Working Paper on Social-Ecological Resilience Series
No. 2009-008

Quantifying the Impact of Climatic Change on Yields and Yield Variability of Major Crops and Optimal Land Allocation for Maximizing Food Production in Different Agro-Climatic Zones of Tamil Nadu, India: *An Econometric Approach*

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Vulnerability and Resilience of Social-Ecological Systems

RIHN Research Project E-04

Research Institute for Humanity and Nature (RIHN)
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Abstract

This paper provides a framework for optimal land use planning in the context of climate change. All agricultural activities are very sensitive to climate change resulting in variability in crop yields. Hence it becomes necessary to study the effect of climate change not only on mean yield but also on variability in yield. The quantitative information so obtained should be used for optimal land allocation in order to utilize natural resources in a judicious way. Previous studies using regression techniques concentrated on the estimation of average productivity only but little attention was given for optimal land allocation to competing crops with climate change induced productivities. The problem becomes more important in the context of gradual decline in available land area for agriculture due to urbanization. The present study focuses on these issues for major crops grown in Tamil Nadu State. It employs econometric modelling for estimating the mean yield and yield variability and also covariance between yields of different crops. The mean yields so obtained which reflect the impact of climate change are then used in multi-objective linear programming models for meeting objectives like maximum food grain production, maximum paddy production and minimization of agricultural land area for maintaining at least the current level of production of crops etc. Finally the study attempts to link the optimal food grain production with the projected population of Tamil Nadu for 2021 and 2026 to determine the quantum of food grain availability per individual. The study shows that precipitation and temperature have varying effect on productivity and variability of crops. Trend has positive impact on most of the crops. Also, climate change, as dictated by HADCM3A2a scenario, will have modest impact on crop productivities across the five zones of Tamil Nadu. Zones where paddy is grown traditionally may witness modest increase in productivity followed by increase in variability while many other crops may have decrease in productivity and there is no uniformity in changes in their variability. The study indicates that when land is the only constraint, with climate change induced productivities, optimal allocation of crop area will result in increased production of food grain. These results will be useful for policy makers in finding the gap between supply and demand of food grain for projected population.

Key words: Impact; Climate Change; productivity; Just-Pope Production function; mean yield; yield variability; optimization

要旨

本研究では、気候変動下での最適土地利用計画のフレームワークを提供する。気候変動が農業生産へ与える影響は多方面にわたる。すべての農業生産活動は非常に気候変動に対して敏感であり、作物収量の変動を伴う。よって、気候変動の影響を平均収量のみではなく、変動について研究することが必要である。定量的な情報は自然資源の賢明な利用と土地配分の最適化のために利用されるべきである。回帰分析を使った過去の研究では、平均生産性にのみ注目し、気候変動にともなう作物生産性の競合による最適土地配分にはあまり注目していなかった。都市化によって農業用地が減少している状況では、この問題はさらに重要度を増している。本研究では、この問題をタミルナドゥ州で生産されている主要穀物について検討する。計量経済分析により、平均収量と変動収量、そして異なる作物収量の共分散を推計する。気候変動の影響を反映している推計された平均収量は、多目的線形計画モデルによって最大穀物収量、最大米収量、現在の作物生産を維持するための最小農業用地などの目的を達成するために利用される。最後に、本研究では、２０２１年と２０２６年のタミルナドゥ州の人口予測と最適食料穀物生産をリンクさせて、一人当たりの可能食料穀物量を決定する。研究の結果、降雨量と温度は生産性と穀物の変動にさまざまな影響を与え、また HADCM3A2a シナリオによる気候変動は、タミルナドゥ州の５区域での作物生産性への影響は小さかった。伝統的な稲作地区では変動の増加と共に生産性も増加した。一方、多くの他の穀物の生産性は減少し、同一的な変化はなかった。土地のみが制約である場合、気候変動による生産性の変化により、作物の最適配分により食料穀物の生産は増加する。これらの結果は政策決定者にとって人口予測下での穀物の供給と需要のギャップを知るために有効である。

キーワード：影響、気候変動、生産性、Just-Pope 生産関数、平均収量、収量変動、最適化

1. Introduction

Climate change or global warming is an important issue on which research is being carried out globally. It threatens to have far reaching environmental changes that could have severe impacts on societies throughout the world. Climate change will have multi-dimensional effect on humanity in terms of several socio-economic parameters. It could affect many sectors of human life including agriculture, human health, natural disasters and sea level rise. Of these, agriculture is prone to be affected very much due to climate change because its input variables, viz., precipitation and temperature are mainly climate related variables. It puts agriculture at great risk. If population growth remains high and economic growth in the developing world is low, the impact of climate change will add to the number of undernourished people in the world (IIASA, 2002). Globally several studies focus on the effect of climate change on agricultural production (Kurukulasuriya and Rosenthal, 2003; Carraro and Sgobbi, 2008; Kameyama *et al.*, 2008).

There are many studies to estimate the effects of environmental changes on crop productivity levels using agro-economic models or regression analysis. Assuming that climate change affects the area and productivity of crops three approaches have been widely used in the literature to measure the sensitivity of agricultural production to climate change; agronomic-economic models, cross-sectional models and agro-ecological zone models.

The agronomic-economic method begins with a crop model that has been calibrated from carefully controlled agronomic experiments (FAO, 2000; Kumar and Parikh, 1998a). Crops are grown in field or laboratory settings under different possible future climates and carbon dioxide levels keeping all farming methods across experimental conditions fixed so that all differences in outcomes can be attributed to the climate variables, viz., temperature, precipitation, or carbon dioxide.

In cross-sectional approach, also known as Ricardian method, farm performances are examined across climate zones (Mendelsohn *et al.*, 1994; 1996;

Kumar and Parikh, 1998b). Ricardo observed that land values would reflect land productivity at a site (under competition). In this approach land value is regressed on a set of environmental inputs to measure the marginal contribution of each input to farm income. The approach has been applied to the United States (Mendelsohn *et al.*, 1994; 1996). In the Ricardian analysis, prices of both inputs and outputs are assumed to remain proportionately constant. Climate parameters are precipitation, minimum, maximum and diurnal temperature. Usually climate normals, based on time series averages over a fairly long period of time are considered.

The third approach to measure the impact of climate change utilizes agro-ecological zones (AEZ) (FAO, 1996). The main advantage associated with the agro-ecological zones is that they have been measured and published for all developing countries (FAO, 1992). Detailed information is available about the climate and soil conditions, crops, and technologies being used throughout the tropical zone. The AEZ model develops a detailed eco-physiological process model. Factors such as length of growing cycle, yield formation period, leaf area index, and harvest index etc that explain plant growth are inputs to the model. Existing technology, soil, and climate are combined to predict Land Utilization Types (LUT). Combining these variables, the model determines which crops are suitable for each cell. The impact of changes in climate variables on potential agricultural output and cropping patterns are thus simulated.

In India several research studies are being done now on the effect of climate change on agriculture. The Indian Council of Agricultural Research has set up a Network project to focus on the issue at various locations. India ranks fifth among the top 25 Green House Gas(GHG) emitting countries with a share of 5.5% world GHG and it is projected to increase its emissions by 70% from the year 2000 to 2025 (Baumert *et al.*, 2004). Agronomic studies of India suggested that extensive warming could cause significant reduction in yield. If temperature rose by 4 degree centigrade, grain yield would fall 25- 40 percent, rice yields will fall by 15-25 percent and wheat yields by 30-35 percent (Kumar and Parikh, 1998b). Mendelsohn, *et al.* (1994) indicated that the global warming would decrease net income by 8 percent. In this context, it is important to address this impact of climate change on future crop area, production and productivity of crops using the available data. The agronomic studies indicate that higher temperature are likely to be harmful in many developing countries where the climate is marginal, water is inadequate and temperature are high. Thus the agronomic studies suggest that the countries of the temperate and polar regions could gain productivity whereas developing countries in the subtropical and tropical zones are likely to lose productivity (IPCC, 1990).

There are studies based on Ricardian approach to quantify the impact of global warming on crop production in Tamil Nadu State, India. For example, Palanisami et al. (2009) employed Ricardian type analysis to study the effect of climate variables on area and production of three major crops of Tamil Nadu, State India. The crops selected for study were paddy, groundnut and sugarcane that account for major cultivated area of the state besides being grown in almost all districts. Dependent variables considered for analysis were area and yield of the crops. To account for Ricardian type climate variables, 30 year averages of precipitation, minimum and maximum temperatures and diurnal variations were included as the independent variables. Data from HADCM3 climate change projections for Tamil Nadu region downloaded and extracted from the GCM outputs of IPCC SCENARIOS subdirectory available from the internet site *http://www.ipcc-data.org/sres/hadcm3_download.html* were used in the Ricardian type regressions to estimate the impact of climate change on the area, yield and production levels of the crops analyzed. The results show that there will be a reduction in both area and yields of major crops by about 3.5 to 12.5 percent due to impact of climate change. Consequently overall production will decrease between 9 to 22 percent for these crops.

Many studies focus on the effect of climate variables on mean yield. But fluctuation in crop yields is also important because agricultural production is very sensitive to changes in precipitation and temperature both of which are climate variables. This aspect has been studied only to a much lesser extent (Bindi *et al.* 1996, Mearns *et al.,* 1997). In the recent past econometric models are employed to study the impact of climate change on yield and yield variability.

Chen et al. (2004) and Isik and Devadoss (2006) have used regression analysis by applying a Just-Pope (1978) production functional form to simultaneously estimate the mean and variability in crop productivity. Chen et al. (2004) showed that changes in climate modify crop yield levels and variances in a crop-specific fashion. For sorghum, rainfall and temperature increases are found to increase yield level and variability. On the other hand, precipitation and temperature are individually found to have opposite effects on corn yield levels and variability.

Isik and Devadoss (2006) employed Just-Pope production function to analyze the impacts of projected climate change on the yield of wheat, barley, potato and sugar bees in Idaho, USA. The explanatory variables used were total precipitation, temperature and trend. Their results showed that climate change will have modest effects on the mean crop yields, but will significantly reduce the variance and covariance for most of the crops studied.

