Spatial Autocorrelation			
			Spatial Lag Model		Spatial Error Model	
	Impacts	% of 1990 Net Revenu	Impacts	% of 1990 Net Revenu	Impacts	% of 1990 Net Revenu
+2oC/7%	-81.2	-9.17	14.2	1.6	-22.9	-2.6
India Specific CC Scenario	-195.1	-22.1	43.4	4.9	-2.1	-0.23

Note: Impacts are in billion rupees, 1999-2000 prices; 1990 net revenue is also expressed in 1999-2000 prices.

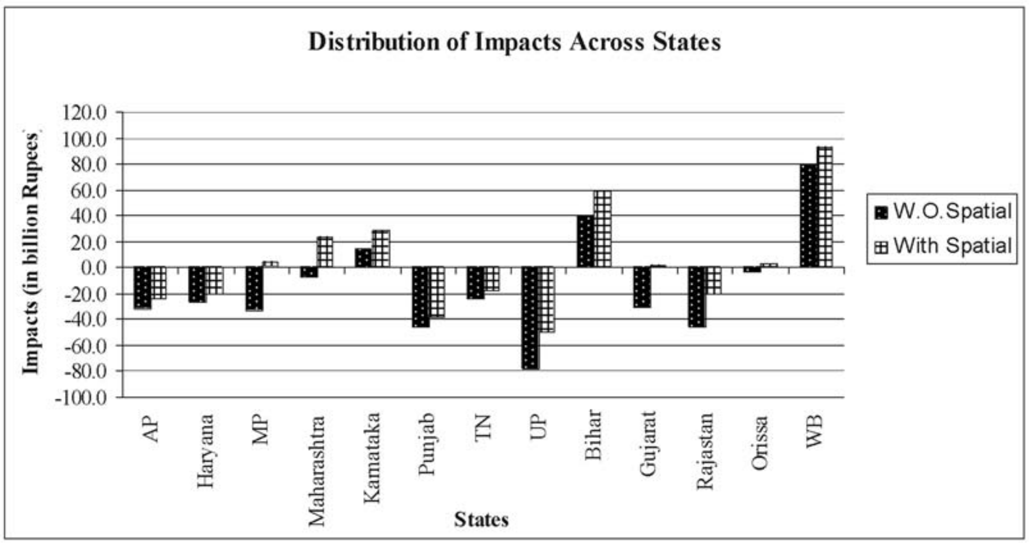

Figure 3. State-wise Distribution of Impacts due to India Specific Climate Change Scenario: With and without Spatial Autocorrelation

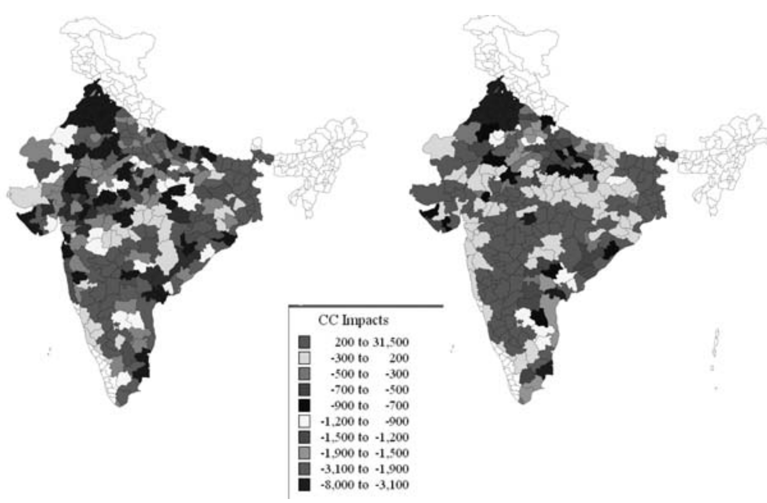

Figure 4. Distribution of Climate Change Impacts across Districts – Without and With Spatial Autocorrelation.

Evidence on inter-farmer communication

In an attempt to understand the scope and extent of information exchange between farmers, focus group meetings are held at around six villages each in Tamil Nadu and Andhra Pradesh. The focus group meetings mainly explored the perceptions of the villagers about the climate change and their views on strategies helpful in ameliorating the climate change impacts. Among other things, special attention is paid to the channels through which information diffusion takes place.

The field level analysis showed that while most farmers are familiar with the term climate change, their understanding is often completely misplaced. All climate / natural patterns are perceived as climate change with little or no distinction between future climate change and present day climate concerns (that manifest in the form of climate extremes like droughts, floods and cyclones, and abnormal weather patterns like un-seasonal rainfall etc.). Also, there is a consensus in most discussions that anthropogenic activities leading to excess pollution are often responsible for the abnormal weather. Most farmers also consider climate / weather concerns to be more threatening than other risks such as price changes. The reasons cited for such perceptions include, bigger scale of impact that climate / weather risks may cause, and limited scope for adaptation. Such perceptions are uniformly held by small, medium and large farmers.

Almost all focus group meetings indicated that there is dearth of information. Farmers irrespective of size are in search of information – which could include advice on input use, pest control, agronomic practices, and soil and water conservation practices. Among the various sources through which information diffusion takes place, most focus group discussions ranked large farmers in the neighborhood as the primary source. Not surprisingly, the agricultural extension services offered by the government are not seen as appropriate source of information, mainly due to the manner in which the extension services provide information. While the information needs are different across farmers based on their scale of operation and kind of crops cultivated, the agricultural extension services often package the information in uniform manner as though one size fits all. Similarly, the usual information diffusion sources such as television and radio also appear to be less effective in reaching out, partly because these sources are often seen as entertainment sources rather than information channels. Discussion in several focus group meetings revealed that farmers often depend on fertilizer and pesticide dealers for information on new varieties and new agricultural practices. While this source has appropriate self regulated checks against provision of wrong information, it is important to ensure that incorrect information does not reach the farmers even inadvertently.

New information does not often reach agricultural laborers. Given the large size of this group and the important role it plays in determining agricultural productivity, it is important to ensure that this group is also targeted along with farmers in providing information on agricultural practices etc. Similarly, the information diffusion must take place to reach female farmers also alongside their male counterparts.

The field studies also revealed that new sources of information diffusion should be explored and experimented. Given the fragmented nature of Indian agricultural lands, large scale participation of corporate sector in providing agricultural extension services could be difficult, and hence other options must be explored. Among other things, the farmers favored participation of agricultural cooperatives, NGOs, and dealers of inputs and fertilizers in information diffusion. In this context, other country experiences should also be carefully studied to identify the routes through which the agricultural extension services could be provided to the farmers. For instance, in Ecuador the agricultural extension workers operate in tandem with the farmers through share cropping to ensure proper information diffusion. On the other hand, Chile finances the costs of private sector firms transferring the technology know-how and information on new agricultural practices to small scale farmers.

CONCLUSIONS

Before discussing the policy issues emerging from the study, it is important to place the climate change issues in the broader context of sustainable development. Given the long-time horizon nature of climate change problem, the climate change operates at the margin along with several other changes over the next several decades. Thus, climate change induced threat operates at the 'margin' of significant threat that societies (especially in developing countries) face through other factors. For instance, quoting other studies Pielke *et al.* (2007) argue that global population at risk from malaria would increase by 100% by 2080 without taking climate change into account, whereas accounting for climate change would further increase this risk by at most 7%. Hence, it is important to design adaptation policies that can be described as win-win strategies – that is, strategies that provide benefits for multiple threats and not focus exclusively on climate change.

The evidence presented in this paper suggests that (a) climate change impacts are increasing over time indicating the increasing climate sensitivity of Indian agriculture; (b) the climate response function is robust to the inclusion of weather variability and annual weather deviation in the model specification; and (c) accounting for spatial autocorrelation is important due to the presence of significant spatial clustering of the data. Further, the climate change impacts are significantly lower after incorporating spatial effects in the model specification. Among other things, inter-farmer communication could be responsible for the presence of spatial effects. Arguing that it can be viewed as effective adaptation strategy, the paper also investigated for the presence of interaction between farmers through focus group meetings at several villages in Andhra Pradesh and Tamil Nadu. The study findings generally support the notion of information diffusion between farmers, with diverse agents acting as the information providers. In contrast to the general belief that agricultural extension centers operate as primary source of information, the evidence from the field discussions indicate that in reality farmers are benefited very little through these government outfits. The main sources of information are in fact the large farmers in the neighborhood, fertilizer and pesticide dealers, seed providers, and family members.

Given the importance of adaptation as suggested by these findings one issue needs careful attention: How to adapt and adapt to what?

How to adapt and adapt to what?

The impact assessment literature mainly focused on what could be termed as engineering / technological adaptation options. One measure of the potential and cost of adaptation is to consider the historical record of past speeds of adoption of new technologies. For example, Reilly and Schimmelpfenng (1999) show the relative speed of adoption of various adaptation measures. While the time taken for relatively soft adaptation measures such as variety adoption and fertilizer adoption could be in the range of 3 to 10 years, the hard options like development of irrigation equipment and irrigation systems take much longer time. Jodha (1989) also provides similar estimates based on evidence from post-independent India. These adjustment times indicate that for effective implementation of adaptation strategies appropriate planning must start well before the manifestation of climate change. Also, soft options could be more cost effective and hence should be explored first. Often the soft options (which include enhancing inter-farmer communication discussed here) may provide dual advantage of gearing up for the future climate change as well as providing benefits under the present-day conditions.

This leads the discussion to the next issue: adapt to what? This has significant policy relevance in the ongoing discussion on ‘mainstreaming’ the climate policies. For vast majority of developing countries (including India) climate change is a distant and invisible threat whereas they are presently exposed to a range of stresses (including climate related shocks such as cyclones, droughts and floods). If climate change response strategies were to be embraced by these countries it is imperative that such response strategies are aligned with development agenda. Also, for adaptation to be employed and to be effective they would need to be shown to be relevant to local people and they would need to be integrated into decision-making structures and processes. It is unrealistic to expect special policy initiatives to deal with climate change adaptation by itself, especially when so many of the suggested adaptation measures (such as drought planning, coastal zone management, early warning etc.) are currently being addressed in other policies and programs. Thus as argued by Smit and Benhin (2004), in order to mainstream, it is essential that the analyst pay serious attention to: (a) the climate related issues that matter now to the community; (b) the management or coping strategies presently employed by the local community to deal with those conditions; and (c) the policy structure that exist now to deal with such conditions.

The integration of climate and development policies (at least in the local context) need not be interpreted as nullification of the need for research on climate change specific adaptation options. On the contrary, the two should be seen as complimentary to each other. There are response strategies that societies undertake in response to non-climatic stimuli such as globalization. It is important to integrate such strategies with the climate change concerns as otherwise there is scope for mal-adaptations. Adaptation in the climate change context is fairly complex but given the long-term nature of the climate change problem and sustainable development goals, it is important to choose actions from a holistic perspective rather than stand-alone approach. Figure 5 presents an integrated conceptual framework for addressing adaptation.

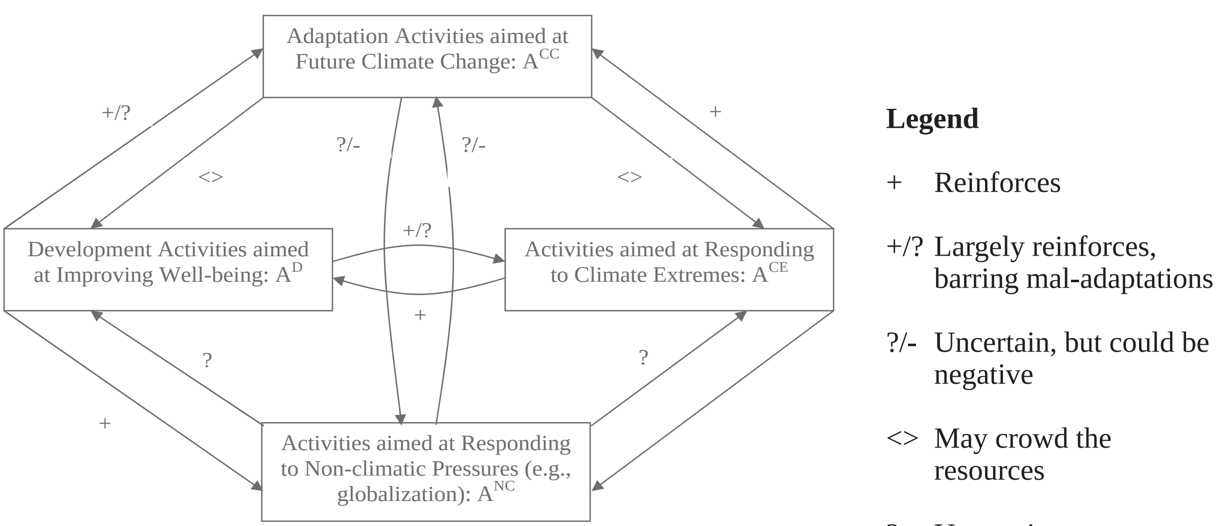

Figure 5. Conceptual Framework for Adaptation Analysis

Underlying this framework is the implicit assumption that adaptation strategies geared to cope with large climate anomalies that society faces currently embrace a large proportion of the envelope of adjustments expected under long-term climate change. In other words the climate policies (at least in the local context) need not be something different from the development policies. However, this need not be interpreted as nullification of need for research on climate change specific adaptation options. On the contrary the two should be seen as complimentary to each other. Similar arguments can also be made with regard to the development policies as well as the policies geared towards non-climatic pressures such as globalization. The recommendations of Interagency Report (2003) are also on similar lines.

Studies of adaptation to current climate also make it clear that human activities are not always as well adapted as one would want them to be. As argued by Burton *et al.* (1993) the losses suffered due to climate extremes cannot be ascribed to the events alone because lack of appropriate human adaptation and sometimes maladaptation account for significant losses. In this context it may be worth noting the experiences with the Super Cyclone in 1999 that devastated the state of Orissa. There is a general agreement that cyclone devastation was worsened significantly by deforestation on the coast. Satellite pictures show that 2.5 square kilometres of mangroves were lost in the 70s every year. In a recent study, Das (2007) has rigorously established that about 92 percent of the deaths could have been avoided at Kendrapada during 1999 super cyclone in Orissa had the mangrove forests that existed in the year 1950 were still in place. Similar savings would have also been possible for animal lives and material losses. Enhancing the inter-farmer communication – suggested as adaptation strategy in this paper – could also lead to improvement in the present coping capacity of farmers.

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Afforestation in Watersheds and WADIs for Carbon Credits and Climate Change Mitigation

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ABSTRACT

NABARD in the 1990s initiated a watershed development programme which involved conservation, regeneration and judicious utilization of natural resources. Among various components of the watershed development programme viz. soil and water conservation, crop management, fodder development, livestock management etc., afforestation activities were also undertaken especially in the ridges with the people's active participation. These activities under Clean Development Mechanism (CDM) of Kyoto Protocol can demonstrate a win-win situation for stakeholders from the point of view of climate change, carbon sequestration, carbon credit and sustainable development. If properly designed, these projects would conserve and / or increase carbon stock and at the same time improve rural livelihoods by supplying firewood, fodder, fruits and timber. Under the watershed approach, NABARD has developed an area of 1.7 million hectares, till January, 2010 in 17 states with grant assistance of Rs. 30.33 crores and with loan cum grant assistance of Rs. 56.97 crores. However, NABARD's total commitment for watershed development with grants is Rs. 65.28 crores and under loan cum grant, it is Rs. 122.32 crores. It has also developed 45,356 ha area under WADI (a small orchard), which are basically horti-silviculture projects and are eligible for Carbon Emission Reduction (CER) and carbon credits. NABARD has also sanctioned a climate change proofing / adaptation project in agriculture under watershed approach to an NGO, "Watershed Organisation Trust" (WOTR) jointly with Swiss Agency for Development and Cooperation (SDC), to develop more insights and working models in the agriculture sector.

Keywords: Watershed, WADI, Afforestation, Carbon credit, Climate Change Mitigation.

INTRODUCTION

National Bank for Agriculture and Rural Development (NABARD) is an apex developmental bank with the mandate to promote sustainable and equitable agriculture and rural prosperity through effective credit support, related services, institutional development and other innovative mechanisms. It's main objective is to facilitate credit flow for agriculture and integrated rural development, promote and support policies, practices and innovations conducive to rural development and strengthening the rural credit delivery system through institutional development measures and effective supervision.

The National Agriculture Policy, (2000) has stressed the need for Agroforestry for efficient nutrient cycling, nitrogen fixation, organic matter addition and for improving drainage systems. Planning Commission, Government of India (2001) has stated that in order to bring 33% of the land mass under tree cover, 28 million ha. revenue land, 18 million ha. under rainfed and 10 million ha. under irrigated conditions are to be brought under Agroforestry cover, besides rehabilitating 15 million ha. degraded forest land by 2012. To fulfill the above objectives, efforts are necessary to promote new agroforestry projects in the 16 different ecological regions of the country.

NABARD is a pioneering developmental financial institution in popularising forest trees under Agroforestry and in collaboration with WIMCO, a wood based industry, had promoted Poplar (*Populus deltoides*) clones under Agroforestry in the 1980s in the States of Punjab, Haryana, Uttarakhand and Uttar Pradesh which has been highly successful and today Poplar is a household name and a highly profitable business activity in these States. While Poplars were promoted under irrigated conditions, Eucalyptus were promoted under Farm-forestry projects in rainfed conditions in the 1990s in collaboration with ITC-Bhadrachalam Paperboards in Khammam District of Andhra Pradesh, which has been successful and today the Paper Mill uses mainly Eucalyptus pulpwood for paper making. NABARD also promoted *Leucaena leucocephala, Casuarina equisetifolia, Anthocephalus chinensis, Tectona grandis,* Bamboos etc. under agroforestry in different parts of the country.

Methodology

Watershed Development Programme: This programme was initiated by NABARD in the1990s to reduce poverty and improve the standard of living of people by introducing conservation, regeneration and judicious utilization of natural resources for environmental sustainability. The programme consists of two phases :

(a) Capacity Building Phase (CBP) : This phase is administered in village communities with NGOs preparing technical plans and implement and supervise the watershed projects on site.

(b) Full Implementation Phase (FIP) : After successful completion of CBP, the project enters FIP which is the main phase administered by NABARD in association with support organizations like NGOs. A very important issue is the routing of all implementing funds through the Village Watershed Committees through the NGOs. Under watershed, another very important activity is women promotion/ gender integration and the activities which have been taken up by the women out of this fund are drinking water schemes, drainage repair, soak pits, kitchen gardens, community halls, flour mill on group basis, dairy, poultry, stall fed goat rearing, health camps, exposure visits, etc.

NABARD’s watershed development fund

The Union Finance Minister in his budget speech for 1999-2000 had announced the creation of a Watershed Development Fund in NABARD with broad objectives of unification of multiplicity of watershed development programme into a single national initiative through involvement of village level institution. In pursuance of this, WDF was created in NABARD with a contribution of Rs.100 crore each by Ministry of Agriculture, Government of India and NABARD. The objective of the fund is to spread the message of participatory watershed development. It will be utilized to create the necessary framework conditions to replicate and consolidate the isolated successful initiatives under different programmes with the Government, Semi-Government and NGO sectors. Thereby, all the partners involved viz. watershed community, Central and State Government Departments, Banks, Agriculture Research Institutions, NGOs and NABARD can act in concert to make a break-through in participatory watershed development. WDF was thus operationalised in close coordination with the Central and State Governments as a continuum of their efforts but with a distinct identify.

Utilization of WDF :

The fund is utilized mainly for the following purposes :

- Promotional effort with community, NGO, SHG, Panchayat, etc.,
- Capacity building on grant basis,
- Selectively full-scale financing of collaborative watershed projects on a pilot basis with grant under loan finance,
- Supplementary flexible financing for watershed project,
- Financing implementation of watershed projects through the State Governments on loan basis,
- Supporting promotional activities for micro credit promotion of SHGs, etc.

The WDF was operationalised with flexibility and apart from the activities stated above, other related and essential activities were also supported.

WADI development Programme under Tribal Development Fund (TDF)

NABARD has been closely associated with the implementation of KfW-Germany sponsored WADI (a small orchard) programme for the poor tribal families in Gujarat and Maharashtra States. The WADI model was found to be very effective in creating sustainable livelihood for tribal families. In order to support similar deserving tribal families in other parts of the country, NABARD from its own resources created a dedicated fund called Tribal Development Fund by making an initial contribution of Rs.50 crore. The fund was operationalised on 1 April 2004 and is being augmented from time to time. The fund is used to support all WADI and other sustainable micro enterprises undertaken by tribal families with loan / grant assistance.

Various components of the programme

The core component of the programme is WADI, which is a combination of fruit crops suitable to the area and forestry species on the periphery of the land. Generally two horticulture tree species are selected with few Forestry species in the model to minimize biological and marketing risks. While, the fruit trees will generate income after 4-5 years, the forestry species will provide firewood and work as a fence and also act as a shelter belt. It also helped in reducing pressure on the existing forest. The main activities of WADI are soil conservation, water resources management, sustainable horticulture and human resource development. The programme has been highly successful with people’s participation.

Results

Among various components of watershed and WADI development viz. soil and water conservation, crop management, fodder development, livestock management etc., aforestation activities with both horticultural and forestry crops were also undertaken especially on the highlands with people’s participation. These activities under Land Use, Land Use Change and Forestry (LULUCF) of Kyoto Protocol (KP) can demonstrate a win-win situation from the point of view of climate change and sustainable development. Properly designed, these projects conserve and / or increase carbon stock and at the same time improve rural livelihoods by supplying firewood, fodder, fruits and timber. Under KP only Afforestation and Reforestation (AR) activities are eligible for claiming carbon credits through Clean Development Mechanism (CDM). After meeting the rules and preconditions, revenue generated from sale of carbon credits from AR projects offer huge potential for diversifying Indian agriculture and increase the livelihood base of Indian farmers. Under watershed approach, NABARD has developed 1.7 million hectare land area till January, 2010 in 17 States. The total fund released so far is Rs. 87.30 crores. It has been roughly estimated that around 5% of watershed areas are with tree plantation cover which will account for 85,000 hectares area under AR and is eligible for Carbon Emission Reduction (*CER*) and carbon credit. The tree species planted in the watersheds are: Mango (*Mangifera indica*), Cashewnut (*Anacardium occidentale*) Shisam (*Dalbergia sissoo*), Arjun (*Terminalia arjuna),* Neem (*Azadirachta indica*), Teak (*Tectona grandis*), Eucalyptus tereticornis, Acacia auriculiformis, Casuarina equisetifolia, Bamboo sp. etc. Generally under well managed AR projects, 20 t carbon emission per ha is reduced. Based on this assumption, NABARD's 85,000 ha area under AR will be responsible for reducing a total of 1.7 million tonne carbon emission.

In case of WADI, the entire 1 acre area of each tribal family will be eligible for claiming carbon credits, as it is a tree based farming intervention. The major horticultural trees planted are mango (M. indica) and cashewnut (*A. occidentale*) with several forest trees like Eucalyptus sp, Acacia sp., Neem (*Azadirachta indica*), Casuarina equisetifolia, Teak (*T. grandis*) etc. on the border including Bamboo plantings. Till August 2009 an area of 45,356 ha has been developed with grant assistance of Rs. 52.43 crores. As these interventions are well planned, well documented and well managed tree plantations i.e. much more organized than watershed plantations, carbon emission reduction will be more and is estimated at around 40 MT per ha within 5- 8 years' of plantation growth and responsible for reducing a total of 1.8 million tonne carbon emission.

In collaboration with GTZ, New Delhi, NABARD has appointed a consultant to undertake detailed studies on the AR implemented projects in Watersheds and WADIs to prepare a Project Idea Note (PIN) for host country approval by making a presentation to Designated National Authority (DNA), which is the Ministry of Environment and Forests for India. If approved by DNA, Project Designed Document (PDD) will be prepared for submitting before United Nations Framework Convention on Climate Change (UNFCCC) for registration. Before this, validation by Designated Operational Entities (DOE) will be necessary to estimate actual CERs that can be obtained from these plantations. In the same pattern, it will be desirable for CRIDA and other similar institutions to initiate a massive programme of Agroforestry plantations on farmer's land for reducing carbon emission for climate change mitigation and claiming carbon credits, besides enhancing the livelihood security of Indian farming community. If necessary, NABARD will assist these organizations in their AR activities in relation to Climate Change Adaptation. In fact, NABARD plans to develop Watershed plus activities in the already implemented watersheds for livelihood security of farmers on a sustainable basis.

NABARD and climate change adaptation project

NABARD has recently approved a study for Climate Change Adaptation measures in Agriculture under Watershed approach jointly with Swiss Agency for Development and Cooperation (SDC), Switzerland to the NGO, "Watershed Organisation Trust" (WOTR), Pune. The project will be implemented in 3 clusters comprising of 25 villages in the Akole and Sangamner blocks of Ahmednagar District of Maharashtra state. The total population that will benefit from the project will be 25,786 persons of 4745 households of 25 villages spread over a geographical area of 20,558 ha. Incidentally, this will be the first such project regarding Climate proofing / climate resilient and Climate Change Adaptation in Agriculture in India.

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Technical Session II

Impacts, Adaptation and Mitigation Strategies in Dryland Copping Systems

Strategies for Developing Climate Ready Crop Varieties

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INTRODUCTION

The impact of global climate change on crop production has emerged as a major research priority during the past decade. Several forecasts for coming decades project increase in atmospheric CO_2 and temperature, changes in precipitation resulting in more frequent droughts and floods, widespread runoff leading to leaching of soil nutrients and reduction in fresh-water availability. With the impending global climate change and the need to secure food supplies for the future, it becomes imperative to understand the consequences of climate change on the productivity of important agricultural crop species (Sinha 1994; Lobell *et al.*, 2008). In India impact of 1-2^{o}C increase in mean air temperature is expected to decrease rice yield by about 0.75 t/ha in efficient zones and 0.06 t/ha in coastal regions and impact of 0.5^{o}C increase in winter temperature is projected to reduce wheat yields by 0.45 t/ha. (Aggarwal 2008). Furthermore, crops may experience both low and high weather extremes like drought and flood, heat and chilling etc. in a single cropping season and such changes will have varying and complex impacts on agricultural production. Cumulative metabolic responses are more related to plant productivity under stress than short term and instantaneous responses. The productivity reductions expected under changed climate scenarios are far more permanent than with events of climatic variability. Thus, from an agricultural perspective, crop improvement in view of the global climate change may require incorporation of traits based on adaptation to abiotic stresses and also to enhanced atmospheric CO_2 levels, which affect crop growth, metabolic processes and yield.

Therefore, programmes to develop climate ready varieties with traits such as temperature and drought-tolerance and high yield in various important crops should be initiated urgently, so that the desired kinds of varieties are available when climate change effects are experienced consistently (Sushil Kumar 2006). The climate 'hotspot' areas are more prone to risks due to weather extremes have to be identified and the possible stress environments be quantified. The genetic resources, especially land races and wild relatives from areas where past climates mimicked the projected future climates for agriculturally prime areas, could serve as the starting genotypes for breeding crops for tolerance, maturity and yield attributes. Considerable progress has been made in the genetic dissection of flowering time, inflorescence architecture, and temperature and drought tolerance in certain model plant systems and by comparative genomics in crop plants. A combination of conventional, molecular marker directed, mutational and transgenic-breeding approaches will be required to evolve the desired kinds of crop cultivars (Edmeades *et al*., 2004).

Abiotic stresses – Cross talk

Almost all of these abiotic stresses lead to oxidative stress and involves in the formation of reactive oxygen species (ROS) in plant cells. Usually, plants have mechanisms to reduce their oxidative damage by the activation of antioxidant enzymes and the accumulation of compatible solutes that effectively scavenge ROS. However, if the production of activated oxygen exceeds the plant's capacity to detoxify it, deleterious degenerative reactions do occur, the typical symptoms being loss of osmotic responsiveness, wilting and necrosis. Therefore, it is the balance between the production and the scavenging of activated oxygen that is critical to the maintenance of active growth and metabolism of the plant and overall environmental stress tolerance. Another important aspect of most of the abiotic stresses is the involvement of signal transduction pathways. The relatively independent functional units that make up the signal transduction network are referred to as modules. In plants, the mitogen-activated protein kinase (MAPK) cascade plays a crucial role in various abiotic stress responses and in hormone responses that include ROS signaling (Moon *et al*., 2003).

Each abiotic stress condition requires a unique acclimation response, tailored to the specific needs of the plant, and that a combination of two or more different stresses might require a response that is also unique (Mittler, 2006). Experimental evidence indicates that it is not sufficient to study each of the individual stresses separately and the stress combination should be regarded as a new state of abiotic stress in plants that requires a new defense or acclimation response.

Abiotic stress tolerance – Multigenic and complex

It is well known that abiotic stresses such as drought and heat elicit multigenic responses and it is important to pyramid tolerance genes to achieve satisfactory levels of benefits. A number of adaptive characteristics have been studied and used to identify tolerance to water limited environments including matching the phenology to the available water supply, early vigour, osmotic adjustment (OA), carbon partitioning, transpiration efficiency, grain growth, membrane integrity, leaf senescence and others.

Temperature is a primary environmental factor controlling growth, development and adaptation of plants (Halford 2009), and also determines phenology. There is ample information in the literature on variation for heat tolerance in different crop species (Wheeler *et al.,* 2008). Different physiological mechanisms may contribute to heat tolerance in the field, for example, metabolic tolerance as indicated by higher photosynthetic rates, stay-green, and membrane thermo stability, or heat avoidance as indicated manifested through canopy temperature depression and stomatal conductance. The development of heat-tolerant varieties is a feasible and cost-effective way to reduce the impacts of climate change.

The degree of salt tolerance varies at different phases of life cycle of most plant species (Munns and Tester, 2008). In the simplest analysis of response of a plant to salinity stress, the reduction in shoot growth occurs in two phases: a rapid response to the increase in external osmotic potential and a slower response due to the accumulation of Na^+ in leaves. Of a number of plant responses to salt stress, over production of different types of compatible organic solutes, Na^+/K^+ ratio, ROS, stomatal closure, are the most common ones (Flowers 2004, Munns and Tester 2008).

The effects of elevated carbon dioxide levels on plants and ecosystems have been extensively studied in the past two decades. Crops sense and respond directly to rising CO_2 through photosynthesis and stomatal conductance, and this is the basis for the fertilization effect on yield (Long *et al*., 2006; Vanaja *et al.,* 2006; 2008). However, at the cellular level the biochemical mechanisms underlying CO_2 mediated protection are still poorly understood. Increased atmospheric CO_2 was shown to reduce stomatal opening (Hetherington and Woodward 2003) and this decline in stomatal conductance may be useful to increase water use efficiency in plants. However, under combination of elevated CO_2 and temperature, plants may elicit a very unique response as compared to these conditions individually. During heat stress for example stomata are kept open by the plants for transpirational cooling. However, if it is combined with elevated CO_2 and water deficit plants may not be able to open their stomata and leaf temperature would be higher. Therefore, the regulation and interactions amongst the CO_2 effects and the various abiotic stresses on plants and ecosystems have to be carefully examined. Further, the C_4 and CAM pathways of CO_2 fixation are well known to be associated with better water use efficiency and high temperature adaptability. Analysis of the response of these crops to elevated CO_2 in combination with heat and water deficit would be interesting and may give clues to mechanisms and traits in developing climate ready genotypes.

Climate change and plant traits

To develop crop genotypes which can perform better under the predicted climate change, it is essential to understand the plant traits that are linked to adaptation (Fig. 1). It is well recognized that pattern of plant adaptation is a response to determined environmental condition. Finding and quantifying these patterns in relation to plant functioning has been the focus of research in this area. Plant traits which favour yield and also which have a direct effect on the mechanism of tolerance is one of the important characteristic that has to be considered when developing climate ready crops. These traits have the ability to directly or indirectly control yield over a time scale influencing either water use, water use efficiency and partitioning of biomass to grain. The traits associated with stress tolerance and yield increase will not be usually the same in most crops hence the breeder is presented with a paradox of choices to select from (Shao *et al*., 2007). Some of the traits that have relevance to drought, heat and elevated CO_2 are described in brief as below.

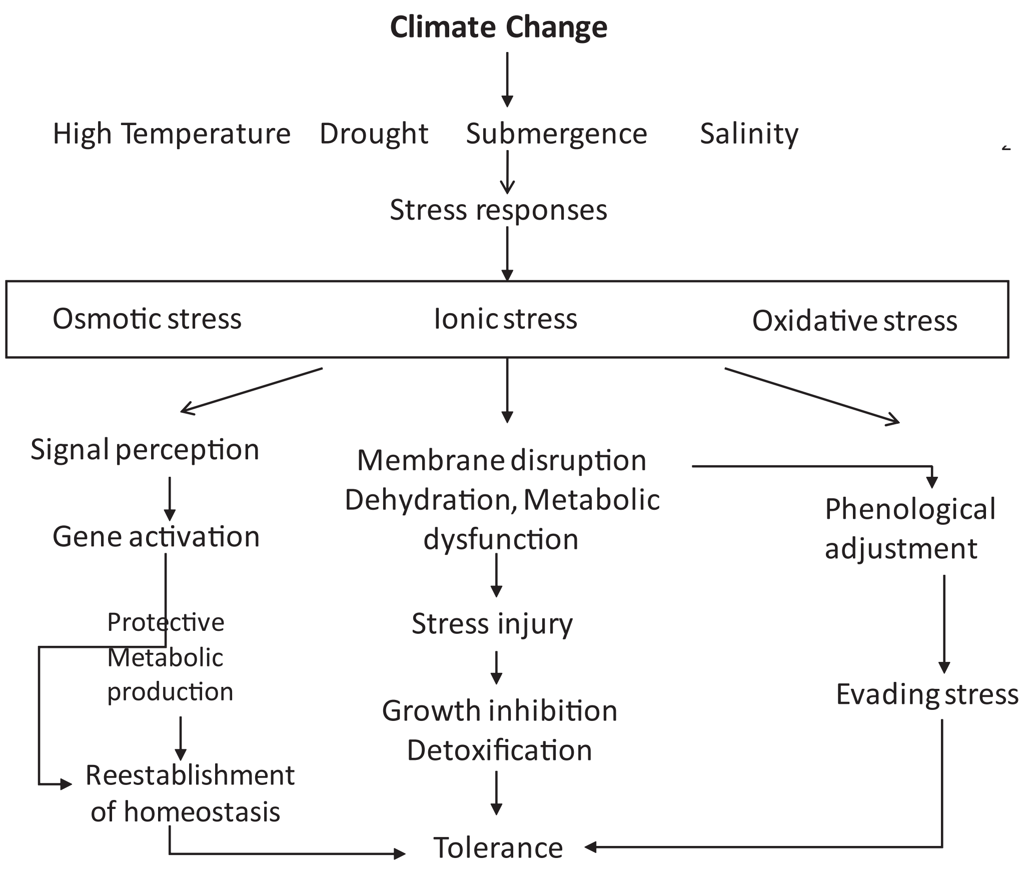


Fig. 1. Physiological and biochemical events in plants resulting in adaptation to abiotic stresses exacerbated due to climate change

Drought tolerance – Traits and genes

In recent years, crop physiology and genomics have led to new insights in drought tolerance providing breeders with new knowledge and tools for plant improvement. A number of physiological studies have recognized some traits for which presence/expression is associated with plant adaptability to drought-prone environments. The reactions of plants to water stress differ significantly at various organizational levels depending upon intensity and duration of stress as well as plant species and its stage of growth. One of the important traits for drought tolerance is better root system with high biomass production. Abscisic acid (ABA) plays a central role in root-to-shoot and cellular signaling in drought stress and in the regulation of growth and stomatal conductance (Zhu 2002). Osmotic adjustment (OA) is another important mechanism facilitating plants under drought to continue water absorption and maintenance of tissue turgor, thus contributing to continued higher photosynthetic rate and expansion growth. Proline and glycine betaine are important compatible solutes accumulating under drought. Similarly stay green trait is relevant in several crops such as maize, rice and sorghum can be used effectively for yield improvement in dry, warm environments, caused by climate change.

One of the major approaches to crop improvement has been to assess drought tolerance on the basis of yield stability or drought susceptible index (Sinha *et al.,* 1986). There is a close relation between the available water in soil profile in post flowering period and yield. Significant progress has also been made in using the variability in water use efficiency for breeding for drought tolerance (Uday Kumar *et al.,* 1998). Since biomass production is tightly linked to transpiration, the effective use of water (EUW) and not high water use efficiency (WUE) is proposed to be the important determinant of plant production under drought (Blum, 2009).

Development of transgenics with an enhanced drought tolerance is another significant achievement and most of these plants are under advanced stages of testing in several crops. Identification, isolation and characterization of drought responsive and adaptation related genes and promoters from several plants as well as microbial sources have been another salient research accomplishment in this area. Several genes have been identified to express in response to drought stress, which include mainly (i) those, which encode products that directly protect cellular metabolism under water deficit and (ii) those regulating gene expression and signal transduction. Stress inducible genes identified so far include functional genes with protective roles in osmoprotection, Reactive Oxygen Scavenging, Ion transport, LEA and HSP. Regulatory genes imparting stress tolerance are those encoding signaling molecules, such as enzymes of phospho-lipid metabolism and various kinases (MAP, CDPKs, histidine kinases etc.) and several transcription factors such as DREB, ABRE etc. These functional as well as regulatory genes with an up-regulated expression under stress are generally treated as ideal candidate genes for imparting stress tolerance. Also, hundreds of genes and their products respond to drought at transcriptional and translational level. Understanding the functions of these stress-inducible genes help to unravel the possible mechanism of stress tolerance. Of late, functional genomic approaches triggered a major paradigm from single gene discovery to thousands of genes by multi-parallel high-throughput techniques. Generation of Expressed sequence tags (ESTs) from cDNA libraries prepared from abiotic stress-treated seedlings in various crops, complete genome sequence information of rice and *Arabidopsis* provided a valuable resource for gene discovery.

Heat tolerance – Traits and genes

Temperature affects most plant-and crop-level processes fundamental to yield determination and hence the development of the final yield response. The impact of increasing temperatures can vary widely between crop species. Species with a high base temperature for crop emergence, such as maize, sorghum, millet, sunflower and some of the legumes such as mungbean and cowpea could benefit from increasing temperatures in cool regions. Most of the small-grain cereals, legumes such as field pea and lentil, linseed and oilseed *Brassica spp.* with a low base temperature could result in an advancement of phenophase with increased temperatures. The optimum temperature for leaf photosynthesis and plant growth is higher for C_4 plants than for C_3 plants.

Under heat stress, differences in photosynthesis have been shown to be associated with a loss of chlorophyll and a change in the a:b chlorophyll ratio due to premature leaf senescence (Al-Khatib and Paulsen, 1984; Allakhverdiev *et al* 2008). Canopy temperature depression (CTD), membrane thermo stability, chlorophyll fluorescence, flag-leaf stomatal conductance, as well as photosynthetic rates were shown to correlate with field performance in several crops (Maheswari *et al.,* 1999; Reynolds *et al.*, 2001; Zhang and Sharkey 2009). Macromolecules, such as Heat Sock Proteins (HSPs) form the integral part of tolerance to high temperature in crops. HSPs are believed to be important for the protection of cells against heat injury both in basal thermo-tolerance as well as in acquired thermo tolerance responses.

Biochemical limitation to heat tolerance in wheat focused on the enzymes involved in grain filling, specifically soluble starch synthesis, which is deactivated at high temperatures (Keeling *et al*., 1994). Many drought-adaptive traits may be useful under heat stress as well. Examples would include leaf glaucousness, awn photosynthesis and early maturity. Nonetheless, not all traits conferring heat tolerance are also associated with genetic variability for drought tolerance.

Elevated CO_2 - Photosynthesis Pathways

There is a strong consensus that elevated CO_2 is capable of eliciting two direct physiological responses in plants viz. enhanced rates of photosynthesis and reduced stomatal conductance. Greater photosynthesis allows greater carbon gain and biomass accumulation, while reduced stomatal conductance leads to lower transpiration and lower soil moisture depletion, which can delay the water deficit (Leakey *et al.*, 2009). In view of the higher adaptability of C_4 plants to warmer and drier environments, transforming C_3 crops into C_4 might be an important strategy to develop climate ready crops (Hausler *et al.*, 2002). Initial attempts involved simply transforming rice with genes encoding C_4 enzymes such as PEP carboxylase, pyruvate orthophosphate dikinase (PPDK) and the NADP-malic enzyme (NADP-ME). Similar transformations have been carried out in potato and tobacco (Murchie *et al*., 2009). It seems tremendously complex to change cellular differentiation, partitioning of enzymes, chloroplast morphology and differential regulation of the metabolic pathways in each cell type. However, support comes from observations that the two metabolic strategies co-exist in both C_3 and C_4 plants species, which can switch between C_3 and C_4 depending on environmental conditions, do exist.

In a more realistic approach, what is envisaged under C_3-C_4 conversion is improving CO_2 concentration mechanism of C_3 crops. The most crucial requirements for a CO_2 concentrating mechanism for efficient photosynthesis include: An active, photosynthetically driven, CO_2 capture system, a supply of photosynthetic energy, an intermediate pool of captured CO_2, a mechanism to release CO_2 from the intermediate pool, a compartment in which to concentrate CO_2 around Rubisco, a means to reduce leakage of CO_2 from the site of CO_2 elevation and modification of the kinetic properties of Rubisco (Leegood 2002).

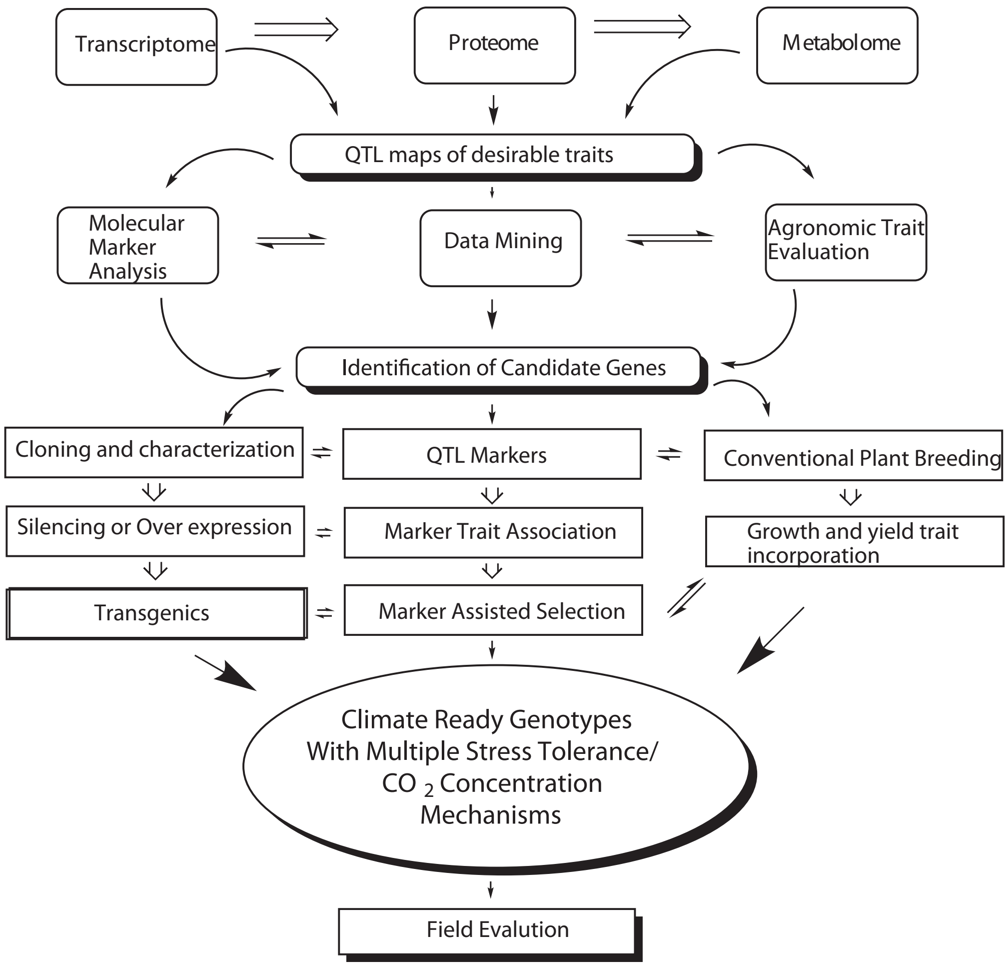
A systematic examination of some of the enzymes of the C_4 pathway such as carbonic anhydrase, PEP carboxylase and PEP carboxy kinase genes in terms of adaptability and diversity across the plant species in various habitats ranging from temperate, arid, halophytic, marine etc. may prove useful in appropriately modifying the enzymes so as to enhance efficiency of CO_2 concentrating mechanism in association with other enzymes of the pathway. This is envisaged to be a step forward in developing climate ready genotypes with improved adaptability and productivity under warmer, drier and elevated CO_2 conditions.

Improving abiotic stress tolerance - Conventional and Molecular approaches

Although considerable progress was made during the 20th century to improve crop yield and quality through conventional breeding progress in improving the tolerance of crops against abiotic stresses, is very modest primarily due to genotype-environment interactions. Nonetheless, the genetic variation of crops was exploited well at intra-specific, inter-specific and inter-generic levels so as to produce stress-tolerant lines/ cultivars. As a result some tolerant genotypes of different crops were developed through conventional breeding and tested under natural field conditions.

Availability of genetic variation in most of the crop species is one of another problem encountered by conventional breeders. The conventional approach as a whole is time-consuming and labor-intensive; undesirable genes are often transferred in combination with desirable ones; and reproductive barriers limit transfer of favorable alleles from inter-specific and inter-generic sources (Chinnusamy *et al*., 2005). Due to these reasons genetic engineering is being employed as a potential option worldwide for improving abiotic stress tolerance.

Plant engineering strategies for abiotic stress tolerance have been focused largely on the expression of genes that are involved in osmolyte biosynthesis (glycine betaine, mannitol, proline, trehalose etc.); genes encoding enzymes for scavenging ROS (SOD, glutathione S- transferase, Glutathione reductase, glyoxylases etc); genes encoding LEA proteins (LEA, HVA1, LE25, Dehydrin etc); genes encoding heterologous enzymes with different temperature optima; genes for molecular chaperons (HSPs);genes encoding transcription factors (DREB 1A,CBF 1, Alfin 1); engineering of cell membranes; proteins involved in ion homeostasis (Murata *et al.*, 1992; Tarczynki *et al* 1993; Bhattacharya *et al* 2004; Zhang *et al.*, 2000; Grover and Minhas 2000; Vinocur and Altman 2005; Maheswari *et al.*, 2010; Trethowan *et al.*, 2010). Development of transgenic plants has undoubtedly opened a new avenue to enhance abiotic stress tolerance in crop plants. However to fine- tune transgenic technology into a successful and practical approach it is important to address issues like using tissue and stage specific and stress inducible promoters to avoid unnecessary biological costs; to target multiple gene regulation rather than single genes; developing near natural field stress evaluation schemes to critically assess the benefits of transgenics rather than at seedling stage and under controlled environments (Bhatnagar-Mathur *et al.*, 2008). Another molecular technology which gained considerable importance in developing abiotic stress tolerance is marker assisted selection (MAS) as it would improve the efficiency of plant breeding through precise transfer of genomic region of interest (foreground selection) and accelerate recovery of the recurrent parent genome (background selection). Considerable efforts were made in crops like maize and rice through MAS (Babu *et al.*, 2002; Mackill and Junjian 2001; Prasanna *et al.*, 2009). With the advent of molecular biology techniques it was presumed that developing stress-tolerant cultivars would be convenient and relatively less time consuming. However, the progress so far does not seem to be as rapid as it was envisaged. An effective integration of transgenic, QTL, MAS and genomic approaches into conventional breeding program seems to be the most essential requirement in developing climate ready genotypes with multiple stress tolerance (Fig. 2).



Process network in development of climate ready cultivars

Challenges and prospects in developing climate ready genotypes

To cope with the scenarios of climate change in terms of elevated CO_2 levels and associated abiotic stresses it is of paramount significance to understand plant responses to abiotic stresses that disturb the homeostatic equilibrium at cellular and molecular level in order to indentify a common mechanism for multiple stress tolerance. A very crucial and highly productive role is envisaged here for biotechnology in identifying metabolic alterations and stress signaling pathways, metabolites and the genes controlling these tolerance responses to stresses and in engineering and breeding more efficient and better adapted new crop cultivars.

Future strategies should take into account several species combinations and the wealth of genetic diversity existing in the land races and wild relatives and should provide a way to harness the existing evolutionary adaptive diversity to develop multiple stress-tolerant crops. Yield stability should be the top priority in climate ready crop breeding programs and it should be kept in mind that increased stress tolerance would be beneficial in terms of only yield stability and not mere survival. An integrated systems approach is essential in the study of complex quantitative traits governing tolerance to multiple abiotic stresses. Selection for yield and stress tolerance *per* se necessitates a "top-down" approach, starting from the dissection of the complex traits to components. Marker-assisted selection (MAS) for abiotic stress related traits should preferably target 'major' QTLs characterized by a sizeable effect, consistent across germplasm and with a limited interaction with the environment.

Analysis of elevated CO_2 response must: quantify on a field scale the genetic variation for the grain yield response of major crops to elevated CO_2; consider both inter-and intra specific variation and identify traits that allow screening of a much wider range of germplasm; use existing genetic variation and new tools from high throughput omics, quantitative genetics, molecular breeding and bioinformatics to elucidate the mechanisms of crop yield response to CO_2; in the longer term determine how yield is impacted by elevated CO_2 in combination with other aspects of climate change and shifts in agricultural practice, specifically rising temperature and altered water availability.

To achieve such a goal, an interdisciplinary and inter institutional approach would be needed with well-defined targets on crops and problems prioritized at the national level.