The main thrust of quantifying the impact of climate variables on crop production is for formulating optimal allocations of agricultural land among crops and for crop production mix. It seems this aspect has not been studied in depth so far. Optimal allocation of land area in the light of climate change will definitely help to use the natural resources in a judicious way. The climate change induced productivities can be used to estimate maximum possible production under different climate change scenarios by formulating suitable optimization models. It will help for optimal land use planning and allocation. The optimality is achieved by selecting suitable objective functions. Possible objectives are maximizing food grain production, maximizing paddy production (because paddy is the staple food grain for majority of people in the study area of the present paper) and minimizing agricultural area. This becomes a multi goal linear programming problem with constraints on land area, water, labour and other resources. It is a suitable tool to predict the possible changes in the food grain production and utilization of resources under different climate change scenarios. This model has been used in several studies for land use planning at the state level (Aggarwal *et al.,* 2001), sub-regional and regional level (Schipper *et al.,* 1995; Veeneklaas *et al.,* 1991), village level (Huizing and Bronsveld, 1994) and farm level (Schans, 1991). In all these studies climate change was not taken into account to project the optimal land allocation.

Accordingly the purpose of the present study is three fold, viz.

- to quantify the mean and variability in agricultural production in Tamil Nadu State, India due to climate change.
- to use the climate change induced crop productivities for optimal land allocation during 2020 with multiple goals (such as) i) maximization of food grain production ii) maximization of paddy production and iii) minimum agricultural land area required to maintain at least the current level of production
- to examine the food security by linking the projected production of crops and population levels of Tamil Nadu for the years 2021 and 2026.

Thus the results presented in the study will help to formulate methods for resilience from the effects of climate change.

This study contributes to the literature in three ways, viz.,

- it employs an econometric model to examine the impact of climate variables not only on mean yield but also on the variability in yield.
- it uses the climate induced productivities for optimal land allocation with several objectives.
- it links food security with population projection in the light of climate change.

The outline of the paper is as follows: Section 2 describes the econometric model employed to estimate the mean, variance and covariance in productivity of crops. Section 3 describes the study area, crops and variables included for the study. Empirical analysis results which include estimated production functions their properties, elasticities of production and covariance between productivities of crops are presented in section 4. Section 5 describes the effects of climate change on mean and variance of crop productivities. Optimal land allocations among competing crops in the context of climate change induced productivities using multi-goal linear programming are presented in section 6. A brief analysis linking population projection and food grain availability is included in section 7 whereas section 8 presents conclusions and last section presents the limitations of the present study and scope for future research.

2. Econometric modelling and multi-goal linear programming

In the present study we focus on the impact of climate change on major crops production in Tamil Nadu using an econometric approach. Following Chen et al. (2004) and Isik and Devadoss (2006), we assume that the relation between productivity (production per hectare) y_{it} of a crop at agro-ecological zone i during year t and the climatic variables x_{it} viz., precipitation and temperature is given by the Just–Pope stochastic production function (Just and Pope, 1978):

$$y_{it} = f(x_{it};\beta) + \omega_{it} h(x_{it};\delta)^{0.5} \tag{1}$$

where ω_{it} is the stochastic term with mean zero and variance σ^2 and β and δ are the production function parameters to be estimated using historical data. The independent variables (x_{it}) used for the estimations include a constant, annual precipitation (P), temperature (T), trend (t) and 4 zonal dummy variables. The expected crop productivity is given by $E(y_{it}) = f(x_{it};\beta)$ and crop variability is given by $V(y_{it}) = \sigma_{\omega}^2 h(x_{it};\delta)$. Hence the functions $f(x_{it};\beta)$ and $h(x_{it};\delta)$ are called mean and variance functions respectively. The derivatives of the variance function $h(x_{it};\delta)$ w.r.t. the input variables, viz., precipitation and temperature can be used to identify whether a climate variable increases or decreases crop variability. So if, $h_x > 0$, it indicates that the corresponding input variable x is risk increasing , if $h_x < 0$ implies risk decreasing. Thus by employing Just-Pope production function, not only the mean yield but also yield variability and effect of an input variable on risk also can be simultaneously estimated.

Estimation of the above production function can be considered as estimation with heteroscedastic errors as in the following equation (Saha et al., 1997; Kumbhakar, 1997)

$$y_{it} = f(x_{it};\beta) + u_{it} \tag{2}$$

where $u_{it} = \omega_{it} h(x_{it};\beta)^{0.5}$ with $E(u_{it}) = 0$ and $Var(u_{it}) = \sigma^2 h(x_{it};\delta)$. There are two approaches suggested in many studies to estimate the mean and variance functions of the Just-Pope production function. They can be estimated using feasible generalized least squares or the maximum likelihood method. However, Saha et al. (1997) have shown that the estimators under the maximum likelihood method are consistent and more efficient than the feasible generalized least squares method. Hence in our study maximum likelihood method was used to estimate the Just-Pope production function.

Before that, the forms of the mean and variance functions have to be explicitly specified. For this it was assumed that the zonal effects are fixed. This in turn implied the use of zonal dummy variables. Following Isik and Devadoss (2006), the following two specific forms are assumed for the mean function $f(x_{it};\beta)$. i) linear form:

$$f(x_{it};\beta,d) = \beta_0 + \beta_1 P + \beta_2 T + \beta_3 t + \sum_{i=1}^{i=R-1} d_i D_i \tag{3}$$

and ii) quadratic form:

$$f(x_{it};\beta,d) = \beta_0 + \beta_1 P + \beta_2 T + \beta_3 t + \beta_4 P^2 + \beta_5 T^2 + \beta_6 PT + \sum_{i=1}^{i=R-1} d_i D_i \tag{4}$$

where D_i, i=1, 2,...,4 are the zonal dummy variables taking values 1 and 0. The variance function $\sigma_\omega^2 h(x_{it};\delta,\eta)$ with $\sigma_\omega^2 = 1$ was assumed to have exponential form

$$h(x_{it};\delta,\eta) = \exp(\delta x_{it} + \eta D) = \exp\left(\delta_0 + \delta_1 P + \delta_2 T + \delta_3 t + \sum_{i=1}^{i=R-1} \eta_i D_i\right) \tag{5}$$

This form was introduced first by Harvey (1976) and subsequently employed by several studies (Isik and Devadoss (2006), Isik and Khanna (2003), Asche and Tveteras, (1999)). The main advantage of this form is that it ensures positive output variance. Another advantage is that the riskiness of an input variable can be readily obtained by the sign of the coefficient of that variable in the function. For example, with the above functional form, it can be easily checked that $\frac{\partial h}{\partial P} = \delta_1 h$. Since the variance function h is always positive, precipitation will be risk increasing if $\delta_1 > 0$ and it will be risk decreasing if $\delta_1 < 0$.

Estimation of the parameters

Under the assumption that $\omega_{it} \sim N(0,1)$ the Likelihood function is given by

$$L = \left[\frac{1}{2\pi}\right]^{N/2} \prod_{t=1}^{T} \prod_{i=1}^{R} \left[\frac{1}{h(x_{it};\delta)}\right]^{1/2} \exp\left[-\{y_{it} - f(x_{it};\beta)\}^2 / 2h(x_{it};\delta)\right] \tag{6}$$

where R is the number of zones and T is the number of time periods and $N=RT$. So the log likelihood function is given by

$$\ln L = -\frac{1}{2}\left[N \ln(2\pi) + \sum_{t=1}^{T}\sum_{i=1}^{R} \ln\left(h(x_{it};\delta)\right) + \sum_{t=1}^{T}\sum_{i=1}^{R} \frac{\{y_{it} - f(x_{it};\beta)\}^2}{h(x_{it};\delta)}\right] \tag{7}$$

which has to be maximised to estimate the parameter vectors β and δ.

Estimation of covariance

Farmers usually produce more than one crop in a given year. So it is important to determine how the covariance among crops is affected by the climate variables. For this, after estimating the production functions, we computed the residuals for the k^{th} and j^{th} crops: $u_{itk} = y_{itk} - f(x_{itk};\beta_k)$; $u_{itj} = y_{itj} - f(x_{itk};\beta_j)$ where β_k and β_j are the parameter vectors corresponding to k^{th} and j^{th} crop respectively. Then the observed covariance between k^{th} and j^{th} crops is given by $u_{itk}u_{itj}$ and it is assumed that, for simplicity, this product is linearly related to the climate variables and so we run the following regression line $u_k u_j = \alpha_0 + \alpha_1 P + \alpha_2 T + \alpha_3 t + \varepsilon$ to estimate the effect of climate variables on the covariance between crops.

Multi-Goal Linear Programming:

Multi-Goal Linear Programming (MGLP) is an effective tool in addressing the situations where multiple goals are to be handled when the resources are constrained. In this study, after estimating the climate change induced productivities of crops, they were used for obtaining optimum land area to satisfy the following objectives and constraints:

I. Objective Functions:-

a) Maximization of food grain production during 2020
b) Maximization of paddy production during 2020
c) Minimization of agricultural area needed for normal production during 2020.

a) ***Maximization of food grain production* (this includes paddy, sorghum , maize and pulses**) in the five agro-ecological zones of Tamil Nadu

The objective function coefficients are the productivities of food grain crops (in tonnes/ha) in five agro-ecological zones in three seasons. The following constraints were imposed:

i) total land area used in each season in each agro-ecological zone by each one of the nine food crops is less than or equal to maximum land area available

ii) areas under annual crops viz., sugarcane and banana are same in all the three seasons

iii) production of each one of the five crops(viz., cotton, chillies, sugarcane, banana and groundnut) should be at least equal to their normal level of production

iv) share of paddy area in North Eastern, Cauvery and Southern zones in each season should be maintained (these are traditionally rice cultivating zones).

An analysis of percentage share of paddy area in each season in each zone shows that out of the five zones, North East, Cauvery Delta and Southern zones occupy major share as shown in the following table:

Percentage share of each zone in paddy area			
Zone	Season 1	Season 2	Season 3
NE	48	25	69
NW	12	7	8
W	5	4	2
CD	22	33	8
SZ	13	31	13
Total	100	100	100

It is likely that these shares of the zones should be continued in future also. Hence constraints were added to reflect the above percentages for the three major zones, viz., NEZ, CDZ and SZ. For example, the constraint for NEZ for first season will be

$$0.52NEZarea - 0.48NWZarea - 0.48WZarea - 0.48CDZarea - 0.48SZarea \geq 0$$

and

v) total cropped area under all crops is less than or equal to normal crop area.

b) ***Maximization of paddy production:***

The objective function is sum of productivities of paddy in 5 zones in each season and all the constraints that were imposed for maximizing food grain production were applied here also.

c) ***Minimization of agricultural area for maintaining at least normal production***

This objective ensures that at least the normal productions of all crops are maintained with minimum agricultural area. So the objective function is the sum of agricultural area allotted to each crop in each season in each zone and all the constraints used for maximizing food grain production were used here also.

3. Study area, data used, variables and their trends

The study area is Tamil Nadu State, India. Based on precipitation distribution, irrigation pattern, soil characteristics and other physical, economic and social characteristics, India is classified into 93 agro-climatic regions and Tamil Nadu falls into seven agro climatic zones: North East, North West, West, South, Cauvery Delta, High Precipitation and High Altitude (Fig.1)

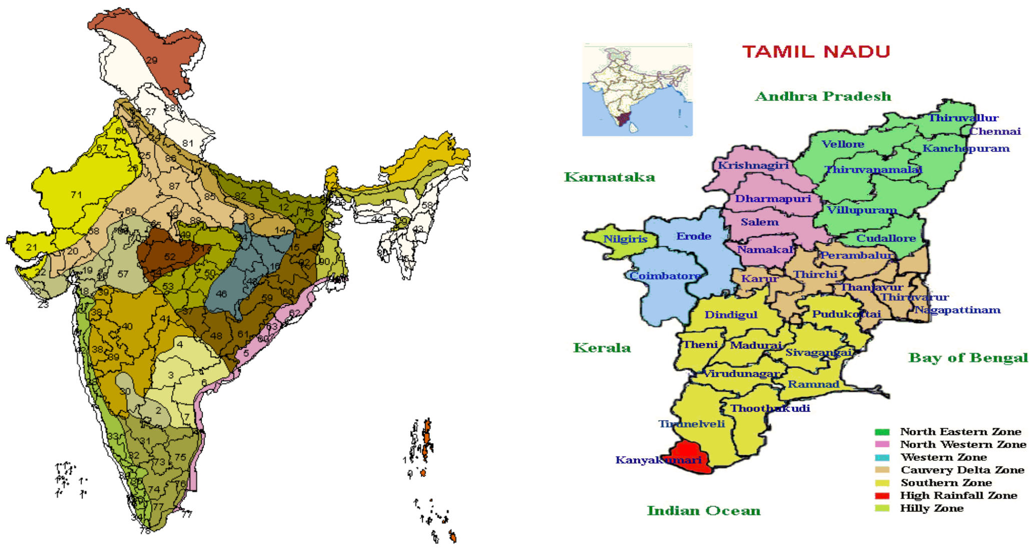

Fig.1. Agro-Climatic Zones of India and Tamil Nadu State

a) Crop Area

Table 1 summarises the districts and geographical area falling under each zone of Tamil Nadu. The present study focuses on the first five zones of Tamil Nadu and it excludes high precipitation and hilly zones which occupy less than 4% of the geographic area. Of the five zones, the Southern zone and North East zone rank the first two places with 31.8% and 24% of the total area. The study aims to quantify the impact of CC on the major nine crops viz., paddy, sorghum, maize, cotton, chillies, pulses, sugarcane, groundnut and banana. Historical data on area and production of these crops for the 30 years period, 1976-77 to 2005-06 were collected from the Government of Tamil Nadu publication, *Season and Crop Report* for the above periods. The data are available district wise only. So zone wise area and production were estimated by aggregating the figures for the districts which correspond to each zone. Fig.2 provides average percentage share of area of these crops in each zone during the last five years viz., 2001-02 to 2005-06. Paddy is the major crop in the three zones North East, Cauvery Delta, North East and Southern with shares in the respective zones being 67%, 50% and 48%.Groundnut and Sorghum are respectively predominant crops in North West and Western zones with shares 24% and 29%. In all zones combined, paddy is grown in about 44% of the total cropped area followed by groundnut and pulses each grown at 15% of the cropped area.

Table 1. Agro-Ecological Zones and Districts of Tamil Nadu

Zone	Districts	Geographical area (sq.km.)	Percentage share to total area
North East	Kancheepuram	4481	
	Thiruvallur	3550	
	Vellore	6077	
	Thiruvannamalai	6190	
	Cuddalore	3706	
	Villupuram	7190	
	Total	**31194**	**24.0**
North West	Salem	5245	
	Namakkal	3404	
	Dharmapuri	4498	
	Krishnagiri	5124	
	Perambalur	3694	
	Total	**21965**	**16.9**
Western	Erode	8209	
	Coimbatore	7469	
	Karur	2901	
	Total	**18579**	**14.3**
Cauvery Delta	Thanjavur	3476	
	Nagapattinam	2417	
	Thiruvarur	2377	
	Trichy	4511	
	Total	**12781**	**9.8**
Southern	Pudukkottai	4651	
	Madurai	3696	
	Dindugul	6058	
	Theni	2869	
	Ramnad	4175	
	Sivagangai	4143	
	Virudhunagar	4283	
	Thirunelveli	6810	
	Thoothukudi	4621	
	Total	**41306**	**31.8**
High Precipitation	Kanniyakumari	1684	1.3
Hilly	The Nilgiris	2549	2.0

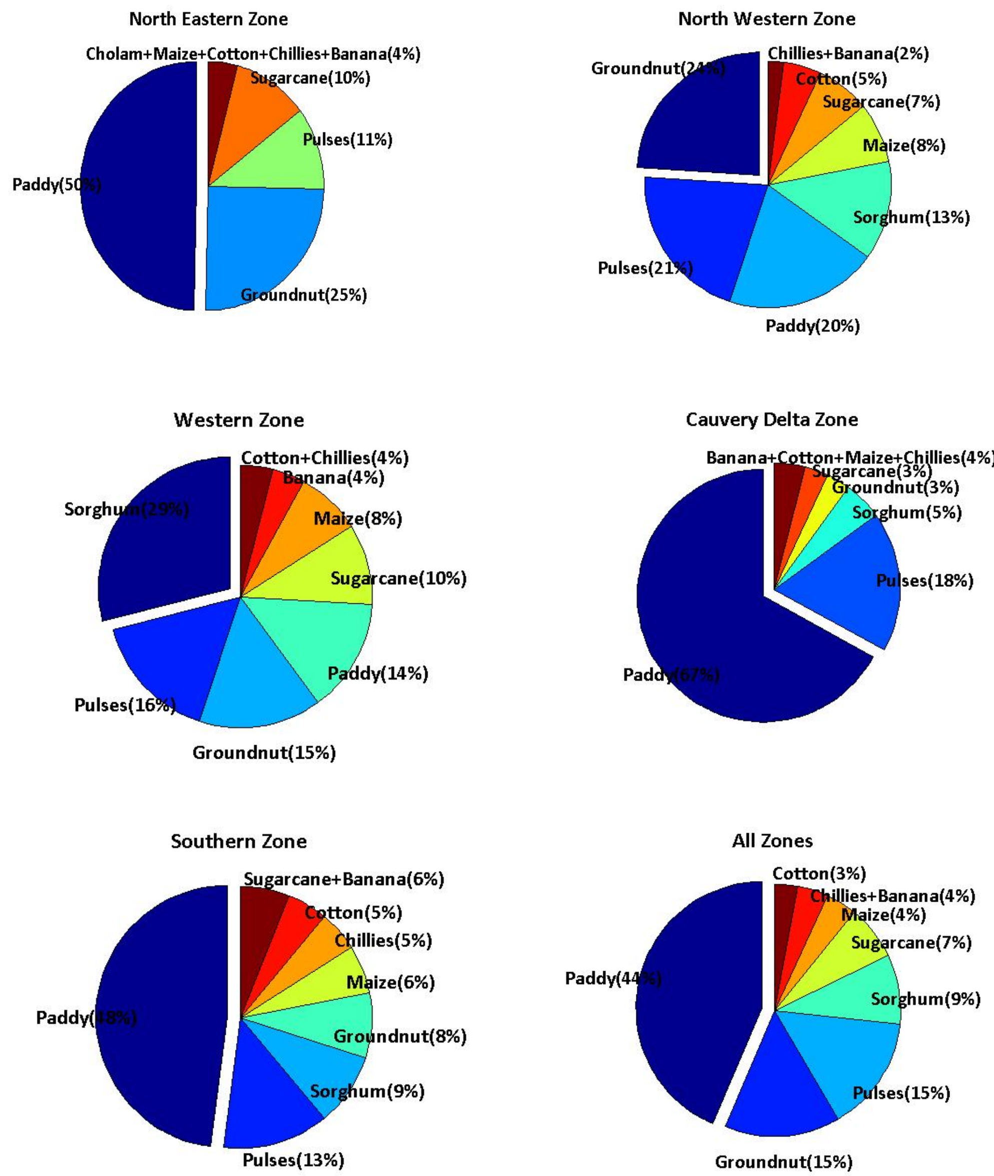

Fig.2. Shares of crop areas in different agro-ecological zones of Tamil Nadu

The total cropped area in Tamil Nadu has declined gradually over years. Table 2 presents the difference between normal area in '000ha (average agricultural area for the last five years viz., 2001-02 to 2005-06) and the base line area (average agricultural area for the last thirty years viz., 1976-77 to 2005-06). It shows that except for maize, sugarcane and banana, area under all other crops have decreased and the total cropped area has also decreased from 4808.15 ‘000ha to 3922.67 ‘000 ha, a decrease of 18.4%. This decrease in cropped area coupled with demand for higher productivity and production due to population explosion, imply that land area has to be optimally allocated to meet the targets of production.