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Climate Risk Management and Contingency Crop Planning

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ABSTRACT

Weather extremes such as floods, droughts, unseasonal rains, hailstorms, heat and cold waves, etc. are a major source of variability in agricultural production across the world. The occurrence of extreme fluctuations in temperature and precipitation in the recent past over many regions in the world are responsible for bad harvests. Also the water resources, the performance of livestock farms, the turnover of processors, the use of chemicals and fertilizers as well as the demand for many food products also depend on the weather. Hence, agricultural production and greater parts of agribusiness are affected by fluctuations in weather parameters.

Indian agricultural production is fluctuating between 210 to 220 m.t. for the last 10 years, yet its sustainability is in ambiguity due to the uncertain weather during the crop season. Two major drought years (2002 and 2009) and deficit rainfall year (2004) occurred in the first decade of this century. Of the ever-increasing population of India, 70 percent population lives in rural areas and two-thirds of this population depends on agriculture and allied activities for their livelihoods. About 40 to 44 percent of agricultural production in the country comes from rainfed areas. Primarily, rain comes from SW monsoon rainfall that accounts for 74 percent of the annual rainfall over India, whereas northeast monsoon, pre-monsoon and winter rainfall contribute 13, 10 and 3 percent, respectively.

A small aberration like drought and flood in these regions may affect lakhs of human beings, livestock and crops and thereby crippling the economy. In order to reduce the impact of these climate-based risks on agriculture, there are some viable options other than the crop management practices such as crop insurance, market management, financial management, etc. that have been practiced in the developed parts of the world, and have recently been extended into Indian markets to benefit the farmers and their families. Climate risk management in agriculture ranges from informal mechanisms-like identification of vulnerability of regions prone to climate extremes and their probability of occurrence, avoidance of highly risky crops, suitable diversification of crops and cropping systems, a suitable farming system approach to formal mechanisms - like agricultural insurance by development of products, minimum support price system and future's markets. Climate risk management is new concept that has been successfully implemented to manage the weather effects on revenue and expenses. This paper will outline climate risk management solutions through a consortium mode and discuss the contingency crop planning for effective management of agricultural production

Risks in agriculture

Risk is an integral part of agriculture and in each season farmers encounters different types of risks. The following are some of the sources of risks identified in agriculture.

Production risks: Includes weather, insects, disease, technology and any other events that directly affect production quality and quantity.

Price risk: Uncertainty in the market for the selective commodity, such as changes in the prices of inputs and/or outputs.

Financial risk: The method in which capital is acquired and financed and the firms' ability to pay financial obligation.

Institutional risks: Changes in governmental and/or legal policies and standards that affect agriculture.

Personal risk: Death, divorce or injury to the personnel.

Major weather risks for Indian agriculture

Break monsoon: The Indian summer monsoon exhibits substantial inter-seasonal variations, associated with a variety of phenomena such as passage of monsoon disturbances associated with active phase and break monsoon periods whose periodicities vary from 3-5 and 10-15 days respectively. The Indian summer monsoon rainfall varied from 604 to 1020 mm. These inter-seasonal variations cause floods and droughts, which are the major climate risk factors in Indian Agriculture.

Floods due to cyclones: The main causes unprecedented floods in India are due to movement of cyclonic disturbances from Bay of Bengal and Arabian Sea on to the land masses during monsoon and post-monsoon seasons – and during break monsoon conditions in some parts of Uttar Pradesh and Bihar. The thunderstorms due to local weather conditions also damages agricultural crops in the form of flash floods.

Droughts

Drought is a normal, recurrent feature of climate associated with deficiency of rainfall over extended period of time to different dryness levels describing its severity. Drought being subtle, its progress is insidious and its affects can be devastating. During the period 1871-2009 there were 24 major drought years, defined as years with less than one standard deviation below the mean All India Seasonal Rainfall (the deviation below –10%): 1871,1873, 1877, 1899, 1901, 1904, 1905, 1911, 1918, 1920, 1941, 1951, 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1985, 1986, 1987, 2002 and 2009. The most recent major drought in 2009 expressed 50 country's continued vulnerability to droughts and the food-grain production in kharif is likely to fall by 1-015 million tonnes.

Heat waves

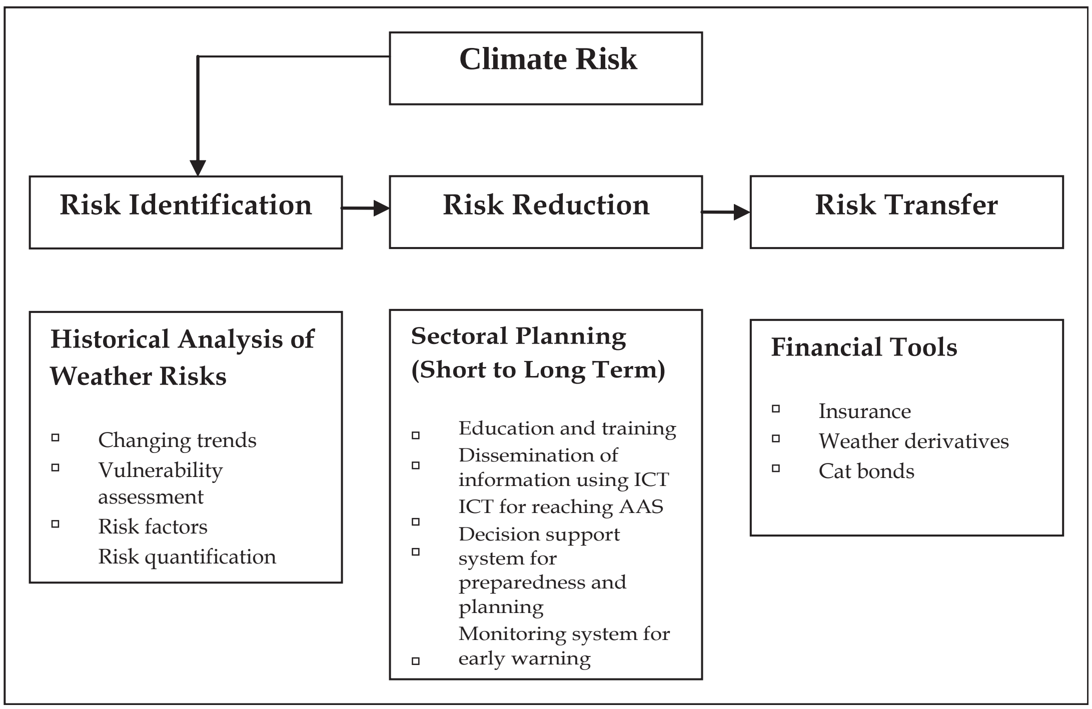
Heat waves generally occur during summer season where the cropped land is mostly fallow, and therefore, their impact on agricultural crops is limited. However, it will have deleterious effect on orchards, livestock, poultry and rice nursery beds. The heat wave conditions during 2003 May in Andhra Pradesh and 2006 in Orissa are recent examples that have affected the economy to a greater extent. Also occurrence of heat waves in the northern parts during summer is common every year resulting in quite a good number of human deaths. Further, the water requirements of summer crops grown under irrigated conditions increase to a greater extent.

Cold waves

The Northern states of Punjab, Haryana, U.P., Bihar and Rajasthan experience cold wave and ground frost like conditions during winter months of December and January almost every year. The frequency of such weather related events has significantly increased in the recent past due to reported climatic changes at local, regional and global scales. Site-specific short-term fluctuations in lower temperatures and the associated phenomena of chilling, frost, fogginess and impaired sunshine may sometimes play havoc in an otherwise fairly stable cropping/farming system of a region.

Climate risk management in agriculture

Risk management strategies (Sivakumar, 2008) involve avoiding damages, preventing / reducing the frequency, developing adaptation measures, transferring risks, responding appropriately to incidents and rehabilitation as soon a possible. Climate risk management in agriculture involves a wide range of decisions and actions as given below:



Identifying risk for a farmer involves defining the time period during which risk is prevalent, and identifying a measurable weather index that strongly correlated to farmers' losses on particular crop. This is followed by risk reduction which requires a consortium approach where all the organizations, institutions, NGOs etc. that can alert, prepare and educate the people in general and the farmers in particular. The risk transfer further supports the farmers to shift the crop loss burden to the insurers.

Climate risk management can be divided into two parts, one in managing of crop for excessive and deficit rainfall conditions through management practices and the other through supporting the farmers providing necessary financial coverage in the form of crop/weather insurance Policies.

Tools for effective risk management

For better management and planning of agricultural operations require policies and tools that allow farmers to face effectively weather risks and their uncertainties. Velazco (2007) describes a number of such policies.

Farmers have many options for managing the risks they face and most of them use combination of strategies and tools such as preparedness, planning, risk assessment improved early warning systems. Some deal with only one kind of risk and others address multiple risks. There is often variability in the risk management strategies, among the locations and among the farmers. These can greatly lessen societal vulnerability to weather and climate risks.

Drought contingency planning, drought preparedness, and drought impact assistance policies need to be urgently considered as to their future effectiveness under long-term climate change. Drought contingency plans on paper should be translated into an effective policy covering the range of activities required to address short and long-term consequences. Use of decision-support systems as risk management tools are an effective means of providing output of integrated climate crop management in the form of scenario analyses relating to impending risks that can be valuable to users. For medium and low input use farmers, crop or agro-ecosystem modeling could be used as a guide for general decision-making. The outputs of current and future trends of simulation model could be analyzed for sensitivity to climatic hazards of different agricultural systems. Based on this, possible modification of crop protection methods, irrigation programs, cultivation techniques, harvesting, storage and commercialization strategies can be evaluated in conjunction with economic aspects. Risk assessment and risk management models for integrated pest management could be used in conceptual framework. Statistical models relating to weather with crop yields in major crop producing regions should be developed

Emergency response system (ERS) based on advanced Information and Communication Technology (ICT) for effective utilization of weather-based agro-advisories using modern tools like GIS and Remote Sensing could be developed to address agricultural hazards and early warning. Climatic risk zoning could be used for quantifying climate-plant relationships and the risk of meteorological extremes in agricultural financing programs.

Strategies in risk management

Some of the approaches in dealing weather related risks are enterprise diversification, crop yield insurance, crop revenue insurance and household off-farm employment or Investment and development of human resources. Tibig and Lansigan (2007) reviewed seven types of management strategies to cope with risks and uncertainties in agrometeorology. These include: optional use of resources (crop diversification); use of appropriate cultivars (varietal diversification); improved cultural/farming practices (organic farming and flexible calendar to fit weather/climate, i.e., farm afforestation, land topography change); local indigenous knowledge (coping mechanisms of farmers to various environmental and natural challenges); technological innovations (direct seeded rice (DSR) cropping system to increase net income); and, farmers can opt to reduce their production area if conditions so warrant. Local indigenous knowledge has been blended with specific and important weather patterns in a cultural tradition in many poor, rural areas. Introducing new scientific-based weather/climate forecast services, which provide accurate and reliable outlooks into this cultural system may help farmers improve yields and cope with risks.

Risk transfer mechanisms

Over many years, crop insurance had been one of the approaches to dealing with risks. Agricultural insurance can help farmers to cope with the increasing risks to their business.

Höppe (2007) described four different groups of crop insurance products:

- Loss insurance (hail) with fixed sums insured (eg. hail insurance in Europe) or adjustable sums insured.
- Yield guarantees insurance with coverage of regional average yield or individual historic yields.
- Index insurance with meteorological triggers (single parameters or indices), area yield triggers (e.g. Group Risk Plan in USA), vegetation indices (increasing use of satellite data) and modelling of yields (a current example being the grassland program in Spain).
- Revenue insurance cover comprising yield and price elements, which are only feasible for crops, traded in existing commodity markets and Boards of Trade.

In India, crop insurance started in 1972 and then expanded in different phases. The insurance products developed by the National Agriculture Insurance Scheme (NAIS by AIC) has provided insurance products in all states and to all farmers since 1999 and at present, is implemented by 19 States and 2 union territories (Chattopadhyay and Lal 2007).

Weather derivatives and weather index insurance play a greater role in developing agricultural risk management strategies. Weather based index insurance is slowly gaining importance as one of the methodologies that can be used to sustain livelihoods and reduce poverty as part of the Millennium Development Goals (MDGs).

Contingency crop planning

Contingency crop planning can be defined as a set of procedure that describes how a crop will continue or recover its critical function in the event of an unexpected disruption to normal activity. It allows to assess alternate crop management options to determine how well the options can function that protects the nation's food security and farmers economy when the critical inputs either are not available or delayed considerably. While preparing contingency plans for different agroclimatic regions, one should make use of traditional wisdom of farming community and input from research findings for the respective region.

India being primarily an agrarian based nation, the influence of monsoon rains on country's agricultural production is well recognized. Many ICAR Institutes and State Agricultural Universities and few NGOs have developed location-specific plans in view of annual variations in monsoon rainfall both spatially and temporarily. Still 60 percent of the net sown area in the country is rainfed and about 40-45 percent of total food grain production in the country comes from these regions. The monsoon system consists of timely onset, movement of low pressures from Bay of Bengal to over land surface which brings in copious rains, location of monsoon trough across the country (Head bay to NW India) and its northward movement towards Himalayas cause break in rainfall conditions, early withdrawal of monsoon system are some of the major weather constraints that affects the agricultural production. Therefore, contingency plans for early commencement or delayed monsoon, intermittent breaks, early cessation or continued wet spells, spatial and temporal distribution of rainfall need to be developed. Some of the crop contingency measures in view of aberrant weather conditions are:

- Resource inventories inclusive of weather, water, land, cropping systems, livestock, literacy and infrastructure facilities need to be prepared for efficient planning and execution of relief measures.
- Renovation of existing water storage structures, water conveying system to meet the water deficit both the crops and humans.
- *In situ* water harvesting to increase the rainwater use efficiency of crops through water conservation techniques such as compartment bunding, ridges and furrows, double cropping, strip cropping, mulching and vegetative barriers for improving soil moisture need to be strengthened.
- Watershed development is the key to success for sustainable and improved agricultural output from rainfed areas.
- Rainwater harvesting through farm ponds for supplemental irrigation and recharging dead open dug wells for increased availability of ground water as well as enhancing agricultural productivity
- Practicing improved irrigation methods such as drip and sprinkler to conserve and improving the efficient water resources for food security
- Crop diversification with less water demanding crops for efficient use of water
- Alternate land use system such as bush farming, agri-silvi-culture, agri-horticulture

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Impact of Climate Change on Insect Pests

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ABSTRACT

The principal components of climate change are increased temperature and atmospheric carbon dioxide (CO_2) concentrations. Since climate change is believed to be more certain now, it is time for researchers to develop management strategies to cope with increased incidence of insect pests as a result of climate change. Of the several environmental factors temperature extremes play critical role in influencing the population of insect pests. Our experience indicated that there is a 'shift' in the pest status of several key species in recent periods, though these shifts may not be solely attributable to climate change. In the present situation, one can expect significant changes in the growth, development and population dynamics of various insect pests. The duration of the insect life cycle is altered under increased temperature and elevated CO_2 concentrations resulting in variable number of generations per year. Under elevated CO_2 higher consumption of foliage by leaf chewing insects with extended larval duration is observed in many studies. Published data reveals that some pests become more serious while others may decline. Evaluating the impact of climate change on insect pests is a very complex exercise and requires greater understanding of interactive factors. A more critical database on biotic stresses and their relationship with drivers of climate change is required for evolving adaptation strategies by farmers.

Key words: Climate change, temperature, carbon dioxide, insect pests.

INTRODUCTION

During the past 100 years the global average earth surface temperatures have increased by 0.6°C with 1990's being the warmest decade and 1998 the warmest year (Houghton *et al.*, 2001).The third Intergovernmental Panel for Climate Change (IPCC) report predicts that global-average surface temperature will increase further by 1.4-5.8°C by 2100 and atmospheric carbon dioxide (CO_2) to between 540 and 970 ppm over the same period. Climate change is likely to significantly affect agriculture by 2100 with wide variation in the estimates of impacts on crop yields across different regions. The principal drivers of climate change are increased temperature and carbon dioxide. These changes will have significant effect on growth of crops. Rise in temperature reduced the biomass and yields of various crops viz., rice, wheat and pulses. In contrary, elevated CO_2 enhanced photosynthesis, leaf area index, biomass and yields of various crops. As a principal source of carbon, it is very clear that changes in concentrations of carbon dioxide have marked effects on growth of crops. Temperature is identified as the dominant abiotic factor 'directly' affecting the insects. There is little evidence of any direct effects of CO_2 on insects and mostly the impact of elevated CO_2 is mediated through host crop, particularly in case of herbivorous or phytophagous insects. Effects of climate change on insect herbivores can be direct (temperature), through impacts on their physiology and behaviour, or indirect, where the insects respond to climate-induced changes mediated through other factors, such as host plant induced growth changes.

The information on effect of increased temperature and CO_2 concentrations on biology and ecology of insect pests was synthesized (Coviella and Trumble, 1999; Hunter, 2001 and Bale *et al.*, 2002). The present paper shares the information on the direct effects of climate change on insect pests available through literature and the experiences of CRIDA and ICRISAT research in the recent past.

Effect of temperature on insect population

Weather and its significant interaction with key pests of several crops is well known among researchers and farming community. However, so far this concept has not been applied in plant protection to minimize the ongoing injudicious use of pesticides. The present day plant protection is mostly concentrated on chemical control and leads to the presence of residues in food and fodder and feed. Pest surveillance and monitoring in relation to weather can considerably reduce the case of chemicals. In order to fine tune the existing pest predictions, understanding the thermal requirements and degree days for key pest and their associated natural enemies are of prime importance.

Groundnut leafminer (GLM), *Aproaerema modicella* is the key pest of groundnut in many parts of India particularly the southern states and some other Asian countries. This pest is favored by the hot dry conditions of the post-rainy season. The life cycle is completed in 21-28 days and this species completes 3-4 generations in a crop season in south India. Fluctuations are regulated by abiotic and biotic factors. Heavy persistent rains, high relative humidity (RH) and low temperatures reduce pest numbers, where as dry weather, bright sunshine and occasional rains favor pest buildup (Ghule *et al*., 1989). In Bangladesh and India, the densest populations of GLM occur at the end of the post-rainy season, March-April (Amin and Mohammad, 1980; Islam *et al*., 1983). GLM is often a problem towards the end of the rainy season (September and October), especially in drought or low-rainfall years (Amin, 1983). GLM populations fluctuate widely between seasons. Reliable and quantifiable data are specifically needed on the effects of temperature, rainfall and relative humidity on GLM population dynamics. Amin (1987) and Khan and Raodeo (1987) have suggested that high rainfall reduces leafminer populations even though data from the latter do not support this conclusion. They observed high populations in August September during a high rainfall period and populations declined in March when no rain was recorded (Khan and Raodeo, 1987).

Reduction in the GLM populations depends upon the insect pest stage and the prevailing weather i.e., during rainy season with heavy rainfall it is likely that adults are easily washed away by rain resulting in reduced incidence of GLM. Several authors have suggested that rainfall may reduce GLM larval populations in some seasons and have tried to correlate high GLM numbers with low rainfall seasons. If rainfall were an important larval mortality factor, then GLM populations should be higher in post-rainy season. This conflicting patterns of rainfall and GLM abundance point out the difficulty of using single factor to explain biological phenomena. It is likely that rainfall may indirectly influence GLM populations by increasing humidity which will favour GLM pathogens. Temperature was also positively correlated with GLM incidence and accounted for more of the variation than rainfall (Lewin *et a*l., 1979). Logiswaran and Mohanasundaram (1986) noted negative associations of light-trap catches with maximum and minimum temperatures and wind speed, and positive relationships with total rainfall and morning evening relative humidity.

Tobacco caterpillar, *Spodoptera litura* is widely distributed throughout Asia and Oceania and is highly polyphagous in nature. There is pronounced peak in the flight activity of moths (adults) during late January and early February that indicates that crops sown after mid-January are prone to pest attack in the east coastal belt of India. The only other factor of applied importance is migration. Clearly, the number of adult females visiting the crop will influence the egg density and the larval density. ICRISAT in collaboration with NARS and other mentor organizations developed, evaluated and shared an effective monitoring systems using pheromones for key insect pests of groundnut. Several groundnut pests recorded zero developmental rates around 10°C. However, *Spodoptera litura* and *Helicoverpa armigera*, developmental thresholds were above the mean winter temperature (<10°C) and emerged as usual in the spring in Southern states of India. A possible increase in the number of generations per year was not clearly shown by the trap capture records (Shanower, *et a*l., 1995 and Ranga Rao, *et al.,* 1989).

Helicoverpa armigera is one of the widely distributed crop pests throughout Asia, Australia, New Zealand, Africa southern Europe and many Pacific islands (Zalucki *et al*., 1986). Frequent outbreaks of this species are common in India on several crops. Generally the females prefer to oviposit on the reproductive parts of the plant (flowers and fruits) in a normal situation. Considerable progress had been made in modeling population outbreaks of this species in Australia and USA. Studies in India in the past two decades revealed simple eco-friendly predictions in farmers fields mainly based on the cumulative rainfall in rainy and post rainy seasons (Trivedi *et al.,* 2004).

Pest surveillance data generated at ICRISAT on key groundnut pests for the past 10 years has been summarized and subject analysis against various abiotic factors such as rainfall, minimum and maximum temperatures and relative humidity (%). The standard week-wise pheromone trap catches and larval population of *Spodoptera* and groundnut leafminer, were correlated with the above abiotic factors. The analysis brought out interesting results with no relationship of maximum temperature and relative humidity on the adult catches and adult populations, irrespective of pooling data, standard week or monthly or yearly. The negative effect of rainfall on *Spodoptera* adult catches and larval populations was very clear through correlation of the data at standard week level and monthly level. But, cumulative yearly rainfall data has not shown any relationship either adult catch or pest incidence in the field. These results clearly indicated high negative correlation of rain fall and adult catch with standard week-wise data set and the correlation efficiency decreased as one approached monthly data and further (Table 1).

Table 1: Correlation between *Spodoptera* larval population in groundnut and adult populations monitored by pheromone trap with weather parameters.

Variables	Standard week data		Monthly data		Yearly data	
	Larvae plant^{-1}	Adult catches trap^{-1}	Larvae plant^{-1}	Adult catches trap^{-1}	Larvae plant^{-1}	Adult catches trap^{-1}
Larvae plant^{-1}	-	✓+	-	✓+	-	X
Adult catches trap^{-1}	✓+	-	✓+	-	X	-
Rainfall (mm)	✓-	✓-	✓-	✓-	X	X
Minimum Temp ^{o}c	✓-	✓-	✓-	X	X	X
Maximum Temp ^{o}c	X	X	X	X	X	X
Relative humidity (%)	X	X	X	X	X	X

✓+: Significant positive correlation, ✓- : Significant negative correlation, X: No correlation

In case of leafminer, all the abiotic factors except minimum temperature and its relation to larval population have not shown any relationship either with adult catch or larval population in the field. However, trap catches have shown strong correlation with larval population but the relationship between these two parameters was shown positive irrespective of pooling of data. Thus, the study revealed the implications of looking at yearly and monthly data than weekly data. The data also tells us the need for more refined data such as daily weather and its relation to adult or larval or egg load rather than cumulative effect of weekly information (Table 2). Hence, it is necessary to produce such a refined data on key species of various crops in order to develop effective pest forecasting systems.

Table 2. Correlation between groundnut leafminer larval population and adult populations monitored by pheromone trap with weather parameters.

Variables	Standard week data		Monthly data		Yearly data	
	Larvae plant^{-1}	Adult catches trap^{-1}	Larvae plant^{-1}	Adult catches trap^{-1}	Larvae plant^{-1}	Adult catches trap^{-1}
Larvae plant^{-1}	-	✓+	-	✓+	-	✓+
Adult catches trap^{-1}	✓+	-	✓+	-	✓+	-
Rainfall (mm)	X	X	X	X	X	X
Minimum Temp °c	✓+	X	X	X	X	X
Maximum Temp °c	X	X	X	X	X	X
Relative humidity (%)	X	X	X	X	X	X

✓+: Significant positive correlation, ✓- : Significant negative correlation, X: No correlation

The information on various egg and larval parasites of leaf miner and *Spodoptera* over 10 years clearly indicated any deleterious effects of environmental factors on these natural enemies. In case of *Spodoptera*, the mean incidence of larval parasitism over 7 years (1985-1991) was 15.1% in rainy season (June-September) compared to 9.8% in the post rainy season (November – February). Similar trend was also noticed in case of groundnut leaf miner during 1984 – 1993 showing mean larval parasitation of 34% in rainy season compared to 40% in post-rainy season, emphasizing no environmental influence on these parasitic fauna.

The general consensus is that extremes of temperature will become more common, with an overall warming trend. In this situation one can expect significant changes in the population trends of various insect pests as experienced at ICRISAT Patancheru location (Table 3).The status of the majority of the pests was shifted over time. Though, the observed pest shifts may not be solely attributable to climate change, the impact of climate change on their status can be observed clearly.

Table 3. Trends in the Pest status of economically important Insect species over the past three decades at ICRISAT Patancheru location (1978-2009).

Insect species	Status	
	1978	2009
Helicoverpa armigera	+	+
Spodoptera litura	+	+
Aproaerema modicella	+	-
Holotrichia serrata	+	-
Amsacta albistriga	+	-
Maruca vitrata	-	+
Melanagromyza obtusa	-	+
Caryedon serratus	-	+
Pseudococcus corymbatus	-	+
Aphis craccivora	-	-
Thrips palmi (as vector)	-	+

+ = Important; - = Not important

Increased temperature

Temperature is identified as dominant abiotic factor directly affecting the insects. It has significant effects on populations of insects affecting their development, reproduction and dispersal which have been expressed in changes in pest activity and abundance. Species with a 'large geographical range' will tend to be less affected. Several observations can be made from literature on influence of elevated temperature on insect growth and development.

1. Increased temperature influenced the larval development and fecundity of *O.brumata* insects (Dury *et al.*, 1998) and long term exposure to increased temperature 3.5^{0}C shortened the insect development (Williams *et al.*, 2003).The temperature enhancement increased the relative growth rate of chrysomelid beetles (Veteli *et al.,* 2002)
2. Increased temperatures can potentially affect the insect survival, development and population size. Insects proliferate more readily in warmer climate, since conditions for growth and multiplication is more favorable compared to cooler conditions. Thus incidence of insect pests will be more in the areas with increased temperature conditions.
3. Because of warm winter and spring, many aphid species started their spring migration much earlier than 'normal' and the peach-potato aphid (*Myzus persicae*), in particular, has been captured in unprecedented numbers in the traps.
4. The rate at which most pests develop is dependent on temperature and every species has a particular 'threshold temperature' above which development can occur, and below which development ceases. As temperature rise, some pest species may be able to complete more generations in a year. This effect may be most noticeable in insects with short life-cycles such as aphids and the diamond-back moth. On

the other hand, the temporary exposure of populations to extremely high temperatures may delay the development of surviving individuals and thus delay the subsequent generation.

5. Warmer winter temperatures may allow larvae to survive the winter where they are limited by the cold. Thus greater infestation is expected in those areas.
7. Climate change may affect our ability to control pests. For example, high temperature is reported to reduce the effectiveness of some pesticides. If pests are able to complete more generations in a season then this may lead to greater pesticide use
8. More no of application of pesticide use which in turn may lead to the more rapid development of pesticide resistance. Strategies to avoid the development of resistance need to be planned in advance and rely on the availability of a range of pesticides and/or alternative control methods.

   In addition to the above observations some more predictions and generalizations were made by several researchers and are given in the table.

Table 4: Impact of increased temperature on insects

Anticipated /Expected effect	References
Under climate change scenario increased asynchrony between host plant and insect herbivore, with obvious adverse consequences.	Dewer and Watt 1992
Higher temperatures keeping all other variables equal, allow faster development of insects and may allow for additional generations of insects within a year.	Pollard and Yates, 1993
Climatic warming will allow the majority of ‘temperate’ insect species to extend their ranges to higher latitudes and altitudes.	Gaston and Williams, 1996
Expand their geographical ranges to higher latitudes and altitudes, as has already been observed in a number of common butterfly species.	Parmesan *et al*., 1999
Elevated temperature is known to alter the phyto-chemistry of the host plants and affect the insect growth and development directly or indirectly through effect on host plants.	Williams *et al* ., 2000
Diversity of insect herbivores and the intensity of herbivory increases with rising temperatures at constant latitude. Individuals may develop faster at higher temperature and survival may even be enhanced, but these insects may consequently have lower adult weight and fecundity.	Bale *et al*., 2002

Predicting insect response to increased temperature is largely based on field and laboratory studies carried out either on single species or combination of species. These predictions of insect population dynamics are complex even at the level of single individual level as life cycles are dependent on both biotic and abiotic factors.

Effect of Elevated CO_2 on insect population

Generally the impact of carbon dioxide (CO_2) on insects is observed to be ‘indirect’ – impact on insect growth and development resulting from change in the host crop. Elevated atmospheric CO_2 expected in the near future as a consequence of increasing emissions will alter the quantity and quality of plant foliage, which in turn can influence the growth and development of insect herbivores. The impact of elevated CO_2 on the phytochemistry of the plants was well documented (Coviella,Trumble, 1998 and Hunter, 2001).

The atmospheric CO_2 concentrations have increased by above 20% and elevated CO_2 effects the plant growth and range of physical and chemical characteristics of the plant/crop. These include reduction in the leaf nitrogen content, changes in the defense compounds, water content, carbohydrates and leaf thickness. Indications are that exposure to elevated CO_2 levels will increase the plant photosynthesis, growth, above ground biomass, leaf area, yield, carbon and C:N ratio. These changes can influence the food quality for herbivorous insects and was well reviewed (Hunter, 2001). These changes in the leaf quality are likely to have varied effect on the performance of insect herbivores. The information on effect of elevated CO_2 on insect pests was compiled and presented by Srinivasa Rao *et al., (*2008).

Succinctly the information revealed that the performance of the same insect varied from host to host-indicating host species specificity. Published data on impact of elevated CO_2 on insect pests indicated a general decrease in foliar nitrogen concentration and increase in carbohydrate and phenolic based secondary metabolites (Bezemer and Jones, 1998 and Whittaker, 1999). The consumption by herbivores was related primarily to changes in nitrogen and carbohydrate levels. The leaf-mining insects could only partially compensate by increased consumption and pupal weights did decline. The phloem-feeding and whole-cell-feeding insects responded positively to elevated CO_2, with increases in population size and decreases in development time.

Experimental findings from CRIDA

Several experiments were conducted using open top chamber (OTC) facility to study the impact of elevated CO_2 levels on insects. Three square type open top chambers (OTC) of 4x4x4 m size were constructed at CRIDA, Hyderabad, two for maintaining elevated CO_2 concentrations of 700±25 ppm CO_2 and 550±25 ppm CO_2 and one for ambient CO_2. An automatic CO_2 enrichment technology was developed by adapting software SCADA to accurately maintain the desired levels of CO_2 inside the OTCs. The concentration of CO_2 in the chambers was monitored by a non-dispersive infrared (NDIR) gas analyzer.

Castor, groundnut plants were grown in the three OTCs and also in the open, outside the OTCs. The concentration of CO_2 in the atmosphere (ambient) was taken as 350±25 ppm. Thus, crops were maintained under 4 CO_2 conditions; 700±25 ppm CO_2 inside OTC (700 CO_2), 550±25 ppm CO_2 inside OTC (550 CO_2), ambient CO_2 inside OTC (350 CO_2 OTC) and ambient CO_2 in the open (350 CO_2 open). Various experimental trials were conducted using the foliage obtained from the crops grown under different OTC's.

To understand the nutritional quality of foliage bio chemical analysis was conducted. Biochemical analysis of leaf samples indicated that the leaf nitrogen content was distinctly lower in elevated CO_2 foliage. In contrast, carbon content was higher in elevated CO_2 foliage. Consequently, the change in the relative proportion of carbon to nitrogen (C:N ratio) was considerably higher in elevated CO_2 foliage. Elevated CO_2 foliage had higher polyphenol content too, compared to ambient CO_2.

Larval growth performance

Larval duration or time from hatching to pupation in larvae of both the species was significantly influenced by the CO_2 condition under which leaves offered to them were produced. Larval duration for both larvae was extended by about two days when fed with elevated CO_2 foliage (Fig. 1). Larval dry weights measured during the feeding period differed significantly among CO_2 conditions .Larvae ingested significantly higher quantity of elevated CO_2 foliage compared to ambient CO_2 foliage. For instance, *A. janata* consumed 62.6% more of 700 CO_2 foliage than 350 CO_2 chamber foliage. The rate of consumption (RCR) was also higher in case of elevated CO_2 foliage. Thus, larvae fed with elevated CO_2 foliage consumed more each day and over a longer period, resulting in considerably increased ingestion. Larval weights prior to pupation were also significantly affected by the foliage offered, being higher with elevated CO_2 foliage, but differences in larval weight were not as marked as differences in the amount of leaf ingested. Larval growth rates (RGR) were significantly lower with elevated CO_2 foliage in case of *A. janata*, while in case of *S. litura*, the differences were not significant (Srinivasa Rao *et al*., 2009).

The efficiency with which ingested food was converted into body mass was lower with elevated CO_2 foliage in case of *A. janata*, but in *S. litura*, there were no significant differences. The efficiency of conversion of digested food into body mass (ECD) was lower with elevated CO_2 foliage for both species of larvae. The digestibility (AD) of elevated CO_2 foliage was significantly higher than ambient CO_2 foliage for both the species, more so in case of *S. litura*.

The data of larval weight were fitted to a compound growth function of the form $y = ax^b$, where 'y' is larval weight in mg, 'x' is time in days, 'a' is a constant and 'b', 'a' coefficient that indicates the growth rate. Differences in growth rates of *S. litura*, which were not visible from relative growth rate calculations, became clear with the growth functions. The daily growth rates of *S. litura* were considerably lower with elevated CO_2 foliage .While the daily growth rate was 30.99% with 350 CO_2 foliage, it was just 18.53% with 550 CO_2 foliage. In *A. janata* also, the daily growth rates were markedly lower with elevated CO_2.

Relationship of larval performance with leaf biochemical parameters was worked out. Biochemical constituent(s) of the leaf influenced larval consumption and growth. Leaf consumption and larval weights were positively and significantly correlated with leaf carbon, polyphenols and C:N ratio, and negatively (-0.804 to -0.834) with leaf nitrogen content. The consumption and weight gain of the larvae were negatively and significantly influenced by leaf nitrogen, which was found to be the most important factor affecting consumption and growth of larvae.

Similarly the consumption pattern and growth of *Spodoptera litura* on groundnut also significantly varied across CO_2 concentrations. The insect performance indices were significantly affected. The 700 and 550 ppm CO_2 foliage was more digestible with higher values of approximate digestibility. The relative consumption rate of larvae increased whereas the efficiency parameters; efficiency of conversion of ingested food (ECI), efficiency of conversion of digested food (ECD), and relative growth rate (RGR) decreased in case of larvae grown on 700 and 550 ppm CO_2 foliage.

Impact of elevated CO_2 on natural enemies

Limited studies are available in the literature on impact of elevated CO_2 on natural enemies at third trophic level. The growth and development of insect herbivores varied with the nutrition quality of their diet (host plant) and the dietary differences showed varied effects on parasitoids. The population size of the insects significantly differed under elevated CO_2 and in turn influencing the insect fecundity. Thus, any dietary differences that prolong developmental time, increase food consumption, and reduce growth by herbivores serve to increase the susceptibility of herbivores to natural enemies (Roth & Lindroth, 1995). On the other hand, poor host nutrition could also decrease parasitoid fitness. Few studies explored the impact of elevated CO_2 on natural enemies (parasitoids and Predators) at third trophic level (Bezemer *et al*., 1999; Stacey and Fellowes, 2002).

Chen *et al*., 2005 showed that increasing CO_2 concentrations could alter the preference of lady beetle to aphid prey and enhance the biological control of aphids by lady beetle in cotton crop. This study provided the first empirical evidence that changes in prey reared on host plant grown at different levels of CO_2 altered the feeding preferences of the predator.

Discussion and Conclusions

Insects are critical to agriculture in several ways since they perform vital services such as breaking down organic matter, pollinating flowers. On the other hand they are also destructive to crops and vectors for several plant and animal diseases. However, it is a well known fact that climate variations bound to influence insects, both insects are also known for their quick adaptation for changing environments. Climate variability affects insects directly and also indirectly, through their change in physiology, population turnover, host plants and migratory responses.

There are still many unknowns in the climate change influencing the insect pests. The general consensus is that extremes of temperature will become more common. In this situation one can expect significant changes in the population trends of various insect pests as experienced at ICRISAT Patancheru location. Our experience at ICRISAT clearly brought out shift in the pest status of several key species over the past three decades. Similarly, an increase in the number of generations can translate into the need for additional controls and would present more challenges of management.

The quantification of the impact of climate variability can be achieved through the adoption of well proven and innovative tools that allow the development of integrated pest management strategies designed for target areas. With increasing ability, reliability of the effective IPM strategies, the decision makers involved in plant protection should consider short medium and long term approaches such as:

1. Decision support frame work to provide medium term strategies addressing temporal and spatial distribution of insect pests and their natural enemies in terms of climatic variability and their impact on the profitability and innovative agricultural practices.
2. Short term seasonal climate forecasting to enable farmers and other stakeholders to fine tune medium term strategies for effective management of variable weather.
3. Long term information on the extent of climate change and its impact on agriculture and the implications on crop productivity / pest management.

Increased temperature would reduce crop duration and causes the change in the growth and development of the insect pests. The duration of the insect life cycle gets reduced under increased temperature resulting in more number of generations per year. Under elevated CO_2 conditions, higher consumption of foliage by leaf chewing insects with extended larval duration is predicted in majority cases. The studies that combine the effects of elevated CO_2 (enriched plants) and increased temperatures on insect performance are rare. The documented information reveals that some pests become more serious while others may decline. The impact of increased temperature and elevated CO_2 on crop and insect herbivore interactions is still unknown as both these variables are counteracting.

However, complex interactions among temperature, host plant quality, and insect performance make pest predictions more complicated. For example, the reduced rates of insect growth that have been observed under elevated CO_2 may be masked by increased temperatures. There is need to have long-term, multifactorial experiments under field conditions to study the interactive and confounding effects of elevated CO_2, temperature and other ecological variables on the insects.

In the present day plant protection though there are effective technologies available in suppressing the pests but proper monitoring and forecasting systems are not in place. Though, the knowledge base is available on the above areas in various fields the information is highly scattered. Hence, there is an urgent need to bring them under single umbrella for better organizing these activities. With the advancement and the availability of the experts in various fields, it is time to put the existing information together to develop efficient and affordable models for key pests and diseases.

To arrive at concrete conclusions in developing sustainable eco-friendly plant protection approaches, evaluation of long term historic data on insect pests need to be examined thoroughly with the involvement of multi-organizational expertise. It must include adaptation and mitigation strategies, more investments in agricultural research and extension, rural infrastructure to ensure the development of resilient and healthy ecosystems.

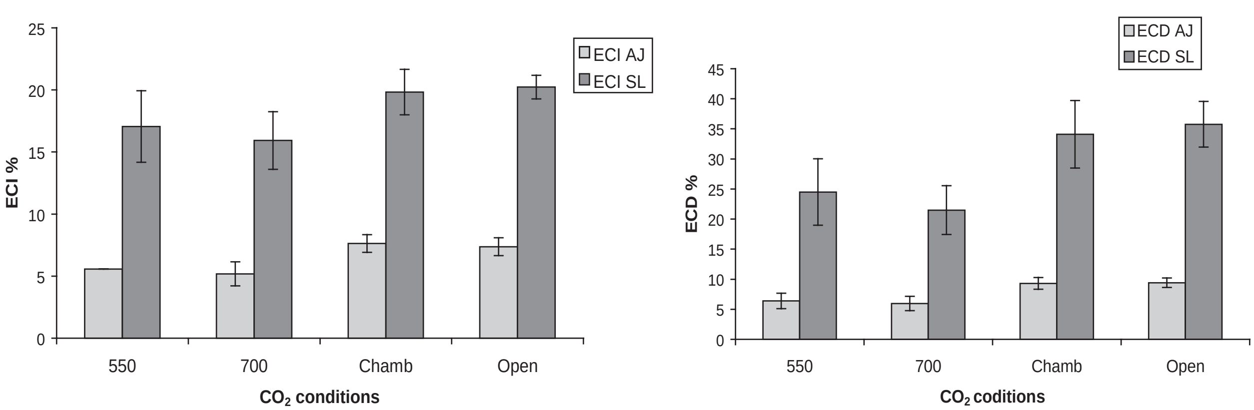

Fig. 1. Effect of elevated CO_2 on insect performance in dices of larvae

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Impacts of Climate Change on Rainfed Crop Diseases: Current Status and Future Research Needs

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ABSTRACT

Weather-host-pathogen interactions over time have been a cause of concern as they hinder the efforts to ensure food security especially in developing and under-developed nations. Climate variability and climate change add a new dimension to this existing problem of managing crop diseases by altering the equilibrium of host-pathogen interactions resulting in either increased epidemic outbreaks or new pathogens emerging as threats or hither to less known pathogens causing sever yield losses. Detailed research is lacking in this domain to develop adaptation and mitigation strategies for sustained food security. Preliminary findings suggest that crops and pathogens respond differentially to altered weather patterns coupled with GHG emissions. These interactions could be either positive or negative. In this paper, an attempt has been made to assess the impacts of climate change on rainfed crop diseases and efforts needed for developing adaptation strategies.

INTRODUCTION

Climate change predictions point to a warmer world with in the next 50 years, a trend that is increasingly being supported by 'ground-truth'. Climate change threatens to increase crop losses, increase in the number of people facing malnutrition, and may change the development patterns of animal diseases and plant pests. Agriculture production of rainfed regions, which constitute about 65% of the area under cultivation and account for about 40-45% of the total production in India, varies a great deal from year to year. Therefore in order to sustain and enhance the production of the rainfed crops of SAT, it will be necessary to use the knowledge of climate variability to tailor of innovative cropping patterns and the disease management practices for each of the agroclimatic zones. It is well established that temperature, moisture and greenhouse gases are the major elements of climate change. Current estimates of changes in climate indicate an increase in global mean annual temperatures of 1ºC by 2025 and 3ºC by the 2100. Variability in rainfall pattern and intensity is expected to be high. Overall, changes in these elements will result in i) warmer and more frequent hot days and nights ii) erratic rainfall distribution pattern leading to droughts or high precipitation and iii) drying of semi-arid tropics (SAT) in Asia and Africa.

Effect of climate change on rainfed crop diseases

The climate variability and climate change has shown both positive and negative impacts on host-pathogen interactions. In the tropics and sub-tropics, with prevailing high temperatures, crops are already growing at a threshold. Under elevated CO_2 levels, the morpho-physiology of the crop plants is significantly influenced. Most of the available data clearly suggests that atmospheric CO_2 enrichment asserts its greatest positive influence on infected as opposed to healthy plants. This influence in turn will modulate the balance of co-evolution between the host and the pathogen as well as pathogen and its natural enemies. Elevated CO_2

and other factors of climate change have the potential to accelerate plant pathogen evolution, which may, in turn, affect virulence. Chakraborty and Datta (2003) reported loss of aggressiveness of *Colletotrichum gloeosporioides* on *Stylosanthes scabra* over 25 infection cycles under elevated CO_2 conditions. On the contrary, pathogen fecundity increased due to altered canopy environment. The reason attributed was to the enhanced canopy growth that resulted in conducive microclimate for pathogen's multiplication. McElrone *et al*. (2005) found that exponential growth rates of *Phyllosticta minima* were 17% greater under elevated CO_2. Lake and Wade (2009) have shown that *Erysiphe cichoracearum* aggressiveness increased under elevated CO_2, together with changes in the leaf epidermal characteristics of the model plant Arabidopsis thaliana. Recent surveys conducted and reports from SAT regions indicated that dry root rot (*Rhizoctonia bataticola*) in chickpea and charcoal rot (*Macrophomina phaseolina*) in sorghum increased many folds in last 2-3 years due to prolonged moisture stress. Preliminary analysis of weather indicated that outbreak of Phytophthora blight of pigeonpea (*Phythophthora drechsleri* f. sp. *cajani*) in SAT regions in last 5 years may be attributed to high intermittent rain (>350mm in 6-7 days) in July-August (Pande and Sharma 2009).

Climate change and changing scenario of pathogens

Climate change may affect plant pathosystems at various levels viz. from genes to populations and from ecosystem to distributional ranges; from environmental conditions to host vigour to susceptibility; and from pathogen virulence to infection rates. Climate change is likely to have a profound effect on geographical distribution of host and pathogens, changes in the physiology of host-pathogen interactions, changes in the rate of development of the pathogens e.g. increased oversummering and overwintering of pathogens, increased transmission and dispersal of pathogens and emergence of new diseases. Similarly, prolonged moisture may create a new scenario of potential diseases in SAT crops, such as anthracnose, collar rot, wet root rot, and stunt diseases in chickpea; to Phytophthora blight, Alternaria blight in pigeonpea, leaf spots and rusts in groundnut , blast and rust in pearl millet, leaf blight and grain mold complex in sorghum. Efforts are underway across laboratories to forecast the changing scenarios of pathogens and diseases of SAT crops under variable climatic conditions through simulation modeling and targeted surveys. Studies are also being initiated to understand behavior of the vectors of pathogens from the point of view epidemic development as well as biosecurity.

Development of adaptation strategies

Climate change is likely to have a profound effect on host plant interaction and is a challenge to the long-term sustainability of crop production. Regional impacts of climate change on plant diseases will be more hence; disease management strategy will require adjustments under climate change. Under elevated CO_2 conditions, mobilization of resources into host resistance through various mechanisms such as reduced stomatal density and conductance (Hibberd *et al*., 1996a, 1996b); greater accumulation of carbohydrates in leaves; more waxes, extra layers of epidermal cells and increased fibre content (Owensby, 1994); production of papillae and accumulation of silicon at penetration sites (Hibberd *et al*., 1996a); greater number of mesophyll cells (Bowes, 1993); and increased biosynthesis of phenolics (Hartley *et al*., 2000), increased tannin content (Parsons *et al*., 2003) have been reported. Malmstrom and Field (1997) reported that CO_2 enrichment in oats may reduce losses of infected plants to drought and may enable yellow dwarf diseased plants to compete better with healthy neighbors. On the contrary, in tomato, the yields were at par (Jwa and Walling, 2001). Similarly, Tiedemann and Firsching (2000) reported yield enhancement in spring wheat infected with rust incubated under elevated CO_2 and ozone conditions. Reduced incidence of Potato virus Y on tobacco (Matros *et al*., 2006), enhanced glyocellins (phytoalexins) after elicitation with ß-glucan in soybeans against stem canker (Braga *et al*., 2006) and reduced leafspot in stiff goldenrod due to reduced leaf nitrogen content that imparted resistance (Strengbom and Reich, 2006). However, no such research effort has been reported on the crop and diseases of the SAT environment.

Alterations in sowing dates may become less reliable. Resistance to pathogens will become more important because of static and dynamic defenses from changes in physiology, nutritional status and water availability. Durability of resistance may be threatened and may lead to more rapid evolution of aggressive pathogen races thus identification of new sources of resistance are of utmost importance. There is a need to view biological control with respect to variation in environment. In addition to improved diagnostics, there is a need for simulation models to assess the potential of emerging pathogens for a given crop production system and also shift in pathogen populations/fitness that may demand modifications in current production systems. In addition to adoption of improved cultivars, forecasting models which allows investigating multiple scenarios and interactions simultaneously will become most important for disease prediction, impact assessment and application of disease management measures. Also, the new scientific tools such as molecular markers will be helpful in speeding the progress of crop improvement.

The plant-pathogen systems are influenced by the population dynamics of beneficial microorganisms such as rhizobia, biocontrol agents and arbuscular mycorrhizal fungi (AMF). Smith and Read (1997) suggested that AMFs can modulate plant responses to elevated CO_2 by increasing resistance/tolerance of plants against an array of environmental stresses. In a study conducted at the Swiss FACE facility near Zurich, root colonization by AMFs increased considerably in the forage crops viz. *Lolium perenne* and *Trifolium repens*, at elevated CO_2, with more intraradical hyphae, arbuscules and vesicles suggesting and increased protection against pathogens (Gamper et al., 2004). In preliminary studies, it was observed that fecundity of *Trichoderma* increased in populations exposed over generations to elevated CO_2 and temperature (S. Desai, personal communication). Similar studies on natural enemies will help to understand the disease development in populations in a holistic way and also develop suitable adaptation strategies.

CONCLUSION

In conclusion, climate change is now real, so there is a need of impact assessment and strategies to cope with vulnerabilities in agriculture sector. Research has started only recently to understand the impacts of climate change on plant – pathogens interactions. In view of variable responses in pathogen behavior to climate variability and climate change, it may be difficult to know the ultimate outcome for specific pathogen-host interactions. A process-based approach to quantify the impact on pathogen/disease cycle is potentially the most useful in defining the impact of elevated CO_2 on plant diseases. More research, especially under field conditions, will be needed to clarify the situation; and, of course, different results are likely to be observed for different pathogen-host associations. Therefore, regional impacts of climate change on plant disease management strategies need a relook using forecasting models and biotechnological approaches in understanding the emerging scenario of host pathogen interactions. Innovative methods may have to be adopted to develop adaptation strategies to overcome the impacts due to climate change and climate variability so that the food and livelihood security of rainfed farmers can be ensured. Studies under Network Project on Climate Change of the Indian Council of Agricultural Research, are underway to understand the variability among major soil borne pathogens such as *Sclerotium rolfsii*, *Macrophomina phaseolina*, *Rhizoctonia solani*, *Botrytis ricini and Fusarium ricini* and biocontrol agents such as *Trichoderma*, *Bacillus and Pseudomonas* for developing projected disease epidemiology on major crops through simulation modeling under climate change scenario. Recently an international net work is also actively anticipating and responding to biological complexity in the effects of climate change on agriculture and crop diseases (Karen et al. 2009).