Table 2. Difference between normal and baseline cropped area (‘000ha)

Zone	Paddy	Sorghum	Maize	Sugarcane	Cotton	Gnut	Chillies	Banana	Pulses	Total
NEZone	-126.35	-24.99	4.18	20.76	-3.12	-97.86	-1.48	1.19	23.07	-204.59
NWZone	1.65	-28.17	38.55	8.20	-6.88	-37.52	1.18	0.23	-30.21	-52.98
Wzone	-31.40	-37.10	13.10	4.16	-13.97	-40.19	-1.54	7.21	-11.46	-111.19
CDZone	-136.92	-62.75	3.66	-6.71	-4.43	-50.66	-7.61	-2.31	-27.27	-295.01
Szone	-100.77	-39.07	35.87	7.13	-74.42	-55.01	4.27	4.69	-4.40	-221.71
Total	-393.79	-192.08	95.35	33.53	-102.83	-281.24	-5.19	11.01	-50.26	-885.48

b) Crop Production

Crops productions exhibit wide variation between the zones. Table 3 exhibits the normal productions, viz., average agricultural production for the last five years viz., 2001-02 to 2005-06. North East zone produces 1726.3 kilotons of paddy followed by Southern and Cauvery Delta zones with 1252.9 and 1088.5 kilotons respectively. These are respectively 37, 27 and 23 percentages of the total production of paddy. Similarly Southern zone produces 39% of sorghum,

Table 3. Normal production of crops in different agro-ecological zones of Tamil Nadu (in kilotons)

Zone	Paddy	Sorghum	Maize	Sugarcane	Cotton	Groundnut	Chillies	Banana	Pulses
NE Zone	1726.3	17.3	9.1	12852.4	19.3	523.8	1.9	403.3	50.6
NW Zone	359.4	73.1	61.8	4724.9	44.5	212.2	3.3	177.3	53.1
W Zone	209.5	39.6	44.3	4901.1	20.8	94.2	2.2	605.3	21.1
CD Zone	1088.5	18.6	8.1	2364.6	16.8	45.9	2	580.7	33.9
S Zone	1252.9	94.4	96.1	3980.2	56.6	121.5	30.3	1436.4	53.6
Total	4636.6	243	219.4	28823	158	997.6	39.7	3202.9	212.2

North West zone (30%) and Western zone (16%). Again, Southern zone produces maximum percentage of maize (44%), followed by North Western zone (28%) and

Western zone (20%). The first three percentages of production of other crops in different zones are provided in the Fig.3.

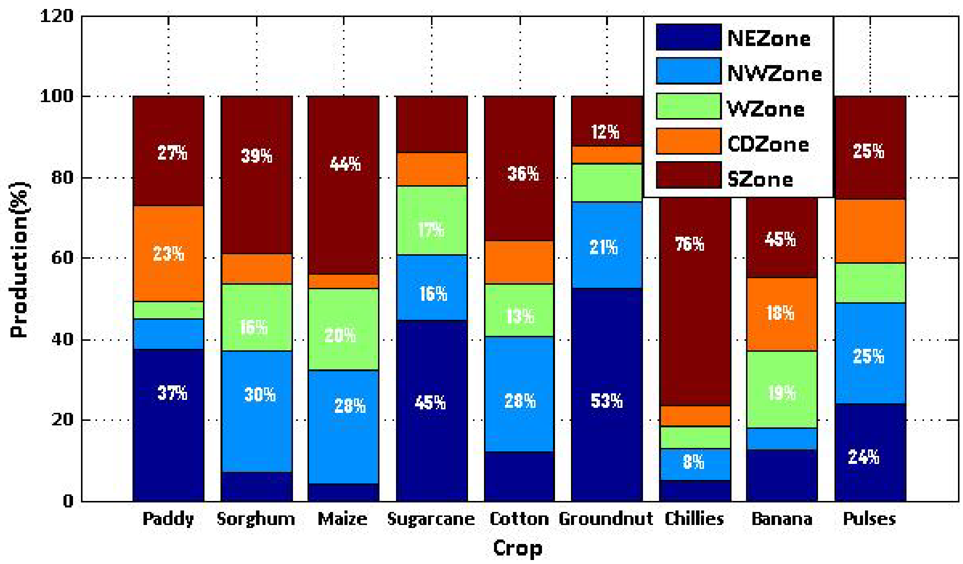

Fig.3 Shares of Agro-Ecological Zones in crop production in Tamil Nadu

c) Crop Productivity

Table 4 gives the descriptive statistics of the crop productivity for each crop in each zone. West zone has the highest productivity of paddy with an average of 3.507 tons/ha followed by North West zone with productivity of 2.964 tons/ha. It should be noted that these two zones rank the last two places among the five zones in terms of area under paddy. Among the other three major zones for paddy production, North Eastern zone has a productivity of 2.768 tons/ha. The average productivity of all the five zones is 2.863 tons/ha. Both North Western zone and Cauvery Delta zone have high variability in productivity with standard deviations of 0.743 and 0.741 tons/ha. Southern zone has the highest mean productivity of 1.222 tons/ha for Sorghum and Western zone has the lowest mean productivity of 0.516 tons/ha. Cauvery Delta zone has the highest mean productivity of 2.027 tons/ha for Maize with a standard deviation of 0.618 tons/ha. Among the five zones, the productivity of cotton by Western zone is maximum followed by North Eastern zone. But the Western zone has highest variability in productivity with a standard deviation of 0.735 tons/ha. The highest productivity of Chillies is 1.034 tons/ha by North Eastern zone.

Table 4. Descriptive statistics of the crop productivity

Zone	NEast	NWest	West	Cauvery Delta	Southern	Tamil Nadu
Paddy (tons/ha)						
Mean	2.768	2.964	3.507	2.613	2.463	2.863
Std.	0.575	0.743	0.727	0.741	0.668	0.775
Min	1.692	1.81	2.229	1.647	1.442	1.442
Max	3.608	4.994	4.792	4.983	3.73	4.994
Sorghum (tons/ha)						
Mean	1.17	1.035	0.516	0.758	1.222	0.94
Std.	0.228	0.275	0.14	0.238	0.26	0.353
Min	0.787	0.504	0.303	0.361	0.74	0.303
Max	1.68	1.63	0.784	1.329	1.845	1.845
Maize (tons/ha)						
Mean	1.564	1.55	1.297	2.027	1.789	1.645
Std.	0.374	0.384	0.231	0.618	0.53	0.506
Min	0.784	0.977	0.958	1.072	0.994	0.784
Max	2.606	2.754	2.056	2.952	3.211	3.211
Cotton (bales/ha) (in bales of 170 Kg lint each)						
Mean	2.041	1.831	2.363	1.701	1.293	1.846
Std.	0.705	0.478	0.735	0.461	0.275	0.656
Min	1.181	0.859	1.004	0.896	0.826	0.826
Max	4.123	2.958	4.701	2.78	1.847	4.701
Chillies (tonnes/ha)						
Mean	1.034	0.636	0.784	0.708	0.653	0.763
Std.	0.287	0.305	0.459	0.272	0.304	0.359
Min	0.597	0.306	0.177	0.262	0.3	0.177
Max	1.91	1.916	2.895	1.499	2.111	2.895
Pulses (tonnes/ha)						
Mean	0.452	0.434	0.354	0.339	0.384	0.392
Std.	0.070	0.096	0.077	0.087	0.061	0.090
Min	0.309	0.234	0.219	0.153	0.237	0.153
Max	0.590	0.597	0.582	0.509	0.472	0.597
Sugarcane (tonnes/ha)						
Mean	99.558	103.266	112.641	104.955	106.153	105.315
Std.	9.097	13.509	8.460	8.488	12.229	11.277
Min	77.463	44.369	93.833	82.780	82.263	44.369
Max	115.198	119.356	131.298	119.322	144.227	144.227
Groundnut (tonnes/ha)						
Mean	1.419	1.313	1.402	1.417	1.304	1.371
Std.	0.376	0.338	0.269	0.340	0.327	0.332
Min	0.827	0.583	0.733	0.945	0.857	0.583
Max	2.133	1.893	1.842	2.162	1.889	2.162
Banana (tonnes/ha)						
Mean	29.055	31.745	31.415	34.916	33.882	32.203
Std.	8.977	10.082	9.242	9.353	11.394	9.930
Min	14.090	15.929	16.447	19.879	16.562	14.090
Max	54.775	50.890	48.448	53.231	56.348	56.348

d) Trends in Crop Productivity

Fig.4 gives a graphical representation of the trends in productivity of crops zone wise and Table 5 gives the growth rates of productivities in different agro-ecological zones of Tamil Nadu. The results show that in all the zones productivity of paddy has registered an increasing trend. The Southern zone has the highest growth rate of 1.91% and the Cauvery Delta zone has the lowest growth rate of 0.82% during the past thirty years. The positive growth rate in productivity of paddy in all the five zones can be attributed to the adoption of new hybrid varieties and new technologies by the farmers. Sorghum (also known as cholam), cotton and chillies had slightly decreasing productivity trend over years while all other crops showed increase in productivity. The overall growth rate of productivity of banana was highest with 2.83% followed by groundnut with 2.28%.