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Technical Session III

Climate Change and Natural Resources: Soil, Water and Biodiversity

Climate Change and Water Resources: Future Research Agenda

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ABSTRACT

Climate change is expected to increase the frequency and intensity of current extreme weather events, greater monsoon variability and also the emergence of new disaster i.e. sea level rise and new vulnerabilities with differential spatial and socio-economic impacts on communities. This unprecedented increase is expected to have severe impact on the hydrological cycle, water resource (drought, flood and drinking water, forest and ecosystems, (losses of coastal wetlands and mangroves), food security, health and other related areas. The impact would be particularly disastrous for developing countries, including India and further reduce the resilience of poor, vulnerable communities, which make up between one quarter and one half of the population of most Indian cities. In the process of development, rapid development of coastal areas, urbanization, agriculture expansion, increasing population and rapid industrialization, more areas/ population are becoming vulnerable to climate risk and many have no choice to migrate to safer places. On the contrary, the 'safer places' are itself getting reduced.

Today, the hydrological cycle is being modified quantitatively and/or qualitatively in most agro-climatic regions and river basins of India, by human activities such as land use change, water uses, inter-basin transfers, cropping pattern, irrigation and drainage. Many of the areas are getting transformed from safe area to critical and over exploited area with the fall in water table. In view of this, sustainable management of surface and ground water and the supporting natural environment have gained considerable importance in recent years. An assessment of the availability of water resource in the context of future national requirements taking particular account of the multiplying demands for water and expected impacts of climate change and variability is critical for resource planning and sustainable development as a basis for economic and social development. This study will focus on availability of surface and ground water resources and the potential for water related developments, keeping in view the possible impacts of climate change to meet the foreseeable demand in India. The study will also focus on how the socio-cultural and economic life would undergo change in such circumstances. The coping and adaptability mechanisms of the vulnerable communities would be studied as how with acute shortage/surplus in India at the micro level is getting affected and how communities are adjusting in all through changing climatic process. The paper is intending to develop an integrated framework for addressing the issue of water, community adaptability and disaster risk reduction.

INTRODUCTION

Climate change is evident from the observations of increase in global average air and ocean temperatures, precipitation and extreme rainfall, widespread melting of snow and ice, storms / storm surges / coastal flooding and rising global mean sea level, as recorded in the Fourth Assessment Report of IPCC. Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906-2005) of 0.74 [0.56 to 0.92]°C is larger than the corresponding trend of 0.6 [0.4 to 0.8]°C (1901-2000) given in the Third Assessment Report (TAR). The linear warming trend over the 50 years 1956-2005 (0.13 [0.10 to 0.16]°C per decade) is nearly twice that for the 100 years 1906-2005. Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year during over 1961 to 2003 and at an average rate of about 3.1 [2.4 to 3.8] mm per year from 1993 to 2003. There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, and suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Observed decreases in snow and ice extent are also consistent with warming. Globally, the area affected by drought has increased since the 1970s (IPCC, 2008). In the 21st Century, according to Fourth Assessment Report of IPCC, during next two decades a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. Afterwards temperature projections increasingly depend on specific emission scenarios. In case of temperature rise, the best estimate for a low scenario is 1.8°C and the best estimate for high scenario is 4°C.

In India, almost 67% of the glaciers in the Himalayan mountain ranges have retreated in the past decades. Available records suggest that Gangotri glacier is retreating about 30 meters per year. A warming is likely to increase the melting far more rapidly than the accumulation. The past 200 years of instrumental observations indicate that the summer monsoon rainfall has undergone multi-decadal epochal variations in terms of the frequencies of droughts/floods (i.e., alternating 20-30 year periods of more and less frequent droughts), however, on a smaller space scale, there are areas showing both increasing (e.g. west coast) and decreasing (e.g. east central India) long term trends in monsoon rainfall and sharp decrease in rainy days (Goswami et al., 2006; Rajeevan et al., 2006; Ramesh and Goswami, 2007). Figure 1 shows the changes in the frequency of extreme rainfall over central India.

Climate change is a global problem and India will feel the heat due to its unique geophysical and hydro-climatic conditions. Presently, about 68% area is liable to droughts, 8% area is prone to cyclone and 40 million hectare area (1/8 th of total area) is prone to floods. In the decade 1990-2000, an average of about 4344 people lost their lives and about 30 million people were affected by disasters every year. In 2006 at global level, the most significant disasters in terms of economic damage was the flood in India i.e. US$ 3.39 billion (0.29% of the previous year GDP) and around 40 millions were victims. The reported natural disasters and number of people killed were 21 and 1521 respectively during 2006 in India (CRED, 2007). Nearly 700 million rural people in India directly depend on climate-sensitive sectors (agriculture, forests and fisheries) and natural resources (water, biodiversity, mangroves, coastal zones and grasslands) for their livelihood. Under changing climate, food security of the country might come under threat. In addition, the adaptive capacity of dryland farmers, forest and coastal community is low. Climate change is likely to impact all the natural ecosystems as well as health (e.g. malaria) and socio-economic systems.

Presently, more than 45% of the average annual rainfall including snowfall in the country is going waste by natural runoff to sea. Artificial recharge/rainwater harvesting scheme is now being implemented in the country to minimize this runoff loss based on present rainfall scenarios over the country. However, for the success of this scheme, we need to focus on how the possible climate change will affect the intensity, spatial and temporal variability of the rainfall, evaporation rates and temperature in different agro-climatic regions and river basins of India.

Ground water has been the mainstay for meeting the domestic water needs of more than 80% of rural and 50% of urban population, besides fulfilling the irrigation needs of around 50% of irrigated agriculture. The impact of rainfall variation on the region's ground water resources is not well understood, even though groundwater forms about half of the region's water supply. This is largely due to the complex interactions among land use, aquifer properties, antecedent water table levels and the actual timing and intensity of individual rainfall events. In cases where the aquifer systems are saturated, reductions in rainfall may not have an immediate effect on water tables, but a reduction in rainfall in other conditions below a critical level could eliminate all infiltration beyond the vegetation root zone. As a gross approximation, recharge to the water table aquifer (from which most of our groundwater is derived) might be expected to respond in a similar way as runoff to decreasing rainfall, but this remains a largely unproven assertion.

There have been very few researches on the potential effects of climate change. Eltahir and Yeh (1999) assessed the asymmetric response of aquifer water level to floods and droughts. They reported that the drought left a significantly more persistent signature in the aquifer water level than the corresponding signature of the flood. To examine the relative importance of climate on groundwater level variation, Chen *et al.* (2004) used cross-correlation analysis between historical climate records and groundwater levels. Their results showed that the annual precipitation explained the variations in groundwater levels significantly. Van der Kamp and Maathuis (1991) investigated the annual fluctuation of groundwater levels as a result of loading by surface moisture considering both the theoretical aspects of aquifer characteristics and empirical data. They observed that the relatively poor correlation between the climatic parameters and the groundwater levels was due to the distance of the observation wells from the climate stations. To link climate variables with ground water levels, the weather station should exist in the re-charge zone of the observation well (Van der Kamp and Maathuis, 1991; Chen *et al.*, 2002). But, for a large-scale groundwater-monitoring network this may not be possible. However, the groundwater level data itself provide a direct means of measuring the overall impacts of both natural and anthropogenic changes to groundwater resources. Although the groundwater monitoring networks have existed for several years, very little research has been carried out internationally to interpret the water table and quality trends. Broers and Grift (2004) studied the groundwater quality trends due to anthropogenic-induced changes in agricultural practices.

In future water resources will come under increasing pressure in Indian subcontinent due to the changing climate. The climate affects the demand for water as well as the supply and quality. Particularly, in arid and semi-arid regions of India any shortfall in water supply multiplied with climate change will enhance competition for water use for a wide range of economic, social and environmental applications. Assessing the potential socioeconomic impacts of climate change involves comparing two future scenarios, one with and one without climate change. Uncertainties involved in such an assessment include: (1) the timing, magnitude and nature of climate change; (2) the ability of ecosystems to adopt either naturally or through managed intervention to the change; (3) future increase in population and economic activities and their impacts on natural resources systems; and (4) how society adapts through the normal responses of individuals and businessman and through policy changes that offer the opportunities and incentives to respond. The uncertainties, the long times involved and the potential for catastrophic and irreversible impacts on natural resources systems raise questions as to how to evaluate climate impacts and investments and other policies that would affect or be affected by changes in the climate. In view of the above, an attempt has been made in this study to give a brief resume of possible impact of climate change on India's surface and groundwater resources.

India's rainfall, population, food and freshwater needs

Long period average annual rainfall over the contiguous Indian area is about 117 cm; however, this rainfall is highly variable both in time and in space. Almost 75% (88 cm ± 10 SD) of the long average annual rainfall comes down in the four months of June to September (SW monsoon).The heaviest rains of the order of 200-400 cm or even more occur over northeast India and along the Western Ghats of the peninsular India. Largely, the annual average rainfall over the northern Indo-Gangetic plains running parallel to the foothills of the Himalayas varies from about 150 cm in the east to 50 cm in the west. Over the central parts of the India and northern half of the peninsular India, it varies from 150 cm in the eastern half to about 50 cm on the lee side of the Western ghats. In the Southern half of the Indian peninsula, average annual rainfall varies from 100 cm to 75 cm as we go from east to west. On the other hand, some regions in the extreme western part of the country, such as western Rajasthan, receive average annual rainfall of about 15 cm or even less. There are considerable intra-seasonal and inter-seasonal variations as well. The summer monsoon rainfall oscillates between active spells with good monsoon and weak spells or the breaks in the monsoon rains.

The year-to-year variability in monsoon rainfall (Fig.1) leads to extreme hydrological events (large scale drought and floods) resulting in serious reduction in agricultural output and affecting the vast population and the national economy. A normal monsoon with an evenly distributed rainfall throughout the country is a bonanza, while an extreme event of flood or drought over the entire country or a smaller region constitutes a natural hazard. Hence the variation in seasonal monsoon rainfall may be considered a measure to examine climate variability/change over the Indian monsoon domain in the context of the global warming.

Droughts, floods and desertification are directly connected with monsoon/rainfall patterns, ocean circulation and soil moisture and water availability. As discussed above the problems of Indian rainfall are diverse in terms of both geographical distribution and seasonality, and spread over a period of years. There are large variations in the total rainfall received in each geographical division, causing both droughts and floods. The fury of these natural disasters has arguably been more intense and more frequent by the abuse of nature and degradation of environment. The adverse impacts of these two natural disasters cannot be assessed merely in economic terms based on destruction of crops, property and infrastructure because the toll of human misery in the form of death, disease, injury, loss of employment, psychological trauma, and above all the set-back to development are too difficult to evaluate (Dash and Hunt, 2007; Attwood, 2005; Prabhakar and Shaw, 2008; Revi, 2008).

The United Nation has estimated that the world population grew at an annual rate of 1.4% during 1990-2000. China registered a much lower annual rate of growth (1.0%) along with USA (0.9%) during 1990-2000, as compared to India (1.9% during 1991-2001). It is investigated that if the National Population

Policy (NPP) is fully implemented, the population of India should be 1,107 million by 2010 (Census of India, 2001). However, country's population is expected to reach a level of around 1,390 million by 2025 and 1,700 million by 2050.

In India, average food consumption at present is 550 gm per capita per day whereas the corresponding figures in China and USA are 980 gm and 2850 gm, respectively. Present annual requirement based on present consumption level (550 gm) for the country is about 210 M tons which is almost equal to the current production. While the area under foodgrain, for instance, fell from 126.67 m ha to 123.06 m ha during the period from 1980-81 to 1999-2000, the production registered as increase from 129.59 M tons to 209 M tons during that period. The food grain production looked quite impressive in 1999-2000, which is more than 4 times the production of 50.82 M tons in 1950-51(Directorate of Economics and Statistics, Ministry of Agriculture, New Delhi, India). It is feared that the fast increasing demand in next two or three decades could be quite grim particularly in view of serious problem of soil degradation. The total gross irrigated area has nearly trebled from 22.6 m ha in 1950-51 to 99.1 m ha in 1998-99. Out of this 34.3 m ha is from major and medium projects, 12.7 m ha from minor schemes using surface water and 52.2 m ha from groundwater. As against the national average of 38% of the total cropped area being irrigated, Punjab had the distinction of achieving highest-level pf irrigation (92%), followed by Haryana (79%) and Uttar Pradesh (66%) (CWC, 2002). The per capita average annual freshwater availability has reduced from 5177 cubic meters in 1951 to about 1820 cubic meters in 2001 and is estimated to further come down to 1341 cubic meters in 2025 and 1140 cubic meters (projected) in 2050 (MoWR, 2003). This clearly indicates the 'two sided' effect on water resources - the rise in population will increase the demand for water leading to faster withdrawal of water and this in turn would reduce the recharging time of the water tables (figure 2). As a result, availability of water is bound to reach critical levels sooner or later.

Surface water resources

India has a large and intricate network of river systems of which the most prominent are the Himalayan river systems draining the major plains of the country. Apart from this, numerous water bodies present in the subcontinent make it one of the wettest places in the world after South America. The annual precipitation including snowfall, which is the main source of the water in the country, is estimated to be of the order of 4000 billion cubic metres (BCM). The Resource potential of the country, which occurs as natural run off in the rivers is about 1869 cu.km. as per the basin wise latest estimates of Central Water Commission, considering both surface and ground water as one system. Ganga-Brahmaputra-Meghna system is the major contributor to total water resources potential of the country. Its share is about 60 percent in total water resources potential of the various rivers. Again about 40 percent of uitlisable surface water resources are presently in Ganga-Brhamputra-Meghna system. In majority of river basins, present utilisation is significantly high and is in the range of 50 - 95 percent of utilisable surface resources. But in the rivers such as Narmada and Mahanadi the utilisation is quite low. The corresponding values for these basins are 23 percent aud 34 percent, respectively.

Some of the studies carried out in the Indian Himalyas clearly point out on an increase in glacial melt (Kumar *et al.*, 2007). For instance Baspa basin of Himachal Predesh has shown an increase in the winter strem flow by 75% as compared to 1966. It is estimated that Himalayan Mountains cover surface area of permanent snow and ice in the region is about 97,020 km^2 with 12,930 km^2 volumes. In these mountains, it is estimated that 10 to 20% of the total surface area is covered by glaciers while an additional area ranging from 30 to 40% has seasonal snow cover (Upadhyay, 1995; Bahadur, 1999). These glaciers provide the snow and the glacial-melt waters keep our rivers perennial throughout the year. Bahadur (1999) reported that a very conservative estimate gives at least 500 km^3/yr from snow and ice melt water contributions to Himalayan streams, while Afford (1992) reports about 515 km^3/yr from the upper mountains. The most useful facet of glacial runoff is the fact that glaciers release more water in a drought year and less water in a flood year and thus ensuring water supply even during the lean years. The snow line and glacier boundaries are sensitive to changes in climatic conditions. Almost 67% of the glaciers in the Himalayan mountain ranges have retreated in the past decade (Ageta & Kadota, 1992; Yamada *et al.,* 1996). The mean equilibrium line altitude at which snow accumulation is equal to snow ablation for glacier is estimated to be about 50-80 meters higher relative to the altitude during the first half of the 19th Century (Pender, 1995). Available records suggest that Gangotri glacier is retreating about 28 meters per year. A warming is likely to increase the melting far more rapidly than the accumulation. Glacial melt is expected to increase under changed climate conditions, which would lead to increased summer flows in some river systems for few decades, followed by a reduction in flow as the glaciers disappear (IPCC, 1998).

On the average, the area actually affected by floods every year in India is of the order of 10 million hectares of which about half is crop land. Rashtriya Barh Ayog (RBA) constituted by the Government of India in 1976 carried out an extensive analysis to estimate the flood-affected area in the country. RBA in its report has assessed the area liable to floods as 40 million hectares, which is nearly 1/8 of the country’s area (Mall *et al.,* 2006).

According to CWC (2002), as many as 99 districts spread over 14 states were identified as drought prone districts in the country. Most of the drought prone areas are concentrated in the states of Rajasthan, Karnataka, Andhra Pradesh, Maharashtra and Gujarat. Human factors that influence drought include demand for water through population growth and agricultural practices, and modification of land use that directly influences the storage conditions and hydrological response of catchments and thus its vulnerability to drought. As pressures on water resources grow so does vulnerability to meteorological drought (WMO, 2002).

Sinha Ray and She wale (2001) used rainfall data from 1875 to 1998 and give the percentage area of the country affected by moderate and severe drought. It may be noted that during the complete 124 years period there were three occasions i.e. 1877, 1899 and 1918 when percentage of the country affected by drought was more than 60%. It may be noted that during last years there was no occasion when the percentage area of the country affected by drought was more than 50%. It also confirms the finding of Sen and Sinha Ray (1997), which showed a decreasing trend in the area affected by drought in the country. In 124 years, the probability of occurrence of drought was found maximum in Rajasthan (25%), Saurastra & Kutch (23%), followed by Jammu & Kashmir (21%) and Gujrat (21%) region.The drought of 1987 in various parts of the country was of “unprecedented intensity” resulting in serious crop damages and an alarming scarcity of drinking water. Only 12 of 35 meteorological sub-divisions in the country had received normal rains (Mall *et al.,* 2006, 2007). With the decreased rainfall contributing to drought, the water levels in major reservoirs in the country, meant for agricultural irrigation purposes and hydroelectric power, naturally declined.

Groundwater resources

Ground water plays a very important role in meeting the ever increasing demands of agriculture, industry and domestic sectors. India is a vast country having diversified geological, climatological and topographic set-up, giving rise to divergent ground water situations in different parts of the country. The prevalent rock formations, ranging in age from Archaean to Recent, which control occurrence and movement of ground water, are widely varied in composition and structure. Similarly, not too insignificant, are the variations of land forms, from the rugged mountainous terrains of the Himalayas, Eastern and Western Ghats to the flat alluvial plains of the river valleys and coastal tracts, and the aeolian deserts of Rajasthan. The rainfall pattern, too, show similar region-wise variations. The topography and rainfall virtually control runoff and ground water recharge is controlled by these two in addition to composition and geometry of the aquifer.

The scarcity: The scarcity of water is understood in a very simple terminology of supply demand imbalances. Initially, the good olden days, generations have grown up with an idea of water as a free gift of nature, meaning thereby, it is available in abundance against the then demand situation. Whereas, now it is a scarce resource (supply and the quality) against the enhanced demand. The challenge would be much more in coming years when the demand curve would shift upwards with relatively inelastic supply (demand growth rate would be higher than the supply growth rate) due to increased demand of agricultural, infrastructure development, uneconomic use, high population pressures etc. And here is the challenge of management of increased demand and low supply. Garg and Hassan (2007) pointed out that water scarcity is alarming and calls for urgent action before it becomes unmanageable. Das (2008), has suggested climatic changes to global warming will make water an increasingly scarce commodity in the coming years.

Scenario of fround water resources

Groundwater is a replenishable, finite resource. Rainfall is the principle sources of its recharge, though in some areas canal seepage and return flow from irrigation also contribute significantly to the groundwater recharge. Groundwater resources comprises of two parts namely dynamic, in the zone of water table fluctuation and static resource, blow this zone, which usually remains perennially saturated. As per the National Water Policy, 2002, the dynamic groundwater resource is essentially the exploitable quantity of groundwater, which is recharged annually, and is also termed as replenish able groundwater resource. The annual replenishable groundwater resource of the country is 433 billion Cubic metres (bcm) and the net groundwater availability is 399 bcm after allocating 34 bcm for natural discharges during non-monsoon season. The annual groundwater draft for the year 2004 was 231 bcm, out of which 213 bcm is utilized for irrigation and 18 bcm is used for domestic and industrial purposes. Overall stage groundwater development is 58% (Chatterjee, 2009). However, 1615 assessment units fall under semi-critical (550), critical (226) and over Exploited (839) category, indicating that the groundwater resources in these areas is already being developed, more than that is being recharged(Fig-3). Further areas of the 30 assessment units are completely covered by saline groundwater. The rainfall contributes 67% of the country's annual replenishable groundwater resource (Chattejee, 2009), indicating the dependence on rainfall for recharge of groundwater resources. The south west monsoon contributes 73% of the country's annual replenishable groundwater recharge, taking place during Kharif period of cultivation. The stage of groundwater development is high in the states of Delhi, Haryana, Punjab and Rajasthan and Union Territories of Daman & Diu, and Pondicherry, where the overall stage of groundwater development is more than 100%.

Groundwater recharge is significantly high is the Ind-Gangetic-Brahmaputra alluvial belt, where the rainfall is plenty and thick piles of unconsolidated alluvial formations are conducive for recharge. Recharge per unit area (ha) in these regions varies from 0.28 to 1.35m. The coastal alluvial belt also has relatively high recharge, in the range of 0.16 to 0.40m. In the Western India, which have arid climate, the annual recharge is only 0.10 m. Similar is the case with major part of the southern peninsular India (Chatterjee, 2009). Based on crop water requirement and availability of cultivable land, utilizable irrigation potential has been estimated as 64.05 million hectares (mha) excluding 6.4 mha kept as reserve for any eventuality. The irrigation potential created till March, 1997 is estimated as 45.73 mha (CGWB, 2002).

During the past four decades, there has been a phenomenal increase in the growth of ground water abstraction structures due to implementation of technically viable schemes for development of the resource, backed by liberal funding from institutional finance agencies, improvement in availability of electric power and diesel, good quality seeds, fertilizers, government subsidies, etc. During the period 1951-97, the number of dugwells increased from 3.86 million to 10.50 million, shallow tubewells from 3000 to 6.74 million and public bore/tubewells from negligible to 90,000. Electric pump sets have increased from negligible to 9.34 million and Diesel pumps from 66,000 to about 4.59 million (Chadha and Sharma, 2000). There has been steady increase in area irrigated by ground water from 6.5 M.ha in 1951 to 41.99 M.ha in 1997. The ultimate irrigation potential from groundwater is 64.05 million ha (m.ha) as per report on 3rd Census of Minor Irrigatio Schemes (2005) as compared to 46 m.ha of land currently under groundwater irrigation, indicationg further scope for developing groundwater in some area like eastern and north-esatern parts of the country (Planning Commission, 2007). During VIIIth Plan, 1.71 million dug wells, 1.67million shallow tubewells and 114, 000 deep tubewells are added (CGWB, 2002).

Growing demands of water in agriculture, industrial and domestic sectors, ground water development has brought problems of over-exploitation of the resource, continuously declining water levels, seawater ingress in coastal areas & ground water pollution in different parts of the country. The falling ground water levels in various parts of the country have threatened the sustainability of ground water resource, as water levels have gone deep beyond the economic lifts of pumping. The adverse effects of groundwater over development are continuous decline of groundwater level, drying of wells, fall in yield of wells, thus reduction in command, reversal of hydraulic gradient in the coastal and seawater intrusion, decline in base flow of streams, extracost to be incurred for deeper wells and deepening of existing wells due to decline in water level, increase in lifting cost of electricity and consumption of more electricity, decline in farm production and in turn income, pollution of groundwater and so many such related ecological issues (Das, 2008). Central Ground Water Board has established about 15000 networkmonitoring stations in the country to monitor the water level and its quality. The water level in the country in major part of the area is generally do not show any significant rise/ fall. However, significant decline in the levels of ground water have been observed in certain pockets of 289 districts in the States of Andhra Pradesh, Assam, Bihar, Chhattishgarh, NCT Delhi, Jharkhand, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Tripura, Uttar Pradesh and West Bengal. The Fig.4 and 5 show the remarkable decline noticed in the NCT Delhi, the capital city of the country in the past 40 years and also in the last decade as a best example to depict the way of groundwater level decline taking place in the urban areas.

The groundwater in most of the areas in the country is fresh. Brackish ground water occurs in the arid zones of Rajasthan, close to coastal tracts in Saurashtra and Kutch, and in some zones in the east coast and certain parts of Punjab, Haryana, Western Uttar Pradesh, etc., which are under extensive surface water irrigation. The fluoride levels in the ground water are considerably higher than the permissible limit in vast areas of Andhra Pradesh, Haryana and Rajasthan and in some parts of Punjab, Uttar Pradesh, M.P, Karnataka and Tamil Nadu. In the north-eastern regions, ground water with iron content above the desirable limit occurs widely. Widespread Arsenic contamination in West Bengal Basin, covering eastern parts of West Bengal and in localized extent in Mid-Ganga basin is recorded (Saha, *et. al.,* 2009). The Upper part of the newer alluvial deposits underlying flood prone areas bordering Ganga River is affected by highincidence of arsenic contamination in groundwater. Pollution due to human and animal wastes and fertilizer application have resulted in high levels of nitrate and potassium in ground water in some parts of the country. Ground water contamination in pockets of industrial zones is observed in localized areas. The over-exploitation of the coastal aquifers in the Saurashtra and Kutch regions of Gujarat has resulted in salinisation of coastal aquifers. The excessive ground water withdrawal near the city of Chennai has led to seawater intrusion into coastal aquifers. The artificial recharge techniques can be utilised in improving the quality of ground water and to maintain the delicate fresh water-salt water interface (CGWB, 2002).

At present, available statistics on water demand shows that the agriculture sector is the largest consumer of water in India. About 83% of the available water is used for agriculture alone. The quantity of water required for agriculture has increased progressively through the years as more and more area was brought under irrigation. Since 1947, irrigated area in India rose from 22.60 Mha to 80.76 Mha upto June 1997. The contribution of surface and groundwater resources for irrigation has played a significant role in India attaining self-sufficiency in food production during the past 3 decades and is likely to become more critical in future in the context of national food security. According to available estimates, the demand on water in this sector is projected to decrease to about 68% by the year 2050 though agriculture will remain the largest consumer. In order to meet this demand, augmentation of existing water resources by development of additional sources of water or conservation of the existing resources through impounding more water in the existing water bodies and its conjunctive use will be needed (Mall *et al.*, 2006). The depletion of ground water and enhanced demand of water will have high impact on the sociocultural and economic fabric. The scarcity of water, might force people to make shift from agriculture to other alternative options. It would also force people to migrate to the cities (as already indicated in the studies conducted, that by 2050, 50% of the people will live in the urban areas) which would have other consequences. More pressure on urban infrastructure, cost of living, sustainable livelihood issues, housing, water sanitation, quality of life etc.

Observed climate change and its impacts during the past century

Recently, Goswami *et al.* (2006) found that the frequency of occurrence as well as intensity of heavy and very-heavy rainfall events have highly significant increasing trends; low and moderate events have significant decreasing trend over Central India (Fig. 2). In India, several studies show that there is increasing trend in surface temperature i.e. 0.5 to 0.6^{o}C during 1901-2005 and 0.05^{o}C/decade year during the period 1901-2003, the recent period 1971-2003 has seen a relatively accelerated warming of 0.22^{o}C/decade (Singh and Sontakke, 2002; Kothawale and Rupakumar, 2005; Mall *et al.,* 2006; Das & Hunt 2007), no significant trend in rainfall and/or decreasing/increasing trends in rainfall and sharp decrease in rainy days (Singh and Sontakke, 2002; Goswami *et al.,* 2006; Rajeevan *et al.,* 2006; Ramesh and Goswami, 2007). Singh and

Sontakke (2002) found that the summer monsoon rainfall over western Indo-Gangetic Plain Region (IGPR) showed increasing trend (170 mm/100 yrs, significant at 1% level) from 1900, while over central IGPR it showed decreasing trend (5 mm/100 yrs, not significant) from 1939, and over eastern IGPR, decreasing trend (50 mm/100 yrs, not significant) during 1900-1984, and insignificant increasing trend (480 mm/100 yrs, not significant) was observed during 1984-1999. Broadly, it is inferred that there has been a westward shift in rainfall activities over the IGPR.

The year–to-year variability in monsoon rainfall leads to extreme hydrological events (large scale drought and floods) resulting in serious reduction in agricultural output and affecting the vast population and the national economy. Droughts, floods and desertification are directly connected with monsoon/rainfall patterns, ocean circulation and soil moisture and water availability. As discussed above the problems of Indian rainfall are diverse, in terms of both geographical distribution and seasonality, and spread over a period of years. There are large variations in the total rainfall received in each geographical division, causing both droughts and floods. The fury of these natural disasters has arguably been more intense and more frequent by the abuse of nature and degradation of environment. The adverse impacts of these two natural disasters cannot be assessed merely in economic terms based on destruction of crops, property and infrastructure because the toll of human misery in the form of death, disease, injury, loss of employment, psychological trauma, and above all the set-back to development are too difficult to evaluate (Dash and Hunt, 2007; Prabhakar and Shaw, 2008; Revi, 2008).

Reddy *et al.,* (2008) reported that during 1990 to 2004 Kosi River showed a significant shift of 3.5 km in northwestern part, followed by central and north eastern parts of river with 2.5 km shift. Course change by the rivers is an environmental problem of serious concern in the Indo-Gangetic Plain Region (IGPR). At different times in the past different rivers changed their course a number of times. During the period 1731-1963, the course of the Kosi river (the sorrow of Bihar) has shifted westward by about 125 km, the courses of Ganga, Ghaghara and son at their confluence have shifted by 35 to 50 km since epic period ~ 1000 BC (Singh, 1971) and that of Indus and its tributaries by 10-30 km in the 1200 years in the same (Wilhelmy, 1967). Between 2500 BC and 500 BC the course of the Yamuna river shifted westward to join Indus and then east to join Ganga thrice (Raikes, 1968).

Das and Radhakrishnan (1991) reported a rising trend in the sea level at Mumbai (Bombay) during 1940-86 and Chennai (madras) during 1910-1933, based on the annual means of tide gauge observations. Srivastava and Balakrishnan (1993) confirmed a rise of sea level by 8 cm with a corresponding fall in the pressure during 1901-1940. Unnikrishnan *et al.,* (2006) estimated sea level rise at selected stations to be around 10 cm per century. Such prediction has been made by analyzing past tide gauge data. The estimation for sea level rise for four major cities like Mumbai, Kochi, Vishakhapatanam and Chennai were 0.78, 1.14, 0.75 and -0.65 mm/year.

By above studies it is clear that the global warming threat is real and the consequences of the climate change phenomena are many, and alarming. The impact of future climatic change may be felt more severely in developing countries such as India whose economy is largely dependent on agriculture and is already under stress due to current population increase and associated demands for energy, fresh water and food. In spite of the uncertainties about the precise magnitude of climate change and its possible impacts particularly on regional scales, measures must be taken to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects.

Projected climatic trend

Rupa Kumar *et al.* (2006) projected that warming is monotonously widespread over the country, but there are substantial spatial differences in the projected rainfall changes. West central India shows maximum expected increase in rainfall. Extremes in maximum and minimum temperatures are also expected to increase in future, but the night temperatures are increasing faster than the day temperatures. Extreme precipitation shows substantial increases over a large area, particularly over the west coast of India and west central India. However, projection over north eastern region shows not satisfactory result and more in depth study is going on.

Lal *et al.* (2001) estimated that CO_2 level will increase to 397–416 ppm by 2010s from the present CO_2 level of 371 ppm and this would further increase by 605–755 by 2070. They projected between 1 to 1.4C & 2.23 to 2.87^{0}C area-averaged annual mean warming by 2020 & 2050, respectively. Comparatively, increase in temperature is projected to be more in winter season than in summer. A large uncertainty is associated with projected winter rainfall than monsoon rainfall in 2050s. Moreover, the standard deviation of future projections of areaaveraged monsoon rainfall centered around 2050s is not significantly different relative to the present-day atmosphere implying thereby that the year-to-year variability in mean rainfall during the monsoon season may not significantly change in the future. More intense rainfall spells are, however, projected over the land regions of the Indian subcontinent in the future thus increasing the probability of extreme rainfall events in a warmer atmosphere.

Rupa Kumar and Ashrit (2001) have projected 13% increase in monsoon or *kharif* season rainfall in India using ECHAM4 model, while Had mods CM2 suggests reduction in *kharif* rainfall by 6% in the greenhouse gas simulation. Both GCMs suggest an increase in annual mean temperature by more than 1C (1.3C in ECHAM4 and 1.7^{0}C HadCM2). Rupa Kumar et al. (2003) concluded that future scenarios of increased greenhouse gas concentrations (GHG) indicate marked increase in both rainfall and temperature into the 21st century, particularly becoming conspicuous after the 2040s in India. Over the region south of 25^{0}N (south of cities such as Udaipur, Khajuraho and Varanasi), the maximum temperature will increase by 2–4^{0}C. during 2050s. In the northern region, the increase in maximum temperature may exceed 4^{0}C. This study also indicates a general increase in minimum temperature up to 4^{0}C all over the country, which may however exceed over the southern peninsula, northeast India and some parts of Punjab, Haryana and Bihar. There is an overall decrease in number of rainy days over a major part of the country. This decrease is more in western and central part (by more than 15 days) while near the foothills of Himalayas (Uttarakhanda state) and in northeast India the number of rainy days may increase by 5–10 days. However, increase in GHG may lead to overall increase in the rainy days intensity by 1–4 mm/day except for small areas in the northwest India where the rainfall intensities decrease by 1 mm/day.

Impacts of projected climate change on water resources

Table 1 shows the selective reports on impact of climate change on water resources during next century over India. The enhanced surface warming over the Indian subcontinent by the end of the next century would result in an increase in pre-monsoonal and monsoonal rainfall and no substantial change in winter rainfall over the central plains. This would result in an increase in the monsoonal and annual runoff in the central plains with no substantial change in winter runoff. They also indicated an increase in evaporation and soil wetness during the monsoon and on an annual basis (Lal and Chander, 1993).

A case study of Orissa and West Bengal estimates that in the absence of protection, one meter sea level rise would inundate 1700 km^2 of predominantly prime agricultural land (IPCC, 1992). The regional effects of climate change on various components of the hydrological cycle, namely surface run-off, soil moisture, and evapotranspiration (ET) for three-drainage basins of central India is analyzed and results indicated that the basin located in a comparatively drier region is more sensitive to climatic changes. The high probability of a significant effect of climate change on reservoir storage, especially for drier scenarios, necessitates the need of a further, more critical analysis of these effects. Chattopadhyary and Hulme (1997) calculated increases in potential evaporation across India from GCM simulations of climate; they found that projected increases in potential evaporation were related largely to increases in the vapor pressure deficit resulting from higher temperature.

The hydrologic sensitivity of the Kosi Basin to projected land-use, and potential climate change scenarios has been analyzed. It was found that runoff increase was higher than precipitation increase in all the potential climate change scenarios applying cotemporary temperature. The scenario of contemporary precipitation and a rise in temperature of 4^oC caused a decrease in runoff by 2-8% depending upon the areas considered and model used (Sharma *et al.*, 2000a, b). It is also projected that soil moisture increase marginally by 15-20% over parts of Southern and Central India. This increase is confined to the monsoon months of June through September. During the rest of the year, there is either no change in soil moisture or a marginal decline possibly due to the increase in temperature leading to enhanced ET (Lal and Singh, 2001).

Gosain et al. (2003, 2006) projected that the quantity of surface runoff due to climate change would vary across the river basins as well as sub basins in India. However, there is general reduction in the quantity of the available runoff. An increase in precipitation in the Mahanadi, Brahimini, Ganga, Godavari and Cauvery is projected under climate change scenario; however, the corresponding total runoff for all these basins does not increase. This may be due to increase in ET because of increased temperature or variation in the distribution of the rainfall. In the remaining basin, a decrease in precipitation was noticed. Sabarmati and Luni basin showed drastic decrease in precipitation and consequent decrease of total runoff to the tune of 2/3rd of the prevailing runoff. This may lead to severe drought conditions in future. The analysis has revealed that climate change scenario may deteriorate the condition in terms of severity of droughts and intensity of floods in various parts of the country. There have been few more studies on climate change impacts on Indian water resources (Roy *et al.*, 2003; Chadha, 2003; Tangri, 2003).

Singh *et al.* (2009) highlighted the assessment of the water resources in changing climate for relevant national and regional long-term development strategies. Goyal (2004) studied the sensitivity of ET to global warming for arid regions of Rajasthan and projected an increase of 14.8% of total ET demand with increase in temperature, however ET is less sensitive to increase in solar radiation, followed by wind speed in comparison to temperature. Increase in water vapor has a negative impact on ET (-4.3%). He concluded that a marginal increase in ET demand due to global warming would have a larger impact on resource poor, fragile arid zone ecosystem of Rajasthan.

Ground water and climate change

Problems in ground water management in India have potentially huge implications for global warming. The most optimistic assumption suggests that an average drop in ground water level by one meter would increase India's total carbon emissions by over 1%. More realistic assumption reflecting the area projected to be irrigated by groundwater in 2003, suggests that the increase in Carbon emission could be 4.8% for each meter drop in groundwater levels. Chadha (2003) recommended studying the aquifer geometry and establishing the saline fresh interfaces within 20 Km of the coastal area, the effect of glaciers melting on the recharge potential of the aquifer in the Ganga basin together with its affects on the trans-boundary aquifer system particularly of the arid and semi-arid regions. Panda *et al.* (2007) studied the influence of repeated droughts and increased anthropogenic pressure on the groundwater levels of Orissa during the period 1994–2003. Preliminary study showed that the groundwater levels of the network observation wells are very sensitive to the monsoon rainfall, and any irregularity in rainfall directly influences the groundwater levels. Due to drought in 2002, the groundwater level dropped significantly in the consolidated formation that covers 80% of the geographical area of Orissa. The fitted curves of both the annual and monsoon rainfall indicated a downward trend although four wet years were experienced during the study period. The effect of droughts and high temperature on groundwater levels should be counterbalanced by the effect of flood, and over years it should remain stable.

Climate change policy

The Government of India is actively involved with climate change activities since long. India is a Party to the United Nations Framework Convention on Climate Change (UNFCC). The Eighth session of the Conference of Parties (COP-8) to the UN convention on Climate Change in 2002, New Delhi ended with a Delhi Declaration which successfully resolved the technical parameters necessary for the implementation of the Kyoto Protocol (1997). The Delhi declaration gave primacy for the implementation of the Clean Development Mechanism (CDM) in the climate change process. The National Clean Development Mechanism Authority is operational since December 2003 to support implementation of CDM projects. The Bali conference on climate change (December 2009) showed all the countries the way forward to the next phase of the campaign to control the planet's changing climate, the specific objective being to put a multilateral arrangement in place that will succeed the 1997 Kyoto Protocol of the UN convention on Climate Change, which will terminate in 2012. The Bangkok meeting (March 2008) was the beginning of the new process, which was continued in December, 2009 at Copenhagen.

To address the future challenges, in June 2007, the Government announced the constitution of a high-level advisory group on climate change and prepared a 'National Action Plan on Climate Change' and that released by the Hon'ble Prime minister of India on June 30, 2008 (http:/pmindia.nic.in/Climate%20 Change_16.03.09.pdf); which is in line with the international commitments and contains eight missions on climate mitigation and adaptation (NAPCC, 2008). Now relevant ministries are preparing and submitting their respective plans to the Prime Minister's Climate Change Council. One of the missions "National Water Mission" will be mounted to ensure integrated water resources management helping to conserve water, minimize wastage and ensure more equitable distribution both across and within states. The mission will take into account the the provisions of National Water Policy and develop a framework to optimize water uses and by increasing water use efficiency by 20% through regulatory mechanism and differential entitlements and pricing. It will seek to ensure that considerable share of water needs of urban areas are met through recycling of waste water, and ensuring that the water requirements of coastal cities with inadequate alternative sources of water are met through adoption of new and appropriate technologies such as low temperature desalination technologies that allow for the use of ocean water (Singh *et al.*, 2009).

Understanding about Climate change adaptation is still growing. In India, many regions and sectors, climate change impact assessment is yet to be completed. The projection of rainfall scenario over north eastern region (Assam & Bihar) of the country is not satisfactory. Given that climate change assessment is still going on, there is need to develop and strengthen the climate change adaptation process which depend on more analysis of the resilience livelihood and the policies that impacts on livelihood and people capacities. Society already encounters large costs in adapting to climate extremes; climate change will only increase these costs. Several policies already exist to address adaptation to climate variability: however there is need to study these policies and their impact on communities' capacities to adapt to climate change in Assam and Bihar.

Given our limited understanding of climate change, extending the range of adaptation strategies seems worthwhile. In this respect, special attention should be given to the following:

1. Alternative livelihood.
2. Capacity Building: to educate people about the effects of their activities on carbon –trapping and about possible responses to the effects of natural climatic variability and potential climate changes in the future.
3. Changes in land-use allocation, including the development of new plant species. Since most of the world's plant food comes from just 20 species, the potential of the majority of species is still to develop.
4. Food security policies and reduction of post harvest losses. Post-harvest losses, due to deficient systems of storage and transport, amount to 50% or more in many states, which means that there is ample room for improvement.
5. Conversion to "controlled-environment agriculture" may invest billion of rupees in an annum.
6. Water resource management: areas where large changes in rainfall regimes (e.g. increased frequency and severity of floods or drought), an improved and more environmentally sound infrastructure will be necessary and policies encouraging water conservation (e.g. pricing mechanisms) will have to be introduced.

Based on the this current study it may be mentioned that for long term adaptation from Climate Variability and Climate Change, several policy instruments are available at different levels and these instruments are functioning in real sense even at the remote village levels but need improved governance, productivity and accountability of the government machinery.

CONCLUSIONS

These studies are still in infancy and a lot more data in terms of field information is to be generated. This will also facilitate the appropriate validation of the simulation for the present scenarios. However, besed above studies it is clear that the global warming threat is real and the consequences of the climate change phenomena are many, and alarming. The impact of future climatic change may be felt more severely in developing countries such as India whose economy is largely dependent on agriculture and is already under stress due to current population increase and associated demands for energy, fresh water and food. In spite of the uncertainties about the precise magnitude of climate change and its possible impacts particularly on regional scales, measures must be taken to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects.

In addition, the uncertainty involved in predicting extreme flood and drought events by the models are large. Also their is no clear role of global warming in the variability of monsoon rainfall over India. Therefore, it is difficult, at this juncture, to convince the water planning and development agencies to incorporate the impact of climate change into their projects and water resources systems. However, given the potential adverse impacts on water resources that could bring about by climate change, it is worthwhile for the authority to conduct more in-depth studies and analyses to gauge the extent of problems that the country may face.

Agricultural water demand, particularly for irrigation water, is considered more sensitive to climate change. A change in field-level climate may alter the need and for timing of irrigation: Increased dryness may leads to increased demands, but demand could be reduced if soil moistures content rises at critical times of the year (IPCC, 2001). Doll and Sibert (2001) concluded that global net irrigation requirements would increase relative to the situation without climate change by 3.5 to 5% by 2025, and 6-8% by 2075. In a recent study by Saeed et al (2009) signified the role of irrigation in effecting the local temperature, which in turn effects large-scale circulations and precipitation.

From the above it can be concluded that Indian region is highly sensitive to climate change and demand for water from groundwater may increase if precipitation decreases and surface water inflows decrease, this leads to a decrease in discharge elsewhere. The elements / sectors currently at risk are likely to be highly vulnerable to climate change and variability and here exist uncertainties in dealing with vulnerabilities associated to climate change and variability. It is urgently required to intensify in-depth research work with following objectives:

- Strengthening observational data and data access network.
- Assess the recent experience in climate variability and extreme events, impacts of projected climate change and variability and associated hydrological events in India at river basin / aquifer level.
- How climate changes might affect groundwater aquifers, including quality, recharge rates, and flow dynamics.
- In-depth study on groundwater recharge, which is so dependent on individual sustained rainfall events as well as on the changes in land use pattern. This study is long due.
- How sea level rise might affect the coastal groundwater regime.
- Determine vulnerability of regional water resources to climate change and identifying key risks and prioritizing adaptation responses.
- Community based water management, to conserve and augment recharge.
- Alternative cropping pattern; possible increase in irrigation demands, and its mismatch with water availability.

As discussed, climate change may have both direct and indirect effects on both recharge and discharge to an aquifer. Increased temperature may lead to higher potential evapo-transpiration and increased water use demand. Therefore, an effective management of ground water resources requires an integrated approach in both planning and implementation of schemes. Different agencies related to water resources, climate, agriculture and other sectors should coordinate and bring out policies on scientific considerations for effective management of ground water resources in changing climate. Uncertainty in predictions from global climate models (GCMs) is currently limiting the ability of groundwater models to predict the impact of climate change on ground water. Greater consistency between GCMs and a finer resolution will allow better prediction of groundwater systems response to climate change that are subject to less uncertainty. The coupling of GCMs with hydrologic (surface water and ground water) models has been necessary due to advances in super-computer technology. A future increase in demand water is likely to have a much greater impact on groundwater than reduced recharge due to climate change. With increased scarcity of groundwater, the time has come when government and community should work together for an integrated management targeted towards providing water to all on a sustainable basis.

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Table 1. Selective reports on impact of climate change on water resources.

Region/Location	Impact	Reference
Indian subcontinent	• Increase in monsoonal and annual runoff in the central plains • No substantial change in winter runoff. • Increase in evaporation and soil wetness during the monsoon and on an annual basis.	Lal and Chander, 1993
Orissa and West Bengal	One-meter sea levels rise would inundate 1700 km2 of prime agricultural land	IPCC, 1992
Indian coastline	One-meter sea level rise on the Indian coastline is likely to affect a total area of 5763 km2, and put 7.1 million people at risk	JNU, 1993
All India	Increases in potential evaporation across India,	Chattopadhyay and Hulme, 1997
Central India	Basin located in a comparatively drier region is more sensitive to climatic changes	Mehrotra, 1999
Kosi Basin	Decrease in runoff by 2-8%	Sharma et al, 2000, a,b
Southern and Central India	Soil moisture increase marginally by 15-20% in monsoon months	Lal and Singh, 2001
Damodar basin	Decreased river flow	Roy et al., 2003
Rajasthan	An increase in ET	Goyal, 2004
River basins of India	General reduction in the quantity of the available runoff, increase in Mahanadi and Brahmini basin	Gossai and Rao, 2006
River basins in northwest & central India	Increase in heaviest rainfall and reduction in number of rainy days	Singh et el., 2008

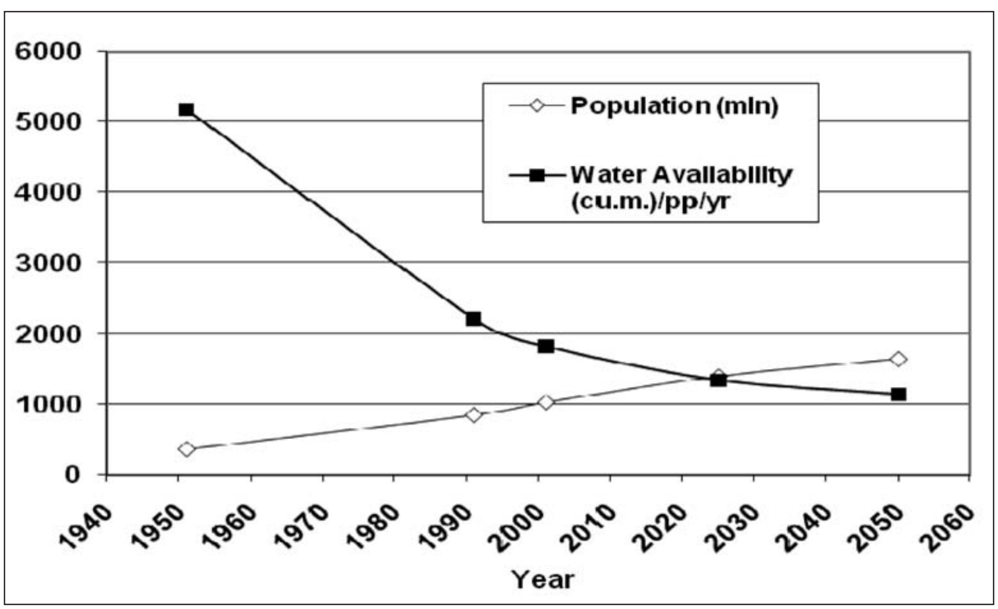


Fig. 1. All India Summer Monsoon rainfall anomalies (1871-2009) (Source: IITM, Pune)

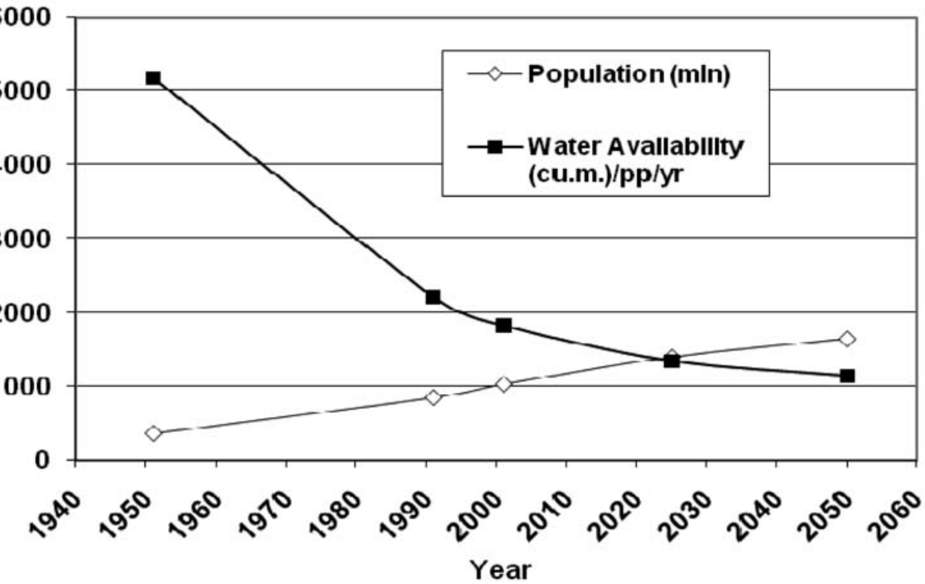


Fig. 2. Observed and projected decline in per capita average annual freshwater availability and growth of population from 1951 to 2050 (Mall *et al.*, 2006).