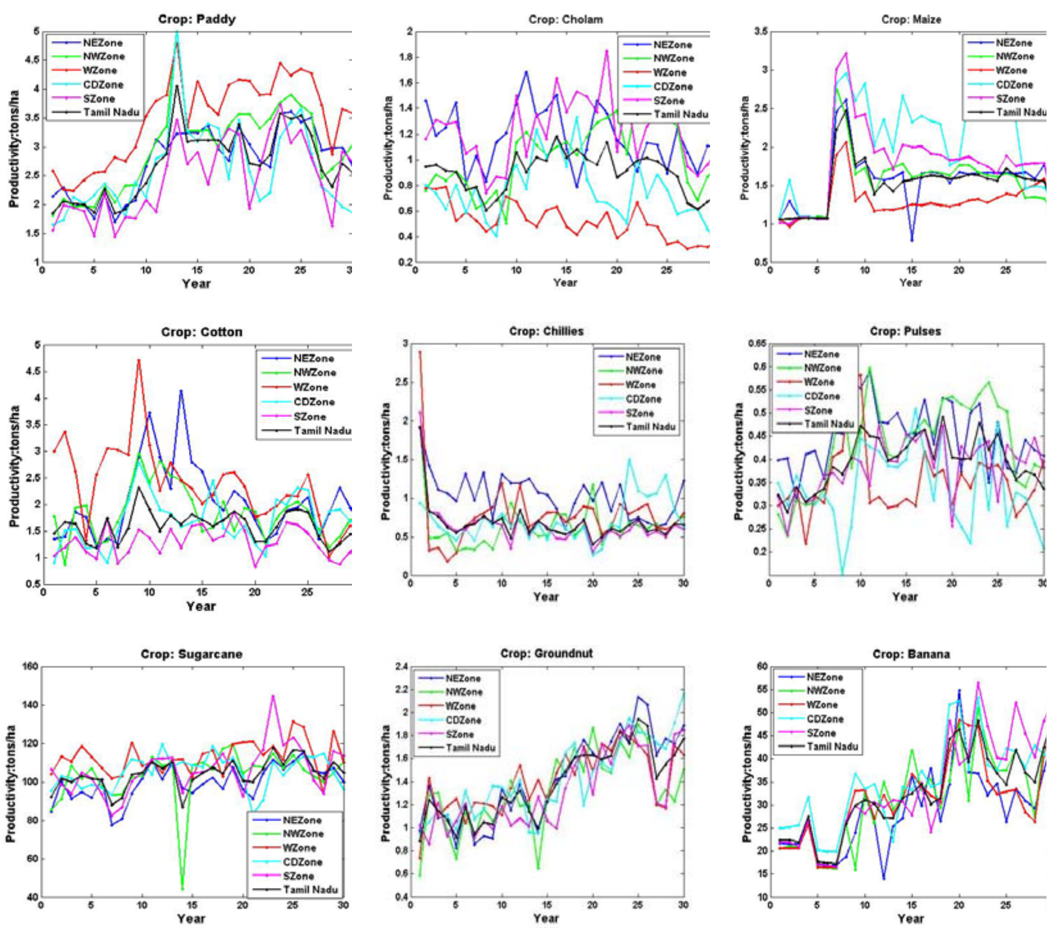

Fig.4. Trends in zone wise productivity of different crops

Table 5. Growth Rates (%) of productivity of crops in different Agro-Ecological Zones of Tamil Nadu

	Paddy	Sorghum	Maize	Sugarcane	Cotton	Groundnut	Chillies	Banana	Pulses
NE Zone	1.82	-0.58	0.83	0.63	0.11	2.66	-1.79	2.50	1.82
NW Zone	1.84	1.38	0.54	0.49	-0.22	2.05	0.73	3.09	1.84
W Zone	1.76	-2.35	0.68	0.26	-2.26	1.57	1.00	2.51	1.76
CD Zone	0.82	-0.88	0.92	0.20	1.06	2.33	1.14	2.48	0.82
S Zone	1.91	0.07	0.89	0.63	0.04	2.19	-1.66	3.53	1.91
Tamil Nadu	1.59	-0.28	0.82	0.44	-0.15	2.28	-1.28	2.83	1.59

e) Crop growing months

The crop growing seasons and months vary over zones. However, for the purpose of the present study, based on the common growing seasons and recommendations from Tamil Nadu Agricultural University and Department of Agriculture, Government of Tamil Nadu (Crop Production Guide), Table 6 was prepared showing the months in which various crops are grown.

Table 6. Growing months of crops in Tamil Nadu

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Paddy	0	0	0	0	0	1	1	1	1	1	0	0
Sorghum	0	0	0	0	0	1	1	1	1	0	0	0
Maize	0	0	0	0	0	0	0	1	1	1	1	0
Cotton	1	0	0	0	0	0	0	1	1	1	1	1
Chillies	1	1	1	1	0	0	0	0	0	0	0	0
Pulses	0	0	0	0	0	0	1	1	1	1	1	0
Sugarcane	1	1	1	1	1	1	1	1	1	1	0	0
Groundnut	0	0	0	0	0	1	1	1	1	0	0	0
Banana	1	1	1	1	1	1	1	1	1	1	1	1

An entry 1 in a cell means that the crop in the row is grown in the month specified in the column

f) Climate variables

The present study aims to quantify the impact of the climate related variables, viz, precipitation and temperature on the productivity of crops. The precipitation data are the time series of the total precipitation within a year, that is, annual precipitation and it reflects both precipitation falling directly on a crop and inter-seasonal water accumulation within a year. These data were obtained from India Meteorological Department, Pune for the thirty year period. Data for stations that belonged to each zone were pooled and average precipitations were worked out to estimate the precipitation for each zone. Table 7 provides a summary of the descriptive statistics related to precipitation used in the present study. It shows that Cauvery Delta Zone had the highest mean annual precipitation of 11.291 cm with a standard deviation of 1.89 cm. The Western Zone had the highest variability in precipitation with a standard deviation of 3.39 cm. It had the lowest mean precipitation of 6.84 cm. On the average, Tamil Nadu had an average precipitation of 9.59 cm during the period under study.

Table 7. Average precipitation (in cm) in different zones

Variable	Zone	Mean	Std.	Min	Max
Precipitation (cm)	N East	11.029	2.314	6.799	17.299
	N West	8.985	1.660	5.365	12.553
	West	6.839	3.390	4.201	22.716
	Cauvery Delta	11.291	1.887	7.155	15.299
	Southern	9.813	1.467	7.189	13.804
	Tamil Nadu	9.591	2.745	4.201	22.716

Temperature data for each crop were worked out for each zone as the average of the observations for the growing season of the crop. The summary statistics for the temperature data used in the presented study are reported in Table 8. The trends in average temperature during growing seasons of different crops in the five zones are depicted graphically in Fig.5.

The mean precipitation and temperature of the observed data for the period 1976-77 to 2005-06 for each zone constitute the baseline scenario climate variables.

To project the mean and variance of crop productivity due to climate change, data for the period 2010-2039 from HADCM3 climate change projections for Tamil Nadu region were downloaded and extracted from the GCM outputs of IPCC SCENARIOS subdirectory available from the internet site *http://www.ipcc-data.org/sres/ hadcm3_download.html*. This website provides the values for a combination of 7008 grids with 96 longitudes starting from 0.00° E to 356.25° E

Table 8. Descriptive statistics of the Temperature (°C) Data

Zone	N East	N West	West	Cauvery Delta	Southern	Tamil Nadu
Paddy						
Mean	29.61	28.44	27.05	29.55	26.29	28.19
Std.	0.38	0.34	0.46	0.49	0.26	1.39
Min	28.83	27.74	25.91	28.28	25.74	25.74
Max	30.33	29.21	28.17	30.51	26.92	30.51
Sorghum						
Mean	30.09	28.74	27.09	29.94	26.62	28.50
Std.	0.41	0.39	0.47	0.49	0.30	1.49
Min	29.31	27.89	25.81	28.65	26.03	25.81
Max	30.88	29.66	28.29	30.87	27.42	30.88
Maize						
Mean	28.08	27.42	26.66	28.39	25.28	27.17
Std.	0.35	0.33	0.41	0.49	0.23	1.18
Min	27.40	26.81	25.79	26.99	24.82	24.82
Max	28.76	28.10	27.60	29.39	25.73	29.39
Cotton						
Mean	26.85	26.57	25.92	27.34	24.43	26.22
Std.	0.28	0.31	0.37	0.44	0.24	1.06
Min	26.17	26.11	25.13	26.17	24.06	24.06
Max	27.44	27.18	26.70	28.09	24.89	28.09
Chillies						
Mean	27.28	28.15	27.55	27.78	24.70	27.09
Std.	0.42	0.46	0.50	0.54	0.38	1.32
Min	26.12	27.07	26.45	26.01	23.70	23.70
Max	28.40	29.17	28.63	28.75	25.88	29.17
Pulses						
Mean	28.51	27.71	26.68	28.74	25.57	27.44
Std.	0.38	0.34	0.41	0.48	0.25	1.24
Min	27.76	27.09	25.75	27.41	25.07	25.07
Max	29.23	28.42	27.68	29.72	26.16	29.72
Sugarcane						
Mean	28.95	28.59	27.49	29.01	25.80	27.97
Std.	0.29	0.27	0.42	0.48	0.25	1.27
Min	28.12	28.01	26.54	27.74	25.15	25.15
Max	29.45	29.07	28.39	29.84	26.54	29.84
Groundnut						
Mean	30.09	28.74	27.09	29.94	26.62	28.50
Std.	0.41	0.39	0.47	0.49	0.30	1.49
Min	29.31	27.89	25.81	28.65	26.03	25.81
Max	30.88	29.66	28.29	30.87	27.42	30.88
Banana						
Mean	28.32	28.05	27.06	28.48	25.36	27.45
Std.	0.26	0.26	0.39	0.46	0.24	1.21
Min	27.63	27.48	26.14	27.27	24.79	24.79
Max	28.75	28.55	27.89	29.22	26.03	29.22