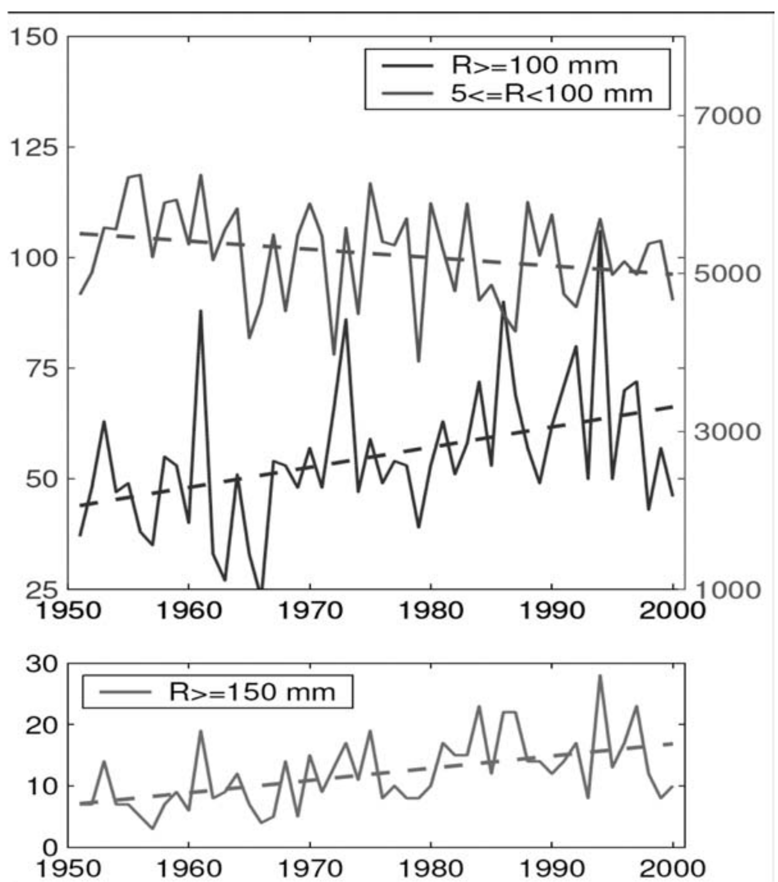
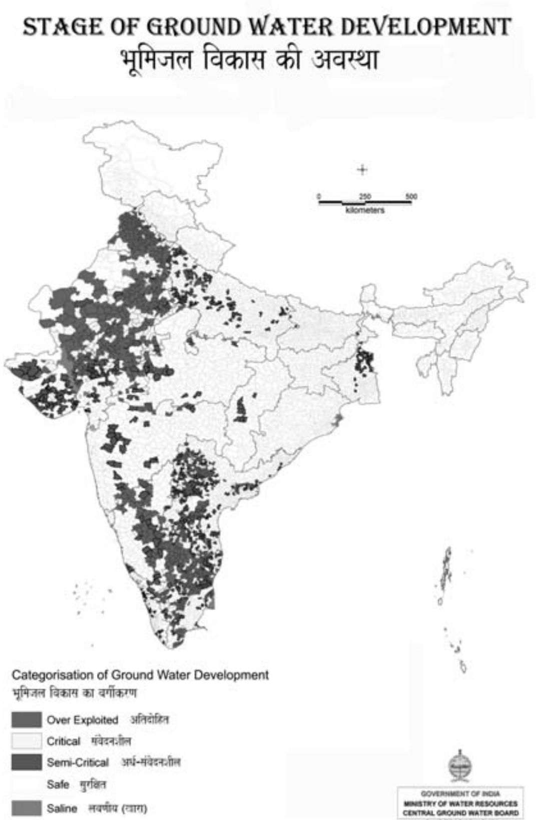
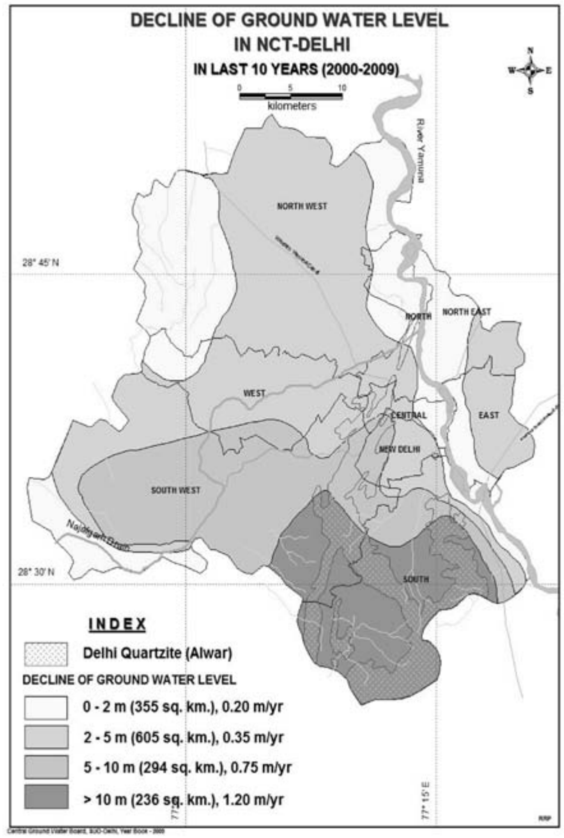
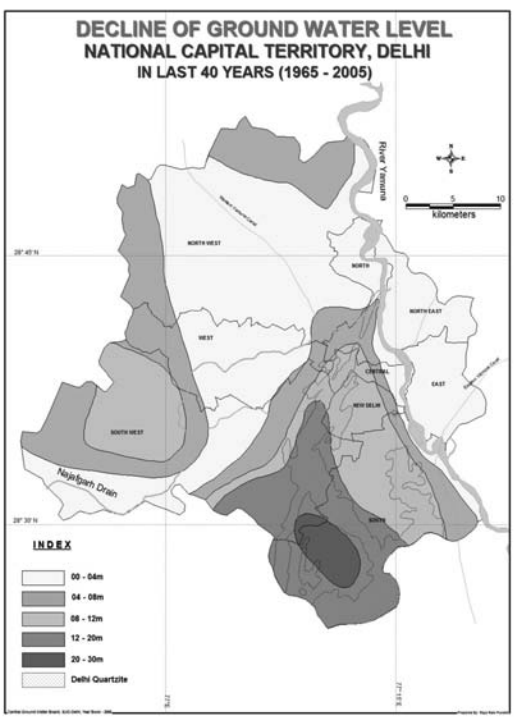
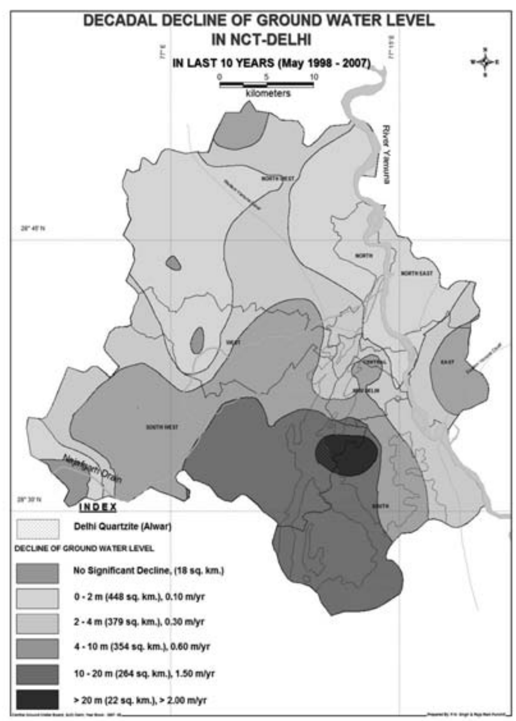


Fig. 3. Changes in the Frequency of Extreme Rainfall over central India (Goswami *et al.*, 2006).


STAGE OF GROUND WATER DEVELOPMENT
भूमिजल विकास की अवस्था
kilometers
Categorisation of Ground Water Development
भूमिजल विकास का वर्गीकरण
Over Exploited अतिदोहित
Critical संवेदनशील
Semi-Critical अर्ध-संवेदनशील
Safe सुरक्षित
Saline लवणीय (खारा)
GOVERNMENT OF INDIA
MINISTRY OF WATER RESOURCES
CENTRAL GROUND WATER BOARD


DECLINE OF GROUND WATER LEVEL
IN NCT-DELHI
IN LAST 10 YEARS (2000-2009)
kilometers
River Yamuna
NORTH WEST
NORTH
NORTH EAST
WEST
CENTRAL
EAST
NEW DELHI
SOUTH WEST
SOUTH
Najafgarh Drain
28° 45' N
28° 30' N
INDEX
Delhi Quartzite (Alwar)
DECLINE OF GROUND WATER LEVEL
0 - 2 m (355 sq. km.), 0.20 m/yr
2 - 5 m (605 sq. km.), 0.35 m/yr
5 - 10 m (294 sq. km.), 0.75 m/yr
> 10 m (236 sq. km.), 1.20 m/yr


DECLINE OF GROUND WATER LEVEL
NATIONAL CAPITAL TERRITORY, DELHI
IN LAST 40 YEARS (1965 - 2005)
River Yamuna
kilometers
Najafgarh Drain
INDEX
00 - 04m
04 - 08m
08 - 12m
12 - 20m
20 - 30m
Delhi Quartzite


DECADAL DECLINE OF GROUND WATER LEVEL
IN NCT-DELHI
IN LAST 10 YEARS (May 1998 - 2007)
kilometers
River Yamuna
Najafgarh Drain
INDEX
Delhi Quartzite (Alwar)
DECLINE OF GROUND WATER LEVEL
No Significant Decline, (18 sq. km.)
0 - 2 m (448 sq. km.), 0.10 m/yr
2 - 4 m (379 sq. km.), 0.30 m/yr
4 - 10 m (354 sq. km.), 0.60 m/yr
10 - 20 m (264 sq. km.), 1.50 m/yr
> 20 m (22 sq. km.), > 2.00 m/yr

Impact of Climate Change on Soil Erosion and Runoff

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ABSTRACT

The climate change is a reality during twenty first century though some people still opine that it is a climatic variability. The term climatic variability implies inherent deviation from within the normal climate of a region which gets nullified over a short period. The word climatic variability is linked with the term probability which conforms that a parameter of certain magnitude is expected to repeat at certain time intervals. The word climate change indicates a shift in the climatological parameters from a long term average (normally of 30 years) of recorded data. The global climatological data analysis clearly confirms a change in the climate. The changes observed in the easily measurable parameters of temperature and solar radiations (radiatve force) clearly show a significant change over time in the recorded instrumental data since 1850. The 100 years linear trend (1906-2005) of 0.74 (0.56 to 0.92)°C temperature has been reported (FAR, IPCC) which is more than 0.6° (0.4 to 0.8)°C (1901-2000) reported earlier (TAR, IPCC). Further eleven of the 12 years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). These are 1998, 2005, 2003, 2002, 2004, 2006, 2001, 1997, 1995, 1999, 1990, and 2000 in decreasing order. The last 50 years period shows an increasing rate of 0.128 ± 0.026 degree per decade whereas last 100 years period shows a rate of 0.074 ± 0.018 degree per decade in the temperature (Fig.1, IPCC). Consequent upon the increasing trend in temperature, a rise in sea level has been observed due to melting of polar ice, glaciers and thermal expansion of sea water. The global average sea level has risen at an average rate of 1.8 (1.3 to 2.3) mm per year since 1961 and at the rate of about 3.1 (2.4 to 3.8) mm per year since 1993. If the sea level continues to rise at this rate then Maldives, Lakshdweep Islands and similar other coastal areas are likely to be inundated. However, some area in temperate region is likely to be additionally available for cultivation as snow line is expected to go up due to retreat of the glaciers. The hypotheses are many and the scientists are trying to be precise in their computations. The temperature increase is widespread over the globe and is greater at higher northern latitudes.

The projections for future are still worse than the tiny changes being observed by individuals. It is projected that the global temperature may even rise by 1.1 to 6.4° during twenty first century. Now we are tired with the observed temperature changes as referred above and the rise in sea level at the rate of only the magnitude of 1.8 (1.3 to 2.3) mm per year since 1961 and at the rate of about 3.1 (2.4 to 3.8) mm per year since 1993.The projected change in the temperature of 1.1 to 6.4° is likely to cause the sea level to rise by about 18 to 59 cm. There is a confidence level of over 90 percent that there will be more frequent warm spells, heat waves and heavy rainfall during twenty first century. There is a confidence level of more than 66 percent that there will be an increase in droughts, tropical cyclones and extreme high tides. The Soil and Water Conservation Society (2003) reported increase in soil erosion ranging from 4% to 95% and increase in runoff from 6% to 100% as evident from crop lands in some locations.

Climate change in India

The Tibetan Plateau has experienced warming in the range of 0.02 °C to 0.03 °C per year over the last fifty years (Yao *et al*., 2006)-much greater than the global average of 0.74 °C total over the last hundred years (IPCC, 2007). Based on regional climate models, it is predicted that the temperature on the Indian subcontinent will rise between 3.5 °C and 5.5 °C by 2100, and on the Tibetan Plateau 2.0 °C by 2050 and 5.0 °C by 2100 (Roop Kumar *et al*., 2006).

The Himalayas have a total glaciated area of around 33,000 sq km (Eriksson *et al*., 2009) which provides important short and long term water storage facilities. "There is about 12,000 cubic kilometer of fresh water stored in the glaciers throughout the Himalayas – more fresh water than in Lake Superior" (Thompson, 2007). Compared to glaciers in other mountain ranges, the Himalayan glaciers are retreating at higher rates, and these rates are accelerating. Projections of glaciers retreat in the region (IPCC, 2007) suggest that the projected increase in the mean annual temperature for High Asia of 1.0°C to 6.0°C by 2100 is likely to result in an extensive diminishing of glacial coverage.

India has skewed pattern of rainfall distribution, receiving 50 percent of its annual rainfall in just 15 days. According to Biswas (2004), Cherranpunji, with highest rainfall in India receives its annual rainfall of 10820 mm between June and August in about 120 hours, but faces a water shortage problem during the dry months.

There is a relationship between the intra-annual rainfall variability in a country and its level of prosperity. Countries with low rainfall variability typically have high GDPs (Gross Domestic Products), while countries struggling with large seasonal variability in water availability typically have low GDPs (Brown and Lall, 2006). Increased storage capacity and reduced seasonal differences in availability may help to reduce this gap.

The mean surface temperature in Tropical Asia has increased by 0.3 -0.8°C over the past 100 years, although there has been no trend in mean rainfall for the past thirty years in the region. There is also no discernible change in the number, frequency or intensity of the tropical cyclones over the past 100 years, although some decadal patterns do exist (McLean *et al.*, 1998). Temperature predictions for India due to anthropogenically-caused climate change for the year 2040 versus 1980 are for a 0.7°C and 1.0°C increase in maximum and minimum surface air temperatures, respectively. However, this warming will be less prominent during the monsoon season. Winter diurnal temperature range is predicted to decrease (McLean *et al.*, 1998). With a doubling of pre-industrial levels of CO_2 in the atmosphere, the United Kingdom Meteorological Office (UKMO) GCM predicts a temperature increase of 16.2% for India, the Goddard Institute for Space Studies (GISS) GCM predicts an increase of 10%, and the Geophysical Fluid Dynamics Laboratory (GFDL) GCM predicts an increase of 23.5%. Some recent studies, however, have indicated that the GCMs temperature predictions are too high (Dinar *et al.*, 1998).

Each of these three models predicts an increase in precipitation with a doubling of CO_2 levels from pre-industrial levels, but they predict differing magnitudes of increase at different times of the year (Dinar *et al.*, 1998). The IPCC predicts that there will be an increase in the magnitude and frequency of extreme rainfall events in tropical Asia, but due to the effect of sulfate aerosols, the mean summer monsoon rainfall in India may decrease by 0.5 mm/day. There is some uncertainty as to how much anthropogenic aerosols are being emitted, thus limiting the confidence of these predictions (McLean *et al.*, 1998).

Soil moisture is also supposed to be altered due to changes in precipitation, runoff, percolation, evaporation and rainfall distribution. However, soil moisture is very hard to predict due to many factors involved and the uncertainty associated in making any climate change prediction (Dinar *et al.*, 1998).

The CO_2 emissions by fuel type for the year 2000-01 in India are given in Table 2 (Anonymous, 2006). The total emissions of CO_2 from India during 2000-01 have been estimated at 880 million tones. The main source is coal with 550 million tones, followed by high speed diesel (114 million tones) and natural gas (59 million tones).

The preliminary information on various aspects of climate change is not adequate in India. Realizing its importance, ICAR has initiated a study on "Impacts, Adaptation and Vulnerability of Indian Agriculture to Climate Change". The CSWCRTI has carried out a study on "Impact of Climate Change on Soil and Water Conservation". Some of the highlights of the study are presented here.

Methodology

As we all understand, the soil loss is generally linked to runoff. Higher the runoff, more is the energy available to transport the dislodged soil particles. The parameters influencing the runoff are either static or dynamic. The parameters, viz; topography and soils are static parameters and the parameters, viz; rainfall, vegetation (land cover) and management practices are dynamic in nature. Under the scenario of climate change, the rainfall is the major dynamic parameter. The rainfall shall have bearing on vegetation (land cover) and management practices. Therefore, in addition to the input parameter of changed rainfall for a given study area, the expected vegetation with suitable management practice has to be evolved to study the rainfall-runoff-soil loss relationships.

It has been reported by most of the workers (IPCC, 2007) that the climate change is expected to completely change the rainfall characteristics, viz; total amount of rainfall for a given duration (annual, seasonal, monthly, weekly and daily), duration of rainfall, intensity of rainfall and number of annual rainfall hours. All these factors were appropriately accounted for in the study.

Seven watersheds having an area ranging between 491 ha (Pogalur, Coimbatore, Tamilnadu) to 816 ha (Jonainala, Keonjhargarh, Orissa) were selected for the study. AVSWAT model was calibrated and validated to generate the projected runoff and soil losses for 1961-1990 and 2071-2100. The available data of daily runoff and soil loss from different land uses of Almas watershed (Uttarakhand) for 2003 to 2006 was used to calibrate and validate the model. The R^2 and slope for calibration period (2003) for runoff were 0.79 - 0.99 and 0.35 - 1.74, respectively against the values for validation period of 2004-4006 (pooled data) of 0.80 - 0.94 (R^2) and 0.82 – 1.04 (slope). The R^2 and slope for soil loss of calibration period (2003) was 0.76 – 0.98 and 0.70 – 1.64, respectively. These values for validation period (2004 2006) were 0.81 – 0.93 and 0.80 – 1.47, respectively. When these standardized parameters were applied on watershed basis, the values of R^2 and slope were 0.67 and 1.68, respectively for soil loss. The sensitivity analysis of the relevant parameter affecting runoff and soil loss (for example soil erodibility (K) is a function of soil texture, soil structure, permeability and organic matter and it was analyzed as to what extent the K will change with a change in temperature and rainfall) was carried out so as to have proper decision support. The daily runoff and soil loss generated from the AVSWAT model was then suitably analyzed. The relevant parameter affecting runoff and soil loss was generated as detailed below:

Rainfall

The projected daily rainfall of seven watersheds located in different agro-ecological regions of the country having an area of 491 ha to 816 ha was obtained from Indian Institute of Tropical Meteorology (IITM), Pune on a pixel size of $0.44^0 * 0.44^0$ run under Regional Circulation Model (RCM; PRECIS; generated from GCM of HADCM3 for A2a Scenario) for the periods 1961-1990 and 2071-2100. These data were analyzed and run off and soil loss was assessed for all the 7 watersheds using Soil Conservation Service (curve number method) method and AVSWAT, respectively.

Topography

The Digital Elevation Model (DEM) layers of the study watersheds were developed/ generated using Arc-view after scanning respective toposheets (1:50,000 or 1:25,000 scale) of the watersheds available with the Survey of India (SOI) following standard procedure.

Land cover and soils layer

The land use and soil layer was generated by processing the LISS III + PAN merged digital data obtained from National Remote Sensing Agency (NRSA), Hyderabad on 23.5 m and 5.8 m resolution, respectively using EASE/PACE image processing software through visual interpretation and ground truth verification. The information available with National Bureau of Soil Survey and Land Use Planning, Nagpur, Survey of India, published literature and physical survey were also used to supplement the observations.

Other ancillary data

The detailed information on soil characteristics (the soil erodibility factor), rainfall characteristics (the rainfall erosivity factor), cropping sequence and its management and land management etc. were computed/ obtained after employing appropriate model with calibration and validation.

Validation of the model

The SCS model has been calibrated and validated for daily runoff from different land uses observed from Almas watershed with R^2 value of 0.80-0.94 (Table 1).

The runoff for the base period of 1961-1990 and for the projected period of 2071-2100 has been assessed under 3 options as follows:

Option l: The existing system of management and cultivation continues irrespective of rainfall.

Option II: The economic and social condition of farmers shall not allow them to practice better improved management and cultivation practices, hence the condition shall deteriorate irrespective of rainfall.

Option III: The technological advancement and social – economic improvement shall help the farmers to adopt better management and cultivation as per changed rainfall.

The change in area, land management, hydrological condition and thus the relevant curve number were arrived in a rational manner by adopting the law of expected acceptance.

Computation of the projected soil loss

The AVSWAT model has been used to assess soil loss from various watersheds. The relevant data on soil, land use and their management practices responsible for sediment yield were used to develop relevant layers along with the development of DEM by scanning the respective toposheet of the watershed area under study. Soil and land use database were created and value inserted in the input data base of main menu of AVSWAT, keeping in view the ranges defined under AVSWAT model. Model was initiated by breaking the watershed into sub-basins. Stream networks were automatically delineated and main outlet of the watershed was selected by defining threshold area of appropriate size with suitable pixel number. Each of the sub-basins were further sub-divided into Hydrologic Response Units (HRUs) using automated GIS processing. After defining HRU, each sub-watershed was linked to the weather generation file which includes the daily rainfall, maximum and minimum temperature, wind speed, solar radiation & relative humidity for five years of the study area. Input data was simulated by defining the initial and final date of simulation. Simulation brought a tiled result window containing files of .bsb, .rch, .sbs, out put map and project window. The model employs daily time step, and can be used for continuous simulation for 1 to 100 years period. SWAT can simulate hydrology, pesticide and nutrient cycle, erosion, and sediment transport. AVSWAT, Arc view SWAT model extension represents at the same time a preprocessor and a user interface to SWAT model.

The model has been calibrated and validated for annual soil loss observed from Almas watershed with R^2 value of 0.97.

Results

Annual rainfall, rainy days and runoff

The daily rainfall data as obtained from IITM, Pune (PRECIS; generated from GCM of HADCM3 for A2a Scenario) for 1961 to 1990 and 2071 to 2100 were analyzed. It is observed that annual rainfall is increasing in all the study watersheds. The minimum increase of 3.4 percent is projected at Udhagamandalam followed by Pogalur (14.7%), Almas (18.0%), Antisar (18.4%), Jonainala (22.8%), Belura (43.9%) and Umiam (46.9%) during 2071-2100 against the annual rainfall of 1961-1990. The Umiam and Almas, being in mountainous region, are likely to be subjected to wetter conditions leading to severe soil loss. The dry region of Belura, expected to witness high rainfall beneficial for agriculture, may lose more soil thus causing loss of crop productivity as soil in this region is shallow in depth. The annual rainfall may not reveal much of the likely effects as seasonal changes.

The annual rainy days are projected to decrease at Antisar (6.4 percent), Udhagamandalam (5.2 percent), and Umiam (-2.8 percent) and increase at remaining locations. However, this change is not significant at Umiam (2.8 percent decrease), Almas (4.5 percent increase), Jonainala (5.0 percent increase), Udhagamandalam (5.2 percent decrease) and Antisar (6.4 percent decrease). The rainy days are likely to change significantly at Pogalur (13.2 percent increase) and at Belura (86.7 percent increase).

The seasonal and annual runoff for all the 7 watersheds has been computed for the period during 1961-1990 and 2071-2100 and is presented in Table 1 and Fig. 1. The runoff at all the study locations is expected to increase during 2071-2100 over 1961-1990. It is expected to increase at Pogalur (by about 12 times), Belura (141.5 percent), Umiam (125 percent), Antisar (123.9 percent), Udhagamandalam (120.7 percent), Jonainala (83.0 percent), and Almas (55.9 percent) during 2071-2100 than the runoff during 1961-90. Most of the increase in runoff has been observed during monsoon season.

Runoff under various options of adaptation of technology and socio-economic condition of the farmers (Table 2)

As one knows, the runoff is a function of (i) Topography, (ii) Soil, (iii) Rainfall, (iv) Land Cover and residue management, and (V) Supportive management. Out of the five parameters, topography, and soil are unlikely to change significantly with change of climate. The rainfall is a major factor and has been taken from models. The cover crop and its management and adoption of supportive practices shall depend upon the (a) Socio-economic condition of the people, and (b) Technological advancements made to mitigate the effect of changed climatic scenario. The runoff projections have therefore been attempted under three options as detailed below:

Option I

Under option I (the existing system of management and cultivation continues irrespective of rainfall), the annual runoff is expected to increase at Pogalur (by about 12 times), Belura (141.5 percent), Umiam (125 percent), Antisar (123.9 percent), Udhagamandalam (120.7 percent), Jonainala (83.0 percent), and Almas (55.9 percent) during 2071-2100 than the runoff during 1961-90. The run off under this option is beneficial in all the seasons except in monsoon. The frequency of floods and droughts is likely to increase.

Option II

The run off under this option (the economic and social condition of farmers shall not allow them to practice better improved management and cultivation practices, hence the condition shall deteriorate irrespective of rainfall) is likely to create more problems and the floods and droughts are expected to be most severe at all the study locations except at Pogalur where the annual runoff is expected to increase by 9.6 times against the increase of about 12 times under Option I in comparison to the annual runoff of 1961-1990. It is projected to increase by 3 times (1.2 times under Option I) at Udhagamandalam, 2.26 times (1.24 times under Option I) at Antisar, 1.81 times (1.41 times under Option I) at Belura, 1.7 times (1.25 times under Option I) at Umiam, 1.32 times (55.9 percent more under Option I) at Almas, and 1.1 times (83 percent more under Option I) at Jonainala in comparison to the annual runoff of 1961-1990.

Option III

The annual runoff under option III (the technological advancement and social economic improvement shall help the farmer to adopt better management and cultivation as per changed rainfall) is expected to have minimum increase under all the options compared to annual runoff of 1961-1990 at Pogalur, Umiam, Udhagamandalam, Antaisar and at Jonainal. It is expected to increase marginally at Belura and Almas than the increase under Option I in comparison to the annual runoff of 1961-1990.

Flood and drought analysis

The runoff data of 1961-1990 and 2071 to 2100 for all the seven watersheds has been computed and analyzed for the frequency of droughts and floods. The number of years with runoff less than 50 mm, 50-150 mm, 150-300 mm and more than 300 mm has been grouped and deviation has been computed between 1961-1990 and 2071-2100. It is observed that Jonainala may have twice the annual runoff of more than 300 mm (16 years out of 30 years) during 2071-2100 than what it has during 1961-1900 (8 years out of 30 years). Annual runoff of more than 300 mm is likely to be observed twice during 2071-2100 while it does not have a single event during 1961-1990. Similarly, Belura and Umiam are also expected to have increased annual runoff years of more than 300 mm by 155.5 and 26.1 per cent, respectively during 2071-2100. Umiam is expected to have more than 300 mm runoff events of 29 against 23 thus having an increase of 23 per cent.

At Belura, the runoff years of 150-300 mm are likely to be reduced to 4 during 2071-2100 from 10 during 2961-1990. Similarly at Umiam, the runoff years of 150-300 mm are likely to be reduced to 1 during 2071-2100 from 5 during 2961-1990. Antisar may have 6 runoff years of 150-300 mm during 2071-2100 in comparison to nil during 1961-1990.

At Antisar, which had 13 years during 1961-1990 of less than 50 mm runoff, is going to have only four years during 2100. This reduction is from 9 to 3 at Almas, 30 to 18 at Udhagamandalam, 30 to 27 at Pogalur and 2 to nil at Jonainala.

It can be concluded that during the end of the 21st century, Jonainala, and Umiam shall be experiencing floods more frequently. Antisar and Belura are expected to experience medium floods more frequently. Drought is expected to be more frequent at Antisar, Almas, Udghamandalam and at Jonianala (Table 3).

Soil loss projections

It is observed that Pogalur watershed is going to experience maximum soil loss (757 percent more) followed by Belura watershed (269 percent more), Umiam watershed (71 percent more), Antisar watershed (60 per cent more), Almas watershed (41 percent more), Jonainala watershed (29 per cent more) and least by Udhagamandalam watershed (4 per cent more) during 2071-2100 than that during 1961-1990. The Umiam watershed may yield soil loss of about 24.8 t ha^{-1} yr^{-1} during 2071-2010 against the soil loss of 14.5 t ha^{-1} yr^{-1} observed during 1961-1990. The Poglur watershed is having insignificant soil loss of 7 kg ha^{-1} yr^{-1} during 1961-1990. However, the soil loss in this area is going to increase to 60 kg ha^{-1} yr^{-1} during 2071-2100 and shall be within permissible limits (Table 4 and Fig 1).

CONCLUSIONS

The study reveals that the runoff and soil loss are expected to increase throughout India during 2071-2100 in comparison to the soil loss during 1961-1990. It is also estimated that during the same period, the soil loss is likely to increase by 3.7 percent in Udhagamandalam (Nilgiris, Tamilnadu) to about 757 percent at Pogalur (Akola, Maharastra). The runoff is estimated to increase by 56 percent at Almas (Tehri, Uttarakhand) to about 600 percent at Pogalur during the same period. The frequency of occurrence of droughts and floods has also been estimated and it does not give a positive trend. Both are expected to increase thus demanding much extensive rainwater management practices. The most feasible and relevant mitigation measure to combat frequent droughts and floods to ensure sustained food production shall be to adopt suitable soil and water conservation measures on watershed basis more earnestly in combination with planting of permanent vegetation i.e. trees and maintaining at least 15-20 percent of undisturbed forest in every watershed of about 500 ha.

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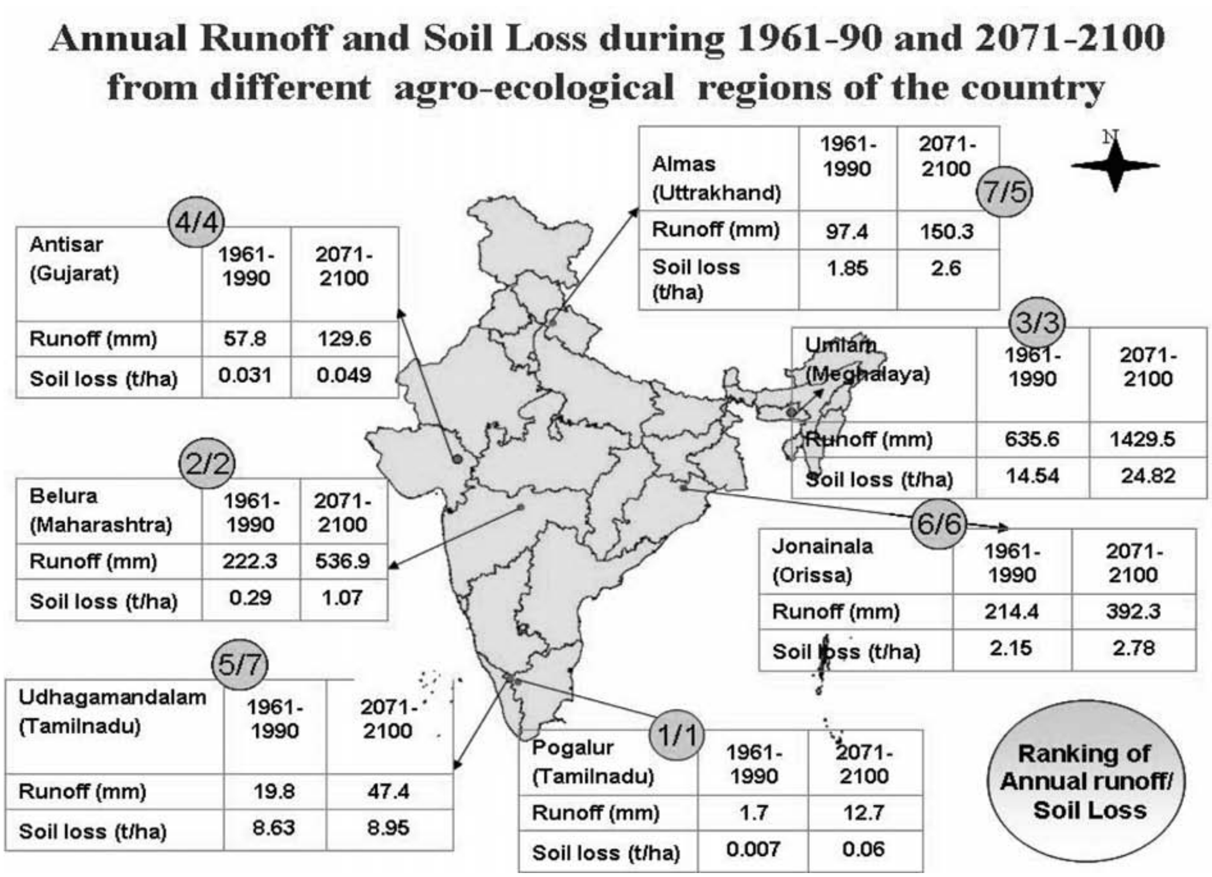

Figure 1. Runoff and soil loss during 1961-90 and 2071-2100 in different agro- ecological regions of the country

Table 1. Change in seasonal and annual runoff (mm) of watersheds located in different agro-ecological regions of India for A2a scenario (PRECIS, IITM, Pune) during 1961-1990 and 2071- 2100.

Season		Watersheds						
		Almas	Antisar	Belura	Jonainala	Ooty	Pogalur	Umiam
Winter Monsoon	1961-90	1.0	0.0	0.3	0.2	0.0	0.0	3.2
	2071-2100	0.9	0.0	0.1	2.8	0.7	0.0	8.2
	% Dev.	-10.0	0.0	-66.7	1300.0	-	0.0	156.3
Pre-Monsoon	1961-90	1.0	1.8	1.5	34.3	4.7	0.0	496.7
	2071-2100	2.0	2.12	5.3	50.2	2.2	0.8	1119.9
	% Dev.	100.0	17.8	253.3	46.4	-53.0	-	125.5
Monsoon	1961-90	79.6	54.0	213.6	162.4	13.2	0.2	94.5
	2071-2100	129.1	121.8	500.7	300.3	19.6	0.9	254.1
	% Dev.	62.2	125.5	134.4	84.9	48.0	350.0	168.9
Post-Monsoon	1961-90	15.0	2.1	6.9	17.5	1.9	0.7	41.0
	2071-2100	18.6	5.7	30.8	39.0	21.2	10.1	47.4
	% Dev.	24.0	171.4	346.4	122.9	1016.0	1342.9	15.6
Annual	1961-90	96.6	57.9	222.3	214.4	19.8	0.9	635.4
	2071-2100	150.6	129.6	536.9	392.3	43.7	11.8	1429.6
	% Dev.	55.9	123.9	141.5	83.0	120.7	1211.1	125.0

Table 2. Annual runoff (mm) and percent variation between 1961-1990 and 2071-2100 from different watersheds under various options

Watersheds	Base period (1961-1990)	Option I		Option II		Option III	
		2071-2100	% Dev.	2071-2100	% Dev.	2071-2100	% Dev.
1. Almas	96.6	150.6	55.9	224.1	132.0	151.1	56.4
2. Antisar	57.9	129.6	123.9	189.2	226.8	125.9	117.4
3. Belura	222.3	536.9	141.5	625.84	181.5	563.72	153.6
4. Jonainala	214.4	392.3	83.0	451.5	110.6	391.4	82.5
5. Ooty	19.8	43.7	120.7	80.8	308.0	38.5	94.4
6 .Pogalur	0.9	11.8	1211.1	9.51	956.7	6.7	644.4
7. Umiam	635.4	1429.6	125.0	1720.9	170.8	1235.9	94.5

Table 3. Frequency of runoff(mm) exceeding in 30 years duration in different watersheds

Duration and percent deviation	Frequency of runoff(mm) exceeding in 30 years				Total
	<50	50-150	150-300	>300	
1. Joninala					
1961-1990	2	9	11	8	30
2071-2100	0	4	10	16	30
Deviation (%)	-100	-55.6	-9.1	100.0	-
2. Pogalure					
1961-1990	30	0	0	0	30
2071-2100	27	3	0	0	30
Deviation (%)	-10	300.0	0	0	-
3. Udhagamandalam					
1961-1990	30	0	0	0	30
2071-2100	18	12	0	0	30
Deviation (%)	-40	1200.0	0.0	0	-
4. Almas					
1961-1990	9	21	0	0	30
2071-2100	3	27	0	0	30
Deviation (%)	-66.6	28.5	0	0	-
5. Umiam					
1961-1990	0	2	5	23	30
2071-2100	0	0	1	29	30
Deviation (%)	0	-100	-80	26.1	-
6. Belura					
1961-1990	0	11	10	9	30
2071-2100	0	3	4	23	30
Deviation (%)	0	-72.7	-60	155.5	-
7. Antisar					
1961-1990	13	17	0	0	30
2071-2100	4	18	6	2	30
Deviation (%)	-69.2	5.8	600	200	-

Table 4. Soil loss (t ha^{-1}) of selected watersheds.

S.No.	Watersheds	Soil loss (t ha^{-1})		
		1961-1990	2071-2100	Deviation (%)
1.	Almas	1.85	2.6	40.54
2.	Antisar	0.031	0.049	60.00
3.	Belura	0.29	1.07	268.97
4.	Joninala	2.15	2.78	29.30
5.	Ooty	8.63	8.95	3.71
6.	Pogalure	0.007	0.06	757.14
7.	Umiam	14.54	24.82	70.70

Effect of Climate Change on Agro-environment and Coping Strategies under Eastern-Indian Conditions

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ABSTRACT

Climate change and global warming pose significant threat to agriculture and global food security. Changes in solar radiation, temperature, CO_2 concentration and precipitation will produce changes in crop yields and hence economics of agriculture. Eastern regions of the country is predicted to be most affected by increased temperatures and decreased radiation, resulting in relatively fewer grains and shorter grain filling durations. It is possible to understand the phenomenon of climate change and its effect on crop production and to develop adaptation strategies for sustainability in food production by using suitable crop growth simulation models. Yields of major crops such as maize, wheat and potato were simulated at a few locations in eastern India namely Kharagpur, Dumdum, Purulia and West Midnapore of West Bengal. It was observed that increase in mean temperature, minimum and maximum temperature as well as solar radiation have negative impact on maize yield. The CERES-Wheat model simulated yield declined by 284.8 kg/ha per degree celcious rise in average seasonal temperature. It was observed from SUBSTOR-potato model simulation that when the minimum temperature increases, tuber yield decreases. From these studies it was revealed that the adverse effect of climate change on yield can be minimized by advancing the sowing date in case of maize crop. It was also observed that higher yield could be obtained with the planting density of 3 plants per m^2 for maize crop, and 200 plants per m^2 for the wheat crop.

INTRODUCTION

The agricultural sector represents 35% of India's Gross National Product (GNP) and as such plays a crucial role in the country's development. Food grain production quadrupled during the post-independence era and this growth is projected to continue. The impact of climate change on agriculture could result in problems with food security and may threaten the livelihood activities upon which much of the population depends. Climate change can affect crop yields (both positively and negatively), as well as the types of crops that can be grown in certain areas. It can have impact on agricultural inputs such as water for irrigation, intensity of solar radiation that affects plant growth, as well as the prevalence of pests.

Climate can affect agriculture in a variety of ways. Temperature, solar radiation, rainfall, soil moisture and carbon dioxide (CO_2) concentration are all important variables which affect agricultural productivity, and their relationships are not simply linear. Recent researches confirm that there are thresholds for these climate variables above which crop yields decline (Challinor et al. 2005; Proter and Semenov 2005). For example, the modeling studies discussed in recent IPCC reports indicate that moderate to medium increases in mean temperature (1–3ºC), along with associated increase in CO_2 concentrations and rainfall changes, are expected to benefit crop yields in temperate regions. However, in low-latitude regions, moderate temperature increases (1–2ºC) are likely to have negative yield impacts for major cereals. On the other hand warming of more than 3ºC would have negative impacts in all regions (IPCC 2007b). The carbon dioxide (CO_2) concentration was in the steady state at 280 ppm till the pre industrial period (1850). It is rising since then at the rate of 1.5 to 1.8 ppm per year. Increase in atmospheric CO_2 concentration can have a positive impact on crops yields by stimulating plant photosynthesis and reducing the water loss via plant respiration.

Not many studies have been conducted in the past to assess the impact of climate change on agro-environment in eastern India, where a major portion of the cultivated area is covered under rainfed rice. Majority of the farmers in this region depend on monocrop and have poor economic background to bear any risk of crop failure. Therefore detailed study of the climate change scenario on the basis of long term historic weather data, forecast of future scenario, its impact on yield of major crops as well as agro-environment and formulation of coping strategy are of paramount importance to reduce the risk of crop failure. The reported study is an attempt in this direction. The effect of coping strategies in terms of adjustment in the date of sowing, planting density, application rate of inputs such as irrigation etc. have been analyzed through some case studies to develop strategy for sustainability in food grain production.

Methodology

Long term historical weather data, experimental results of major field crops and corresponding crop growth models viz. CERES-Wheat, CERES-Maize and SUBSTOR Potato models of DSSAT v.4.0 were used to analyze the effect of climate change on crop production and to develop adaptation strategies for minimizing risk.

Case studies were conducted at a few locations in eastern India namely Kharagpur (22.33°N latitude and 87.33°E longitude), Dumdum (latitude 22.38°N, longitude 88.38°E), Purulia (latitude 23.2°N, longitude 88.28°E) and West Midnapore (86°45' E 21°45' N and 88°E 23' N) district of West Bengal. Results of field crop experiments with variable rate of inputs were used for model calibration.

The soil of this region is of lateritic type with sandy loam texture, which is taxonomically grouped under the group 'Alfisol'. The soil is partly eroded due to high intensity rainfall in the area during monsoon season. The information on physical and chemical properties of soil for Kharagpur required for this study was collected from the soil report of a past study (Kashyap, 2001). The surface soil depth varies from 0 to 60 cm. The clay content varies from 14.3 to 28.6 percent, whereas the silt and sand contents vary from 26.2 to 19.2 percent and 59.5 to 52.2 percent respectively. The pH of the soil varied from 5.5 to 5.9. The bulk density of the soil ranged from 1.62 to 1.58 g cm^{-3}. Soil organic carbon content varies from 0.36 to 0.15 percent. The data of other areas namely Dumdum and Purulia were also collected. In case of Dumdum the soil depth varied from 0-111 cm, the clay content varied from 37.7-45.7 percent, silt and sand content varied from 51.5-57.9 percent and 2.4-4.4 percent respectively. The pH varied from 6.4-7.4, organic carbon 0.17-0.64 percent and bulk density varies from1.38-1.45 g cm^{-3}. For Purulia, the soil depth varied from 0-150 cm, the clay, silt and sand content varied from 39.4-45.0 percent, 18.0-24.0 percent and 33.1-47.1 percent respectively, pH varied from 6.2-6.3, organic carbon 0.29-0.69 percent and bulk density 1.35-1.48 g cm^{-3}.

Weather Data

Daily values of the weather variables such as: solar radiation, maximum and minimum temperature, maximum and minimum relative humidity, wind speed and precipitation were obtained from the India

Meteorological Department (IMD), Pune, India and from automatic weather station installed near the experimental site.

Crop Data

For Maize and Wheat crop, the parameters were measured during different stages of growth. The crop data included planting date, date of emergence, 20% cover date, full cover date, maturity date, harvest date, maximum rooting date, crop coefficient at full cover, planting depth and maximum root depth. The data on grain yield, above ground dry matter yield and leaf area index were recorded at different stages of crop growth during each crop experiment. In case of potato the cultivar Kufri-Jyoti was selected, which is a popular 90-110 days vegetable crop of the locality and suits to the prevailing climate in the winter season (November to February). Data related to the crop parameters such as planting date, date of emergence, maturity date, harvest date, planting depth and maximum root depth were collected. The data on fresh tuber yield, dry tuber yield, above ground dry matter yield and leaf area index were also recorded at different stages of crop growth of potato.

Dssat Group of Models

DSSAT version 4.0 models were used for modeling crop growth, soil, weather and management or husbandry interactions and has been used to assess climate change impacts (Holden *et al.*, 2003). The DSSAT was developed to allow users to interactively select any of the functions without knowing where the programmes are or how they are communicating. The main components of DSSAT v4.0 are shown in Table 1. A new Weather Data Manager Weather Man is built in for entering, analyzing and generating weather and climate data, which is a part of DSSAT v4.0 program. The Soil Data tool SBuild is used for entering and editing of soil data. The Crop Management Data tool XBuild is used for entering and editing experimental crop data. The Graphics program GBuild is used for graphical display of simulated and experimental data.

Table 1. Components of DSSAT v 4.0.

Components	Description
Databases	Weather, soil, genetics, pests, experiments, economics
Models	Crop models (maize, wheat, rice, barley, sorghum, millet, soybean, peanut, dry bean, potato, cassava, etc.)
Supporting software	Graphics, weather, pests, soil, genetics, experiments, economics
Applications	Validation, sensitivity analysis, seasonal strategy, crop rotations

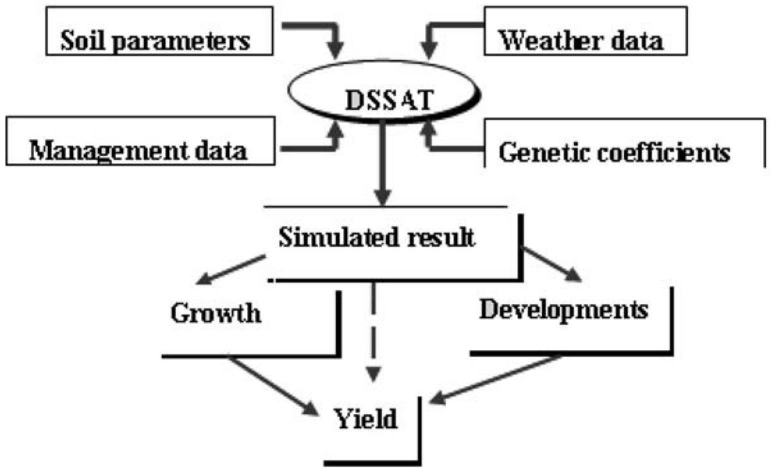

Fig. 1. The Dssat Models

Performance of CERES-Maize model

CERES-Maize requires six parameters, known as “genetic coefficients”, to characterize different cultivars. These cultivar–specific genetic coefficients affect development rates, organ growth and plant ontology. These coefficients are constants in the model and are used to quantify differences in growth and development responses between different maize cultivars. These genetic coefficients primarily depend upon the photoperiod, temperature and the genetic potential of the cultivar.

Calibration of CERES-Maize model

The model was calibrated using the experimental data on grain yield, above ground dry matter and maximum leaf area index. The well-watered treatment (10% MAD) of each experiment was selected for calibration. The values of genetic coefficients were estimated using the best-fit method. Model calibration was performed for each experiment separately and an average value of each genetic coefficient was considered for further use. The best set of genetic coefficients was obtained by trial and error method. All the genetic coefficients have a pre-assigned range prescribed by the model developers and calibrated values need to fall within that range. A fairly good agreement was found between simulated and measured grain yield of maize. It was also found that the simulated and measured above ground dry matter and leaf area index were matching reasonably well with each other during calibration.

Validation of CERES-Maize model

The model was validated for the four treatments of irrigated crops i.e. 30, 45, 60, 75% depletion of available soil water using all three years of field experiments during 1996 to 1998. The genetic coefficients determined by the process of calibration were used for validation. For validation, the model was run independently for the T2, T3, T4 and T5 treatments of irrigation.

Calibration of CERES-Wheat

The CERES-Wheat model was calibrated by using the experimental data on the grain yield, straw yield and maximum leaf area index (LAI). The file containing genetic coefficients was used to estimate the genetic coefficient values. Model was calibrated using the experimental data for two years 2002-04 separately and an average value of each genetic coefficient was estimated. The file containing genotype coefficients was used to estimate the genetic coefficients for wheat cultivar 'Sonalika'. The final set of genetic coefficients was obtained by the best-fit method. A fairly good agreement was found between simulated and measured grain yield of wheat (Table 2).

Table 2. Performances of CERES-Wheat in simulating the crop growth parameters

Crop parameters	R^2	RMSE	ME	EF
Grain yield (kg/ha)	0.84	341	524	0.82
Straw yield (kg/ha)	0.81	421	681	0.80
Leaf area index	0.78	0.16	1.46	0.78

R^2 = coefficient of determination, RMSE = root mean square error, ME = maximum error and
EF= modelling efficiency.

Validation of CERES-Wheat

The CERES-Wheat model was calibrated using experimental data for two years 2002-04. Then the model was validated using experimental data for the year 2004-05. The genetic coefficients determined by the process of calibration were used for validation. The performance of CERES-Wheat model in simulating crop growth parameters such as grain yield, straw yield and maximum leaf area index (LAI) of wheat crop is discussed in this section. The validation of CERES-Wheat was performed by comparing the simulated grain yield, straw yield and maximum leaf area index of wheat crop under different irrigation and fertilizer treatments with their measured counterparts for the year 2004-05.

Calibration of SUBSTOR-Potato model

The SUBSTOR-Potato model was calibrated by using the experimental data on the date of tuber initiation, date of physiological maturity, fresh tuber yield, plant dry matter yield and maximum leaf area index. The model was calibrated for four years (1995-1998) separately and an average value of each genetic coefficient was estimated. These genetic coefficients primarily depend upon the photoperiod, temperature and the genetic potential of the cultivar. The value of genetic coefficient G3 (Potential tuber growth rate), which depends on the potential tuber growth rate, was considered for simulating fresh tuber yield. The accurate estimation of leaf area index is important since canopy photosynthesis and subsequent plant dry matter is highly dependent on leaf area development.

Validation of SUBSTOR-Potato model

The SUBSTOR-Potato model was calibrated for three years 1995-97. Then the model was validated for the year 1998. The genetic coefficients determined by the process of calibration were used for validation. The results of simulations at various stages of crop growth for all experiments are discussed separately in Table 4.

Table 4. Stage-wise variations in total dry matter with respect to difference between mean temperature and required temperature.

Year	Stage 1		Stage 2		Stage 3	
	Temp. difference in ^{0}C	Total dry matter in kg/ha	Temp. difference in ^{0}C	Total dry matter in kg/ha	Temp. difference in ^{0}C	Total dry matter in kg/ha
1995-96	-2.36	60	2.13	2700	2.89	6064
1996-97	-3.11	20	1.17	3034	1.78	6603
1997-98	-2.49	35	1.89	2749	2.46	6249
1998-99	-1.01	100	1.31	3019	3.08	5571

Results

Effect of minimum and maximum temperatures on growth and yield of crops

Effect of varying temperature on maize yield was studied using the crop growth model with 31 years (1977-2007) of daily weather data. Rising maximum temperature was observed to have negative impact on the maize yield at Kharagpur as seen during the years 1979, 1990, 1999 and 2003(Fig. 2). Lower temperature prolongs the growth duration of maize and reduces the crop growth rate. Maize grows well where the night temperature does not go below 15.6 °C (Wilson et al, 1995). In the reported study the minimum temperature never dropped below 19 °C during the growing season of maize, thereby minimum temperature had no adverse effect on the yield of maize.

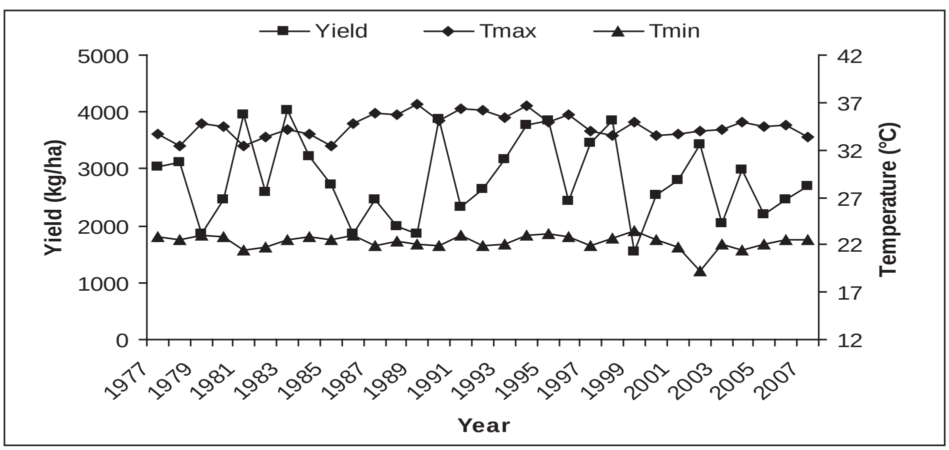

Fig 2. Variation in maize yield with maximum and minimum temperatures at Kharagpur during the years 1977-2007

The validated CERES-Wheat model was used for simulation of wheat grain yield using historical weather data for 27 years (1974-2002) and a fixed climate change scenarios (Fig.3). It was observed that increasing day time temperature (Maximum temperature) increases the yield due to higher CO_2 concentration. But beyond a certain level, grain yield again decreases with the increment in maximum temperature. The grain yield decreased with increase in maximum temperature above 27 ^{0}C.

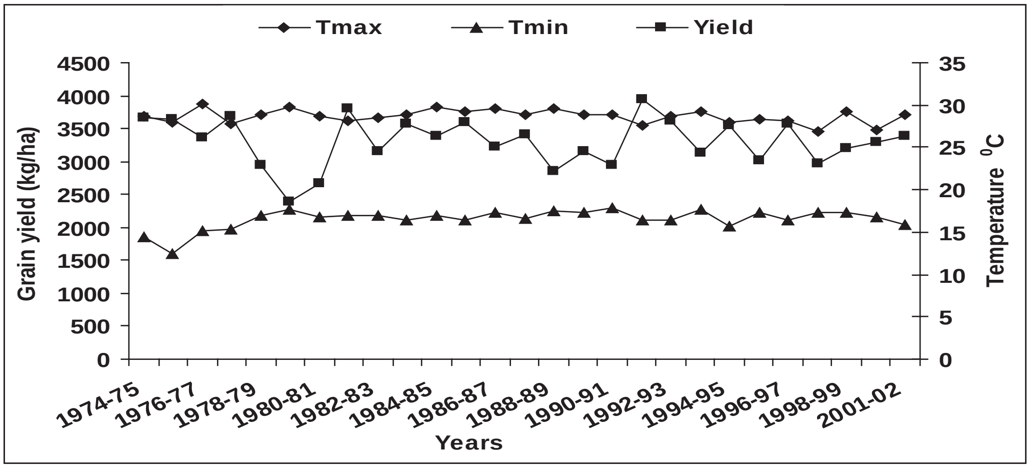

Fig 3. Variation in wheat grain yield with annual mean maximum and minimum temperatures during the years 1974-2002

On the other hand rising night time temperature (minimum temperature) can lead to decrease in tuber yield of potato as revealed during the years 1978-79, 1997-98, 2000-2001. Low temperature at night reduces the expansion of leaves. As a result, less photosynthesis occurs and specific leaf weight increases and thereby the proportion of assimilate partitioned to the roots increases.

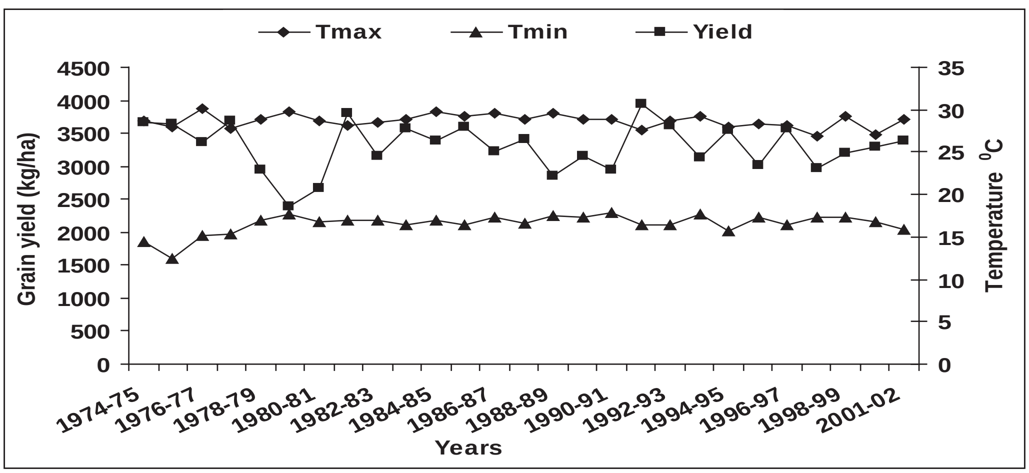

Fig 4. Variation in potato yield with maximum and minimum temperature during 1977-2007

Effect of plant density on wheat and maize yield

The effect of change in wheat plant density was studied in the range of 100-350 plants/m^2 to cope with climate change scenario. It was observed that with increase in plant density, grain yield increased while with decrease in plant density grain yield decreased considering 160 plants/m^2 as reference plant density. This is due to the fact that increased plant density increased tiller density but decreased the number of grains per spikelet and spikelets per ear. The highest grain yield was observed at 200 plants/m^2 (Fig. 5). The effect of change in plant density was also studied in the range of 1to 9 plants/m^2 for maize crop. It was observed that the plant density of 3 plants/m^2 (Fig 6) produced the highest yield at Kharagpur.

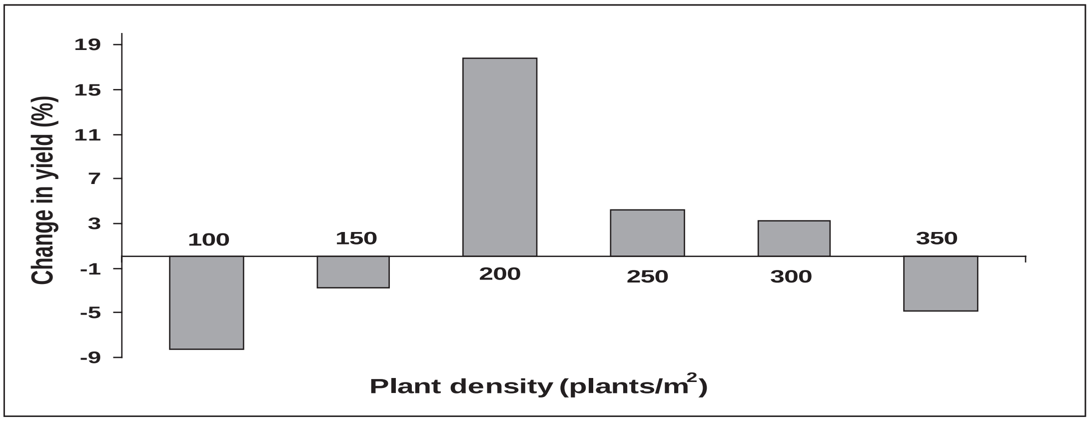

Fig. 5. Response of grain yield to planting density for wheat

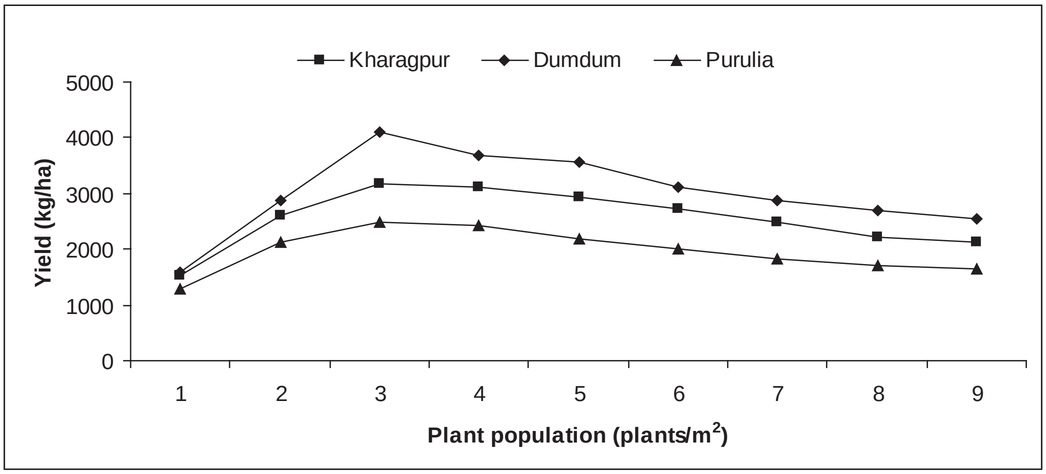

Fig. 6. Maize yield at various plant densities at Kharagpur, Dumdum and Purulia

CONCLUSIONS

Food security and environmental sustainability are the major focuses of global agriculture. Since beginning of 1980s, a threat to agriculture that has attracted much attention is the climate change due to global warming. Many climatologists predict significant global warming in the coming decades due to increasing concentration of CO_2 and other green house gases in the atmosphere. Higher temperatures will have negative impact on crop production directly through heat stress. Changes in rainfall patterns can have both negative and positive effects on agricultural production. It is important to understand this phenomenon of climate change on crop production and to develop adaptation strategies for sustainability in food production, using a suitable validated crop simulation model.

The objectives of this study were to simulate the maize yield under various climate change scenarios and to identify the possible adaptation measures to reduce the negative impact of climate change on yield using Crop Growth Simulation models. These models were also used to assess suitable date of sowing, suitable plant density, and appropriate rate of application of nitrogen and irrigation water in the climate change scenarios. Based on the results of the study, the following conclusions could be drawn:

1. There is no definite trend of variation for solar radiation, maximum temperature and minimum temperature at Kharagpur and Purulia in case of maize crop
2. Increase in temperature affects maize yield negatively while increase in CO_2 concentration has positive effect on maize yield up to certain concentration
3. The highest maize yield can be obtained with a plant population of 3 plants/m^2 at all the three locations namely, Kharagpur, Dumdum and Purulia
4. Increase in temperature affects wheat yield negatively while increase in CO_2 concentration has positive effect on yield
5. Alternative management practices such as appropriate sowing date and planting density will help to mitigate the negative effects of climate change
6. Tuber yields of potato decrease marginally with temperature rise and considerably increase with increasing CO_2 concentration.
7. DSSAT group of crop growth models can be successfully used for simulating the effect of climate change on crop growth and for formulation of coping strategies.

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Climate Change: Soils on Global Agenda

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INTRODUCTION

Soil is the stomach of the plant, said Aristotle. Essentially all life depends on soils. There can be no life without, soil and no soil without life; they have mutually evolved together, opined. Charles E. Kellog (1938). Copernicus (543 BC) also reminded us that man, despite his artistic pretentions, his sophistication, and many accomplishments, owes his existence to the six inches layer of topsoil.

Agricultural production is largely dependent on soil's productivity. Soil science should be up-front in providing the much needed data on soil resources on how soil and land use change affects food production. The link with real world issues viz. climate change, food production and hunger alleviation and environmental degradation is essential as pointed by FAO and ISRIC – World Soil Information (Bai *et al.,* 2009). The degradation in India is estimated to be @ 4.9 ha/minute @ 1981-2003.

At this juncture, let us recall the remarks by Indira Gandhi while delivering the Frank McDougall Memorial Lecture. "The Earth is ravaged, desecrated, made sterile, perhaps through ignorance in the initial stages but lately driven by greed and arrogance. Today it is not the ignorant but the knowing who pose the main danger to human survival". Also interesting are the comments of Jones (2006) who said:

"Listen for a while
Earth is tying naked and barren
Crying for help without words
Calling so softly for carbon
There is no time to bargain"

Thus, it is the challenge for producers, soil conservationists and researchers to enhance the soil organic matter (SOM) to make the soil live. Organic carbon is the basic building block for all life on-and in-the earth. We cannot live without it. Neither can our soils. Thus, "A Nation that destroys its soil, destroys itself" as rightly pointed by Franklin D. Roosevelt.

Coming to water, it is vital for life and a finite source. The four interacting components in the hydrological cycle are the atmosphere (rain and snow), surface water, soil water and groundwater. The climate change (CC) is leading to global warming resulting in changing precipitation patterns. Water that flows over the land surface finally reaching the sea or that is stored in ponds, lakes, wetlands and other water bodies constitute the surface water. Over centuries, human beings adapted to changes in the climate (Pandey *et al* 2003). Soil water is the least understood and difficult to manage. The groundwater (GW) is the primary source of drinking water to ½ the world population. It provides irrigation to 70-80% food production (Ramachandra and Nagarathna, 2010). With CC leading to variability in rains, the GW uses are increasing. In fact, GRAPHIC (2009) points out that GW is being depleted @ 4.0 $\pm$ 2.0 cm / year. The hot spots identified in our country are western and peninsular regions. Water was taken for granted (as was the case with the soils).

The present decade (2000-09) had been the warmest one as per WMO. During the last two decades, land is used much more intensely. No doubt, yields increased from an average of 1.8 to 2.5 t/ha. But this has led to land degradation (GEO_4 of UNEP).

Take the case of Green Revolution (GR). It is reductionistic in approach. The consequences were not considered. Some eminent persons like C.N. Rao of Indian Statistical Institute suggested going for less intensive cultivation (reduced / low level of inputs) benefiting more people. Prem Narain of IARSI called for a dialectical approach i.e. care for the consequences of high inputs on the ecosystem. But it is only with the recent mid-term review of the X FYP, that the GOI realized that GR led to ecological crisis and showing technology fatigue.

At this juncture, we feel like quoting the Nobel Laureate Richard Feynman who said “the difficulty with science is often not with the new ideas, but in escaping the old ones. A certain amount of irreverence is essential for creative pursuit in science”. Citing him, Mashelkar pointed out that “our existing hierarchical structure kills irreverence. Bureaucracy overrides meritocracy. Risk taking innovations are shot”.

Taking some courage, we like to plead for a dialectical approach in our production systems. They need be inclusive, comprehensive, doable and flexible leading to sustainable rural development and also be a part in carbon sequestering.

The attitude of the government towards water and soil as two important natural resources merit consideration.

Scope of the presentation

In the following pages, we like to focus on climate change with reference to selected natural resources (NRs) – soil and water and the need for their retrieval avoiding overexploitation.

Trends

The recent surge in prices of agricultural commodities is trend driven that are undermining world food production. The trends include

- Falling groundwater levels
- Eroding soils
- Raising temperature due to global warming
- Depleting petroleum products and phosphate rock reserves with consequent fueling of their prices
- Anomalies in weather

In the processes, the era of cheap fossil-fuel-produced fertilizers comes to an end. Conventional high-input agriculture will be neither sustainable nor resilient. In fact GR effectively divorced from soil stewardship. It devastated soil life, reducing native fertility (Montgomery 2010).

The estimates in USA indicate that soil is washed away 10 times faster than it is replenished (Montgomergy 2007). And 1.0% change in total precipitation (as a consequence of global warming) leads to 1.7% change in soil erosion (Neering *et al* 2004). A 10% increase in intensity leads 24% increase in soil erosion (Thacker 2004).

Global efforts on soils

The World Soil Charter of FAO (1981) calls for management of the land for long-term advantage rather than short-term expediency. Land resources include soil, water and associated plants and animals. The measures include land resources inventories, assessment of degradation hazards, evaluation of production capacity, improvement of soil fertility, combating desertification, land reclamation, integrated landuse planning, training and institution building.

We, have a Land Use Policy and Land Use Boards at central and state level (1986) which are non functional even though the Prime Minister at central level and the Chief Ministers at state level are the chairpersons. No doubt some mention is made of their revival whenever a FYP is under preparation for approval by NDC.

Presently, the European Commission (2006) adopted the thematic strategy on the protection of soils giving same importance to soil as air and water. It sets out a road map to address soil degradation by preserving and restoring soil and its functions.

Similarly, the US Senate recognized (2008), the need to effectively bring tools for soil legislation to improve knowledge, exchange information and develop and implement best protection practices for soil management, soil restoration, carbon sequestration and long-term use of the Nation's soil resources.

We must realize our lack of seriousness in protecting the soil which presently is either getting eroded or becoming sterile. With global warming the scenario is going to be more disastrous.

Efforts at the national level

That soil conservation is necessary for sustenance has been realized by the Government. Programmes like River Valley Project (RVP), Flood Prone Area (FPR) programme were initiated way back in 1962-63 and 1981-82 respectively. Then came soil conservation in arable lands, executed as a governmental programme. It was largely formation of contour bunds. Both the programmes have not yielded the desired results and the land owners were only mute spectators. In most cases, they dismantled the bunds. Even the Government could rarely follow scientific principles in forming contour bunds. It culminated in strengthening the existing field bunds across the slope which was accepted by the land owners. The logic was that the existing bunds already occupied about 5% of their land and the additional contour bunds would cover another 8% area. Further, these bunds were cutting across the fields making their agricultural operations difficult. In any case, conservation of soil that belongs to farmers needs their active participation. And the technologies need be simple, doable and socially acceptable.

Paradigm shift from soil conservation to land husbandry

Retrieving degraded lands which is largely soil erosion, calls for a paradigm shift from the traditional soil conservation through mechanical structures to land husbandry. Here, we like to quote the doyen in soil conservation, Hudson (1992). He said "Current changes include even the term soil conservation will probably fade away to be replaced by land husbandry because that better describes the fundamentals of the new approach. The idea of the care of crops and their management and improvement has for years been called crop husbandry. Animal husbandry has described the care and management of livestock. Soil conservation was appropriate when we were mainly concerned with increasing knowledge and awareness of soil degradation and learning how to decrease the process. But that was mainly a defensive strategy and what we now seek is a positive approach where care and improvement of the land resource comes first and control of erosion as a result of good land husbandry".

Thus, the primary objective of land management should be improved, sustainable production through good land husbandry. Control of soil erosion follows as a consequence. This is a reversal of the previous idea that it is necessary to conserve the soil in order to get better crops. Instead, improve the soil condition for root growth and crop production and in so doing achieve better conservation of water and soil. And to achieve this goal, use of biological measures is more relevant. Among others, they include agroforestry, soil cover with good vegetation (plant cover) and improving soil organic matter (SOM). All these measures sequester more carbon, an ecological protection service.

Improving soil productivity

Soil conservation not only includes protecting the soil from erosion / degradation but also calls for attention on improving its productivity. The famous adage is "drylands are not only thirsty but hungry too". Present thinking (at various decision making levels) on correcting the malady of hunger in soils of rainfed areas is through additional use of fertilizers with add-on of even micronutrients. To support the latter some questionable data are reported. These external inputs not only increase the costs in production, but also lead to pollution, if used overenthusiastically (largely true). Unscrupulous traders can cheat the innocent farmers. Even smallholders are spending 35% of their costs in production on fertilizers (21%) and pesticides (14%) as per NSSO report 497. Consumption of fertilizers works out 126 kg/ha by marginal farmers and 102 kg/ha by small farmers. Still yields are declining. The correction lies in moving from this 'external input driven' agriculture to 'knowledge, skill based and local natural resource' model says SERP of Government of Andhra Pradesh (Vijay Kumar 2007). This community managed sustainable agriculture (CMSA) of SERP aims at low or zero level in use of external inputs with a paradigm shift from agriculture distress to viable farming. In the process, more and more of biomass recycling is taking place leading to more carbon sequestration thereby cooling the climate.

Soil and moisture conservation practices (SMCP)

Several traditional methods existing in SMCP have been highlighted by Mishra *et al* (2002) in their recent NATP study. These conservation practices, in any case, would be of great help in mitigating mild stresses during the crop growth and development. The institutional technologies also may need attention (Sharda 2006).

Water harvesting

There are several traditional water harvesting systems (Agarwal and Narain 1997) and also many institutional systems (Sharda, 2006) have been developed. Both need consideration. Traditional sources including tanks were contributing 32% of irrigation in 1950-51. But now (2000-01) its contribution is only 9.24%. The individual owned wells and tube wells are contributing 28.67 and 62.34% respectively during these years (MoWR 2007).

All these sources are rain dependent. Now, with overexploitation of groundwater, concern is on their sustainability. Fortunately, civil societies like CWS, Hyderabad are working for participatory groundwater irrigation management. It is a happy augury that Govt. of Andhra Pradesh has launched a pilot on these lines in the State. Govt. of India has launched two programmes on (a) renovation of traditional tanks and (b) artificial groundwater recharge in hardrock areas of 7 state for recharging the groundwater, since groundwater circulation is shallow subject to local topographical control in the hardrock areas (Narasimhan and Gaur 2009).

Rainwater

Save rain to save the world (Schmitt 2009). Intensification of hydrological cycles results in dryer day seasons and water wet seasons with the impact of global warming (Chattopadhya 2008). This results in frequent floods and droughts. Availability and quality of water would be poorer affecting 1/6th of the world population. Thus, global warming amplifies water scarcity and consequently affects food production.

In semiarid and arid regions, there will be exacerbation of threats caused by landuse / coverage change and population pressure. It results in significant increase in surface air temperatures, increased evaporation from plants leading to acute water shortages.

The floods will be more frequent in middle / high altitude winters with more intense mid-altitude storms. In general, more extreme precipitation events are likely. All those culminate in landuse changes and surface degradation.

We need to adapt to such impending disasters. The approaches include watershed development, right to water, creating awareness, reducing runoff by enhancing SOM so as to reduce water stress, rainwater harvesting and alternating cropping patterns.

Ravi Singh (2009) emphasizes the strategies in adaptation should also include security of food, natural resource and energy. He further said the drinking water increased over 6 fold while increase in population was 3 fold over the last 100 years.

Increasing WUE is the focal point to avoid conflicts and ensure availability of water in all sectors. To achieve this goal, provide incentives for efficient use of water. Next is harvesting the rainwater. It could be (a) *in situ*, (b) surface structures and (c) as groundwater.

For *in-situ* water harvesting create land forms to capture the rain. Several options have been worked out by AICRPDA (Table 1). Massive tree plantation also helps in capturing more rainwater. In fact, water is an important by-product of forests.

With climate change, the water harvesting calls for a revisit to hydrology (DFID 2004). Evanari's (1982) study needs consideration in this context. He called for smaller catchment to harvest more rainwater under arid conditions.

Table 1. Imapct of catchment size on rainwater harvesting.

Catchment size (ha)	Rainwater harvested (m^3 / ha)			
	Normal	% rainfall	Drought	% rainfall
0.1	160	15.2	80 – 100	16 – 20
20	100	9.5	20 – 40	4 – 8
300	50	3.3	Negligible	0

In a much earlier study Reija *et al* (1988) found that in arid (drier) regions, the design and the costs would be different and the designs should emanate from the traditional techniques and environmental knowledge.

Thus, it is our conviction that even the present drive of one water harvesting structures (WHS) in each holding under NREGA needs reconsideration, lest the money spent be a waste.

Groundwater scenario

Hiscock and Tanaka (2009) discussed the potential impacts of Climate Change (CC) on groundwater resources. Groundwater is an important natural resource. Worldwide more than 2.0 billion people depend on it besides a large number of industries. Groundwater is a component in the hydrological cycle which is an integral part of the climate system. The CC is expected to have negative effects on water resources including groundwater. GRAPHIC (2009), in the analysis, points out that CC leads to change in precipitation decreasing runoff by an average of 1 mm/day. As a result, surface water becomes unreliable. Rapid runoff with high intense rains induces surface runoff resulting in poor groundwater recharge. In the process, mean annual groundwater recharge (mm) would come down even upto 50% of what it was in seventies. Global warming further accentuates the problem with increased Et (Taniguchi and Aureli 2002).

There has been a caution that India's groundwater is critically depleted. Rodell *et al* (2009) pointed out that in North West (NW) India groundwater is depleting @ 4 $\pm$ 1 cm / year equivalent to 18 km^3 of water a year. In another study conducted for 6 years, it was found that groundwater depletion was 109 km^3, roughly double of the capacity of the largest surface water reservoir, Upper Wainganga. This estimate of 18 km^3 is higher by 5 km^3 over the estimates of MoWR. About 114 million people live in this region. Thus, the use of groundwater is unsustainable and shortage of importable water and reduction of agricultural output are to be expected leading to extensive socio-economic stresses.

Duma (2007) showed that the number of irrigation wells equipped with diesel or electric pumps in the country stood at more than 19 million compared to 150,000 during 1950. The country's food basket will be seriously threatened in the next 10-15 years as most of this water begins to run out (Sinha, 2006).

Shah (2009) opines that CC will enhance groundwater criticality for drought proofing agriculture and also multiply the threat to the resource. Groundwater pumping with electricity and diesel accounts for 16-25 million mt of carbon emission, 4-6% of India's total. From the CC point of view, the groundwater hotspots are in western and peninsular India.

As a part of the solution to the overexploitation, Evans (2007) suggested deficit irrigation strategies. A great attention to timing as well as the amount of application supported by better crop selection and plant breeding for drought tolerance are the components in the strategy. He says, the resultant savings can range from 10-50%.

Ramachandra and Nagarathnan (2010), while reviewing the book of Gragone and Sukhija (2007) on climate change and groundwater indicate that it maintains surface water systems through flows into lakes and base flow to rivers. These become increasingly vulnerable with CC leading to ecologic and socio-economic consequences. Groundwater will continue to be of prime importance as it is best protected water resource, they said. Climate extremes effect groundwater recharge. In the process 50% irrigation, 80% rural and 40% urban population for potable water will be affected.

Supplemental irrigation

The supplemental irrigation or deficit irrigation is more relevant in rainfed farming. There are two ways of implementing this concept. In *kharif* season, it should synchronize with critical phonological stages of crops and moisture stress due to skewness in the distribution of rainfall. On the other hand, in *rabi* season, a come-up irrigation to saturate the root profile needs consideration. For instance, a good crop of mustard need a stored moisture of 18cm in the root profile. Such critical irrigation (of 5cm) leads to 200 kg cereal or 100 kg legume or oilseed / ha (AICRPDA). High potential for such irrigation lies in rainfed systems (Theo Dillha 2008).

Better crop husbandry

Increasing agricultural productivity per drop of water depleted will allow more food to be grown with less water (IWMI 2005). Let us realize that average water productivity with us is only 0.34 kg/m^3 as against 0.75 with China. For crop production, the water needs would double from 600 km^3 to produce the present 2.7 t/ ha level (1995) to 1200 km^3 if yield increases cannot be achieved to meet the growing population by 2025. Otherwise, we have to improve the water productivity (Sakthivadivel *et al* 1999).

Further, the water requirements (m^3/kg) on an average, work out 15 or more for beef production (grain fed) as compared to 0.4 – 3.0 in the case of cereals and 11 for pulses, roots and tubers (IWMI 2005). The lamb and poultry need 100 and 6 m^3 / kg. And the global warming potential (GWP) for various products is as follows (Foster *et al.*, 2006) (Table 2).

Table 2. Global warming potential of various products

Product	GWP kg CO_2 – eq/kg
Sheep	174
Beef	130
Pig	6.4
Poultry	4.6
Milk	1.3
Bread wheat	0.8
Potato	0.2

So food habits have to change to low GWP products. And that is what Britain is advocating. To achieve such an objective, the traditional systems of agriculture should not be weakened by introducing new and inappropriate technologies which lead to higher emission levels (FAO 2009) considering the indigenous knowledge systems as "low production, primitive and old". It should be the basis for developing technologies and innovations to achieve sustainable agriculture (Pulamte 2008). Let us see the CO_2 emission (kCO_2/kg produce) of the inputs used in agriculture (Table 3).

Table 3. Amount of CO_2 emission (kCO_2/kg produce)

Nutrient	Emission
N	3.3 – 6.6
P	0.37 – 1.1
K	0.37 – 0.73
Manure	0.02 – 0.03

Source (Lal 2004)

All these indicate the organic farming which needs 27 less energy and leads to carbon sequestering in the soils must be supported. It is a win-win situation resulting in not only mitigating climate change but also improving soil quality.

Enhancing SOM improves soil health, improves soil productivity, leads to better use of water, reduces erosion, silting and salinization, improves water tables and increases water tables. All these culminate in more employment opportunities (Kimber 2007). And 1.0 t/ha increase of soil carbon leads to increases in yield of crop (Wales 2009) (Tabel 4).

Table 4. Relationship between soil carbon and yield improvement

Crop	Yield increase (kg/ha)
Wheat	20 – 40
Maize	10 – 20
Cowpea	0.5 – 1.0

Adaptation

Charles Darwin, long ago, said "It is not the strongest of the species that survive, nor the most intelligent person that survives". It is the one that is most adaptable to change. We are aware that, depending on the ecology 1 kg of wheat needs 500 – 4000 litres of water while meat needs 5000 – 20,000 litres (Lindqvist *et al* 2008). Options available are (i) improve water use efficiency and (ii) more to less water consuming products and (iii) adopt best practices in biomass production like direct seeding mulch based cropping system evolved by Forest *et al* (2009) and SRI cultivation of rice.

Now let us consider different related issues. These include

i. Water in crop production
ii. Soil organic carbon and its importance in CC
iii. Droughts in our country
iv. Desertification

1. Water in crop production

India's water supply and demand from 2025 to 2050 on a 'Business as usual' basis was presented by IWMI (Amarasinghe *et al* 2007). The water demands are expected to be Table 5.

Table 5. Feture water demand estimats

Water demands (BCM)			
	2000	**2025**	**2050**
Total	680	833	900
Groundwater	303	365	423
Withdrawals as % of potentially utilizable water resources (PUWR)	37	52	61

The proposed increase in yield of foodgrain has to be (t/ha)

	2000	**2025**	**2050**
Irrigated	2.6	3.6	4.4
Rainfed	1.0	1.3	1.8

The WUE is to increase

	2000	**2025**	**2050**
Surface water	30-45	35-50	42-60
Groundwater	55-65	70	75

The Et for India is 67.5% as per Jain *et al* (2007). Based on world-wide estimates of Et, Narasimhan (2008), pointed out the utilizable water would be only 654 km^3 and not 1123 km^3 (Gupta and Deshpande, 2004), which had been adopted by the Planning Commission. The former estimates are in agreement with the assessment of utilizable water resources of India carried out by Garg and Hassan (2007). In other words, water is already scarce in availability and the future scenario would be rather bleak. The 2030 water resource group (2009) in their study on charting our water future pointed out that India's demand for water would increase from the present 744 km^3 to 1496 km^3 by 2030.

Further, with 500 ppm CO_2 increase due to CC, the yields may increase by 10-20%; but with higher temperature (target 2°C rise) the estimated loss in yield would be more 10-40% (Aggarwal *et al* 2009). Even Chattopadhyaya (2008) projected the production of wheat may decline to 58 Mts by 2070. The reduction is bound to be more in rainfed crops, he said.

Also the picture of external inputs for production of foods are not encouraging. Reserves of phosphate rock begin to run out. P extraction will be at peak by 2030. The cost of phosphate rock increased from 50 US $ / tonne to 350 US$ as of now (7 times). China, the second largest reserve country, is imposing 135% tariff on exports to save its resource for the future. P is a key non-renewable resource. It may become a constraint by 100-150 years from now (Vaccari, 2009).

Similarly, petroleum is also a non-renewable product. We burnt ½ of the known global reserves in 125 years or so. It took 50-300 million years to form. We are consuming 40,000 gallons / second of oil. The consumption is growing exponentially. In course of time, it may also be a constraint. In a post petroleum world, as the era of cheap fossil-fuel-produced fertilizers come to an end, conventional high input agriculture is neither sustainable nor resilient (Montgomery, 2010).

So we must choose a new path. Green revolution effectively divorced agriculture from soil stewardship. It devastated soil life reducing native soil fertility (Montgomery, 2010).

Options could be that of Cuban model; increase SOM more crop per drop, and non-till, minimum-till.

a) Cuban model includes (Barsein and Douglas 2005: Rosset 1999)

- Oxen in the place of tractors
- Crop rotation
- N-fixing crops
- Reduced monoculture
- Use helpful bacteria and fungi
- Use of natural predators for control of insects
- Green manure as cover crop
- Knowledge intensive technological innovations
- Site specific production systems

b) Increase of SOM (Bot and Benites 2005)

- SOM is important
- Create drought resistant soil, thereby increases soil moisture, increases soil porosity for sustained food production
- Reduce soil erosion, and runoff
- Reduce water logging
- Increase yields
- Reduce use of external inputs
- Increases biodiversity
- Provides resilience
- Improves biogeochemical cycles of nutrients
- Provides surface protection
- Reduce input costs

c) More crop per drop (Zarkaasht 2008, Theo Dillaha 2009)

- Look at water as a finite, fragile, scarce high economic value resource
- Adopt micro-irrigation
- Huge potential for supplemental irrigation lies in rainfed ecosystems
- Improve WUE
- For rainfed agriculture
  - i. Conserve on farms
  - ii. Provide supplemental irrigation

iii. Adopt water harvesting
iv. Alternate crops
- Adopt watershed approach
- Better crop husbandry
- But, need
  i. Market
  ii. Credit
  iii. Inputs

d) No-till / minimum till (Montgomery 2010; Abrol and Sangar 2006)

- Minimum soil disturbance
- Minimum traffic for agricultural operations
- Leave and manage crop residues
- Adopt temporal and spatial crop sequencing / crop rotation to maximize benefits from inputs
- Minimize adverse environmental impacts
- Enhance the productivity
- No-till reduces erosion levels
- Agricultural production comes not at the expense of soil fertility or soil
- Living soil is the nation's most strategic resource
- Business as usual as NOT an option when it comes to soil, food and people
- It is time for a greener revolution

But it must be noted that with the current trends in precipitation even such a technology may not be able to protect the surface soil from being washed away (Hatfield and Prueger, 2004).

Soil organic carbon (SOC): its importance in climate change

Now, it is realized that turnover of organics into soil not only improves the productivity but also help in carbon sequestration leading to a cooler climate. As mentioned earlier, SOC is the basic building block for all life in-and on-the earth (Jones 2006). About 5-82% SOC is lost to the atmosphere from the topsoil reflecting on the level of degradation. So by inference, degraded lands have a potential to store upto 5 times more SOC in the surface layer than they currently hold (Lal 2004).

Let us first consider some basics. Plants contain 45% carbon by weight. Soil organic matter (SOM) contain 58% carbon. One unit loss of SOC represents 37 units of CO_2 removal from soil. SOC increases with increasing rainfall. Soil-wise carbon storing is Vertisols > Inceptisols > Alfisols > Aridisols. Humus holds water 4 times its weight. It reduces runoff and erosion. Even under irrigation 25-50% reduction is observed in irrigation requirement (Homes *et al* 1998; Niggli *et al* 2007).

Organic carbon is the basic building block for all life on- and in- the earth. We cannot live without it. Neither can our soils as earlier pointed out (Jones 2006). About 50-80% of organic carbon from top soil is lost to the atmosphere over the last 150 years or so as we failed to care for earth as a living thing. So by inference degraded soils have a potential to store upto 5 times more organic carbon in their surface layer than they currently hold.

In their studies, Srinivas Rao *et al* (2009) could achieve improvement in most cases (Table 6) nearing to what it was in late fifties (Jenny and Raychoudhary 1961). With proper inputs, the increasing trend can be kept up.

Table 6: Build up of SOM with intigrated nutrient management options in rainfed regions of India

System	SOM (%)		Late 50's ★
	Initial	Build up	
20 years of groundnut (Alfisols): 50% RDF+ 4t FYM	0.25	0.59	NA
20 years of pearlmillet (Aridisols): 50% RDF+ 50%N as FYM	0.30	0.25	0.55
28 years of fingermillet (Alfisols): 50% RDF+ 10t FYM	0.46	0.74	0.83
20 years of *Rabi* sorghum (Vertisols): 25 kgN each from crop residue + leucaena + FYM + Urea	0.38	0.58	0.70
15 years of soybean – safflower (Vertisols): FYM 6t/ha + 20N + 15P	0.50	0.67	0.94
21 years of rice – lentil (Inceptisol): 100% organic	0.25	0.35	0.52

Source: Srinivasa Rao et al (2009)

★ *Jenny and Rayachoudhary* (1961)

In fact Jenny and Rayachoudhary already indicated that due to exploitative agriculture, the SOC was drastically reduced during the Mughul-British regimes.

Benefits of organic agriculture (OA)

To improve SOC, organic agriculture (OA) could be the route.

Organic Agriculture addresses both emission avoidance and carbon sequestration (Muller 2009). The N_2O emission will be reduced. The prevention of soil erosion by vegetal cover (e.g. cover crop) reduced CO_2 loss due to erosion. The CH_4 emissions from livestock and paddies can be brought down through better quality and improving pastures and moving to SRI system but solely using organic sources for crop nutrition and protection. The potential of OA in reducing emissions works out to 55-80% of global GHGs due to agriculture.

Green peace (Bellarby *et al* 2008) showed that fertilizer use in Europe is reducing in recent times. With increased organics, the GHGs emissions are reduced. Not only that. It is improving nutrient balance and efficiency, reducing costs on fertilizers and allowing the governments to spend on more beneficial projects.

Soil carbon sequestering is a win-win situation. It improves soil productivity. For instance, besides the above cited advantages humus holds 833 kg N, 200 kg P, 143 kg S per 10 tonnes which would be gradually available to crops / plants. Further it mitigates CC. It also reduces soil erosion and runoff.

Droughts in India

Droughts are associated with high temperatures, high winds and low rainfall. All these factors lead to more evapotranspiration. And in rainfed areas droughts accentuate as the rainfall in the area is low. The scenario of droughts in our country are briefly presented below (Table 7). Droughts are increasing over the last three centuries (Karunakaran 2008).

Century	No. of droughts
18	24
19	38
20	60

Coming to major droughts of 20th century, five of them may be considered in term of (a) departure from the rainfall and (b) decrease *kharif* foodgrain output (Table 8).

Table 7. Major droughts in 20th century: Departure from normal rainfall

Region / Year	1965	1972	1979	1987	2002
All India	-18	-25	-19	-19	-19
NW	-28	-36	-18	-46	-48
Central	NA	NA	-33	-28	-31
East	-30	-22	-28	+14	+2
Peninsular	-22	-31	-14	-27	-27

Source: IMD

Table 8. Impact of droughts on *kharif* foodgrain output

Year	Monsoon rainfall departure	% decline in *kharif* foodgrain production
1972	-24	-6.9
1979	-19	-19.0
1987	-19	-7.0
2002	-19	-19.0

Source: MoA

The data indicate that in 1987, the decline was much less than 1979 and 2002. This was primarily because the rainfed rice area of East was not affected due to fact that the rainfall was normal and well distributed. Further, the high investment technologies were just showing up at that time. On the other hand even though the rainfall was more deficient in 1972, the decline was not serious, as the rainfall was well distributed both spatially and temporally.

In any case, droughts accentuate the problem of food security and is the poor that are more vulnerable.

Desertification

Droughts induce desertification. This is besides human indulgence in overexploitation of natural resources. It is pertinent to consider the climatic factors in land degradation. Sivakumar (2009) points out that the climate stresses result in rainfall extremes that would be variable leading to increased soil erosion and land degradation. Floods result in suspended sediments. High temperatures and winds with low relative humidity culminate in dust storms. Wild fires become more frequent.

Eswaran *et al* (2001) classified the desertification tension zones into 4 classes insofar as human induced desertification is concerned.

Type of human induced desertification	Area		Population %
	Million km^2	%	
Low risk	7.1	11.2	18.9
Moderate risk	8.6	10.5	15.9
High risk	15.6	5.5	6.8
Very high risk	11.9	4.6	4.4
Total	43.2	33.3	46.0

In other words, the human induced desertification is in 1/3rd of the globe affecting 46% of the population. What is more? The very high risk zone has 1.4 billion inhabitants with scare resource that include drinking water.

EPILOGUE

While dealing with land and water management issues, Kerylenstierna (2009) pointed out "There are certain things that are so simple that 10 years of intensive university studies are required to misunderstand them". Scarcity of water, food and energy besides economic security are all linked to land and water issues and thus to climate change adaptation. Many water issues are "local" while most of the discussion are "global scale".

For instance, water is a state subject and groundwater is managed on individual basis. The CWS (Centre for World Solidarity) has shown that under limited groundwater (due to overexploitation), the community can come together to share water from the functional wells and this participatory groundwater management has been accepted by GoAP and being put on ground in the state on a pilot scale. In any case, water harvesting for upgrading rainfed agriculture is a large window of opportunity (Falkenmashand *et al* 2001). Similarly, we preach proper landuse systems without considering that the poor largely own only class IV and above lands. The DDS (Deccan Development Society) and the NATP study of CRIDA have clearly shown that in such marginal lands, farmers practice mixed cropping. They attempt to improve their soils overtime with the leaf litter and the sloughed off burrows of deep rooted crops like niger, castor, etc. besides adding fine soil like silt.

Thus "the best way to have a good idea is to have lots of ideas".

While discussing the options to face the dangers of CC, Holdren (2007) pointed out three options – mitigation, adaptation and suffering the adverse impacts. Neither of their singly can be a solution 'Mitigation only' strategy will not work because it is too late to avoid substantial CC. 'Adaptation only' strategy won't work because these measures are too expensive and less effective as the magnitude of CC is becoming larger. So win-win approach is the need. Measures to improve water conservation and water management have great value even in the absence of climate-driven increases in stress on water systems. Similar is the case with enhancing SOC, which makes the soil drought-resistant and also productive besides reducing erosion levels. No-till is a case in point.

While discussing the Indian climate policy, Mahanta (2009) reminded us that the failing monsoon of 2009, followed by the unprecedented rains in early October in the southern states, establish the need for addressing such anomalies more frequently than ever.

We must realize that annual rainfall renewability is finite and subject to uncertainty. Similarly products like petroleum and phosphate rock are also finite. And we all know our land is also finite.

With CC, rainfall and its intensity as well as distribution stand highly skewed. Only 15-20% of rainfall is generally used by crops. With degradation of the soils due to CC, this would be only 5%. With loss of top soil, the productivity will be further accentuated.

We have already burnt ½ of known global resources of oil in 125 years or so. The rock phosphate situation is no better. Its price has shot by 7 times over the last 14 months. Restrictions by way of enhanced tariffs in countries like China make the problems more serious.

So we have to choose a new path or one will be forced upon us. Organic Agriculture (OA) that saves about 27% energy is one route. Organic Agriculture sequesters more carbon (55 to 80% of global GHGs due to agriculture). Zero-tillage as with rice-wheat of Indo-Gangetic plains covering 1.7 Mha involving 620,000 farmers is another example. However, as rainfall intensity and frequency of storms increase the above may not provide adequate protection to the soil. The researchers, producers and soil conservationists have to aggressively pursue soil management practices to protect the soil under these changing rainfall conditions, as pointed by Hatfield Prueger (2004). Land husbandry preached by Hudson (1992) could be one possible solution. All such systems are in some form or other under practice by the smallholders. In fact, SERP of GoAP adopted a paradigm shift from 'external input driven agriculture' to 'knowledge, skill-based and local natural resources' model in their community managed sustainable agriculture (CMSA-Eco-agriculture). This is unlike the findings of Shackleton *et al* (2002) of ODI who felt it more as a rhetoric. SERP strongly believe that this CMSA will lead smallholders from agricultural distress to viable farming. All such systems do cool the climate and protects top soil which is the most strategic resource. Business as usual (making it dirt) is NOT an option when it comes to soil, food and people. It is time for a greener revolution (Montgomery 2010). And those who practice non-chemical farming need be paid for the cological protection service rendered by them. It is the time that is now a scarce resource. Think globally but act locally.

We like to end our presentation with the quote of Eleventh Commandment of Lowdermilk (1994). "Thou shalt inherit the Holy Earth as a faithful steward, conserving its resources and productivity from generation to generation. Thou shall safeguard thy fields from soil erosion, thy living waters from drying up, thy forests from desolation, and protect thy hills from overgrazing by thy herds, that thy descendants may have abundance forever. If any shall fail in the stewardship of the land, thy fruitful fields shall become sterile stony ground and washing gullies, and they descendants shall decrease and live in poverty or perish from off the face of the earth".

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Technical Session IV

Impacts, Adaptation and Mitigation Strategies in Livestock and Fisheries

Climate Change Impacts on Livestock and Dairy Sector: Issues and Strategies

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ABSTRACT

The impact of climate change and global warming is now recognized worldwide. Climate change poses formidable challenge to the development of livestock sector in India as it is likely to aggravate the heat stress in dairy animals, adversely affecting their productive and reproductive performance. Livestock which will be the sufferer of climate change are itself of large source of methane emission contributing about 18% of total enteric methane budget. Livestock methane emission can be reduced by using the methane mitigation options based on herbal additives and indigenous knowledge on feeds and feed additives. Impact of global warming on livestock can be minimized by enhancing adaptation by formulating strategies and building adaptive capacity of vulnerable economically poor farmers of different agro-climatic zones.

INTRODUCTION

Agriculture and allied sectors contribute nearly 18 per cent of India's Gross Domestic Product and about 70 per cent of the population is dependent on agriculture for their livelihood. In 2003, Indian livestock sector consists of about 185 million cattle, 97 million buffaloes, 61 million sheep and 124 million goats and 18 million other animals. It ranks first in the world in respect of cattle and buffalo population, third in sheep and second in goat population. Presently, dairy sector contributes about 5.3% to India's agricultural GDP. Livestock contributes to GDP by providing milk, meat, eggs, hides and skins, in addition to this livestock also provide draught power. Among the various products provided by livestock only milk and milk products alone accounts for about 66% of total value from livestock sector. During the last decade, the annual growth rate for livestock production has remained steady at 4.8 to 6.6%. The livestock sector has registered a compounded growth rate of more than 5.0% during last decade, in spite of the fact that a majority of the animals continue to be reared under sub-optimal conditions and milk productivity per animal is low. However, in future the situation is likely to change due to global warming as ambient temperature higher than 25˚C with relative humidity greater than 50% negatively impacts livestock productivity, growth and reproductive capacity.

Climate change and temperature variability are the most significant development challenges facing the international community as most systems (biological or socio-economic) are sensitive to this change. According to Intergovernmental Panel on Climate Change (IPCC) world ambient temperature will increase by 1 to 3.5°C and sea level by 15 to 95 cm over 1990 levels. The annual mean temperature of India has risen to 0.51°C for the period 1901-2005. The annual mean temperature has been consistently above normal (normal based on period, 1961-1990) since 1993. This warming is primarily due to rise in maximum temperature across India. However, since 1990, minimum temperature is steadily rising and rate of rise is slightly more than that of maximum temperature. Season-wise, maximum rise in mean temperature has been observed during the Post-monsoon season (0.7°C) followed by winter season (0.67°C), Pre-monsoon season (0.50^{o}C) and Monsoon season (0.30^{o}C). During the winter season, since 1991, rise in minimum temperature is appreciably higher than that of maximum temperature over northern plains.