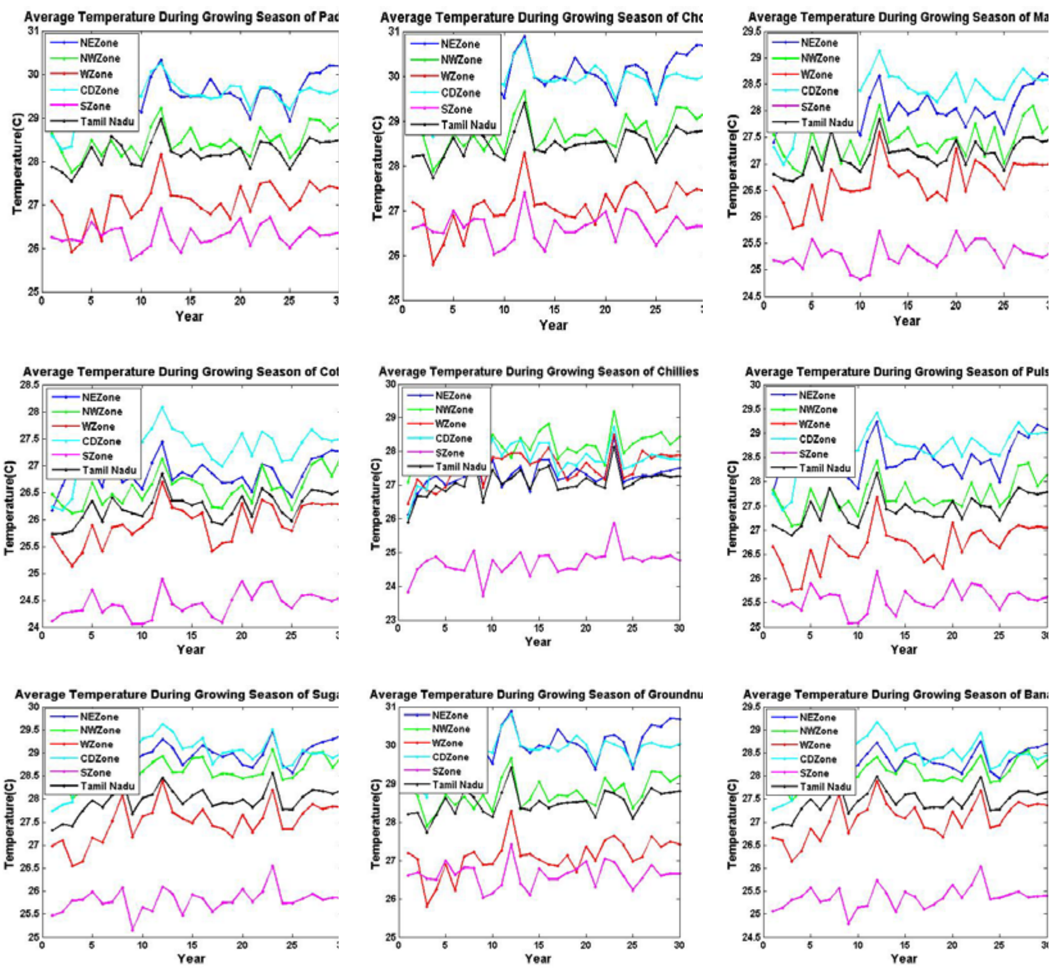

Fig. 5 Average temperature during growing seasons of different crops

at an increment of 3.75° and 73 latitudes starting from 90.0°N to 90.0°S with an increment of 2.5°. Tamil Nadu has six regions falling in the grid range 75° to 82.5° longitude and 7.5° to 12.5° latitude (Fig.6).

The mean precipitation and temperature so computed are called projected values. Table 9 below gives the baseline and projected climate variables and expected percentage increases. Thus the HADCM3 climate change projections predict that there will be an 8% increase in precipitation in Cauvery Delta zone. Similarly Southern zone will have an increase of 6.1% in precipitation during 2010-39. In other zones the increase will be comparatively less. The percentage increase in temperature will be between 2.8 to 3.5 in the five zones with maximum percentage increase of 3.5% in North East zone.

Fig.6 Climate change scenario - Regionalization

Based on HADCM3 runs
Latitude : 2.5 deg
Longitude : 3.75 degree
Tamilnadu has 6 regions

Region 1: Northeast
(78.75 to 82. l on x 12.5 to 15 lat)

Region 2: Northwest
(75 to 78.5 lon x 12.5 to 15 lat)

Region 3: Centraleast
(78.75 to 82.5 lon x 10 to 12.5 lat)

Region 4: Centralwest
(75 to 78.75 lon x 10 to 12.5 lat)

Region 5: Southeast
(78.75 to 82.5 lon x 7.5 to 10 lat)

Region 6: Southwest
(75 to 78.75 lon x 7.5 to 10 lat)

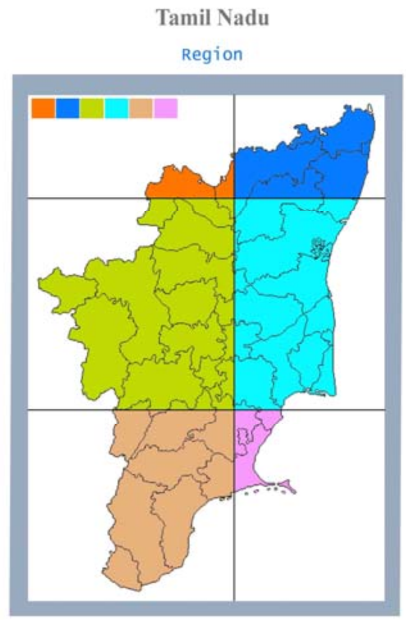

Table 9 Baseline and projected climate variables

zone	Baseline Precipitation (in cm)	2010-39 Precipitation (in cm)	Percentage Increase	Baseline Temperature (°C)	2010-39 Temperature (°C)	Percentage Increase
NEZ	11.0	11.3	2.1	28.3	29.3	3.5
NWZ	9.0	9.0	0.2	28.0	28.8	2.8
WZ	6.8	6.9	1.6	27.1	27.8	2.6
CDZ	11.3	12.2	8.0	28.5	29.4	3.2
SZ	9.8	10.4	6.1	25.4	26.0	2.6

4. Empirical Analysis

Before fitting the production functions, it is important to test whether there exists significant differences between zones in productivity of crops. Introduction of dummy variables for the zones in the empirical model described in section 2 is justified only if the crop productivities differ significantly across the zones. This was tested by performing analysis of variance for each crop with zones as treatments and crop productivities for each year as observations with the null hypothesis that there is no difference between the five agro-ecological zones w.r.t. productivity of the crops under study. The tests showed that except for Sugarcane, Groundnut and Banana for all other crops the productivities differ significantly and so for all these six crops introduction of dummy variables for the zones was justified.

Next for each crop, the Just-Pope production function was estimated by maximizing the log-likelihood function (equation 7) separately for linear and quadratic mean functions. Table 10 provides the estimated coefficients for the mean functions and variance function, standard errors of the coefficients, log-likelihood function, Wald's chi-square statistic and the root mean square error.

The sign and significance of the estimated coefficients for the precipitation in the mean function for paddy differ between the two alternative functional forms. In the linear form, precipitation had strong (1%) negative influence on productivity whereas it had weak (10%) positive effect for the quadratic form. For temperature the sign of the coefficient is positive for both forms but the level of significance is different; it is not significant in the linear form but strongly significant in quadratic form. The square terms of precipitation and temperature and their interaction terms all have negative effect on mean paddy productivity. Trend has positive and significant impact on productivity at 1% level for both linear and quadratic forms. The Western zone dummy variable was strongly significant for both forms. All other dummy variable coefficients are not statistically significant. For the variance function of paddy productivity, precipitation had significant negative impact and the impact of temperature is significant and positive. This means that precipitation is a risk decreasing input variable and temperature is a risk increasing input. That is, higher the precipitation lower will be the variability in productivity of paddy and higher the temperature, higher will be the variability. For both linear and quadratic models, trend had positive and significant impact on variability as in the case of mean function. Since time variable is used as a proxy for technology, this implies that paddy productivity increases over time because of the technological progress but at the same time yield variability also increases. This finding confirms the results of Isik and Devadoss (2006) and that of Anderson and Hazell (1987) who found that improved technology augments both the mean and variability of crop

Table 10. Just and Pope Production Function – Parameter Estimates

Mean Productivity	Paddy				Sorghum				Maize			
	Linear		Quadratic		Linear		Quadratic		Linear		Quadratic	
	Coefficient	Std.Err.	Coefficient	Std.Err.	Coefficient	Std.Err.	Coefficient	Std.Err.	Coefficient	Std.Err.	Coefficient	Std.Err.
Precipitation (R) (in Cm)	-0.0198***	0.007	0.5776*	0.322	0.0076*	0.004	0.0879	0.124	-0.0135	0.012	0.0441	0.333
Temperature (T)(in °C)	0.1501	0.094	5.9877***	1.524	-0.0135	0.038	-0.7812	0.724	0.0061	0.074	2.7459	2.350
Trend(year)	0.0569***	0.006	0.0569***	0.005	-0.0094***	0.002	-0.0098***	0.002	0.0033	0.004	0.0023	0.004
R^2			-0.0020	0.002			-0.0008	0.001			-0.0033	0.002
T^2			-0.1009***	0.028			0.0142	0.013			-0.0502	0.044
R*T			-0.0203*	0.012			-0.0023	0.005			0.0001	0.013
NE zone	-0.1542	0.315	-0.1616	0.311	-0.0404	0.147	-0.0843	0.157	-0.1656	0.221	-0.3108	0.256
NW zone	0.0903	0.230	-0.2356	0.218	-0.1186	0.108	-0.1039	0.110	-0.2424	0.176	-0.4306*	0.235
W zone	0.6535***	0.119	0.5788***	0.122	-0.7109***	0.058	-0.6791***	0.064	-0.4855***	0.128	-0.6326***	0.206
CD zone	-0.2786	0.285	-0.4242	0.275	-0.4638***	0.145	-0.4948***	0.152	0.2645	0.261	0.1587	0.279
Constant	-2.0747	2.435	-86.2056***	21.125	1.6819*	0.983	11.9678	9.963	1.6797	1.870	-35.7227	31.576
Variability in Productivity												
Precipitation (R)	-0.1534**	0.077	-0.2645***	0.095	-0.0461	0.086	-0.0104	0.102	0.1586*	0.093	0.1503*	0.087
Temperature (T)	0.9893**	0.412	1.3852***	0.440	0.1532	0.320	0.2564	0.353	1.0827**	0.538	1.0642**	0.522
Trend	0.0655***	0.019	0.0685***	0.019	-0.0381*	0.021	-0.0482**	0.023	-0.1195***	0.017	-0.1242***	0.017
NE zone	-3.3830**	1.461	-4.5724***	1.574	-1.0335	1.226	-1.4339	1.340	-4.0140**	1.669	-3.9433**	1.636
NW zone	-1.8485**	0.921	-2.6501***	0.986	-0.0517	0.770	-0.2376	0.832	-2.6326**	1.177	-2.7335**	1.187
W zone	-1.4253***	0.525	-2.2595***	0.617	-2.4051***	0.463	-2.3474***	0.473	-2.6117***	0.829	-2.7433***	0.854
CD zone	-2.3839*	1.409	-3.4830**	1.509	-0.7115	1.220	-1.1592	1.348	-2.6810	1.812	-2.6955	1.779
Constant	-26.9652**	10.955	-36.4321***	11.708	-5.6882	8.590	-8.6318	9.500	-28.9359**	13.966	-28.2762**	13.490
Wald'sChiSq.	230.36		377.3000		472.8300		496.9600		93.9800		106.4600	
Likelihood Fun.	-112.08		-103.7191		26.8400		27.8000		-44.5600		-42.4600	
RMSE~	0.5970		0.5814		0.2378		0.2380		0.4345		0.4404	

Table 10 Just and Pope Production Function – Parameter Estimates-Contd..