The main issue about the global warming is that, climate change is already happening, and will continue to happen, even if global greenhouse gas emissions are curtailed significantly. There is now more confidence that global climate change is a threat to sustainable development, and could undermine global poverty alleviation efforts and have severe implication for food security, clean water, energy supply, environmental health and human settlements. In addition to this major issue on climate change relating to livestock is:

- The livestock sector is likely to be negatively impacted in terms of yields and production affecting marginal GDP from livestock sector.
- The decline in yields and production will cause fluctuations in market prices of milk products and other livestock products.
- What type of livestock management is suited to changing climate and where?
- Which animals (species & breed) should be kept in which areas and what are the trade-offs?
- Which animal diseases should we focus on?
- How can we add value to existing livestock based adaptation strategies?

Future change in climate of India

A number of modelling systems have been used by different workers in order to determine the future change in climate of India. According to PRECIS (Providing Regional Climates for Impacts Studies) modelling the all-round warming is likely to occur in the seasonal mean temperatures and in the extreme temperatures also. Both the days and nights will be warmer in the future scenarios and the night temperatures are likely to increase at much higher rates than the day temperatures. The lowest minimum temperatures are expected to be warmer by more than 5°C over most parts of the country; however, the highest maximum temperatures are likely to rise by only about 2°C. The minimum temperatures are increasing more rapidly than the maximum temperatures not only over India (Rupa kumar *et al.*, 2006; Dash and Hunt, 2007) but also across several regions in the world. PRECIS simulation for 2071–2100 also indicates an all round warming over Indian subcontinent associated with increasing greenhouse gas concentrations. The annual mean surface air temperature is likely to rise by the end of the century from 3 to 5ºC in A2 scenario, whereas the rise lies between 2.5 and 4ºC in the B2 scenario. The warming seems to be more pronounced over the northern parts of India.

Impacts of climate change on livestock production in India

The impact of climate change and global warming is now recognized worldwide. There are numerous studies and reviews which address the effect of climate change on the physical environment and on human health over the past two decades. However, there are limited studies which show the impact of climate change on animal health and production especially in Asian countries. The Asian continent now considered as “hub” of livestock production, may be significantly affected by the changes in climate.

Climate change poses formidable challenges to the development of livestock sector in India. The climate change impact directly livestock production and also affects indirectly through availability of feeds, fodder and pastures. Climate also determines the type of livestock suitability and adaptation in different agro-ecological conditions and therefore the animal species or breeds that are able to sustain rural communities. Climate change is expected to affect not only livestock at the species level but also decide sustainability of a breed or a species. Benefits of temperature rise that might be realized during cooler seasons will be less than that of negative impacts during hot and hot humid conditions. Climate changes will also affect nomadic, landless and small farmers with few heads of livestock.

Animal stress level due to temperature rise has been worked out using Temperature Humidity Index in India (Upadhyay et al., 2008). All animals have a range of ambient environmental temperatures termed the thermoneutral zone and temperature below or above this thermoneutral range of the animal creates stress conditions in animals. Analysis of stress level revealed that for 160-165 days during the year average THI was less than 65 in northern India and for about 50 days the THI ranged between 66 and 70. THI remained more than 70 for 40-42 days and THI ranged between 75 and 80 for 95-100 days during the year. The uncomfortable THI (>80) due to high temperature were observed for about 40 days in a year (mention time period). Climate change scenario constructed for India revealed that temperature rise of about or more than 4˚C is likely to increase uncomfortable days (THI>80) from existing 40 days (10.9%) to 104 days (28.5%) for Had CM3-A2 scenario and 89 days for B2 scenario for time slices 2080-2100. This change in THI has a negative impact on the livestock production both directly and indirectly.

Milk Production

One of the direct impact of climate change is on the milk yield production. Studies carried out at NDRI revealed that a temperature rise of 1.0 or 1.2°C with minor change in precipitation during March - August for India (Region 23- HADCM3 A2/B2 scenario) will marginally affect milk production and during other months productivity will remain relatively unaffected. The estimated annual loss at present due to heat stress at the all-India level is 1.8 million tones, that is, nearly 2 percent of the total milk production in the country. In value terms this amounts to a whopping Rs. 2661.62 crores (at current prices). The economic losses were observed to be highest in UP (>Rs.350 crores) followed by Tamil Nadu, Rajasthan and W. Bengal.

A sudden changes in temperature, either a rise in T max during summer i.e. heat wave or a fall in T min during winter i.e. cold wave; cause a decline in milk yield. Both increase in T max (>4°C above normal) during summer and decline in T min (>3°C than normal) during winter negatively impact milk production of crossbred cattle and buffaloes. The decline in yield varies from 10-30% in first lactation and 5-20% in second and third lactation. The extent of decline in milk yield occurs less at mid lactation stage than either late or early stage. The negative impact of cold wave or heat wave on milk yield of buffaloes are not only observed on next day of extreme event but also on the subsequent day(s), thereby indicating that heat and cold waves cause short to long term cumulative effect on milk yield and production in cattle and buffaloes. Therefore, global warming due to climate change with increased number of stressful days (THI more than 80) and increase in frequency of warm days will impact yield and production of cattle and buffaloes (Upadhyay et al., 2007).

The negative impact of global warming on total milk production for India has been estimated about 1.6 million tones in 2020 and more than 15 million tones in 2050 (Upadhyay *et al.*, 2009a). The partitioning of milk production impact indicated that high producing crossbred cows and buffaloes will be affected more, accounting 0.4 million and 0.89 million respective annual decline in 2020. Warming will also negatively impact the productivity of indigenous cows and productivity loss will be about 0.33 million tones milk in 2020. The Northern India is likely to experience more negative impact of climate change on milk production of both cattle and buffaloes due to rise in temperature during 2040-2069 and 2070-2099. The decline in milk production will be higher in crossbreds (0.63%) followed by buffalo (0.5%) and indigenous cattle (0.4%). The stress as a result of increased thermal load days due to global warming in 2020 will cause an additional loss in milk production (1.6 million tonnes) accounting about Rs 2365.8 crores at current price rate. The annual loss in milk production of cattle and buffaloes due to thermal stress in 2020 will be about 3.4 million tonnes milk costing more than 5000 crores at current price rates. The increase in stress days on account of global warming due to rise of more than 4^0C from March to October by 2100 will accentuate the magnitude of economic losses attributable to heat stress.

Animal growth and reproduction

The rise in temperature due to global warming will negatively impact growth and time to attain puberty of livestock species. In addition to this the reproductive efficiency of livestock is also negatively influenced by high ambient temperatures. The negative impact of THI rise on animals growing at higher rates (500g/day or more) will be more than slow growing (300-400g/day) cattle. The crossbred cattle have been observed to be more sensitive to rise in temperature and humidity than either Zebu cattle or buffaloes. Time to attain puberty was observed to prolong from 5 to 17 days due to decline in growth rate at high temperatures.

Assessment of the potential direct impacts of climate change on livestock reproduction indicated that a temperature rise of 2-5°C for time slices 2040- 2069 and 2070-2099 are likely to increase incidence of silent estrus, short estrus and decline in reproduction efficiency of buffaloes. The reproductive rhythm of buffaloes may have impacts of temperature rise and variability as number of buffaloes in silent estrus has been observed to increase with increase in THI, and conception rate declined with an increase in THI above comfortable levels. Buffaloes at high ambient temperatures have been reported to fail in conceiving due to silent heat or poor expression, loss of conception, causing long dry periods and inter calving intervals. A temperature rise of more than 2°C in unabated buffaloes may cause negative impacts due to low or desynchronized endocrine activities particularly pineal-hypothalamo-hypophyseal-gonadal axis altering respective hormone functions (Upadhyay *et al.*, 2009b).

Impact on physiological functions

Physiological functions of livestock species exhibit diurnal variations and are affected by ambient temperature and humidity levels. The magnitude of response and change depends upon species, breed and physical environment factors. The speed of change in physiological functions (Respiratory frequency, heart rate and energy expenditure) with rise in temperature doubles or trebled for an increase of 10°C in temperature .One of the physiological responses to heat stress is reduction in their heat production, which in turn is caused by reduction in feed intake (Thomas and Razdan, 1973), thyroid hormone secretion (AI-Haidary *et al.*, 2001).

Stress may contribute to the development and course of a range of illness by inducing changes in immune function by inhibiting spontaneous lymphocyte stimulation, which may be indicator of depressed immune status. The susceptibility to infection has been increased in cows suffering from heat stress. The reduced animal response to heat stress is due to release of cytokine IL-1 that causes further release of CRH from the hypothalamus for modulating glucocorticoids that down regulates to keep the immune system in check (Borell, 2001). Lymphocytes from Brahman and Senepol cows were found to be most resistant to heat-induced apoptosis than lymphocytes from Angus and Holstein cows. There were no significant differences between Brahman, Senepol and Angus in the amount of heat shock protein 70 (HSP70, a thermal stress induced protein) in heat-shocked lymphocytes although the non-significant tendency for lower amount in Brahman and Senepol may indicate that protein denaturation in response to elevated temperature (one of the signals for HSP70 synthesis) is reduced in Brahman and Senepol (Kamwanja et al., 1994). HSP induction in buffaloes has also been observed to be of low magnitude during thermal stress (Patir and Upadhyay, 2007, 2009). Recent studies at NDRI on induction of HSP in lymphocytes of Sahiwal have indicated that thermotolerance in Sahiwal is due to difference in induction of HSP and low induction makes crossbreds thermal intolerant.

Animal diseases

Direct impact of climate change includes the temperature related illness, morbidity and mortality of animal during extreme weather condition. Indirect impacts of climate change follow more intrinsic pathways or drivers that influence microbial density and distribution, distribution of vector borne disease and decrease in the host resistance to infection. Global temperature rise is likely to cause an increase in incidence of animal diseases (bacterial, protozoan and viral diseases) that are spread by insects and vectors due to temperature and humidity rise in tropical and subtropical climatic conditions. Incidence of certain diseases and their distribution may change both temporally and spatially. Frequency and incidence of mastitis and foot diseases affecting crossbred cows and other high producing animals may increase due to increase in number of stressful days.

Contribution of Indian livestock sector to climate change

The livestock sector, which is vulnerable to climate change, is itself a large contributor to climate change through emission of methane and nitrous oxide. Livestock sector contributes about 18% of the global greenhouse gas (GHG) emissions, and as much as 37% of anthropogenic methane. Methane emissions from livestock have two components: ‘enteric fermentation’ and ‘manure management’.

Recent estimation of livestock methane production using IPCC methodology indicate that the total methane emitted due to enteric fermentation and manure management of 485 million heads of livestock was 9.37 Tg/annum for the year 2003. The major contributors to methane emission were Indigenous, Crossbred Cattle, Buffalo and sheep & goat accounting 40, 8, 40, and 10% respectively. The other livestock with minor population consisting of equines (horses, ponies, mules and donkeys), pigs, yak, mithun and camels contributed only 2% (0.15Tg) of total emission from livestock sector. The ruminants, both small and large, were the main contributors (98%) to the enteric methane emission in India. Lactating animals comprising of buffaloes and cattle contributed 3.42 Tg with a major share of 2.04 Tg from lactating buffaloes (Upadhyay *et al.*, 2009c).

The indigenous female cattle (82.9 million) contributed 2.2Tg and 77.53 million indigenous males emitted 1.55Tg methane. Crossbred females though in small number compared to indigenous cattle, emitted more methane per animal (0.63Tg methane from 19.74 million heads) indicating that crossbreds produce more methane than indigenous animals. The emission from buffalo females was also higher and 80 million females produced 3.42Tg in 2003. The contribution of buffalo females was about 36.5% to total methane emission from livestock sector. The contribution of milch buffaloes was 59.6%, crossbred cows 11.4 and Indigenous cows 28.9% to the total emissions from dairy animals (Upadhyay et al, 2009c).

A Large uncertainties in GHGs emission estimates from livestock sector exist due to classification and categorization of animal population, their body weights, feed intake, feeding systems, feed characteristics, animal nutrition, milk data, emission co-efficient etc resulting in variation in quantification of methane from enteric fermentation. Enteric methane emissions from Indian livestock presented by other workers are 9.02Tg for 1992 (Singh, 1998) and 10.08Tg for 1994 (Singhal, et. al., 2005). The estimated value of methane emission from livestock has been reported 7.26 TG (Garg and Shukla, 2002), 7.4Tg (Mitra, 1992), 10Tg (WRI, 1990) and 10.4Tg (US-EPA, 1994).

Strategies used for the mitigation of thermal load

In India livestock production has become vulnerable to the impact of climate change on the one hand and on the other hand the livestock productivity will have to be raised to meet future demand. So there is an urgent need to improve the livestock production through scientific breeding, feeding and management strategies.

The livestock employ physiological mechanisms to counter the heat stress. The physiological mechanisms are also complemented by the behavioural process and buffaloes use wallowing during summer to reduce thermal loads and maintain thermal equilibrium. However, to counter the adverse effect of heat stress change on animal production and health, human intervention for physical modification of the environment and improvement in nutritional management practices would be additionally required (Beede and Collier 1986; West 1999). An integrated farm approach may be adopted for reducing thermal stress of livestock. This include: reduce overcrowding, use of trees, shelter/shade and provision of good designed animal sheds to reduce direct solar exposure and heat exchange. The provision of foggers, sprinklers and high velocity fans in animal sheds may help in cooling of livestock. Pregnant and high producing animals require special protection from direct solar radiation exposure and thermal stress. Altering feeding and milking time to cool hours (evening/morning) is low likely to increase milk yield. Use of mosquito nets particularly in morning and evening protects livestock from insects and may help in bringing down diseases spread by insects and vectors. Provision of clean and cool water for drinking also reduces thermal stress in buffaloes.

Strategies used for the mitigation of methane emission from livestock

While considering the loss as well as the harmful effect caused by the methane on the livestock, it is essential to control or decrease the methane emission from all the sources including the enteric fermentation of livestock. Several mitigation options are available for methane emissions from livestock:

Improved feeding management – composition of diet has the effect on the rumen microbial ecosystem so any manipulation in the diet by means of forage, concentrate and their components results in change in the microbial community and may decrease or inhibit activity of methanogenic bacteria. There are several strategies which can be used to reduce methane production from livestock: Supplementation of nutrients to poor quality roughage based ration, Forage processing, Feed additives: A large number of inorganic, organic compounds and ionophores are known to modify the microbial activity to reduce to methane production such as carbon tetrachloride, trichloroethyl pivalate, nititrates ionophores, rumensin/monensin etc, Feeding of lipids, Defaunation of ruminants, Manipulation of rumen microbes, Reduction of ruminants population. Field experiments in India showed that dietary manipulation through increased green fodder decreased methane production by 5.7% (Singhal and Madhu Mohini 2002). Increasing the concentrate in the diet of animals reduce methane by 15–32% depending on the ratio of concentrate in diet (Singh and Madhu Mohini 1999). The methane mitigation from molasses urea supplementation was 8.7% (Srivastava and Garg 2002) and 21% from use of feed additive monensin (De and Singh 2001). Also the amount of feed intake is related to the amount of waste product. The higher proportion of concentrate in the diet results in a reduction of CH4 emission.

Improved waste management – improving management of animal waste products through different mechanisms such as covered storage facilities can reduce the methane emission. The GHG emission from manure (CH4, N2O, and CH4 from liquid manure) is dependent on the temperature and duration of the storage and any changes in temperature is likely to reduce emissions. In India, the possibility of reducing emissions from animal manure storage is restricted as it is extensively used as fuel in the form of dry dung cakes or spread in field.

Selection of faster growing breeds - improved livestock efficiency to convert energy from feed into production, and reducing losses through waste products. Increasing feed efficiency and improving digestibility of feed intake are potential ways to reduce GHG emissions and maximize production from livestock. This includes all the livestock practices - such as genetics, nutrition, reproduction, health and dietary supplements and proper feeding (incl. grazing) management – that result in the improved feed efficiency.

Grazing management – one of the major GHG emission contributions from livestock production is from forage or feed crop production and land use of feed production. Thus pasture grazing and proper pasture management through rotational grazing is the most cost effective way to mitigate GHG emissions from feed crop production. Animal grazing on the pasture also helps reduce emission due to animal manure storage. Introduction of grass species and legumes into grazing lands can enhance carbon storage in soils.

Lowering livestock production consumption - lowering consumption of meat and milk in areas having high standards of living will support short term response to the GHG mitigation.

All these strategies calls for formulation of long-term policies at governmental level and significant investment in the livestock production and processing industry; which may help in improvement and boost of livestock production. While there are many aspects still to be understood about climate change as we have known very limited about the range of impacts, the magnitude of risks, and the potential for adaptation. Therefore, in addition to mitigation, there is an urgent need to develop and implement climate change adaptation plans. The biodiversity in livestock and Indigenous technologies available with traditional farmers particularly can help in development of strategies for the adaptation to climate variability and change.

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Climate Change Impacts on Livestock Production and Adaptation Strategies: A Global Scenario

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Importance of livestock in present and future and how climate change can affect it

Globally, livestock contributes 40% to agricultural GDP, employs more than a billion people and creates livelihoods for more than 1 billion poor (Steinfeld *et al.* 2006). From a nutritional standpoint, livestock contributes about 30% of the protein in human diets globally, and more than 50% in developed countries. In many developing countries, livestock was also considered to be the backbone of agriculture, as they provided draught power and farmyard manure, often the sole source of crop nutrition, before promotion of modern agriculture in the middle of the 20th century. As outlined in the livestock revolution scenario (Delgado et al. 1999) consumption of animal products will rise particularly in so-called developing countries in response to urbanization and rising incomes. While the increasing demand for livestock products offers market opportunities and income for small holder producers and even landless, thereby providing pathways out of poverty (Kristjianson, 2009), livestock production globally faces increasing pressure because of negative environmental implications particularly because of greenhouse gas emissions (Steinfeld et al. 2006). Besides green house gases, high water requirement in livestock production systems is a major concern.

The relationships between livestock and the environment are complex and appear to be viewed very differently from developed and developing country perspectives. The FAO report, *Livestock's Long Shadow*, focused on the effects of livestock on the environment (Steinfeld et al. 2006). The climate change impacts of livestock production (calculated in Steinfeld et al. (2006) at 18% of the total global greenhouse gas emissions from human sources) have been widely highlighted, particularly those associated with rapidly expanding industrial livestock operations in Asia. Yet, in smallholder crop-livestock and agro-pastoral and pastoral livestock systems, livestock are one of a limited number of broad-based options to increase incomes and sustain the livelihoods of an estimated 1 billion people globally, who have a limited environmental footprint. Livestock are particularly important for increasing the resilience of vulnerable poor people, subject to climatic, market and disease shocks through diversifying risk and increasing assets. Given that almost all human activity is associated with GHG emissions, those from livestock in these systems are relatively modest when compared to the contribution that livestock make to the livelihoods of this huge number of people. This complex balancing act of resource use, GHG emissions and livelihoods is almost certain to get more rather than less complicated. The demand for energy supply through biofuels is yet another factor that is putting increased pressure on the natural resource base and the balance between different natural resource uses, especially in mixed crop-livestock systems.

Unfortunately, in the past most of the livestock owners in India as well as the development agencies engaged in livestock development, were not aware of the extent of potential damage caused by livestock through emission of greenhouse gases. In the absence of efficient livestock extension and veterinary services, there has been severe genetic erosion, resulting in low productivity. This compelled small farmers to expand their herd size, resulting in shortage of fodder and feed. As it was not economically viable to feed low productive livestock, farmers facing shortage of fodder let them out for free grazing on common lands and forests which suppressed the productivity further, while accelerating the pressure on bio-diversity. In the absence of a national policy on control of livestock population, there has not been any pressure on the livestock owners either to cull their uneconomic animals or to control their herd size. With the growing threat on food security arising due to global warming, small farmers dependent on rainfed agriculture are likely to be affected more severely, which may compel them to shift over to livestock husbandry for their livelihood. Therefore, the development strategy should be to promote the productivity of livestock, while reducing the population and conserving water and fodder resources.

As livestock is an important source of livelihood, it is necessary to find suitable solutions to convert this industry into an economically viable enterprise, while reducing the ill-effects of global warming. In relation to climate change, livestock will have to play a dual role: one of mitigation and one of adaptation.

Adaptation of livestock systems to climate change

Feeds and water

Water scarcity has become globally significant over the last 40 years or so, and is an accelerating condition for 1-2 billion people worldwide (MEA 2005). The Comprehensive Assessment of Water Management in Agriculture (CA) (2007) states that if today's food production and environmental trends continue into the future, they will lead to crises in many parts of the world. The CA calls for concerted action to improve water use in agriculture, if the freshwater challenges of future decades are to be overcome. The localised impacts of global change on water resources are starting to receive attention, but in the same way as for localised agricultural impacts, there is a great deal of work that needs to be done. The response of increased temperatures on water demand by livestock is well-known. For *Bos indicus*, for example, water intake increases from about 3 kg per kg DM intake at 10°C ambient temperature, to 5 kg at 30°C, and to about 10 kg at 35°C (NRC 1981). The impacts of climate change on water supply changes in livestock systems, however, are not well-studied. The key contribution of groundwater to extensive grazing systems will probably become even more important in the future in the face of climate change, although the impacts on recharge rates of the aquifers involved are essentially unknown (Masike 2007).

However, one of the most evident and important effects of climate change on livestock production is mediated through changes in feed resources. Although indirect, effects on feed resources can have a significant impact on livestock productivity, the carrying capacity of rangelands, the buffering ability of ecosystems and their sustainability, prices of stovers and grains, trade in feeds, changes in feeding options, greenhouse gas emissions, and grazing management. The main pathways in which climate change can affect the availability of feed resources for livestock are as follows:

1. Land use and systems changes: as temperature increases and rainfall increases or decreases (depending on location) and becomes more variable, the niches for different crops and grassland species change. For example, in parts of East Africa, reductions in the length of growing period are likely to lead to maize being substituted by crop species more suited to drier environments such as sorghum and millet (Thornton and Herrero 2008). These land-use changes can lead to a different composition of animal diets and to a change in the ability of smallholders to manage feed deficits in the dry season. These two effects can have substantial effects on animal productivity and on the maintenance of livestock assets.

2. Changes in the primary productivity of crops, forages and rangelands: this is probably the most visible effect of climate change on feed resources for ruminants. However, the effects are different depending on location, production system and on crop and pasture species. In C4 plant species, increases in temperature up to 30-35°C will in general increase the productivity of crops, fodders and pastures, as long as the ratio of evaporation to potential evapotranspiration and nutrient availability do not significantly limit plant growth. In C3 plants such as rice and wheat, temperature effects have a similar effect but increases in CO_2 levels will also have a significant (positive) impact on the productivity of these types of crops (IPCC, 2007). For food-feed crops, since harvest indexes change with the amount of biomass produced, the end result for livestock production is a change in the quantity of grains and stovers and availability of metabolisable energy for dry season feeding.

3. Changes in species composition: Species composition in rangelands and some managed grasslands is an important determinant of livestock productivity. As temperature and CO_2 levels change, the optimal growth ranges for different species also change, species alter their competition dynamics, and the composition of mixed grasslands changes. For example, in the temperate regions and subtropics, where grasslands often contain C3 and C4 species, some species are more prominent than others in the summer, while the balance of the mix reverts in winter. Small changes in temperature alter this balance significantly and often result in changes in livestock productivity. The proportion of browse in rangelands may increase in the future as a result of increased growth and competition of browse species due to increased CO_2 levels (Morgan et al. 2007).

4. Quality of plant material: Higher temperatures increase lignification of plant tissues and therefore reduce the digestibility and the rates of degradation of plant species (Minson, 1990). This leads to reduced nutrient availability for animals and ultimately to a reduction in livestock production, which may have impacts on food security and incomes through reductions in the production of milk and meat for smallholders.

Livestock genetics and breeding

Traditionally, the selection of animals in tropical breeds has been an adaptive one, but in recent times, market pull has stimulated a rapidly changing demand for higher production that could not be met quickly enough by breed improvement of indigenous animals. Widespread cross-breeding of animals, mostly with "improver" breeds from temperate regions, crossed with local animals, has occurred-often with poor results. Little systematic study has been conducted on matching genetic resources to different farming and market chain systems from already adapted and higher producing tropical breeds. However, given the even greater climatic variability and stresses anticipated, this is a logical response to the adaptive challenges that will be faced. The greatest role for using adaptive traits of indigenous animal genetic resources will be in more marginal systems in which climatic and other shocks are more common. Indigenous breeds, which have co-evolved in these systems over millennia and have adapted to the prevalent climatic and disease environments, will be essential (Baker and Rege, 1994). These systems are under substantial pressure arising from the need for increased production as well as land-use changes. Under these circumstances, ensuring continuing availability of these adapted animal breeds to meet the needs of an uncertain future is crucial. The adaptive challenge will be to improve productivity traits while maintaining adaptive traits. This co-evolution will take place at different speeds within different systems. Within this context, there will be a constant need to improve productivity since increasing demand will need to be supplied from a relatively constant land and water resource base. Current animal breeding systems are not sufficient to meet this need and the improvement of breeding programs under different livestock production and marketing contexts is a critical area for new research.

The preservation of existing animal genetic diversity as a global insurance measure against unanticipated change has not been as well appreciated as has that for plants, although the recent report on the state of the World's animal genetic resources (FAO 2007) and the accompanying Interlaken Declaration have highlighted this important issue. When conservation through use is insufficient (as is the widespread situation with indiscriminant cross-breeding), *ex-situ*, especially *in vitro*, conservation needs to be considered as an important component of a broad-based strategy to conserve critical adaptive genes and genetic traits.

Livestock (and Human) Health

The major impacts of climate change on livestock and human diseases have been on diseases that are vector-borne. Increasing temperatures have supported the expansion of vector populations into cooler areas, either into higher altitude systems (for example, malaria and livestock tick-borne diseases) or into more temperate zones (for example, the spread of bluetongue disease in northern Europe). Changes in rainfall pattern can also influence an expansion of vectors during wetter years. This may lead to large outbreaks of disease, such as those seen in East Africa due to Rift Valley Fever virus, which is transmitted by a wide variety of biting insects.

An example is the complexity of climate change influences with other factors associated with vector populations of tsetse flies in sub-Saharan Africa (McDermott et al. 2001). Tsetse flies transmit African trypanosomes widely in livestock (ruminants, equids, and pigs). Predictions of climate and population change on tsetse density indicates that tsetse populations and animal trypanosomosis will decrease most in semi-arid and sub-humid zones of West Africa and in many but not all areas of Ethiopia and eastern and southern Africa through a combination of population pressure on savannah species and climate change pressure on riverine species. Helminth infections, particularly of small ruminants will be greatly influenced by changes in temperature and humidity. Climate changes could also influence disease distribution indirectly through changes in the distribution of livestock. Areas becoming more arid would only be suitable for camels and small ruminants. If these species are forced to aggregate around water points, the incidence of parasitic diseases could increase.

Changes in cropping patterns and livestock systems

With changes in climate there is likely to be a shift if cropping patterns. Jones and Thornton (2003) have suggested that in areas of Africa where cropping is marginal, changes in climate by 2050 may result in increased probability of crop failure and an increased reliance on livestock farming. Many of these areas are already characterized by high levels of poverty and vulnerability.

Livestock contribution to climate change and strategies for counteracting negative environmental effect caused by livestock.

While climate change will affect the way livestock is produced and will also decrease and increase the role and importance of livestock for livelihoods depending on localities, livestock does also contribute to climate change. As cited by Gill and Smith (2008), in 2005 agriculture in general contributed about 10 to 12% or between 5.1 and 6.1 gigatons (Gt) of CO_2 equivalents to human-induced GHG emissions globally. Enteric CH_4 production, that is the CH_4 released mainly from the digestive tract of ruminants, was estimated at 1.9 Gt of CO_2 equivalents, representing about 37% of agriculture contribution to GHG. However, these estimates did not include carbon emissions from fossil fuel used in cropping, animal housing and land change use. Considering carbon emissions along the entire commodity chains, Steinfeld et al. (2006) estimated that livestock contribute about 18% to the global warming effect. These contributions are of course significant, and require urgent attention.

Feed mitigation options for reducing carbon emission

Considerable efforts have been expended in reducing carbon emission from livestock, even before the awareness of climate change took hold, simply because feed carbon losses to the environment reduce feed conversion efficiency. The mechanisms that result in enteric carbon emissions are, therefore, quite well understood. Put simply, digestion in the rumen is characterized by feed conversion to short chain fatty acids (SCFA), the 2, 3 and 4-carbon acids, acetate, propionate and butyrate which provide the primary energy source for ruminants, microbial biomass (MBP) which is the major or even only source of protein and finally the gases, mainly CO_2 and CH_4 which are digestive waste products and obviously of major environmental concern. Since diversion of feed carbon away from gaseous losses has livestock nutritional and environmental benefits, considerable research was invested in devising feeding strategies that achieve this, and our knowledge about the underlying causes is expansive (Van Soest, 1994). Briefly, high proportional feed conversion into MBP, that is a high efficiency of microbial production (EMP), and high proportion of propionate in the SCFA, reduce digestive carbon losses (see Figure 1).

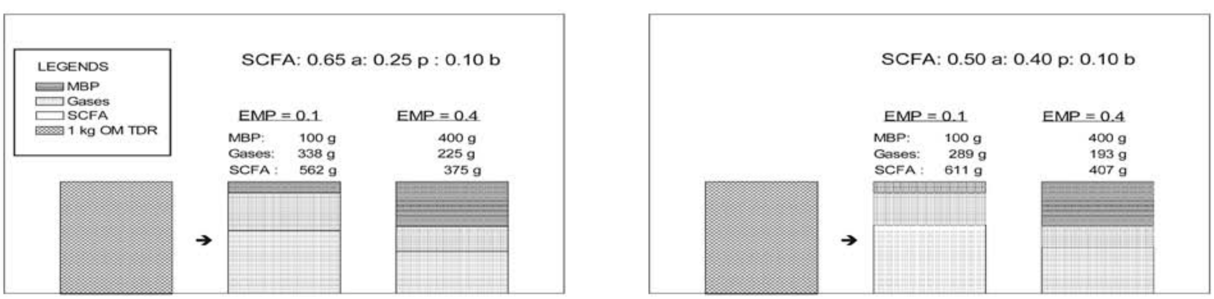

Figure 1: Partitioning of one kg of organic matter truly degraded in the rumen (OMTDR) under varying efficiencies of microbial production (EMP) and acetate (a), propionate (p) and butyrate (b) proportions (from Blümmel *et al.* 2001)

Thus total feed loss into gases (including fermentative H_2O) under high EMP and high proportional propionate production per kg feed digested in the rumen is only 193 g compared to 338 g under low EMP and proportional high acetate production (Figure 1). Increasing EMP and proportional propionate concomitantly has very substantial effect on enteric carbon emission (see also Figure 2).

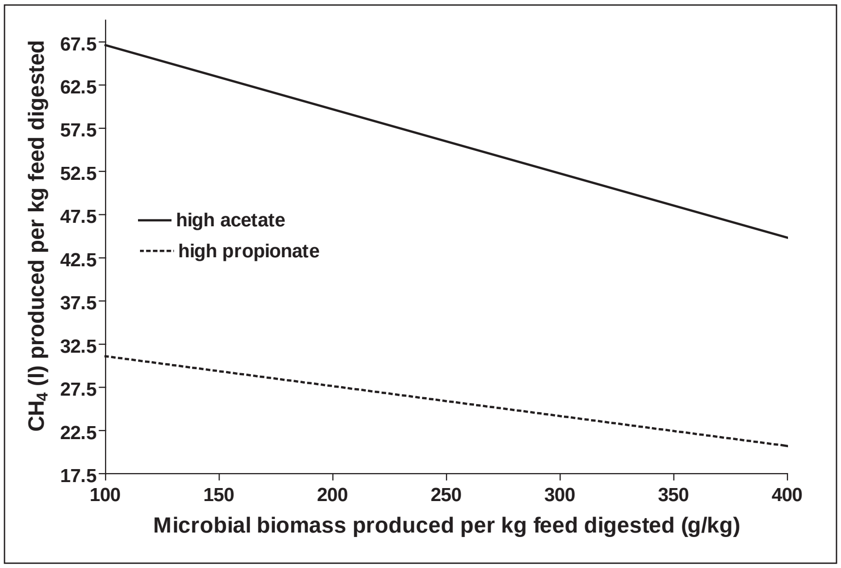

Figure 2: Methane production from 1 kg of feed digested in the rumen in relation to SCFA proportion and EMP (modified from Blümmel and Krishna 2003)

Clearly, increasing proportional propionate production will have the most substantial effect on methane emission relative to feed digested. While under proportional high acetate production methane emission could range from about 45 to 70 liter per kg digested feed depending on EMP, only about 20 to 30 liter of methane are produced under high proportional propionate production (Figure 2). In other words methane emissions could be halved. From a mere technical feed perspective, high proportional propionate production can be "simply" achieved by increasing the proportion of concentrate in the diets. In fact this approach is frequently recommended for reduction of methane emissions from livestock (for review see Martin et al. 2008). There are, however, severe draw backs associated with increased concentrate feeding to ruminants, particularly in developing countries (see also below). First, food security might be in jeopardy and food prices might increase, further burdening poor people. Also, natural resource usage of land, water and biomass is more efficient where livestock production (mainly from ruminants but not only) is based on by-products such as crop residues that do not contain human edible nutrients or on biomass harvest – through grazing and otherwise - from areas not suitable for arable land.

Besides shifting from acetate to propionate production through increase feeding of concentrate, a range of interventions have been proposed to alter the fermentation products outlined in Figure 1 for reduced carbon losses for example through use of synthetic and natural feed additives (Martin *et al.* 2008). There might be also scope for introducing new species of anerobic bacteria, capable of breaking fibre, without or with low emission of CH_4. This calls for a search of such bacteria and to introduce it in the digestive system of ruminants. A similar strategy was adopted for eliminating the ill-effects of feeding leucaena, where mimosine was converted into DHP (3,4 – Dihydroxy pyridone) which is a goitrogen. However, anerobic bacteria found in ruminants of certain countries could convert DHP into harmless compounds. Subsequently, this bacteria was isolated and introduced in the digestive system of ruminants in these countries, particularly, Australia (Hegde and Gupta 1994; Jones and Lowry 1984).

Effect of increasing milk production per animal on feed resource requirements and greenhouse gas emissions'

"Environment-Friendly' development of livestock production systems demands that the increased production be met by increased efficiency of production and not through increased animal numbers (Leng, 1993). Feeding strategies that increase the efficiency of production by producing more from fewer animals and less feed will result in reduced green house gas emissions. This can be demonstrated by analyzing livestock population in India and their respective level of productivity. Thus, in India in 2005/2006 the proportion of milch animals relative to total livestock numbers was less than 0.25. In addition, the daily milk yield of cross bred, local cows and buffalo was low, averaging on a 365 days lactation basis 6.44, 1.97 and 4.3 liters, respectively. The mixed herd mean milk yield can be calculated as 3.61 liters. This low productivity resulted – across the three types of livestock – in a ratio of feed metabolizable energy (ME) for maintenance and production of 1.9: 1, see Table 1.

Table 1: Summary of total livestock population, milch animal and their production and feed requirements for maintenance and production in India in 2005/2006.

	Cross Bred Cows	Local Cows	Buffalos	Total
Milch animals	8 216 000	28 370 000	33 137 000	69 759 000
Total animals	28 391 000	155 805 000	101 253 000	285 449 000
Milk yield (kg/d)	6.44	1.97	4.4	3.6 (mean)
ME required (MJ 10^9)				
Maintenance	148.0	423.3	601.2	1172.5
Production	122.6	136.4	370.8	629.8

Adopted from Blümmel *et al.* (2009)

By increasing daily milk production in a herd model (of a mixed cross-bred, local cow, buffalo population) from 3.61 to 6, 9, 12 and 15 liter per day energy expended for maintenance becomes less than energy expended for production, see Table 1. As a result the same amount of milk can be produced by less numbers of livestock leading to drastically reduced emissions of methane (see Figure 3 and 4).

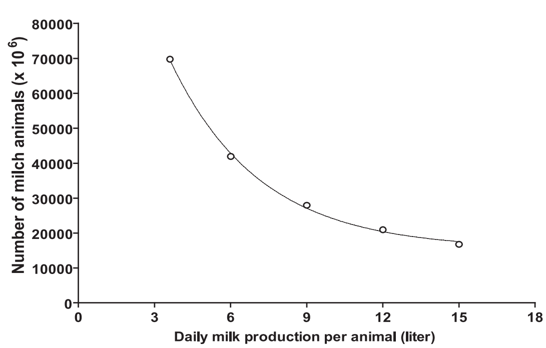

Figure 3: Relations between average daily milk production and livestock numbers

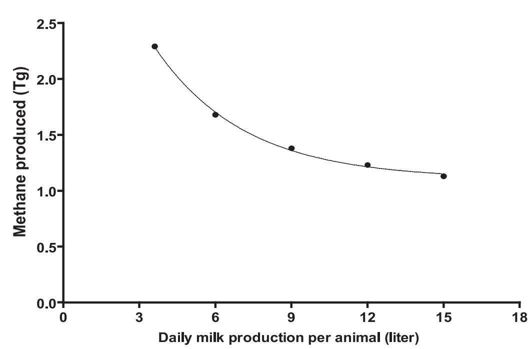

Figure 4: Relations between average daily milk production and methane emissions

Adopted from Blümmel et al. (2009)

Increasing milk productivity can be accomplished by improving the intake of feed, nutrient density of the diet (quality) or a combination of both. In the Indian context the option of improving the intake of feed (DMI > 3% of body weight) is limited due to the nature of the diet where crop residues are predominant feed resources and greens and concentrates constitute a minor proportion (Ramachandra *et al.* 2007). Assuming that there would not be any import of feed ingredients, the second option of improving the quality of diets is very limited due to limited availability of concentrate ingredients and preferential use of concentrate ingredients in the poultry sector. Allocation of additional land and water for feed/fodder cultivation is also ruled out due to competition from the food and commercial crops. In view of the above, improving the average productivity of animals from the present level to 6 liters/day appears to be more feasible while achieving 9 liters/day would be difficult due to shortage of concentrates (Ramachandra *et al.* 2007). For achieving an average productivity level of 9 liters /day with a diet of metabolizable energy content of the diet of 7.36 ME, the dry matter intake (DMI) should be around 3.6% of the body weight. Achieving a DMI of 3.6% in milch animals with a metabolizable energy content of the diet of 7.36 ME would be difficult and the diet quality would need to be improved by increasing the proportion of concentrates. Achieving high DMI is possible with an increase in the proportion of the concentrate in the diet as in the case of feed blocks where concentrate constitutes around 50% of the diet. The total feed requirement for achieving 9 liters/day on diets with a metabolizable energy content of 7.36 and 8.50 MJ works out to be 146 and 126 million tons corresponding to 3.6 and 3.1% DMI of body weight respectively. While achieving a DMI of 3.1% with better quality diet (8.5MJ ME) is feasible the, concentrate requirement would work out to be 63 million tons and concentrate availability would be a constraint. Looking into the potential availability of total concentrates at the national level, the available concentrate of 35 million tons (Ramachandra *et al.* 2007) will not be sufficient to achieve the average productivity level of 9 liters/day. Limited concentrate availability will further constraint options of mitigating CH_4 emissions by shifting from acetate to propionate production.

With current feed resources and no changes in the ratio of milk to no-milk producers the achievable level of milk production appears therefore to be between 6 and 9 liters per day (for more detailed reasoning see Blümmel et al. 2009). In fact long term field studies from 1997 to 2001 of BAIF (Gokhale *et al.* 2007) show average milk yields (converted to 365 days lactation) in cross-bred cows of 7.7 (on irrigated area) to 8.5 (irrigated area) liter per day. This was achieved by providing critical breeding and health care services coupled with regular guidance on feeding and culling of animals. The experience of BAIF, a leading NGO engaged in promoting dairy husbandry, has confirmed that with ownership of high yielding cattle and buffaloes, farmers prefer to adopt stall feeding, maintain a smaller herd and try to meet the fodder shortage by bringing marginals lands under drought-prone fodder crops. This experience can be widely replicated across the developing countries for providing livelihood to small farmers (Hegde 2006). Thus an effective extension network will have to be established to create greater awareness among small farmers to adopt best practices in livestock husbandry to increase the production, without increasing the population.

CONCLUSION

As livestock is, and will remain, an important source of livelihood, it is necessary to find suitable solutions to convert this industry into an economically viable enterprise, while reducing the ill-effects of global warming. In relation to climate change, livestock is part of the problem but also part of the solution where cropping becomes too risky and where livestock will serve as an important tool for risk mitigation and diversification. Increasing the efficiency of livestock production, that is harvesting higher productivity from fewer numbers of livestock will play a key role in mitigating environmentally adverse effects from livestock. There are, however, ceilings to this approach mainly defined by feed resources. Feeding of livestock should not lead to competition for human food sources and should be based on converting non-human edible feed sources into human edible ones. Some trade-offs between positive and negative effects of livestock have to be accepted.

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Climate Change Impacts on Inland Fisheries –Issues and Strategies

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INTRODUCTION

The climate of the earth in the past few decades has shown perceptible changes both on global and regional scales manifested by increase in atmospheric and water temperatures. Some of the observed changes of climate in India as reported by Indian National Communication (NATCOM) (2004) to UNFCCC indicate an increase of 0.4^0C in surface air temperature over the past century. Regional monsoon variations have been recorded though the monsoon rainfall at the all India level does not show any significant trend. There is a trend of more frequent multi decadal drought followed by less drought and an overall increase in severe storm incidence especially in the states of Gujarat and West Bengal. There are indications of recession of some of the Himalayan glaciers, the source of water for the perennial rivers such as Ganga, Indus and Brahmaputra, but the trend is not consistent across the entire mountain chain. There are 12 major rivers in India with a cumulative catchment area of 252.8 Mha. Of the major rivers, the Ganga-Brahmaputra Meghna system is the largest with a catchment of about 110 M ha and about 40% of the surface water resources are utilized presently in this system. These river systems in India harbor one of the richest fish biodiversity resources in the world. The Gangetic river system alone harbours around 265 species of fish and supports a complex mix of artisanal, subsistence, traditional and semi-intensive culture fisheries based on the main river and adjoining water bodies of the gangetic plains situated mainly in the three Indian states of Uttar Pradesh, Bihar and West Bengal (Vass *et al.,* 2009). In a warming scenario, water problems would increase and would be critical in terms of goods and services from the inland water bodies related to inland fisheries. Balancing the needs of the aquatic environment and other users would become critical in many of the aquatic eco-systems in the country as population and associated demands increase (Das, 2009).

Time series data on various aspects of climate and inland fisheries related to the Ganga river system and of aquaculture water bodies in its plains *viz.* air / water temperature, river current velocity, rainfall, plankton availability, availability of spawn, and fish landings were collected from a review of approximately 200 scientific papers, CIFRI Annual Reports (1947 to 2004), Reports of Central Pollution Control Board, *Handbook of Fisheries Statistics,* and other publications of the Government of India on Ganga river systems. The entire length of Ganga river with a span of 2,525 km (the tributaries have a combined length of approximately 10,000 km and the total system is about 12,500 km in length) was divided in three main stretches- upper (Tehri to Kannauj), middle (Kanpur to Patna) and lower (Sultanpur to Katwa). The data were analysed to evaluate the impact, if any, on inland fisheries. Investigations were also conducted to ascertain the impact of elevated temperature on the breeding and growth of Indian major carps and impact on the fishers in the 50 fish hatcheries in 4 districts viz., North 24 Parganas, Bankura, Burdwan and Hooghly of West Bengal and also in Orissa. Air temperature data from 1986 to 2005 were collected from the Indian Institute of Tropical Meteorology, Pune for these districts. Water temperature was calculated from air temperature as per known relationships.

Impact on Inland water resources

Rivers

The major river systems of India which will be impacted in a climate alteration scenario are the Himalayan glacier-supported, mighty, perennial rivers such as Indus, Ganga and Brahmaputra. About 75 percent of discharges in Himalayan rivers occur during May-September. Similarly, other major rivers which are not snow fed arising in the mid Deccan platue of India like the Narmada, Mahi, Tapi, Godavari and Mahanadi shall have either acute or regular water shortage or face excessive flood condition as in Mahanadi (IINC; Ministry of Environment and Forest, 2004). Some of the changes in the hydrologic system (Arnell *et al*., 2001) that are relevant to fish and fisheries are: increase in flood magnitude and frequency owing to more intense precipitation events; increase in water temperature more severe low flows owing to increased evaporation; shift in peak stream flow from spring to winter owing to earlier thaw. It is apparent that global warming will affect the flow regime of rivers and will have a profound effect on the life history of fishes as is evident in temperate fishes (Meisner and Shuter, 1992).

Climate change and water availability

Projections of water balance components for the 12 river basins (IINC; Ministry of Environment and Forest, 2004) compare water balance components expressed as percentage of rainfall for both a control and climate change scenarios (Table 1). The control is based on the daily weather generated by HaD RM2 control climate scenarios (1981-2000). The model was run using climate scenarios for the period 2041-2060. It is observed that the impacts are different in different catchments. The increase in rainfall due to climate change does not result in an increase in the surface run-off as may be generally expected. For example, in the case of the Cauvery river basin, an increase of 2.7 per cent has been projected in the rainfall, but the run-off is projected to reduce by about 2 per cent and the evapotranspiration to increase by about 2 per cent. This may be either due to increase in temperature and/or change in rainfall distribution in time. Similarly, a reduction in rainfall in the Narmada is likely to result in an increase in the run-off and a reduction in the evapotranspiration that is again contrary to the usual myth. It may be observed that even though an increase in precipitation is projected for the Mahanadi, Brahmani, Ganga, Godavari, and Cauvery basins for the Climate Change Scenario, the corresponding total run-off for all these basins has not necessarily increased. The Sabarmati and Luni basins are likely to experience a decrease in precipitation and consequent decrease of total run-off to the tune of two-thirds of the prevailing run-off. This may lead to severe drought conditions under a future climate change scenario.

Rivers differ a great deal in the amount of water they carry depending upon the precipitation in their catchments and other sources of water (e.g., snowmelt) as well as factors that determine runoff, infiltration and evaporation. Flow is an important factor determining the physical structure of a river and thus maintaining in-stream habitats for fish and associated fauna and flora. Changes in any of the flow characteristics are marked by a reduction in habitat complexity and the diversity of plants and animals. Further, flow variability directly affects many life cycle stages of fish; for example, flooding or its receding serves as a cue for migration and spawning.

Wetlands

Hydrological processes in the watershed, and the rate of downstream discharge, determine the depth, duration and frequency of inundation of the floodplain, which periodically becomes a part of the river. The area of floodplain immediately adjacent to, and influenced by the river is often distinguished as the riparian zone. The riparian zone and the floodplain are important riverine habitats; they form a critical link between terrestrial and aquatic ecosystems. River flows determine the nature and strength of a river's interaction with its floodplain, and consequently the diversity of habitats and biotic communities. Any human activity that directly or indirectly impinges upon the flows has an impact on fishery resources.

Climatic changes in the Gangetic areas

Seasonal pattern of rainfall in the middle stretch of river Ganga:

Analysis of the monthly data of rainfall at Allahabad site of the middle stretch of river Ganga from 1974 - 2003 split into three equal periods (Jan-April), (May-Aug) and (Sep.-Dec) revealed that the percentage of total rainfall in the peak breeding period (May- Aug.) declined by 5% whereas it increased by 7% in the post- breeding period when resorption of eggs of Indian Major Carps begins (Fig. 1).

Water temperature changes in the upper stretch of river Ganga:

In the upper stretch of river Ganga at Haridwar during the period 1970-86 the annual mean minimum water temperature was 12.9 ºC (13ºC), while during the period 1987-2003 it increased to 14.5ºC, an increase of 1.5ºC is thus evident. As a result the stretch of river Ganga around Haridwar has become a more congenial habitat for these warm water fishes.

Air and water temperature and rainfall pattern changes in the Gangetic plains (West Bengal):

The analyses of the trend of air, water temperature and rainfall in the Gangetic plains (West Bengal) from 1986 to 2005 **r**evealed that during the breeding months of Indian carps(March to September), the mean maximum air temperature has increased by 0.37°C while mean minimum air temperature increased by O.67°C in the N 24 Paraganas. Considering the already known and validated relationship between water and air temperature (water temperature = 1.15* air temperature - 3.73, $R^2 = 0.96$) (Dey *et al., 2007*). The mean maximum and minimum water temperature has increased by 0.78°C and 0.43ºC respectively in 24-Paraganas during past two decades.

In district Bankura, the mean minimum air temperature increased by 1.57°C and in Burdwan district the mean minimum air temperature increased by 0.18 °C whereas the mean maximum air temperature increased by 0.09°C. Simultaneously, the differences of temperature between the months Jan-Feb, Feb-Mar and Mar-April during the period 1961-2005 indicated a shift towards higher temperature during Jan- Feb months (Fig. 2).

The pattern of rainfall which is another important criteria that triggers the early maturation of brood fish was analysed from the rainfall data (1976-05). It showed that the proportion of annual total rainfall occurred in monsoon months (May-August, 68% during 1976-85). But this proportion is gradually decreasing over the time (May-Aug, 65% during 1985-95 & 62% during 1996-05) and increasing in post monsoon months (in Sept-Dec, the proportion increased at 30% whereas this was 23% during 1976-85) at Dumdum during 1976-05 (Fig 3). Similar pattern rainfall distribution were observed at Alipur district of West Bengal during 1976-05.

Water Quality and Pollutants

Warming effect could exacerbate the existing the existing environmental problems for rivers and wetlands. It may change the chemical composition of water that fish inhabit; the amount of oxygen in water may decline, while pollution and salinity levels may increase.

Dissolved oxygen

Water holds less oxygen at higher temperature as such fish require more oxygen as temperature rises. Indian major carps and the exotic carps cultured in India are appreciably tolerant of warm water and low oxygen conditions. Many other Indian fish species of Anabantidae, Heteropneustidae and other catfishes are capable of tolerating oxygen depleted conditions.

Fish species	Lethal Dissolved Oxygen mg/l
Catla catla	0.7
Labeo rohita	0.7
Cirrhinus mrigala	0.7
Hypopthalmicthys molitrix	0.3-1.1
Ctenpharyngodon idella	0.2-0.6
Cyprinus carpio	0.2-0.8

Source: Varga and Chowdhury, 1992.

Eutrophication and effect of pollutants:

Existing environmental problems for lakes and streams could be exacerbated by climate change. In India, majority of the wetlands located in Assam, West Bengal and Bihar are in various stages of eutrophication (Das, 2007). Increases in more intense rain events and winter rain events should increase runoff and increase external loading (increasing apparent eutrophication); reduction in precipitation should reduce runoff and reduce external phosphorus loading (decreasing apparent eutrophication). Global warming leads to increase in anthropogenic pollution. The relative toxicity of a typical pollutant in water such as the heavy metal copper is found to be temperature dependent.

Impact on inland fisheries

River Ganga

Breeding and recruitment of fish:

The fish spawn availability index declined from 2984ml in the 1960s to 27ml in recent years (1994 to 2004) (Natarajan 1989; CIFRI Annual Report-1971-2004). It also showed a continuing deterioration of Indian major carps seed with decreasing percentage of major carp seed (78.62% in 1961-1965 to 34.48% in 2000-04) where as minor carps (from 20.68% in 1961-65 to 52.95% in 1991 to 1995) and other fish seed (from 0.7% in 1961-65 to 47.8% in 2000-04) showed an increasing percentage in the total seed collection.

Majority of fishes of the Ganga river system breed during the monsoon months i.e. June to August because of their dependence on seasonal floods, which inundate the Gangetic floodplain areas essentially needed for reproduction and feeding. The monthly data from the middle stretch of the river at Allahabad from 1974 - 2003 (Fig. 1) revealed that the percentage of total rainfall in the peak breeding period (May- Aug.) declined by 5% whereas it increased by 7% in the post- breeding period when resorption of eggs of Indian Major Carps sets in.

This shift and decrease in the rainfall pattern resulting in the alteration of the required flow and turbidity during breeding season is a major factor responsible for failure in breeding and consequent recruitment of young ones of Indian major carps in the river Ganga.

Predator–prey relationship:

Clearly, any effect of climate warming on the top predators will depend on prey availability and prey fish population. One of the more suitable effects of changes in the thermal structure of an aquatic ecosystem is the impact on the prey densities.

Climate warming may produce a large volume of thermal habitat for the fish and if the same number of prey is distributed across this large volume of habitat, prey densities encountered by a predator would be reduced. Reduced prey densities would reduce the predator encounter rate with prey, which would reduce predator consumption rate.

Predator (large cat fish) and prey (miscellaneous groups of fish and prawns) ratio in middle stretch (Buxar) and lower stretch (Bhagalpur) has markedly narrowed down from 1:4.2 to 1:1.4 and 1:2.3 to 1:0.9 respectively in four decades (1958-1997) Vass *et al*., 2009.

Geographic distribution of fish:

Temperature has long been a focus of biogeographic studies because of its overwhelming influence on the physiology of exothermic organisms (Hutchins, 1947). Because fish are exothermic organisms, their survival, growth, egg development and even competitive ability all are temperature dependent. Biogeographic distributions often provide insight into thermal limits for ectotherms such as fish whose physiology and reproductive success are strongly influenced by temperature. These thermal limits can be used to project distributional changes following climate change by assuming fish will migrate along isotherms to remain within a suitable thermal envelope (Rahel, 2002). With this background the distributional pattern of fishes and plankton of river Ganga were analysed from the published records available.

There is a perceptible shift in geographic distribution of the fishes of river Ganga. The warm water fish species *Glossogobius giuris, Puntius ticto, Xenentodon cancila* and *Mystus vittatus,* earlier available only in the middle stretch of river Ganga, are now available in the colder stretch of the river around Haridwar where they were never reported (Menon, 1954). In the Haridwar stretch, the annual mean minimum water temperature was 12.9°C from 1970 to 1986, while it was l4.5°C from 1987 to 2003. This increase of 1.5°C temperatures, the stretch of river Ganga around Haridwar has become a congenial habitat for these warm water fishes.

At Karnal, Haryana the average minimum water temperature during winters is 4 to 8.5°C and the maximum is 15 to 20°C. During December to January, 2006, this was warmer (minimum temperature was 5.1 to 8.9°C and maximum temperature was 17.3 to 21.4°C). In this warmer year, Mahseer *(Tor putitora)* descended for the first time upto Karnal, although it formed only a small population (l to 1.4%) of the total fish population. This descending run in river Jamuna upto Kamal may have been to avoid lower temperatures in the upland. The normal preferred temperature of the fish species is 15 to 28°C.

Geographic distribution of plankton:

At present, in the colder stretch of Haridwar and above, some of the stenothermal genera of phytoplanktons like *Amphicampus, Tetracycles, Diatoma* and *Ceratoneus,* which predominantly inhabit the cold mountainous waters, have become insignificant. With the increase in the annual mean minimum water temperature by 1.6°C, depletion of these stenothermal phytoplankton has occurred.

Influence of climate change on fish species richness in Indian Rivers:

Variations in freshwater fish species richness were analysed in 14 major rivers of India with a macro ecological approach to identify predictors of freshwater fish species richness in rivers of India under climate change scenarios. The rivers selected for study were distributed in four climatic zones of India lying to the north of the equator between 8°4' and 37°6' north latitude and 68°7' and 97°25' east longitude. Data available in published literature on the nine parameters of 14 rivers for the years (1994-2007) viz., fish species richness, mean annual water temperature, temperature range, annual rainfall in the area, annual discharge, sediment load, total surface area of drainage basin, mean weighted latitude were compiled. Linear relationships among variables were studied and the best possible combination of exposures for species richness was determined by regression method. Average residual values of fish species richness plotted against climatic zones and were analyzed. The river fish species richness was found significantly co-related with four variables among which three independent significant variables (river discharge, rainfall and surface area of the drainage basin) together explained 73.3% of the total variability, in species richness. The data and analyses presented here lead to the conclusion that climatic variable rainfall and to a lesser extent, river discharge and surface area of the drainage basin, are the most important factors influencing fish species richness patterns in rivers of India.

Aquaculture in gangetic plains

Inland aquaculture is centered around the Indian major carps (IMC), *C. catla, L. rohita and C. mrigala*. These fishes are bred in captivity by the technique of hypophysation and their spawning occurs during the monsoon season (June-July) and extends till September. In recent years the phenomenon of IMC maturing and spawning as early as March is observed, Temperature is one of the important factors influencing the reproductive cycle in fishes. This climatic factor along with rainfall and photoperiod stimulate the endocrine glands which help in the maturation of the gonads of Indian major carp. In West Bengal, the average temperature is on the rise over the last 60 years. The average minimum and maximum temperature throughout the state has increased in the range of 0.1 to 0.9ºC and rainfall pattern has changed. Investigations conducted by Dey *et al.* (2007) indicate an extended breeding period of Indian major carps by 45-60days with breeding season extending from 110-120 days (Pre1980-85) to 160-170 days (2000-2005) at present in fifty fish seed hatcheries in four districts of West Bengal, India *viz*. North 24 Parganas, Bankura, Burdwan & Hooghly (Fig.4). Interactive response with hatchery operatives and fishers indicate that 90-95% assigned water temperature rise as the main reason for advancement of breeding period in hatchery farms with 90% reasoning to demand and high sell price which is obtained from fish culturists when spawn is available as early as April.

Impact on fish

Reproductive integrity:

All the stages of reproduction in fish viz., gametogenesis and gamete maturation, ovulation/spermiation, spawning and early development stages are affected by temperature. Imbalance or rapid change in temperature are stressful to fish and may also be linked with other stressors. If stress is maintained, then the effects start manifesting by the inhibition of reproductive function, cessation of ovulation, depression of reproductive hormones in blood and ovarian failure. Temperature change modulates the hormone action at all levels of reproductive endocrine cascade. Investigation was conducted on *C. carpio* subjected to enhanced temperature. The optimum range of the fish is 15-32ºC and its upper critical range 30-41ºC. It spawns optimally in the range of 12-30ºC. Mature female *C. carpio* fishes were subjected to an enhanced temperature of 34ºC to study the effect on the reproductive integrity of the fish. A decrease in the Gonado somatic index occurred. There was accumulation of liver and ovarian cholesterol as a result depletion of the hormone estradiol was evident. Histology of the ovary of *C. carpio* exhibited impaired vitellogenesis in oocytes. Failure of incorporation of vitellogenin due to increased temperature (which is mainly responsible for increase in gonadal weight) has resulted in lower GSI and estradiol level in serum. (Das *et al.,* 2008).

Growth of fish

Water temperature strongly affects metabolism, consumption, growth fish behaviour, habitat selection, spawning, foraging, and predator-prey interaction. Previous work has shown that the growth rate potential provides a good measure of habitat quality (Tyler and Brandt, 2001) and effectively incorporates biotic and abiotic characteristics of the environment in a metric that directly relates to the fitness of fish (Brandt & Kirsch 1993; Mason *et al.,* 1995).

Investigations were conducted to assess the impact on the growth of Indian Major Carp, *Labeo rohita* fingerlings reared simulating temperature rise in tropical countries like India in seven thermostatic aquarium for five weeks at water temperature of 29ºC, 30ºC, 31ºC, 32ºC, 33ºC, 34ºC and 35ºC. Fish reared at 34ºC water temperature exhibited a significantly ($P<0.05$) faster growth (SGR-2.36% body weight per day) than those at other temperatures. The change in growth rates were insignificant between 29ºC, 30ºC, 31ºC and 32ºC treatment groups but growth rates significantly increased in the temperatures ranging from 32ºC to 34ºC and there after it decreased. A linear growth model of *Labeo rohita* fingerlings growth has been developed using the data generated. This simple growth model provides a reliable projection of growth (SGR %) with unit rise of temperature within the range of 29º to 34ºC (CIFRI, 2008).

Fish health

Fluctuating temperature very often disturb the homeostasis of fish and subject them to physiological stress and shift in habitat or mortality. In the climate warming scenario fishes will be subjected to the hazard of rapid temperature changes. It is more so in the tropical waters where daily variations in water temperature and thermocline in deep water bodies will assume significance. These effects would often become additive or synergistic with those of other adverse (e.g. low pH, algae, oxygen shortage). It is essential to understand that these temperatures change though sublethal, can place a stress of considerable magnitude on the homeostatic mechanism of fishes at the primary, secondary and tertiary level.

High temperature

Investigations were conducted by Das *et. al*, 2002 on the alteration occurring in the levels of various stress sensitive blood and tissue parameters of the fish *L.rohita* and *Rita rita*, acclimatized at 29°C and subjected to a rapid sublethal rise to 35°C and then maintained at this temperature.

The results indicated that the homeostatic mechanism of the fish is stressed. The changes evident were hypercholesterolemia indicating impaired sterol mechanism, hyperglycemia and decreased blood sugar regulatory mechanism. Pituitary activation as evidenced by interrenal ascorbic acid depletion and cortisol elevation is pronounced. Oxygen consumption in both the fishes increased as judged by increased haemoglobin. Simultaneously, it is observed that compensatory responses were initiated in the fishes within 72 hrs. Obviously adaptation to the stress of elevated temperature occurs. But if the sresss of enhanced temperature is of chronic nature as in a climate warming scenario then the tolerance limits woud be exceeded in fishes.

Vulnerability and adaptation of inland fisheries to climate change

Vulnerability assessment

The extent to which people and systems are affected by climate change (their vulnerability) is determined by three factors; their exposure to specific change, their sensitivity to that change, and their ability to respond to impacts or take advantage of opportunities.

Many comparative studies have noted that the poor and marginalized have historically been most at risk from natural hazards and that this vulnerability will be amplified by climatic changes (IPCC, 2007). Poorer households are, for example, forced to live in higher risk areas, exposing them to the impacts of coastal flooding and have less capacity to cope with reduced yields in subsistence fisheries. Women are differentially at risk from many elements of weather related hazards, including, for example, the burden of work in recovery of home and livelihood after a catastrophic event. A recent study conducted under the NPCC project in 17 districts of West Bengal to assess the vulnerability of fisheries to climate change revealed that the districts of 24 Parganas (S) (VI- 0.61), Murshidabad, (VI-0.55), 24 Parganas (N) (VI- 0.54), Nadia, (VI-0.52) and East Midnapore, (VI-0.51) were most vulnerable as indicated by the vulnerability index (VI) since their exposure to extreme climatic events was frequent and the adaptive capacity of people was less. Whereas some of the districts like Dinajpur (S) (VI 0.31) and Purulia (VI0.32) are less vulnerable due to less exposure to floods or storms. (CIFRI, 2009)

Adaptation options for inland fisheries in India

Enhanced water temperature: In the fish culture system, enhanced water temperature will decrease the dissolved oxygen content in water. Water holds less oxygen at higher temperature as such fish require more oxygen as temperature rises. Increased growth and food conversion and enhanced breeding period in hatcheries will occur along with increased disease incidence. Operationally, there will be changes in the level of production with increase in the fish production cost.

Adaptation Options*:* The Indian Major Carps cultured in India maintain their normal metabolic activities upto 34^0C. Beyond this temperature growth and food conversion is affected. Since low oxygen is a problem with enhanced temperature substitution with low oxygen tolerant species like catfishes in the culture system is essential. Though Indian major carps and the exotic carps *Cyprinus carpio* cultured in India are tolerant to low oxygen conditions (Varga and Chowdhury, 1992) they remain stressed physiologically (Dutta *et. al.*, 2005).

Floods: Fish culture facilities will be impacted by damage to the facilities, loss of fish stock and introduction of fish predators and disease germs. Operational cost of the facilities will increase.

Adaptations options: To offset the loss of fish due to recurrent floods, provision for continuous supply of seed from fish hatcheries is required. Management practice should emphasize harvesting of fish at smaller size and selection of fish species that require short culture period with minimum expenditure on inputs.

***Drought*:** The impact on the culture system will reflect in reduced water quality and limitation in the culturable water area and volume. As a result there will be loss in fish production.

Adaptation options: Smaller ponds that retain water for 2-4 months can be used for fish production with fish species like catfish and appropriate management practices.

Cyclones and storms: Inundation , flooding and salinity changes occur in the fish culture facilities resulting in the loss of fish/prawn stock and introduction of predators. Operationally, damage to the facilities occurs with financial loss.

Adaptation options: An the early warning systems of weather events is essential to cope up with post cyclone management. It is essential to optimally utilize the normal culture periods and maximize fish production and profit by selecting suitable fish species and appropriate cultural practices.

Water stress: In the coming years availability of water will be a major constraint for aquaculture considering its varied users. Impacts on the fish culture facilities will manifest through decrease in water quality, increased diseases, reduced pond level and altered and reduced freshwater supply. Operationally cost of maintaining pond level artificially increases along with conflict with other water users. Reduced production capacity will occur.

Adaptation options: Aquaculture should be integrated with other farming system for many fold use and reuse of water areas. Integrating aquaculture with other practices,including agro-aquaculture, and culture-based fisheries, also offers the possibility of recycling nutrients and using energy and water much more efficiently. Short-cycle aquaculture may also be valuable, using new species or strains and new technologies or management practices to fit into seasonal opportunities. Aquaculture could be a useful adaptation option for other sectors, such as coastal agriculture under salinization threats. As is evident from the work conducted under the NPCC project during post AIYLA period in Sunderban area of West Bengal The resource of waste water and degraded water should be extensively used with modified aquaculture practices. Smaller seasonal type ponds of (1-4) months can be used for rearing of appropriate species of fish/ prawn. Increasing infrastructure sophistication of hatcheries for assured seed production of 34,000 million carp fry, 8000 and 10000 million scampi and shrimp PL respectively (Das *et al.,* 2008, 2009)

Human adaptation to changes in climate

Negative impacts on Aquatic ecosystems an fisheries can be further aggravated by human adaptation to changes in climate. For adaptation to the increased demand for water for irrigation, the supply side option aims at increasing supply. Increasing the water source for irrigation is expensive and has the potential environmental impacts. The demand side options aim at reducing demand. They include increasing irrigation efficiency through improved technology and higher prices for water, and changes in cropping pattern by switching to crops that require less or even no irrigation. For flood management, supply side options include increasing flood protection with levees and reservoir; these are expensive and have potential environmental impacts. Demand side options include improvement in flood warning systems and information and to curb floodplain development. So, a variety of options are available; influences on fish and fisheries depend on the details of such choices. The demand side options in most cases, would appear to be better choices for those interested in fish and fisheries.

CONCLUSION

Development of a unified strategy for offsetting the impact of climate change in the need of the hour. Therefore a common framework should be created at the country level that can be used towards implementing the integrated watershed management strategy starting from Gram Panchayat (village council) to the river-basin level in a unified manner. Integrated watershed management does not merely imply the amalgamation of different activities to be undertaken within a hydrological unit. It also requires the collection of relevant information, so as to evaluate the cause and effect of all the proposed actions. This framework will need regular maintenance and updating to fully reflect the most accurate ground truth data. Local planning and management strategies have to be evolved and validated through the proposed framework, so as to generate and evaluate various options suitable for local conditions. This would greatly help inland fisheries development in future.

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Table 1: Comparison of change in Water Balance Components runoff and actual evapotranspiration (ET) as percentage of rainfall in controlled and increased greenhouse gas (GHG) scenarios (Source: IINC, Ministry of Environment and Forest, 2004).

Basins	Scenario	Rainfall (mm)	Run off (mm)	As a proportion of Rain fall (%)	Actual ET (mm)	As a proportion of rain fall (%)
Cauvery	Control	1309.0	661.2	50.5	601.6	46.0
	GHG	1344.0	650.4	48.4	646.8	48.1
Brahmani	Control	1384.8	711.5	51.4	628.8	45.4
	GHG	1633.7	886.1	54.2	698.8	42.8
Godavari	Control	1292.8	622.8	48.2	624.1	48.3
	GHG	1368.6	691.5	50.5	628.3	45.9
Krishna	Control	1013.0	393.6	38.9	585.0	57.7
	GHG	954.4	346.9	36.4	575.6	60.3
Luni	Control	317.3	15.5	4.9	316.5	99.7
	GHG	195.3	6.6	3.4	207.3	106.1
Mahanadi	Control	1269.5	612.3	48.2	613.5	48.3
	GHG	1505.3	784.0	52.1	674.1	44.8
Mahi	Control	655.1	133.9	20.4	501.0	76.5
	GHG	539.3	100.0	18.5	422.7	78.4
Narmada	Control	973.5	353.4	36.3	586.8	60.3
	GHG	949.8	359.4	37.8	556.6	58.6
Pennar	Control	723.2	148.6	20.6	556.7	77.0
	GHG	676.2	110.2	16.3	551.7	81.6
Tapi	Control	928.6	311.2	33.5	587.9	63.3
	GHG	884.2	324.9	36.7	529.3	59.9
Ganga	Control	1126.9	495.4	44.0	535.0	47.5
	GHG	1249.6	554.6	44.4	587.2	47.0
Sabarmati	Control	499.4	57.0	11.4	433.1	86.7
	GHG	303.0	16.6	5.5	286.0	94.4

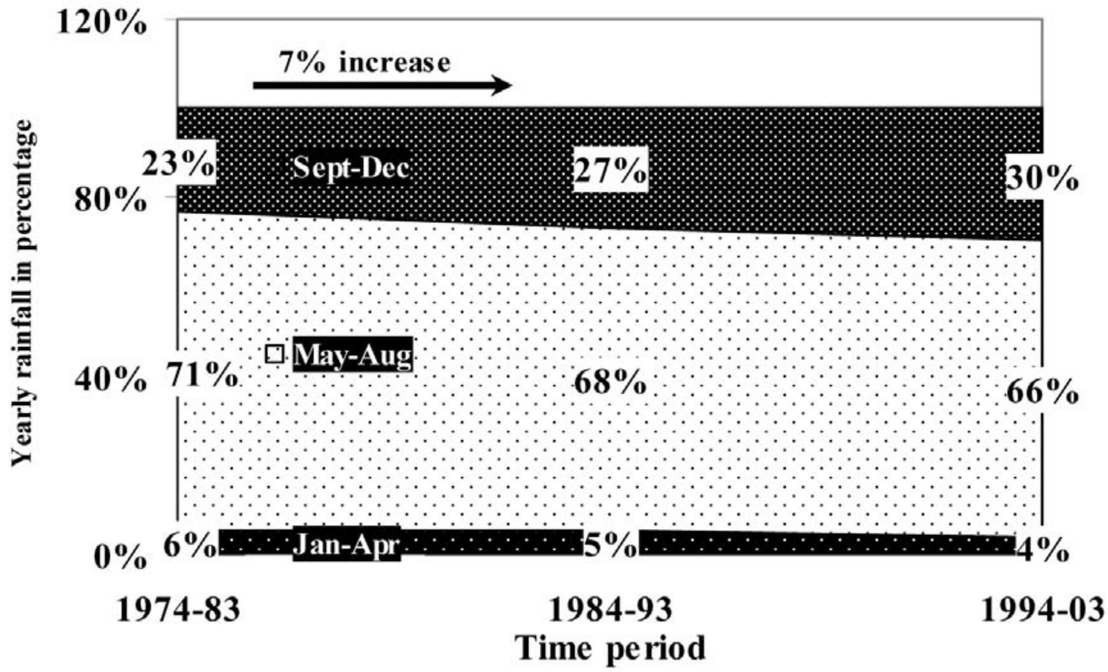

Fig. 1. Shifting seasonal patterns of rainfall at Allahbad during 1974 to 2003. (Source -Das and Saha, 2008)

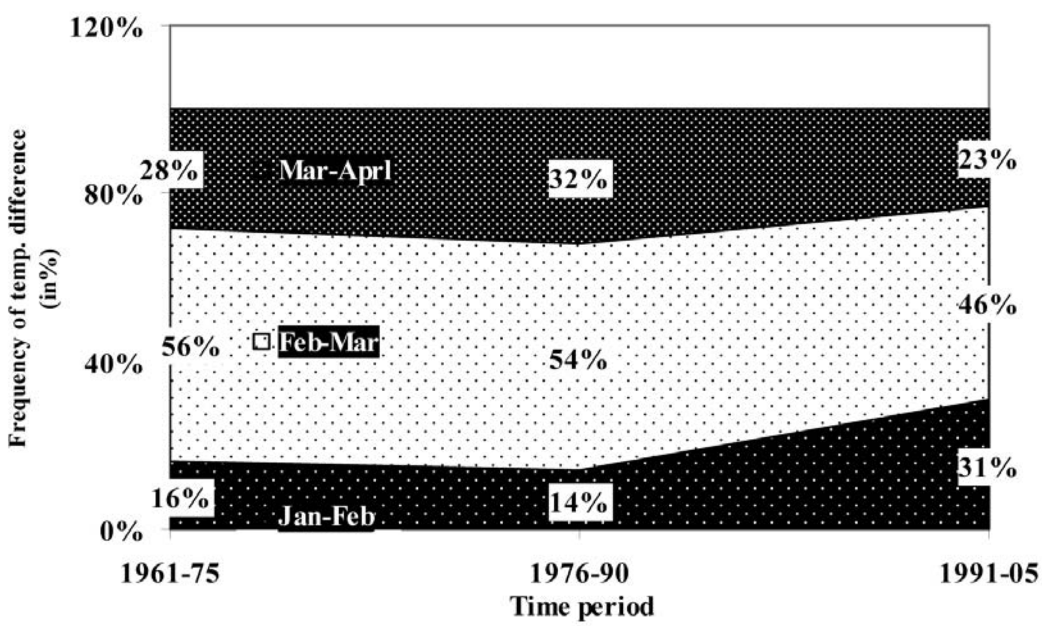

Fig. 2. Shift of temperature differences at 24 Parganas (N) during 1961 to 2005. (Source: Das and Saha, 2008)

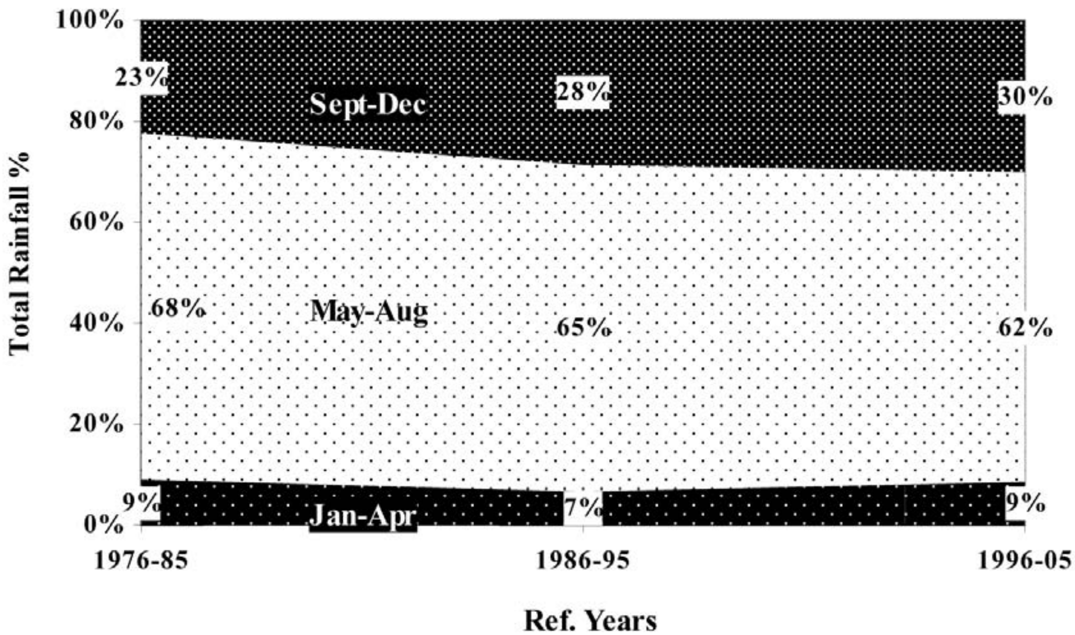

Fig. 3. Rainfall pattern at Dum Dum during 1976 to 2005.
(Source Das and Saha, 2008)

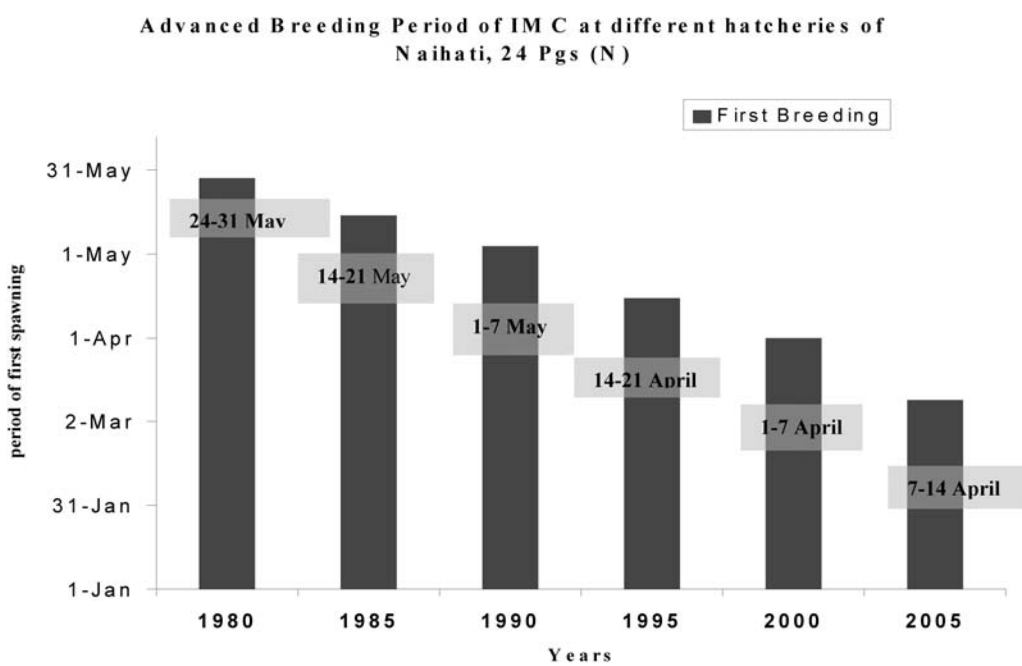

Fig. 4. Advanced Breedimg Period of IMC at different hatcheries of Naihati, 24 pgn (N)

Technical Session V

Social and Economic Impacts, Risk Management and Policy Issues

Agromet Advisory Services in India for Enabling Farmers to Cope up with Climate Variability and Climate Change

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INTRODUCTION

Climate change is a threat to mankind. Since the end of the 19th century the earth's average surface temperature has increased by 0.3-0.6 ^{0}C. Over the last 40 years, the rise has been 0.2-0.3^{0}C. Recent years have been the warmest since 1860, the year when regular instrumental records became available. The potential impact on the global climate of increasing atmospheric concentrations of carbon dioxide (CO_2) and so called green house gases is now well documented. Many studies of climate change have shown that the Earth's atmosphere is being modified by anthropogenic and biogenic emission of carbon dioxide and other radiatively active gases. According to Raper *et al.* (1996), the most likely rate of future global warming over the period 1900-2100 due to combined human modification of the atmosphere is estimated to be between 0.1^{0}C and 0.3^{0}C decade-^{1} several times the mean rate of warming over the past 100 years.

Global and regional weather conditions are also expected to become more variable than at present, with increases in the frequency and severity of extreme events such as cyclones, floods, hailstorms, and droughts. Changes in temperature and precipitation associated with continued emissions of greenhouse gases will bring changes in land suitability and crop yields. The Fourth Assessment Report of Intergovernmental Panel on Climate Change (IPCC) (2007) concluded that 'there is high confidence that recent regional changes in temperature have had discernible impacts on many physical and biological systems'. Climate change affects agriculture and food production in complex ways. It affects food production directly through changes in agro-ecological conditions and indirectly by affecting growth and distribution of incomes, and thus demand for agricultural produce. By bringing greater fluctuations in crop yields and local food supplies and higher risks of landslides and erosion damage, they can adversely affect the stability of food supplies and thus food security. The importance of the various dimensions and the overall impact of climate change on food security will differ across regions and over time and most importantly, will depend on the overall socio-economic status that a country has accomplished as the effects of climate change set in.

Indian agriculture and its linkage to weather

Agriculture represents a core part of the Indian economy and provides food and livelihood activities of the Indian population. Climate induced vulnerability of agriculture cause plateau in agriculture productivity in the country. Wide variation of rainfall and temperature not only affect the crops in *kharif* season, but the effects are also being manifested on *rabi* crops in winter season. As per the FAO & IPCC assessment, agricultural productivity in India would be reduced substantially in future [2020 (2.5 to 10%), 2050 (5 to 30%)]. While the magnitude of impact of climate variability and climate change varies greatly by region, climate change is expected to impact on agricultural productivity and shifting crop patterns. Study of the multi-decadal changes considering the data of past 50 years in break days during monsoon season in the country show that numbers of break days are more (Table.1) in July as compared to August.

Table 1. Data of past 50 years show that number of break days are more in July as compared to August

Period	Number of break days during					
	July			August		
	01-10	11-20	21-31	1-10	11-20	21-31
1888-1917	46	49	53	43	84	26
1918-1947	14	36	21	55	54	25
1948-1977	22	44	64	21	33	41
1978-2003	23	32	39	6	14	37

Heat / cold wave, more variable rainfall, increased extremes weather events, erratic onset, advance and retrieval of monsoon, shift in active/break cycles, intensity and frequency of monsoon systems often affect the agricultural production in the country. Crops have to cope with increased variability of weather, extreme events, and changing climate patterns throughout the growing season. Agriculture may learn to adapt to climate change but climate variability needs to be combated. The frequency of occurrence of extreme climate conditions dictates the response of agriculture to climate variability/change**.**

Signals of climate change in India based on historic data

Global temperature has increased by 0.15 to 0.3^{0}C decade^{-1} for 1990 to 2005. Next two decades, warming of 0.2^{0}C decade^{-1} is also projected. Indian scenario is not different. Climate change studies for India with respect to temperature and rainfall have already been made by a number of workers. Studies show that Indian temperatures are steadily increasing and mean annual temperature has increased by about 0.4^{0}C in India during the past century. In general, it can be mentioned that an increasing trend in temperature has observed in Southern and Central India in the post monsoon season. The warming is generally been accompanied by increased diuranality. As per the study of Das and Hunt (2007) frequency of intense rainfall events has increased over past 53 years. Extreme rainfall events also increased over the west coast of India (based on analysis of 100 years of data; 1901-2000). In spite of general increase in temperature over recent decades, there has been decreasing trend in Pan Evapotranspiration (Ep) in almost all the parts of India particularly significant in premonsoon and monsoon season (Chattoadhyay and Hulme, 1997). Seasonal and spatial pattern of changes in Potential Evapotranspiration (PE) are similar to those for Ep, but magnitude of changes is less. In monsoon and post monsoon seasons, PE has decreased over the whole country whereas in the winter and pre-monsoon season the trend had fewer consistences.

Projection of climate change in India

Using a number of Global Circulation Models, different scenarios have been generated for the future climate change in India. It has been projected that average surface temperature will increase by 2 - 4°C during 2050s, marginal changes in monsoon rain in monsoon months (June, July, August and Septeber) and large changes of rainfall during non-monsoon months. Number of rainy days set to decrease by more than 15 days and intensity of rains to increase by 1-4 mm/day. The increase in frequency and intensity of cyclonic storms is projected. The hydrological cycle is predicted to be more intense, with higher annual average rainfall as well as increased drought (Bhattacharya, 2006). These projections showed more warming in winter season over summer monsoon. In case of rainfall, a marginal increase of 7 to 10 per cent in annual rainfall is projected over the subcontinent by the year 2080. However, the study suggests a fall in rainfall by 5 to 25% in winter while it would be 10 to 15 % increase in summer monsoon rainfall over the country.

Future changes in PE over India and adjoining countries will increase in all the global climate models. In the winter seasons, all the models show increasing trend in PE over southern and Central India up to around 25^0N. In most of the model experiments, maximum winter increased in PE is of the order of 3-4% per degree Celsius of global warming and is seen in peninsular and most central parts of India. In the monsoon season maximum increased in PE over northwestern India. Inter relationship between PE and rainfall was assessed by mapping the number of GCM experiments which yield and increased the P/PE ratio for the monsoon season. A number of GCMs agree that P/PE ratio becomes more favorable over northeastern India and changes in this ratio are less favorable in post monsoon season and in the extreme south in the country (Chattopadhyay and Hulme 1997).

Impact of climate change on agriculture

India, located in south central Asia, has great economic dependence on agriculture. A likely impact of climate change on agricultural productivity in India is causing great concern to the scientists and planners as it can hinder their attempts for achieving household food security. Any major changes in water budget and change in temperature have major consequence in hydrologic processes and agriculture and in turn economy of the country. The potential effect of climate change on agriculture in India would be the shift in the sowing time and length of growing season which would ultimately alter planting and harvesting dates of crops and varieties currently use in a particular areas. With warmer temperatures, evapotranspiration rates would rise, which would call for much greater efficiency of water use. Also weeds and insect pests could sift.

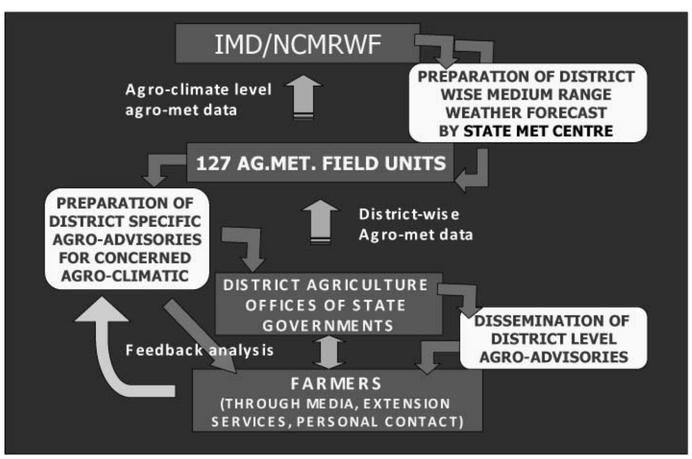
As per the findings in the AR4 of the IPCC, Working Groups I, II and III, there will be decrease up to 30% in south and central Asia by 2050. Increased temperature is likely to reduce the wheat production particularly in north India. Decrease in yield of crops would be due to the temperature increase in different parts of India Major impacts of climate change will be on rainfed crops (other than rice and wheat), which account for nearly 60% of cropland area. In India, poorest farmers practice rainfed agriculture. The study found that increase in temperature (by about 2^0C) reduced potential grain yields in most places. Regions with higher potential productivity (such as northern India) were relatively less impacted by climate change than areas with lower potential productivity (the reduction in yields was much smaller). Climate change is also predicted to lead to boundary changes in areas suitable for growing certain crops. Reduction in yields as a result of climate change are predicted to be more pronounced for rainfed crops (as opposed to irrigated crops) and under limited water supply situations because there are no coping mechanisms for rainfall variability. Different studies indicate that the yield of wheat, mustard, barley and chickpea show sign of stagnation or decrease following rise in temperature at all the four northern states. However, the extent of decrease was different for crops as well as theie locations.

Adaptation to climate variability and climate change through Agromet Advisory Service

Adaptation can be defined as any action that seeks to reduce the negative effects of climate change. Several adaptation measures are available to reduce vulnerability to climate change by enhancing adaptive capacity and increasing resilience. There is a considerable scope for decreasing the vulnerability of agriculture to increasing weather and climatic variability and climate change through weather forecast based agro-advisories. India Meteorological Department (IMD), Ministry of Earth Sciences (MoES), is operating an integrated Agro-Meteorological Advisory Service (AAS) at district level, in India, which represents a small step towards agriculture management in rhythm with weather and climate variability leading to weather proofing for farm production. Under AAS, needs of farming community was defined through ascertaining information requirement of diverse groups of end-users. It emerged that, prime need of the farmer is location specific weather forecast in quantitative terms. Hence, the same was developed and made operational in June, 2008. Thereafter, mechanism was developed to integrated weather forecast and climatic information along with agro-meteorological information to prepare district level agro-advisories outlining the farm management actions to harness favorable weather and mitigate impacts of adverse weather. A system has also been developed to communicate and disseminate the agro-meteorological advisories to strengthen the information out reach. The institutional dissemination channels such as farmer association, non-governmental organizations (NGOs), input suppliers, progressive farmers are also employed.

Weather forecasting system for agromet advisory service

IMD has started issuing quantitative district level (612 districts) weather forecast up to 5 days since 1st June, 2008. The products comprise of quantitative forecasts for 7 weather parameters viz., rainfall, maximum temperature, minimum temperatures, wind speed, wind direction, relative humidity and cloudiness. In addition, weekly cumulative rainfall forecast is also provided. IMD, New Delhi generates these products using Multi Model Ensemble technique based on forecast products available from number models of India and other countries. These include: T-254 model of NCMRWF, T-799 model of European Centre for Medium Range Weather Forecasting (ECMWF); United Kingdom Met Office (UKMO), National Centre for Environmental Prediction (NCEP), USA and Japan Meteorological Agency (JMA). The products are disseminated to Regional Meteorological Centres and Meteorological Centres of IMD located in different states. These offices undertake value addition to these products using synoptic interpretation of model out put and communicate to 130 AgroMet Field Units (AMFUs), located with State Agriculture Universities (SAUs), institutes of Indian Council of Agriculture Research (ICAR) etc., on every Tuesday and Thursday.



District Level Agro-Met Advisory Service System

Translating forecast into crop advisories

Application of weather forecast to generate crop advisories is linked to accuracy, spatial domain of validity and temporal range. In view of these requirements of farming community, district level forecasts are issued for above listed parameters for next 5 days and same are translated into crop specific advisories keeping in view their phenological stages for farmer's guidance on cultural practices.

District-specific medium-term forecast information and advisories help maximize output and avert crop damage or loss. It also helps growers anticipate and plan for chemical applications, irrigation scheduling, disease and pest outbreaks and many more weather related agriculture-specific operations. Such operation include cultivar selection, their dates of sowing/planting/transplanting, dates of intercultural operations, dates of harvesting and also performing post harvest operations. Agromet advisories help increase profits by consistently delivering actionable weather information, analysis and decision support for farming situations such as: to manage pests through forecast of relative humidity, temperature and wind; manage irrigation through rainfall and temperature forecasts; protect crop from thermal stress through forecasting of extreme temperature conditions etc.

Under the AAS system, more focus has been started to be given to use the crop/soil simulation models to decide crop management strategies, for the given weather condition. Agricultural scientists at Agrometeorological Field Units have started using crop simulation models as a decision support tool for helping with weather forecast based farm management decision making as they are more objective. For example, the Agro-meteorological Field unit can objectively assess the impact of skipping irrigation at a particular phenophase of a crop on its dry matter yield though with some uncertainties. Agrometeorologists can consider many of the factors involved, and answer the question with a reasonable estimate. The crop models are also be used as technique for prediction of different phenophases and final yield.

Agro-meteorological support for farm management

Weather based farm advisories as support system has been organized after characterization of agro-climate, including length of crop growing period, moisture availability period, distribution of rainfall and evaporative demand of the regions, weather requirements of cultivars and weather sensitivity of farm input applications. All this is used as background information. Following are the ingredients of a typical Agromet Advisory Bulletin to reap benefits of benevolent weather and minimize or mitigate the impacts of adverse weather;

i) District specific weather forecast, in quantitative terms, for next 5 days for rainfall, cloud, max/min temperature, wind speed/direction and relative humidity, including forewarning of hazardous weather event likely to cause stress on standing crop and suggestions to protect the crop from them.

ii) Weather forecast based information on soil moisture status and guidance for application of irrigation, fertilizer and herbicides etc.

iii) The advisories on dates of sowing/planting and suitability of carrying out intercultural operations covering the entire crop spectrum from pre-sowing to post harvest to guide farmer in his day–today cultural operations.

iv) Weather forecast based forewarning system for major pests and diseases of principal crops and advises on plant protection measures.

v) Propagation of techniques for manipulation of crop's microclimate e.g. shading, mulching, other surface modification, shelter belt, frost protection etc., to protect crops under stressed conditions.

vi) Reducing contribution of agricultural production system to global warming and environment degradation through judicious management of land, water and farm inputs, particularly pesticides, herbicides and fertilizers.

vii) Advisory for livestock on health, shelter and nutrition.

The support on above is rendered through preparing district specific agrometeorological advisory bulletins which are tailored to meet the farmers' need and are made relevant to his decision making processes. The suggested advisories generally alter actions in a way that improves outcomes. It contains advice on farm management actions aiming to take advantage of good weather and mitigate the stress on crop/ livestock. Hence, while formulating the bulletin one ought to know the crop condition. Ideally, farmer should place request to the AMFU/IMD either directly or via the extension officer. But more often than not, such information has to be assessed through field observation, media reports, farmers' feedback, and remote sensing (NDVI etc) observations. The desired information is also obtained by exploratory surveys or participatory methods of personal interactions with farmers. The critical issues in this regard as summarized by Hansen (2002) are followed and include: a) site specificity – that farmers are aware of spatial variability and can recognize scale mismatches between the forecasts and their on farm decisions; b) temporal specificity – including timing relative to decisions and impacts, highlighting factors such as onset of rainfall, dry spell distribution, and weather conditions during harvest; and, c) skill of the forecast – often in different terms from the forecasters but relative to the other risks within their farming operations.

The bulletins are encoded in a format and language which is easy to comprehend by the farmer. The agrometeorologists first interpret the immediate past weather and the forecast for next 5 days and translate it into layman's terms so that the farmers can understand it. Thus, the agrometeorologists play a vital role in the encoding and decoding of the messages from the meteorologists to the agricultural sector. Also, interaction between the AMFUs and farmers to identify the weather sensitive decisions is promoted under the service. This step enables a relationship between the IMD, AMFUs, and the farmers so that they can identify or diagnose the gaps in weather information available from the IMD. As the interaction between the weather and agriculture is complex, it is not just a case of applying a simple solution and expecting implementation by the farmers. So, an awareness process to understand the influence of weather and climate on sustainable agricultural production as outlined by Sivakumar, *et al.*, (2000) is followed.

Dissemination of agrometeorological bulletins

The task of AAS is to provide information to help farmers make the best possible use of weather and climate resources. While disseminating the information, it is presumed that the farmers possess relevant knowledge and skills. Although concerted efforts are being made to set up two way communications, but as of now the information flow is largely one-way. As agro-meteorologists at Agrometeorological Field Units (AMFUs) have less frequent interaction with the farmers, good communication and working relationships have been set up with the agricultural extension, Krishi Vigyan Kendra (Agriculture Science Centres), Kisan (Farmer) Call Centre etc., to promote participatory methods for interactions with farmers. Due care is being taken regarding content of the message which must be relevant to the weather based decision making by the farmer. This involves the identification of weather & climate sensitive decisions and interactions between the weather forecasters from meteorological Centres of IMD and the agriculture scientists from Agriculture Universities and/ or Institutes of Indian Council of Agriculture Research to develop weather based advisories and technological. Information is disseminated through multi-modes of delivery including mass and electronic media. It include, All India Radio, Television, Print Media (local news paper in different vernacular languages), internet (Web Pages) as well as group and individual relationships through email, telephone etc. The use of electronic media such as e-mail or the Internet is picking up as the access of these methods to the farming community is on significant rise. The agrometeorological bulletins always contain dynamic information hence, repetitive dissemination is being made. This reiterative process also helps to address large temporal and spatial variability having significant influence of weather & climate on agriculture. Critical factors for successful dissemination include relevance of information to weather & climate sensitive decision making in agriculture, followed by good outreach.

Based on the climatic variability and climate trends specific information are being communicated to the farmers of the country through agromet service. Based on this inputs farmers can adopt coping mechanisms that withstand climate variability through activities such as the use of drought-resistant or salt-resistant crop varieties, the more efficient use of water resources and improved pest management. Adjustments may include the introduction of late-maturing crop varieties, switching cropping sequences, sowing earlier, adjusting timing of field operations, conserving soil moisture through appropriate tillage methods and improving irrigation efficiency. Options such as switching crop varieties might not be expensive while others such as irrigation entail major investments. Changes in cultivation patterns can include the reduction of fertiliser use, better management of crop production, improvement of livestock diets and better management of their manure. In areas of recurring drought, one of the best strategies for alleviating drought is varietal manipulation, through which drought can be avoided or its effects can be minimised by adopting varieties that are drought-resistant at different growth stages. If drought occurs during the middle of a growing season, corrective measures can be adopted; these vary from reducing plant population to fertilisation or weed management. Rainfall can be harvested in either farm ponds or in village tanks and can be recycled as lifesaving irrigation during a prolonged dry spell. The remaining water can also be used to provide irrigation for a second crop with a lower water requirement, such as chickpea.

CONCLUSIONS

Climate change is a global problem and India will also feel the heat. The various studies conducted in the country have shown that the surface air temperatures in India are going up at the rate of $0.4^{o}C$ per hundred years, particularly during the post-monsoon and winter season. Using models, they predict that mean winter temperatures will increase by as much as $3.2^{o}C$ in the 2050s and $4.5^{0}C$ by 2080s, due to Greenhouse gases. Summer temperatures will increase by $2.2^{0}C$ in the 2050s and $3.2^{0}C$ in the 2080s. Extreme temperatures and heat spells have already become common over Northern India, often causing loss of human life Climate change, it appears is now underway. Nearly 600 million rural people in India directly depend on climate-sensitive sector (agriculture, forests, and fisheries) and natural resources for their subsistence and livelihood. Under changing climate, food security of the country might come under threat. In increased in weather extremes like torrential rain, heat wave, cold wave, flood besides year to year variability in rainfall affects agricultural productivity significantly and lead to stagnation/ decline in production across various agro-climatic zones. Higher temperatures reduce the total duration of a crop cycle by inducing early flowering, thus shortening the 'grain fill' period. The shorter the crop cycle, the lower the yield per unit area. There is growing need to qualify the effects of rising temperature on yield of crops in different agroecologies and agri-production environments.

There is an urgent need to address the climate change and variability issues holistically. Under the AAS different adaptation strategies are being communicated to the farmers to offset the negative effect of the climatic variability on the crops. Besides, efforts are being made in collaboration with other organizations of the country to frame short as well as long term planning to issue adaptation strategies with respect to the future projection of climate change in different agroclimatic regions of the country.

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Managing Climate Risks through Weather Insurance

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INTRODUCTION

Agriculture sector is subject to a great many uncertainties. Yet, more people in developing countries like India earn their livelihood from this sector than from all other economic sectors combined. Agriculture in India despite its relatively diminishing contribution to Gross Domestic Product (GDP), accounts for national, 52 percent of employment (RBI Annual Report 2006-07), and sustains 69 percent of the population. In addition to satisfying all the food and nutritional requirements of the nation, agriculture also provides important raw materials to some major industries and accounted for about 14 percent of total exports valued at about US $ 15 billions during 2006-07 (RBI Annual Report 2006-07). Another feature of the Indian agriculture sector is the large number of small sized landholdings. Of the estimated total 120 million farm-holdings, nearly 63 per cent of farm-holdings were less than 1 hectare size, with average holding size of merely 0.4 hectares. As a consequence, the performance of agriculture in the near future will be crucial not only for the Indian farmers and the Indian agribusiness entities, but also for the Indian economy as a whole.