Mean Productivity	Cotton				Chillies				Pulses			
	Linear		Quadratic		Linear		Quadratic		Linear		Quadratic	
	Coefficient	Std.Err.	Coefficient	Std.Err.	Coefficient	Std.Err.	Coefficient	Std.Err.	Coefficient	Std.Err.	Coefficient	Std.Err.
Precipitation (R) (in Cm)	0.0406**	0.019	0.3720	0.419	0.0230**	0.011	0.1801	0.189	-0.0033	0.003	0.0036	0.060
Temperature (T) (in ^{o}C)	-0.1436	0.127	-1.2780	2.813	-0.0614	0.037	-1.0036*	0.590	-0.0363*	0.019	0.5056	0.452
Trend(year)	-0.0138***	0.005	-0.0142***	0.005	-0.0029	0.002	-0.0024	0.002	0.0014	0.001	0.0008	0.001
R^2			-0.0075*	0.004			-0.0006	0.003			-0.0006	0.001
T^2			0.0229	0.053			0.0186	0.011			-0.0099	0.008
R*T			-0.0064	0.017			-0.0054	0.007			0.0003	0.002
NE zone	0.9768***	0.332	1.0665***	0.340	0.6137***	0.108	0.6627***	0.109	0.1720***	0.059	0.1431**	0.064
NW zone	0.8260***	0.290	0.8929***	0.311	0.2394*	0.139	0.2316*	0.134	0.1290***	0.046	0.0966*	0.055
W zone	1.1025***	0.239	1.2772***	0.292	0.4914***	0.142	0.5042***	0.137	-0.0051	0.028	-0.0196	0.042
CD zone	0.8361**	0.383	0.8823**	0.375	0.2613**	0.122	0.2936**	0.121	0.0652	0.064	0.0382	0.068
Constant	4.6850	3.092	17.7459	37.080	1.9310**	0.892	13.6887*	7.719	1.3275***	0.495	-6.1268	6.183
Variability in Productivity												
Precipitation (R)	-0.0349	0.071	-0.0175	0.068	0.0175	0.047	0.0053	0.070	-0.0173	0.073	-0.0222	0.090
Temperature (T)	-0.4897	0.455	-0.6447	0.484	-2.0504***	0.341	-2.0258***	0.331	0.1034	0.428	0.0002	0.471
Trend	-0.0733***	0.019	-0.0805***	0.019	-0.0176	0.020	-0.0194	0.021	-0.0335*	0.019	-0.0460**	0.020
NE zone	2.8179**	1.144	3.0680**	1.190	6.3657***	1.017	6.4029***	0.983	0.1387	1.216	0.4315	1.328
NW zone	1.7280*	1.044	2.0770*	1.105	7.8240***	1.304	7.9407***	1.281	0.6476	0.920	0.8407	1.001
W zone	2.1832***	0.782	2.6322***	0.826	7.0375***	1.139	6.9414***	1.107	0.2969	0.542	0.3067	0.616
CD zone	2.4244*	1.308	2.8295**	1.411	7.5496***	1.075	7.6187***	1.042	0.6044	1.399	0.9777	1.511
Constant	10.9152	11.196	14.6080	11.896	46.9411***	8.131	46.3753***	7.919	-7.7280	11.281	-4.8509	12.324
Wald'sChiSq.	100.6800		116.8900		97.3100		121.3600		59.2900		66.7000	
Likelihood Fun.	-95.3954		-93.5302		8.9953		10.3917		180.0243		181.5673	
RMSE	0.5572		0.5710		0.3275		0.3241		0.0760		0.0766	

Table 10 Just and Pope Production Function – Parameter Estimates-Contd..

Mean Productivity	**Sugarcane**				**Groundnut**				**Banana**			
	Linear		**Quadratic**		**Linear**		**Quadratic**		**Linear**		**Quadratic**	
	Coefficient	**Std.Err.**	**Coefficient**	**Std.Err.**	**Coefficient**	**Std.Err.**	**Coefficient**	**Std.Err.**	**Coefficient**	**Std.Err.**	**Coefficient**	**Std.Err.**
Precipitation (R) (in Cm)	-0.4241	0.345	2.8970	10.166	0.0245	0.006	-0.2626	0.127	0.2375	0.162	4.6539	4.719
Temperature (T) (in °C)	-1.4906	0.717	61.5521	44.850	-0.0069	0.012	0.3041	0.563	-0.3408	0.371	38.6218*	22.639
Trend(year)	0.4874	0.100	0.5182	0.098	0.0291	0.002	0.0289	0.002	0.8991***	0.059	0.9006***	0.058
R^2			0.0727	0.057			0.0021	0.001			-0.0625***	0.022
T^2			-1.1163	0.819			-0.0069	0.010			-0.7063*	0.421
R*T			-0.1647	0.355			0.0085	0.004			-0.1033	0.167
NE zone												
NW zone												
W zone												
CD zone												
Constant	143.5190	19.629	-739.9345	620.949	0.8819	0.326	-2.1769	7.971	25.4913**	10.097	-519.7368*	307.617
Variability in Productivity												
Precipitation (R)	0.0175	0.047	-0.0240	0.063	-0.0519	0.053	-0.0731	0.058	-0.0761	0.051	-0.1154**	0.052
Temperature (T)	-0.0632	0.101	0.0420	0.103	-0.0200	0.092	0.0518	0.097	0.1658*	0.095	0.2122**	0.093
Trend	0.0037	0.016	0.0104	0.017	0.0331	0.014	0.0391	0.013	0.0519***	0.015	0.0588***	0.016
NE zone												
NW zone												
W zone												
CD zone												
Constant	6.1979	2.859	3.5091	2.844	-2.6071	2.522	-4.5904	2.583	-0.9804	2.612	-2.0315	2.521
Wald'sChiSq.	28.5800		36.4100		229.2200		253.7000		235.3000		268.7000	
Likelihood Fun.	-562.0291		-559.0880		24.1708		27.8782		-486.2497		-482.8500	
RMSE	10.2774		10.0807		0.2119		0.2091		6.6009		6.5600	

***, **,* respectively denote significance at 1%, 5% and 10%.

~ This is calculated as the square root of the mean of the squares of the deviations of observed productivities from their corresponding estimated mean values.

yields. The root mean square error for the linear and quadratic mean functions are respectively 0.5970 and 0.5814 implying the quadratic mean function is slightly better than linear mean function in prediction.

In the case of sorghum, precipitation had positive effects on mean yield for the two functional forms and temperature had negative but non-significant effect. Trend coefficients in the two models are negative and significant at 1% level, implying that mean productivity of sorghum decreases over time. The same conclusion can be derived by observing the graph of the productivity of sorghum in Fig.4. Also as shown in Table 5, its overall growth rate for Tamil Nadu is -.28%. Sorghum is purely a rain fed crop and majority of the farmers grow it for fodder only. They switch over to other crops when sufficient water is available and hence its production shows a declining trend. As in the case of paddy, the coefficient of precipitation is negative in variance function for linear and quadratic forms but the coefficient of temperature is positive. But the coefficients of both variables are not statistically significant. The trend coefficient in variance function is negative and significant for the two alternative functional forms which means that as technology advances, variability in sorghum productivity decreases. This emphasizes that risk due to productivity differences may also reduce over years. The root mean square errors for both linear and quadratic models are equal and so any model can be used.

For maize, coefficients of most of the variables including climate related variables viz., precipitation, and temperature and trend in the mean function, for the two functional forms are insignificant. In the variance function, precipitation and temperature both have positive and significant effect implying that these two variables are risk increasing. All the coefficients for the dummy variables are significant except for Cauvery Delta zone. The root mean square errors for the two models do not differ much.

For cotton precipitation had positive and significant effect for the linear form of mean function. Temperature has non-significant effect for both forms. Trend effect is strongly significant but negative for the two functional forms implying that the cotton productivity declines over years. This result is confirmed by noting that the overall growth rate of cotton productivity is -0.15% (Table 5), in the case of variance function, the coefficients of the climate related variables are all negative for the two functional forms. The trend coefficients are negative but statistically significant at 1% level and this in turn means that variability in cotton productivity also decreases over years. The root mean square error for the linear model is 0.5572 and quadratic model is 0.571 and hence linear model is better than the quadratic model as mean function.