Risks in agriculture

Literature documents agricultural risk in association with negative outcomes that stem from indeterminable biological, climatic, and price variables. These variables include natural adversities (for example, pests & diseases) and climatic vagaries (for example drought, floods etc.) that are beyond the control of the farmer. They also include adverse changes in both input and output prices (World Bank, 2005).

Because of the dominance of the monsoon, India’s climate and weather risk exhibit the heaviest seasonal concentration of precipitation in the world. Nearly 2/3rd of the land is rain-fed, and almost 20 percent of India’s total land area is perennially drought prone. The frequency of droughts has been increasing over time: there were six severe droughts between 1900 and 1950 compared to 12 in the following 50 years, and three droughts have already occurred since the beginning of the 21st century.

The Ganges-Brahmaputra and Indus river systems are highly prone to flooding. The magnitude of flooding has increased in recent decades. Floods have occurred almost every year since 1980, and their extent substantially increased in 2003 due to widespread rains, which affected even some of the most drought-prone areas. North-western parts of the country are prone to frost during winter, and heat wave (March to May) is also quite frequent in many parts of the country.

Agriculture though faces risks including price risks, financial risks, institutional risks, personal risks etc., production risk however is the most important one. Indian agriculture is often and rightly termed as ‘gamble of monsoon’ and is characterized by high variability of production outcomes. Many external and internal factors during crop cycle make it almost impossible for farmers to predict with certainty the amount of output that the production process will yield.

Climate change and agriculture

Climate change is a long term issue. It is expected to be a major factor to contribute to extreme temperature, floods, droughts, intensity of tropical cyclones, and higher sea levels. While the magnitude of impact varies greatly by region, climate change is expected to impact on agricultural productivity and shifting crop patterns. The policy implications are wide-reaching, as changes in agriculture could affect food security, trade policy, livelihood activities and water conservation issues, impacting large portions of the population. The impact of climate change on agriculture could result in problems with food security and may threaten the livelihood activities upon which much of the population depends. Climate change can affect crop yields (both positively and negatively), as well as the types of crops that can be grown in certain areas, by impacting agricultural inputs such as water for irrigation, amounts of solar radiation that affect plant growth, as well as the prevalence of pests.

The climate has always presented a challenge to those whose livelihoods depend on it. Climate cannot be blamed for poverty. But, where people are poor, it presents an additional risk that can critically restrict options, and limit development. Climate has thus become an urgent issue on the development agenda. For poor people, a variable and unpredictable climate presents a risk that can critically restrict options and so limit development. Poor people have few assets to fall back on, and may be forced to sell these in order to survive so that when the crisis is over they are in a much worse position than before. These impacts can last for years in the form of diminished productive capacity and weakened livelihoods. And climate change threatens in terms of both more frequent and more severe extreme events (IPCC, 2007).

Crop insurance in India

Agriculture, particularly prone to systemic and co-variant risk (a single risk affecting a large number of crops across large geographical regions), doesn’t easily lend itself to insurance. Lack of past yield data, small sized farm holdings, low value crops and the relatively high cost of insurance, have further made it more difficult to design, a workable crop insurance scheme (Rao 2007). Despite these constraints, India debated the feasibility of crop insurance schemes, since late nineteen forties. However, the first concrete attempt could be made only in the 1970s. A brief evolution and present status of Indian crop insurance is presented below:

Crop insurance evolution

(i) Program based on ‘individual’ approach (1972-1978): The first ever crop insurance program started in 1972 on H-4 cotton in Gujarat, and was extended later, to a few other crops & states. The program by the time its wound up in 1978, covered merely 3,110 farmers for a premium of Rs. 454,000 and paid claims of Rs. 37.90 lakhs.

(ii) Pilot Crop Insurance Scheme – PCIS (1979-1984): PCIS was introduced on the basis of report of Prof. V.M. Dandekar and was based on the ‘Homogeneous Area’ approach. The scheme covered food crops (cereals, millets & pulses), oilseeds, cotton, & potato; and was confined to borrowing farmers on a voluntary basis. The scheme was implemented in 13 states and covered about 627,000 farmers, for a premium of Rs. 197 lakhs and paid indemnities of Rs. 157 lakhs.

(iii) Comprehensive Crop Insurance Scheme – CCIS (1985-1999):

The scheme was an expansion of PCIS, and was made compulsory for borrowing farmers. Sum insured which was initially 150 percent of the loan amount, reduced to lower to a maximum of Rs. 10,000 per farmer. Premium rates were 2 percent of the sum insured for cereals & millets and 1 percent for pulses & oilseeds, with premium and claims, shared between the Centre & States, in 2:1 ratio. The scheme when wound up in 1999, was implemented in 16 States & 2 Union Territories and cumulatively covered about 763 lakh farmers, for a premium of Rs. 40356 lakhs and paid indemnities of Rs. 231900 lakhs.

National Agriculture Insurance Scheme –NAIS (1999)

NAIS replaced CCIS starting from Rabi 1999-00 season, presently administered by Agriculture Insurance Company of India Limited (AIC), that provides coverage to approximately 35 different types of crops during the Kharif season and 30 during the Rabi season. NAIS covers about 22 million farmers annually, making it the world's largest crop insurance programme in terms of the number of farmers covered.

Till Rabi 2008-09, NAIS cumulatively covered 134.66 million farmers with cultivated area of 210.90 million hectares for a premium of Rs. 4426 crore and paid / finalized indemnities of Rs. 15230 crore. The overall loss cost (indemnities to sum insured) stands at 10.27 percent (Source: Agriculture Insurance Company of India Limited).

The Government constituted Joint Group in 2004 to review crop insurance in the country and the Planning Commission set up a Working Group on Risk Management in Agriculture in 2006 to strategize to formulate the XI Five Year Plan (2007-2012). In between (2005-06) the World Bank extended technical assistance program to Agriculture Insurance Company of India (AIC), which inter-alia worked on product design and pricing of area yield insurance. The major shortcomings identified during the review process are: (i) Insurance Unit (IU) is presently too large. And basis risk is too high; (ii) Guaranteed Yields do not reflect the reasonable aspirations of farmers; (iii) Present indemnity levels are inadequate; (iv) Need for individual farm assessment in case of localized calamities; (v) Inordinate delays in the settlement of claims; (vi) Poor infrastructure facilities for coverage of non-borrowing farmers; (vii) High claim ratio of non borrowing farmers; (viii) Insurance pricing issues and high claim ratio, etc. The Government is expected to shortly come out with a policy announcement on the proposed amendments to NAIS.

Weather risk based crop insurance model

Literature documents that 65 percent of Indian agriculture is highly dependent on rainfall, and, therefore, is extremely weather risk sensitive. Several studies including the one by Gadgil have established that rainfall variations account for more than 50 percent of variability in crop yields. Many agricultural inputs, such as soil, seeds, fertilizer, management practices, etc., contribute to productivity. However, weather risk, particularly rainfall, has overriding importance over all other factors. The reason is simple - without proper rainfall, the contributory value of all the other inputs diminishes substantially.

The basic idea of weather risk insurance is to estimate the percentage deviation in crop output due to adverse deviations in weather conditions. There are crop modeling and statistical techniques to precisely workout the relationships between crop output and weather parameters. For example, Fig.1 illustrates the impact of dry-spells on sorghum crop in Rajasthan. These linkages between the weather and yield could be captured in terms of financial losses using financial tools like insurance.

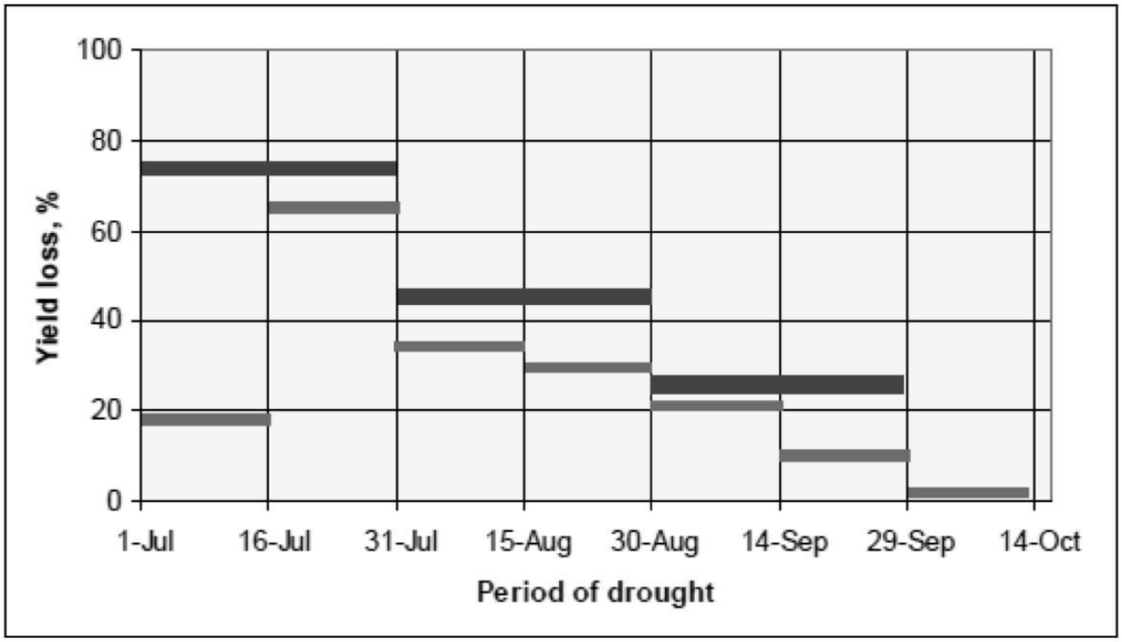

Fig. 1. Yield Loss in Sorghum due to 'short periods of drought' – Rajasthan (Source: IARI)

It may be important to mention that the credit for thinking of rainfall index as a mechanism to compensate crop losses should go to Mr J.S. Chakravarthi as far back as 1912. It was between 1912 and 1920 Mr Chakravarthi of Mysore State (India) published technical papers on the subject of 'Rainfall Insurance' and a book entitled 'Agricultural Insurance: A Practical Scheme Suited to Indian Conditions', in 1920, describing how rainfall index could be used to guarantee payouts to farmers arising out of adverse rainfall deviations. He used rainfall data from 1870 to 1914 from India Meteorological Department (IMD) to demonstrate the utility of the index. Surprisingly, this piece of pioneering work, which is probably one of the earliest monographs on the subject, does not appear to have been taken into account in the analytical literature on agricultural insurance (Mishra 1996). It was some 85 years later that the policy makers of the modern world started advocating the same index.

Weather risk insurance: Key advantages

One key advantage of the weather risk based crop insurance is that the payouts could be made faster, besides the fact that the insurance contract is more transparent and the transaction costs are lower. Because index insurance uses objective, publicly available data it is less susceptible to moral hazard. When used as a disaster management tool, rapid payouts are the crucial advantage of weather risk index insurance. This offers an alternative to the notoriously slow response to disasters in the form of relief aid, and the ad-hoc nature of this. It allows governments and relief agencies to plan ahead of crises, knowing that funds will be available when they need them.

At the same time, several critical components need careful attention if weather risk index insurance is to be workable. Weather risk insurance is complex and difficult for stakeholders to understand – time and resources must be invested to explain this new approach. It depends on the availability and reliability of quality weather data. But perhaps most importantly, weather risk insurance is vulnerable to basis risk (basis risk is when insurance payouts do not match actual losses), which may lead to losses but no payout, or a payout even though there are no losses. Contract design, and in particular selection of an appropriate index, are crucially important here; while various external factors are also important, such as having a good density of weather station network, etc.

Pilot weather risk based crop insurance

In order to address some of the shortcomings of NAIS, Agriculture Insurance Company of India (AIC) developed a pilot weather risk index-based insurance product in 2004. Building on the existing weather risk insurance products, the Government asked AIC in 2007 to design the Weather risk-Based Crop Insurance Scheme (WBCIS) as a pilot.

AIC through WBCIS, introduced a location-specific (Tehsil / Block) and crop-specific pilot on weather risk index-based insurance product on rainfall outputs for the Kharif season, and a composite weather risk index-based insurance like rise in temperature, un-seasonal rainfall, humidity, frost risks, etc. during Rabi season, as a substitute for NAIS during 2007-08. AIC availed technical assistance from Indian Agriculture Research Institute (IARI) to design weather risk insurance products on Crop Growth Simulation Modeling platform. AIC has been using various components of weather parameters, an illustration of it is shown below in Table-1:

Table 1. Weather index parameters

S.No.	Weather Parameter	Components
1	Rainfall	Deficit rainfall, Consecutive Dry Days (CDD), Rainy Days, Excess rainfall, Consecutive Wet Days (CWD)
2	Temperature	Max. Temperature (heat), Min. Temperature (frost), Mean Temperature, Hourly Chilling units
3	Relative Humidity	High Humidity
4	Wind Speed	High Wind Speed
5	Disease proxy	Combination of Weather parameters like rainfall, temperature & humidity

An illustrative weather risk insurance product (contract structure) for cotton crop (rainfed) in Karnataka is shown under Table-2 below:

Table 2. Weather risk Insurance Product for Cotton (Rain-fed) in Karnataka

State: Karnataka	Dist: Bidar	Hobli: Aurad	Crop: Cotton (Rainfed)	Season: Kharif 2009

1. **Deficit Rainfall**

1 A: Rainfall Volume

	Phase -I	Phase -II	Phase -III
Period	**15th June to 10th July**	**11th July to 20th August**	**21st August to 30th Sept.**
Trigger 1 (<)	40 mm	120 mm	80 mm
Trigger 2 (<)	20 mm	60 mm	40 mm
Exit	0	0	0
Rate 1 (Rs./mm)	15.00	6.00	10.00
Rate 2 (Rs./mm)	60.00	23.17	40.00
Max. Payout (Rs.)	**1500**	**1750**	**2000**

TOTAL PAOUT (Rs.) 5250

1 B: Rainfall Distribution (Consecutive Dry-days)

Period	**1st July to 31st August**		
Trigger Days (>=)	17	25	30
Payout (Rs.)	750	1500	2000

TOTAL PAOUT (Rs.) 2000

Note: Rainfall of less than 2.5 mm in a day shall not be counted as a rainy day; and multiple events shall be considered for payout

2. **Excess Rainfall**

	Phase -I	Phase -II	Phase -III
Period	**20th June to 20th July**	**21st July to 15th Sep.**	**16th Sep. to 31st Oct.**
Daily rainfall Trigger (>)	70 mm	85 mm	70 mm
Exit	130 mm	150 mm	130 mm
Rate (Rs./mm)	12.50	7.69	16.67
Max. Payout (Rs.)	**750**	**500**	**1000**

TOTAL PAOUT (Rs.) 2250

3. **Pest / Disease Congenial Weather**

Period	**16th August to 30th Sept.**	**1st Sept. to 31st October**
Event definition	When average RH for a day is between 46% to 60% and mean temperature (o C) between 20 and 24	When average RH for a day is between 52% to 72% and mean temperature (o C) between 25 and 33
Index (>)	No. of consecutive congenial days (multiple events)	No. of consecutive congenial days (multiple events)
Trigger	6	6
Exit	12	12
Payout (Rs. /congenial day)	166.67	250.00
MAXIMUM PAYOUT (Rs.)	**1000**	**1500**

TOTAL PAOUT (Rs.) 2500

TOTAL MAXIMUM PAOUT (Rs./Hectare): 12000

AIC developed parametric weather risk based crop insurance for a variety of crops ranging from seasonal to perennial crops and low value to high value crops. The details of the crops presently covered under Weather risk Insurance by AIC are listed in Table 3.

Table 3. Crops covered by AIC under Weather Risk Insurance

S.NO.	CROP	SEASON
CEREALS & MILLETS		
1	Paddy	Kharif & Rabi
2	Sorghum	Kharif 2
3	Pearl millet	Kharif
4	Maize (Corn)	Kharif
5	Finger millet	Kharif
6	Wheat	Rabi
7	Barley	Rabi
PULSES		
1	Blackgram	Kharif 9
2	Greengram	Kharif
3	Pigeon Pea	Kharif
4	Chick Pea	Rabi
OILSEEDS		
1	Groundnut	Kharif 3
2	Soyabean	Kharif 4
3	Linseed R	abi
4	Rape Seed & Mustard	Rabi
5	Sunflower	Kharif
6	Sesamum	Kharif

S.NO	CROP	SEASON
COMMERCIAL CROPS		
1	Potato R	abi
	Coriander	Rabi
3	Cumin	Rabi
4	Fenugreek	Rabi
5	Isabgol	Rabi
6	Onion	Kharif
7	Chilly	Kharif-Rabi
8	Cotton	Kharif
	Tomato	Kharif & Rabi
10	Banana	Annual
PERENNIAL HORT. CROPS		
1	Grapes	Rabi
2	Mango	Rabi
	Cashewnut	Rabi
	Pepper	Kharif
5	Apple	Rabi
6	Coffee	Annual
7	Orange	Annual

The progress of pilot WBCIS implemented by Agriculture Insurance Company of India (AIC) till *Kharif* 2009 is detailed in Table-4 below:

Table 4. Performance of Weather Risk based Crop Insurance

Sl. No.	Season	No. of States	Districts / Blocks	Farmers Covered	Area (Ha.)	Sum Insured (Rs. Crore)	Premium (Rs. Crore)	Claims (Rs. Crore)	Farmers Benefited
1	*Kharif* 2007	1	13 Dists/ 70 Hoblis	43790	50075	53.01	7.03	5.24	35275
2	*Rabi* 2007-08	4	36 Dists/ 139 Tehsils	627168	984553	1704.95	138.45	100.72	187790
3	*Kharif* 2008	11	57 Dists/ 269 Blocks	165109	178655	313.13	31.68	14.40	104483
4	*Rabi* 2008-09	12	59 Dists/ 259 Blocks	177577	245120	477.18	38.79	44.17	119550
5	*Kharif* 2009	14	139 Districts/ 536 Blocks	1126843	1483138	2001.88	200.05	225.00*	901400
			TOTAL	**2140487**	**2941541**	**4550.14**	**416.00**	**389.53**	**1348498**

Note: Claims of Kharif 2009* are estimates only

Source: Agriculture Insurance Company of India Limited (AIC)

Weather risk insurance – Challenges

The two biggest weaknesses and challenges of the present weather risk index-based insurance product are (i) designing a proxy weather risk index with predictive capability to realistically measure crop losses and (ii) basis risk. Basis risk results if the actual experience of weather risk (rainfall) in the neighborhood significantly differ the data recorded at the weather station. The two aspects lead to compounding of the problem: both may not trigger a payout despite the occurrence of damages at an individual farm, or these may trigger a payout when loss did not occur. The combined effect of the two challenges represents a significant barrier to the scale up of the product. Nevertheless, weather risk index-based insurance performs well on data accuracy, transparency and quick claims settlement, which are very attractive to both farmers and the reinsurance market.

Another barrier to scale up is the current limited scope of weather risk index-based insurance. There are still many weather events, such as hailstorm, thunderstorm, and floods that are difficult to cover under this insurance modality due to the highly technical requirements in the designing of the product. Moreover, pests and diseases, highly dependent on weather parameters, are also very challenging to cover. Nevertheless, an accurate disease index has been designed for the common late blight disease affecting potato crops assessed through temperature and humidity levels. Basis risk using the late blight disease index was significantly satisfactory. Technical difficulties encountered thus far with weather risk index-based insurance can be resolved as product designers become more knowledgeable about this insurance modality. Additionally, the installation of more weather stations capable of capturing real-time data will immensely reduce current basis risk-related problems.

Lack of available historical weather data and weather stations that cover India's extensive territorial area present an impediment to the scalability of the product. Present network of public weather stations is very sparse and simply cannot meet the requirements of weather risk based crop insurance programme. Also sparse network of weather stations is a huge bottleneck in giving timely agro-advisories to farmers at micro level. It's, therefore, suggested that India Meteorological Department (IMD) effects manifold increase in the weather stations.

Ideally every village requires a rain gauge and a cluster of 4-5 village, a weather station. However, practically it would not be feasible in the short run to have such a good network. In order to meet the basic requirements, its' suggested that a rain gauge can service no more than 5 KM radius and a weather station no more than 10 KM radius, the no. of rain gauges required is to the tune of 32,000 and the weather stations to the tune of 8,000. The detailed working is given Table-5 below:

Table 5. Optimum Network of Weather Stations

Total Area (KM^2)	3280000
Agricultural Area (KM^2)	2500000
Weather station (WS) Radius (Km)	10
Weather station Area (Km^2)	314.29
Rain gauge (RG) Radius	5
Rain gauge Area (Km^2)	78.57
No. of WSs	7,955 (Roughly 8,000)
No. of RGs	31,820 (Roughly 32,000)

Insurers have to find a way to offer a technically sound product that is, at the same time, simple and easily accessible to farmers. Farmers must be able to understand the program sufficiently in order to calculate claims and expect realistic payouts. The lack of benchmarking for weather risk index-based insurance products further complicates its promotion and distribution for insurance companies willing to distribute the product. In addition to these constraints, price calculation, frequency of payout, data calibration and subsidy are also aspects that need to be addressed for the diffusion of weather risk index-based insurance.

AIC has found weather risk index-based insurance to be specifically useful for insuring crops that do not have adequate historical yield data. Many of these crops do not lend themselves to 'individual-based insurance' due to either low value or high complexity. Weather risk index-based insurance, thus, can be part of an insurance program in which it is combined with a area yield index-based insurance. That is, in a double-trigger relationship, weather risk index-based insurance provides a trigger to release early payout with a provision that these will be further adjusted against final yield estimates. Additionally, weather risk index-based insurance can be an ideal alternative for protecting a large portfolio at the macro level against drought or floods.

Ultimately, the success of weather risk insurance program in India will depend on: product design; minimizing the basis risk; adopting reliable and sustainable pricing (including governmental subsidies); adequate product servicing; and, ensuring timely payouts. Weather risk insurance can neither modify weather conditions, nor can it eliminate weather risk. However, it can certainly help manage weather risks in a more efficient way, if designed and used appropriately.

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Mutual Crop Insurance and its Relevance to Climate Change Adaptation of Small Rainfed Farmers - The Experience of DHAN Foundation

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ABSTRSACT

Though climate change seems like a new issue, farmers in India, particularly rainfed farmers, were facing various issues related to variation and changes in rainfall, for the last two decades. Specific rainfall changes experienced in some parts of Tamil Nadu include late onset of South West monsoon, decrease in South West monsoon rainfall, early withdrawal of North East monsoon and increase in pre-summer rainfall. The time tested *pattam* (optimum seasons) for sowing, particularly the Vaigasi *pattam* (May-June) and Ani *pattam* (June-July), are loosing their relevance in many parts of the region. These issues have led to repeated crop loss and significant reduction of area under rainfed crops. Though climate change is happening everywhere, it affects each location differently. So the adaptation measures for climate change should also be specific in nature. Farmers are aware of climate change and have been taking various efforts to cope with the risk. But these coping mechanisms are not sufficient to address the issues and are not available to all the affected farmers. One of the means of addressing climate related risks is mutual crop insurance. DHAN Foundation has piloted Mutual Deficit Rainfall Insurance, Mutual Pest Insurance and Mutual Crop Income Insurance, as part of a package of measures to address the crop risks faced by the farming community in six locations. The experience in the last four years highlight the fact that mutual crop insurance is better suited as an adaptation strategy for climate change than conventional crop insurance, due to customized nature of mutual crop insurance, its dynamic design and other critical *"process outcome"* advantages, namely awareness generation and motivating for collective and individual action for prevention of risks. It is necessary to address various challenges related to scaling up mutual crop insurance, namely promotion of community organization of rainfed farmers on a large scale, educating farmers on climate change and insurance, designing customized products and reinsurance support. These challenges can be overcome only if all the stakeholders namely State, agriculture development organizations, donor agencies, the insurance and agriculture research institutions, and insurance companies work together and do their roles in a complementary way.

INTRODUCTION

Rainfed agriculture plays an important role in Indian economy. In India, 58.53 percent of total net sown area (141.4 m ha) comes under rainfed lands, spreading over more than 177 districts. In the total agricultural production, about 86 percent of pulses, 77 percent of oil seeds, 66 percent of cotton and 50 percent of cereals are contributed by rainfed agriculture. Nearly 50 percent of the total rural workforce and 60 percent of cattle heads of the country is located in the dry districts. Besides the above mentioned facts related to economic importance, rainfed farming is important for the nation in terms of agrobiodiversity and nutrition. Rainfed farming systems are by nature diverse and houses wide varieties of various crops, which are disappearing day by day. This is particularly so with regard to Sorghum, Pearl millet, Finger millet, minor millets like Little millet, Kodo millet, Italian millet and Barnyard millet and rainfed rice. The rainfed crops are nutritionally superior to commonly consumed Rice and Wheat. In spite of the various benefits, rainfed farming is on the decline over years. There are multiple systemic reasons for stagnation in growth of rainfed agriculture like inadequate policy, research and investment attention, deteriorating soil health, lack of commensurate increase in price of produce with reference to the cost of inputs, inadequate credit supply, ineffective extension and research.

Climate variation and change

Adding to the above mentioned issues, the productivity of rainfed crops has been affected by variation and change in rainfall very significantly in the last two decades. The weather related risks are the predominant risks faced by rainfed farmers, as more than 60 to 80% of the yield is decided by the adequate quantity and proper distribution of rainfall. Further the risk due to long dry spell and drought are recurrent. A research study conducted in various parts of Tamil Nadu found that there has been many long term changes in rainfall pattern which adversely affect the rainfed agriculture. Specific rainfall changes documented include late onset of South West monsoon, decrease in South West monsoon rainfall, early withdrawal of North East monsoon and increase in pre-summer rainfall. The time tested *pattam* (optimum seasons) for sowing, particularly the *Vaigasi pattam* (May-June) and *Ani pattam* (June-July) were loosing their relevance in many parts of the state. The dry spell pattern within the crop period has changed, making the available rainfall less useful to the crops grown. The major inference of the above study is that though climate change is happening everywhere, it affects each location differently. This can be clearly seen from the Table 1. So the local level impact due to these changes also varies across the locations. In parts of Madurai district, the practice of pre-monsoon sowing has been declining and Groundnut crop has vanished due to uncertainty and delay in onset of monsoon. In Nattarampalli, mixed cropping of Pearl millet and Gingelly sown during summer has almost vanished. Many of these changes can be attributed to climate change, which is getting lot of attention since 2007. These rainfall changes along with the other issues mentioned earlier, led to repeated crop loss, large scale increase in fallow land, loss of livelihoods and migration. Farmers are aware of climate change and have been taking various efforts to cope with the risk. The coping efforts include shifting sowing season, changing crops/ varieties and diversifying to tree crops. But these coping mechanisms are not sufficient to address the issues arising from rainfall change and are not available to all the affected farmers. As rainfed farmers form the majority of poor in India, it is essential to support them to adapt to climate change to reduce poverty, to ensure food security of the nation and to bring balanced development. As the climate change impacts are location specific, the adaptation measures should also be location specific, rather than generic in nature.

Table 1: Changes in rainfall pattern across three locations in Tamil Nadu

S.No.	Aspects	Nattarampalli, Vellore Dt.	Tirumangalam, Madurai Dt.	Vedaranyam, Nagapattinam Dt.
1	Focus crop	Groundnut	Cotton, Blackgram and Greengram	Paddy, Groundnut
2	Frequency of occurrence of drought and excess rainfall	Moderate droughts increasing; Excess rainfall decreasing	No trend	No variation across the two decades

3	Trend in mean annual rainfall	Declining over the four decades and the decline has been drastic in the last decade	No clear trend	No significant change
4	Changes in Seasonal rainfall	Absolute decline in SWM rainfall		Decline in both SWM and NEM rainfall.
				Increase in summer and winter
5	Changes in Monthly rainfall	Decline in June, September and November	Decline in July, September and December	Decline in August, September, November and December
		Increase in April	Increase in April	Increase in February, April, May and October
6	Mean seasonal rainy days	Absolute decline in number of rainy days in SWM period		NA
7	Mean monthly rainy days	Decline in November and December during NEM	Decline in September and December	NA
		Increase in April and May.	Increase in April and October	NA
8	Length of growing period	Reduced	Reduced	Not reduced
9	*Pattam* (optimum sowing season)	Uncertainity increased	Uncertainty increased	NA

Source: ACEDRR research study, 2008.

Insurance as an adaptation strategy for CC

The role of insurance in adaptation to climate change is gaining ground at various levels. The study by Tata Energy Research Institute found that policies that are designed to fortify current coping capacity also have the power to strengthen long-term adaptive capacity. This is best exemplified by measures such as crop insurance. UN Climate Convention and the Kyoto Protocol have included the provision of insurance as a mechanism to address the risks from climate change. It is reflected in Article 4.8 of the UNFCCC, which calls upon Parties to 'consider' actions, including those related to insurance, to meet the specific needs and concerns of developing countries with respect to both the adverse impacts of climate change and the impact of the implementation of response measures. Article 3.14 of the Kyoto Protocol calls for the implementation of Articles 4.8 and 4.9 of the UNFCCC in fulfilling obligations of the Kyoto Protocol, and explicitly calls for the consideration of the 'establishment' of insurance.There is also growing interest in "*ex ante*" financial mechanisms, where the funding is arranged in advance, for meeting the financial needs related to relief and reconstruction, due to shortages and uncertainties of "*ex post*" financing. These include insurance, derivatives and catastrophe bonds, which spread risk geographically, and savings, reserve funds or contingent credit arrangements, which spread risk over time. Out of these mechanisms, there is growing experience with insurance tools to manage climate risks in developing countries and the instruments vary with the scale. Meso-scale solutions like micro insurance include Index-based drought insurance in Malawi and India, and government supported herder insurance in Mongolia. Country-level insurance schemes include the parametric weather derivative in Ethiopia to help government protect rural poor and Mexico's FONDEN. Regional (multi-country) insurance pools include Caribbean Catastrophe Reinsurance Facility (CCRIF). While this is the case about insurance as an adaptation mechanism in general, there is fast growing literature on micro crop insurance as an adaptation strategy. This paper discusses the role of mutual crop insurance, a type of micro insurance, in climate change adaptation.

The experience of DHAN Foundation in piloting Mutual Crop Insurance (MCI)

Concept of crop risk management in DHAN Foundation

DHAN Foundation has been working with farmers depending on tank-fed agriculture since 1989 and with rainfed farmers since 2002. It follows livelihood enhancement approach along with promotion of farmers' organizations and creation of enabling environment. Risk management is seen as an integral part in development of farming livelihoods. It believes that insurance, *a risk transfer measure*, will be effective only in combination with *risk reduction measures* like physical measures (E.g. Bunding, Silt application), biological measures (E.g. Quality seeds), timely cultivation practices (sowing in the *Pattam*, optimum season) and diversification measures (E.g. Diversification to livestock/ tree crops) and *risk coping measures* like timely credit availability. So insurance is offered as one of the interventions for risk management of farming livelihoods, along with many other farming interventions.

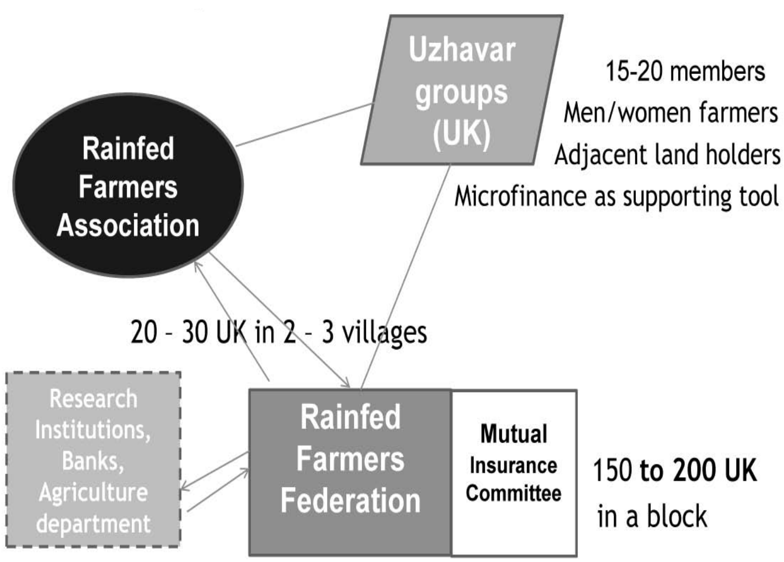
The need for Mutual Crop Insurance

DHAN Foundation started with piloting of weather (deficit rainfall) insurance through insurance company for three years. Pilot was taken up in two locations covering Groundnut, Cotton and Blackgram farmers, as a measure to protect them from various rainfall related risks, arising mainly from changes in rainfall pattern. Based on the experience, each year the product was improved by bringing in new features. By the end of second year, it was clear that there is a limit to which the effectiveness of the product done through insurance company can be improved. The main problem was basis risk (i.e.) difference in the risk assessed by the insurance product and the actual risk faced by the farmers. This was mainly due to variation between villages rainfall and the reference weather station rainfall. Effectiveness of the product largely depends on synchronizing the policy initiation date and the sowing date and in calculating compensation based on actual rainfall in each village. But the insurance companies rely on a reference station, which is usually an Indian Meteorology Department (IMD) station, meant for a large number of villages and so are not capable of offering customized policies on a micro scale. So there was always the possibility of basis risk. Another source of basis risk was inability of the weather insurance product for groundnut to reflect the relationship between crop performance and rainfall. It has been the repeated experience of farmers to get better yield, if the crop is sown in the optimum sowing period between June 25th and July 15th and lower yields if sown after that. But the rainfall insurance showed that the premiums were more for the optimum sowing period than for the delayed sowing, indicating that there is more risk of loss if sown in the optimum season. Yield is influenced by factors beyond just 'quantity of rainfall' that is taken for designing rainfall insurance product.

Another major issue in taking up crop insurance through insurance company in the context of a member owned farmer organisation was that the farmers tried to externalize the issue of yield loss and did not see their individual and collective role in prevention. The situation got complex as farmers did not adequately imbibed the concept of insurance. There are also many location specific risks, which are not covered by the insurance companies like that of Red Hairy Caterpillar (RHC) issue. So there was need for an insurance mechanism which addresses the location specific risks faced by farmers and at the same time lead to efforts by the same farmers to prevent those risks. We shifted to Mutual Crop Insurance as it offered these advantages.

Mutual crop insurance

Mutual crop insurance (MCI) is a type of crop insurance where those farmers protected by the insurance (policyholders) also have certain “ownership” rights in the insurance organisation. It is a ‘process based’ insurance mechanism, build on time tested mutuality practice in the farming community. It is designed and managed by the wiser farmers of the insured farming community, who are nominated as Mutual Insurance Committee members. MCI not only manages risk, but also result in motivating the farming community to look for all means of preventing the risks and lead to empowerment of local farmers in the long term. This is so because they own the premium pooled and any loss would affect all. On the other hand, any means of reducing the risks at their farm level or at the neighbor’s farm would decrease the premium for every body. So they would look for all the ways that can result in prevention. Farmers were very critical to what type of farmers was accepted as members of the insurance pool and taken efforts to abandon the fraudulent farmers and those who have not taken preventive measures. This became possible due to the environment of social control and familiarity of representative farmers with production circumstances. The other advantage was quick compensation. Because their representative farmer was responsible for assessing claim, it is possible to provide a good judgement of crop damage quickly. Further as the premium was with them they were favourably placed to give compensation at the earliest. DHAN Foundation was impressed with the experience of mutual crop insurance in Netherlands. Netherlands is known for mutual insurance and mutual crop insurance products like AVIPOL, Potato Pol were in vogue for more than a decade and found to be effective. The training and reinsurance support by People Mutuals, technical support given by Mutual Insurance Association of Netherlands (MIAN) and financial support and back up guarantee support given by Eureko Re were instrumental in initiating mutual crop insurance pilots.



Community organization (CO) for livelihood enhancement and risk management

Community organization of farmers forms the platform on which mutual crop insurance is placed. So well functioning CO of farmers is a prerequisite for taking up MCI. DHAN Foundation believes that poverty reduction and grassroots democracy go hand in hand and are necessary for sustained development. So it starts with promoting member owned people institutions of farmers. These COs are seen as demand stream for the State. The shape and size of COs will vary with theme like Tank-fed agriculture and Rainfed farming and see Figure 1 for CO model of rainfed farming development. Each CO has a general body, executive body and staff (s) and the executive body is rotated every 2-3 years. They have meeting on a regular basis. There is intense face to face interaction between office bearers and staffs with individual members, as part of implementation of farming activities. All COs have a full-fledged accounting system and focus on cost coverage from the beginning. Mutual crop insurance is taken up as one of the activities of such promoted farmers' organizations.

A Mutual insurance committee (MIC) is formed at the federation level (see Figure 1). The number of members in MIC is around 15 to 30. The *generic roles* of this committee is:

- Policy making related to the insurance product and reviewing the policy at periodical intervals,
- Implementation of the insurance product along with the concerned staff and
- Managing the funds related to insurance.

The *specific roles* will vary depending on the product. The capacity of selected MIC are enhanced by exposing to similar initiatives in other places, training on the basics of mutual insurance and ensuring their intense participation in all the steps starting from design of the product, enrollment of members to claim payment.

Mutual Crop Insurance Products

Three kinds of mutual crop insurance products were piloted by DHAN Foundation namely, Mutual Deficit Rainfall Insurance, Mutual Pest insurance and Mutual Crop Income insurance.

Mutual Deficit Rainfall Insurance (MDRI)

It is a weather insurance product which uses rainfall data during different stages of the crop period as a proxy for assessing the rainfed crop yield loss. It was piloted in Tirumangalam in Madurai district, as a climate change adaptation for the first time in India. The pilot which was started with one location in 2006, was implemented in five locations in 2009. In the last three years the crops covered include Cotton, Blackgram and Maize. The main difference between the similar products piloted earlier with Insurance Company and MDRI is that, MDRI is based on data from automatic rainfall gauges in the insured villages to reduce basis risk. The rainfall received in these gauges is measured on a daily basis. The results of these measurements are communicated to Mutual Insurance Committee and are used to calculate benefit payments. Using village level rain-gauges provided a better reflection of rainfall than the weather station, which was initially used. A comparison of rainfall data collected at the village level, with data received from the weather station, proves this point (see Table 2). A sample of insurance policy is given in the annexure. The premium varied across the sowing dates. The results of five years pilot are shared in Table 3.

Table 2. Rainfall recorded across villages at Tirumangalam in 2007

Month	Sengapadai	Sennampatti	Madurai Airport	Threshhold rainfall for compensation (Rs.)	
				60	120
August	135	45.8	84	42-66	<42
September	21	57.7	166	60-95	<60
October	143.2	158.6	208		<89
November	170.7	161	222	68-109	<68
December	0	0	6	26-41	<26
Total	469.9	423.1	686		

Table 3. Details of Mutual Deficit Rainfall Insurance

Year	Farmers covered	Acres covered	Contribution received	Benefits paid
Thirumangalam Rainfed Location				
2006-07	85	45.25	13,385	12,005
2007-08	212	56.63	16,980	25,340
2008-09	196	117.50	21,750	68,268
2009-10	83	57.00	17,300	10,800
Mudukulathur Tank Location				
2007-08	356	484.50	163,761	654,075
2008-09	788	1278.75	432,218	225,619
2009-10	280	562.00	148,930	Risk period is upto 15.01.2010
Kottampatti Tank Location				
2009-10	94	69.56	36,171	Risk period is upto 31.12.2009
Singampunari Tank Location				
2009-10	53	32.84	17,076	Risk period is upto 31.12.2009
Kadaladi Tank Location				
2009-10	321	657.5	187,461	Risk period is upto 31.12.2009
All locations				
2006-07	85	45	13,385	12,005
2007-08	568	541	180,741	679,415
2008-09	984	1,396	453,968	293,887
2009-10	831	1,379	406,938	NA

Mutual Pest Insurance (MPI)

MPI is a crop insurance product in which the farmers are indemnified based on actual losses due to specified pest attack, on which farmers do not have control. It was piloted in Tirumangalam in Madurai district, for the first time in India. In the two years of piloting the crops covered include Cotton and Blackgram. Damage by Red Hairy Caterpillar is a recurring problem in Cotton and Black gram in the pilot area. Control of this pest is beyond the power of individual farmers. The damage could be specific to villages; even specific to few farms. There is requirement for intensive monitoring for implementing this insurance product, which is only feasible through mutual insurance. Further the mainstream insurance companies do not offer such a product. The premium was fixed based on the historical data on occurrence of pest collected from farmers. The insured plot was marked in the beginning and periodical monitoring of infestation was done by committee members and the field staff. The claim payment was based on pest attack. Summer ploughing, a pest preventive measure was also taken into account in the design of the product through premium differentiation, thereby encouraging crop rotation.

Table 3. Details of Mutual Pest Insurance, Tirumangalam.

Sl.No.	Particulars	2006-07	2007-08
1	Crop	Cotton & Blackgram	Cotton & Blackgram
2	No. of policies	192	157
3	No. of farmers	192	157
4	Area covered	135.35	115.5
5	Premium paid (Rs.)	20845	16980
6	Sum insured (Rs.)	67675	57750
7	No. of claims	66	103
8	Amount claimed (Rs.)	17750	17690

Mutual Crop Income Insurance (MCII)

MCII is a crop insurance product in which the farmers are indemnified based on actual loss in income, with loss assessment and price monitoring done by wiser farmers from the community. It was piloted by the Groundnut farmers of Nattarampalli in Vellore district, as a climate change adaptation for the first time in India. The pilot has completed three years.

A Mutual Insurance Committee (MIC) was formed by selecting two to three wiser farmers from each watershed. Based on the data collected from the farmers in the location related to frequency, levels and causes of loss in Groundnut cultivation, variations across the location and cost of cultivation, a product was developed by MIAN. In the product the sum insured per acre was Rs. 2000 and the premium was Rs. 500. The design of the product was such that cost of cultivation was considered as the bench mark for compensation and not the expected income, to make the product affordable to farmers. MIC also evolved the norms and methods for implementing this mutual insurance product for groundnut in three meetings. Concerted efforts were taken to avoid the conventional problems of crop insurance (i.e.) adverse selection, moral hazard and delayed compensation in MCI. Moral hazard risk was addressed by introducing retention, requiring farmers to pay a pre-determined percentage of their loss themselves.

Table 4. Details of Mutual Crop Income Insurance, Nattarampalli

Sl.No.	Particulars	2007-08	2008-09	2009-10
1	Crop	Groundnut	Groundnut	Groundnut
2	No. of farmers	190	50	133
3	Area covered	74.1	20.2	52.88
4	Premium paid (Rs.)	38375	10600	27500
5	Sum insured (Rs.)	148260	40360	105760
6	No. of claims	64	41	114
7	Amount claimed (Rs.)	21250	22010	67430

The extent of retention of losses by the farmer herself/himself was 35% (i.e.) Rs. 1000 out of total expected loss of Rs. 3000 per acre. Further, the organization of the claims assessment process was also designed in such a way to ensure a further reduction of moral hazard risk through abandoning fraudulent farmers and those who have not taken preventive measures. See annexure to view the norms evolved for MCII for Groundnut crop.

REINSURANCE

Reinsurance support is essential to make MCI effective. Eureko Re came forward to offer reinsurance to MCI pilots of DHAN Foundation. The structure of the reinsurance agreement between People Mutuals and Eureko Re is a stop loss contract. For the federation mutual, the safety net construction was made in such a way that they pay the claim to the extent of the available solvency fund plus the collected premium, minus the reinsurance premium which is paid to People Mutuals. Claim in excess of this will be paid by People Mutuals. The reinsurance premium paid to People Mutuals is 12% of the premium collected from the farmers. The safety net construction for People Mutuals is that the People Mutuals would pay the claims up to the level of crop mutual solvency fund available with it and the reinsurance premium received. Claim in excess of this will be paid by Eureko Re.

The reasons for MIC to be a better adaptation strategy for CC than conventional crop insurance

- **The product design of MIC is customized to a specific issue:**

  MIC reflects the specific issue faced by the farming community in a location. This is very important as the climate change impacts are specific to location. This is not the case of mainstream crop insurance, which offers a single product for a large geographical area.

- **The product design of MIC is dynamic:**

  The learning from one year of piloting MIC becomes input for design in the next year, as the decision is with the farmers. This flexibility is not the case of mainstream crop insurance.

- **Other critical *"process outcome"* advantages of MIC, like that of *"decentralization"*:**

  MIC not only manages risk but also results in increase in awareness about climate change among the farmers and motivates them to look for all means of preventing the risks. This can lead to relevant collective and individual action for prevention E.g. Plough animal purchase for timely sowing. In the long term this will lead to empowerment of local farmers. These advantages are very critical for climate change adaptation.

Way forward

Our experience indicates that mutual insurance has the potential to serve as an important climate change adaptation strategy for enhancing the livelihoods of small rainfed farmers. It empowers them to address the risks they face on a collective basis in the manner they want. Further MCI has improved awareness of farmers on climate change and it is expected that this will help them to make informed decisions at individual farm level over time. But the prerequisites for mutual insurance are effective community organization, effective insurance education, effective design of customized products and support for reinsurance. These prerequisites and replication of MCI on a large scale will be possible, only if all the stakeholders like State, development organizations, insurance and agriculture research institutions and insurance companies work together and do their roles in a complementary way.

State: State has obligatory role to support poor rainfed farmers facing risks due to climate change. Supporting MCI can become an effective and cheaper *ex ante* measure when compared to conventional crop insurance and drought relief. State can support MCI by supporting 1) large scale insurance education, 2) data infrastructure like automatic rain gauges, 3) capacity building of stake holders, 4) pilots in various agro-climatic regions and 5) transfer of learning on MCI arising from pilots. More importantly, State can cover the extreme risks events, leaving out moderate risks to farmers, there by resulting in reduction in premium leading to large scale out reach. State can also take initiatives for creating favourable regulatory framework and can act as reinsurer of last resort. The current support of State and Central Governments to Weather insurance products by AIC and other private companies in Rajasthan and Tamil Nadu are good examples for possible State support to MCI.

Development organizations working on rainfed farming development can support MCI by promoting viable COs, taking up insurance education and facilitating MCI implementation as one of their important interventions. The insurance and agriculture research institutions can offer technical support in evolving effective customized products and can participate in pilots of these products. Insurance companies can also offer technical support and can serve as reinsurers for MCI. Donor agencies can support MCI by supporting insurance education, capacity building, piloting and transfer of learning from pilots. As development of rainfed farming in predominantly rainfed areas is seen by a wide spectrum of people as the route for equitable development, supporting effective Mutual Crop Insurance for addressing various risks of rainfed farmers would serve not only as CC adaptation, but also as part of focused development interventions to bring about sustainable and balanced development.

Annexure 1:

Mutual Help Program: Rainfall Indexed Crop Loss Compensation Program Maize Crop – Year 2008-2009

Eligibility

Rainfed maize farmers who are members of farmers group of Rainfed Farming Development Program (RFDP), Tirumangalam.

How to become member?

1. Application duly filled up and signed has to be produced
2. Contribution amount has to be remitted. The contribution varies with the extent of crop grown.

Details

Period	:	August 2008 to November 2008
Benefits	:	Maximum Rs.2000 per acre
Contribution	:	Rs.210 per acre
Villages covered	:	Villages in and around Sengapadai, Vellakualm and Thummanayakkanpatti, where automatic rain gauge have been installed.
Ostensible sowing date	:	August 30, 2008, Premium Amount Rs.367/-
	:	August 23, 2008, Premium Amount Rs.524/-
	:	September 13, 2008, Premium Amount Rs.210/-

Benefit details

Period	Stage of Crop	Rainfall Requirement	Benefits
15-45 days after sowing	Vegetative and flowering phase	Not less then 60mm	Rs.2000

Base information

Rainfall data recorded in the rain gauge installed at the villages.

Mode of payment of benefits

The rainfall data from September to November 2008 would be complied and analyzed by December 2008 and benefits would be provided before January 2009 based on the decision of the mutual help program executive committee.

Other Details

Contribution paid would not be refunded under any circumstance.

Annexure 2:

Norms evolved for Mutual Crop Income Insurance, Groundnut

- All the farmers enrolling into the scheme have to specify the plot of land insured with survey number.
- The team of MIC member, professional and associate would visit each farm to identify the insured plot of land and to take basic details of the Groundnut crop. A separate notebook would be used to record the particulars of crop.
- If the sowing is taken up in shaded area, such area to be deleted from total area covered.
- If low seed rate was practiced, seed rate based area to be taken for coverage.
- All insured farmers should inform the MIC before one week of intended harvest. The plot harvested without giving information would be removed from coverage.

- Just before harvest each farm would be visited by the same team to assess the yield. A sample from the farm would be taken to assess the yield of the insured plot of land.
- Compensation will not be given for human negligence, which will be identified during periodical visit.
  - o If there is yield loss due to heavy weed infestation the plot will be removed from coverage.
  - o If there is yield loss due to damage by wild animals the plot will be removed from coverage.
- Sample yield measurement would be taken in all plots of the insured land.
- Sample yield measurement would be done using cycle tyre. Sample yield measurement would be taken near four corners of the plot at a distance of 10 feets from each corner and also in the centre.
- Litre measure would be used to measure the sample harvest. Crown filling method to be followed for measurement.
- The conversion ratio is 12 litres = one *vallam*; 42 *vallams* = one *putti*.
- One eighth of volume of the fresh produce to be deducted for wages.
- Fifteen vallams to be deducted for half acre seed material.
- The value of Groundnut plant residue will not be taken for calculating total income.
- Any one of the two MIC members who are considered as an expert on groundnut will also accompany the team for harvest measurement.
- So by the end of the season there will be information regarding the actual yield of each insured plot of land and the reasons for the same.
- The current year farm gate price will be used for calculating value of the produce. Average price for the season would be found after taking into account high and low prices in the season.
- If the quality of produce is poor, pertinent price would be used.