For chillies coefficient of precipitation is positive and significant for the linear model but coefficient of temperature is negative and significant for quadratic model. All other coefficients of climate variables are non-significant. Further trend coefficient is negative but insignificant for both models and this implies that productivity of chillies has not changed over time. The coefficients of the two climate variables in the variance function suggest that precipitation is risk increasing whereas temperature is risk decreasing. Trend has insignificant negative effect on the variance. All the coefficients of the dummy variables are strongly significant at 1% implying that the variance in productivity differs very much between the zones. The root mean square errors for the two models do not differ much.

For pulses most of the coefficients in both models are not significant. Only temperature is negatively significant at 10% level for the linear form of the mean function. Coefficients of precipitation and trend are not significant. Similarly for the variance function, coefficient of trend is significant and all other coefficients are not statistically significant. Further the root mean square errors are almost equal for both functional forms.

In the case of sugarcane and groundnut none of the coefficient for any variable is significant for both mean and variance functions. For banana, trend is positive and strongly significant implying that technological progress increases banana productivity. Also both precipitation and temperature are risk increasing inputs.

In summary, the climate variables viz., precipitation and temperature have similar effect on paddy and maize productivity; precipitation decreases the productivity for the linear form and it increases the productivity for the quadratic form and temperature increases the mean function for the two alternative functional forms. Similarly for sorghum, cotton and chillies, for both forms, precipitation increases and temperature decreases the mean function.

Table 11 gives a summary of the effect of the climate variables on the mean productivity for the two different functional forms.

Table 11 Signs of the coefficients of precipitation and temperature in the mean function

	Paddy and Maize		Sorghum, Cotton and Chillies		Pulses and Sugarcane		Groundnut		Banana	
Mean Function	L	Q	L	Q	L	Q	L	Q	L	Q
Precipitation	-	+	+	+	-	+	+	-	+	+
Temperature	+	+	-	-	-	+	-	+	-	+

As far as trend is concerned, it has positive effect on the productivities of six crops, viz., paddy, maize, pulses, sugarcane, groundnut and banana. It has negative effect in the case of the other three crops, viz., Sorghum, cotton and chillies.

The risk increasing (↑) / decreasing (↓) effects of climate variables on the productivity are summarised in Table 12.

Table 12 Effect of climate variables on the variability (risk) in productivity

Crop	Paddy, Sorghum, Pulses, Banana		Maize		Chillies		Sugarcane		Groundnut		Cotton	
Form of Mean Function	L	Q	L	Q	L	Q	L	Q	L	Q	L	Q
Precipitation	↓	↓	↑	↑	↑	↑	↑	↓	↓	↓	↓	↓
Temperature	↑	↑	↑	↑	↓	↓	↓	↓	↓	↑	↓	↓

Table 13 provides a summary of the estimated elasticities calculated at the mean values of precipitation and average temperature for the two mean function forms. Elasticities which are unit free can be used to evaluate and compare the impacts of explanatory variables. A brief discussion on the estimated elasticities is given below:

The elasticities of precipitation in the mean crop yield function are all numerically less than 1 for all crops. They vary from -0.289 to +0.563 and this implies that the response of mean productivities of all crops to the changes in the precipitation level is inelastic. An increase in the precipitation level generally reduces the mean precipitation in the case of paddy, maize, pulses and sugarcane crops while it increases the mean productivity of all other crops. The elasticities of temperature vary from -5.512 to +4.884. The estimated elasticities of the temperature for the mean productivities for both linear and quadratic functional forms are greater than one in most of the zones for paddy, cotton, chillies and pulses and therefore are elastic. In the case of other crops except groundnut the elasticities of temperature are less than 1 for linear form and greater than 1 for quadratic form. For groundnut, for both functional forms, all the elasticities of temperature are less than 1 and so inelastic. A similar discussion can be given in the case of variance function (see Table 14). The elasticities for precipitation vary from -2.987 to + 26.008 and that of temperature vary from -57.714 to 41.020.

The impact of climate change variables on the covariance between all combinations of crops (there were 36 combinations) were worked out and Table 15 reports the results for selected crops only. The estimated coefficients of precipitation are not statistically significant whereas temperature had significant effect in most of the covariance models. Trend had strong significant effect in all combinations except for cotton and groundnut.

5. Effect of climate change on yield and yield variability

The estimated production functions have been used to study the effect of climate change on productivities of the nine crops for the long term climate change scenario (HADCM3 A2a) for the period 2010-39. For this, as already stated, the projected values of precipitation and temperature for Tamil Nadu State were downloaded from the website *http://www.ipcc-data.org/sres/hadcm3_download. html.*

Table 13 Elasticities of precipitation and temperature: Mean productivity

	Linear						Quadratic					
	NEzone	NWzone	Wzone	CDzone	Szone	Overall	NEzone	NWzone	Wzone	CDzone	Szone	Overall
Paddy												
Precipitation	-0.076	-0.059	-0.040	-0.081	-0.076	-0.065	-0.257	-0.104	0.004	-0.289	0.021	-0.106
Temperature	1.543	1.428	1.199	1.618	1.541	1.453	-2.175	0.653	3.044	-2.306	4.884	1.036
Sorghum												
Precipitation	0.072	0.062	0.102	0.114	0.060	0.076	0.029	0.075	0.218	0.045	0.100	0.089
Temperature	-0.347	-0.354	-0.716	-0.537	-0.288	-0.402	1.181	0.327	-1.551	1.629	-1.043	0.129
Maize												
Precipitation	-0.094	-0.079	-0.070	-0.076	-0.076	-0.079	-0.189	-0.079	0.004	-0.161	-0.108	-0.103
Temperature	0.107	0.108	0.123	0.085	0.087	0.100	-1.314	-0.151	1.389	-1.483	2.997	0.289
Cotton												
Precipitation	0.220	0.198	0.130	0.249	0.293	0.211	0.184	0.327	0.342	0.167	0.490	0.313
Temperature	-1.891	-2.068	-1.750	-2.135	-2.577	-2.044	-1.525	-1.690	-1.671	-1.424	-3.939	-1.953
Chillies												
Precipitation	0.235	0.342	0.187	0.370	0.379	0.289	0.206	0.276	0.199	0.278	0.563	0.290
Temperature	-1.551	-2.856	-2.003	-2.427	-2.544	-2.173	-1.224	-0.237	-0.530	-1.244	-5.512	-1.703
Total Pulses												
Precipitation	-0.082	-0.068	-0.065	-0.113	-0.084	-0.081	-0.034	0.016	0.059	-0.056	-0.020	0.000
Temperature	-2.304	-2.275	-2.747	-3.131	-2.392	-2.535	-3.515	-2.509	-1.562	-5.194	0.148	-2.428
Sugarcane												
Precipitation	-0.045	-0.036	-0.027	-0.046	-0.038	-0.039	-0.029	-0.043	-0.040	-0.027	0.007	-0.029
Temperature	-0.418	-0.407	-0.382	-0.420	-0.355	-0.396	-1.378	-1.024	-0.241	-1.440	0.564	-0.657
Groundnut												
Precipitation	0.193	0.162	0.127	0.197	0.173	0.171	0.304	0.123	-0.022	0.309	0.029	0.132
Temperature	-0.148	-0.146	-0.142	-0.147	-0.132	-0.143	-0.323	-0.294	-0.187	-0.230	0.439	-0.111
Banana												
Precipitation	0.081	0.067	0.051	0.083	0.070	0.070	0.118	0.176	0.220	0.105	0.239	0.184
Temperature	-0.298	-0.299	-0.290	-0.300	-0.261	-0.289	-2.192	-1.670	-0.272	-2.453	1.361	-0.979

Table 14 Elasticities of precipitation and temperature : Variability in productivity

	Linear						Quadratic					
	NEzone	NWzone	Wzone	CDzone	Szone	Overall	NEzone	NWzone	Wzone	CDzone	Szone	Overall
Paddy												
Precipitation	-1.692	-1.379	-1.049	-1.732	-1.506	-1.472	-2.917	-2.377	-1.809	-2.987	-2.595	-2.537
Temperature	29.296	28.134	26.759	29.233	26.008	27.886	41.020	39.393	37.468	40.932	36.415	39.046
Sorghum												
Precipitation	-0.509	-0.415	-0.316	-0.521	-0.453	-0.443	-0.114	-0.093	-0.071	-0.117	-0.102	-0.100
Temperature	4.610	4.404	4.151	4.588	4.080	4.367	7.713	7.368	6.946	7.676	6.826	7.306
Maize												
Precipitation	1.749	1.425	1.084	1.790	1.556	1.521	1.658	1.351	1.028	1.697	1.475	1.442
Temperature	30.398	29.690	28.869	30.735	27.367	29.412	29.879	29.184	28.377	30.211	26.900	28.910
Cotton												
Precipitation	-0.385	-0.314	-0.239	-0.394	-0.343	-0.335	-0.193	-0.157	-0.119	-0.197	-0.171	-0.168
Temperature	-13.149	-13.011	-12.694	-13.387	-11.961	-12.840	-17.311	-17.131	-16.713	-17.625	-15.748	-16.906
Chillies												
Precipitation	0.193	0.157	0.120	0.197	0.172	0.168	0.058	0.048	0.036	0.060	0.052	0.051
Temperature	-55.940	-57.714	-56.485	-56.960	-50.647	-55.549	-55.269	-57.022	-55.807	-56.276	-50.039	-54.883
Total Pulses												
Precipitation	-0.190	-0.155	-0.118	-0.195	-0.169	-0.165	-0.244	-0.199	-0.152	-0.250	-0.217	-0.213
Temperature	2.948	2.865	2.759	2.972	2.644	2.837	0.006	0.006	0.006	0.006	0.005	0.006
Sugarcane												
Precipitation	0.193	0.157	0.120	0.198	0.172	0.168	-0.264	-0.215	-0.164	-0.270	-0.235	-0.230
Temperature	-1.830	-1.807	-1.738	-1.834	-1.631	-1.768	1.217	1.202	1.156	1.219	1.084	1.176
Groundnut												
Precipitation	-0.572	-0.466	-0.355	-0.585	-0.509	-0.497	-0.807	-0.657	-0.500	-0.826	-0.718	-0.702
Temperature	-0.600	-0.574	-0.541	-0.598	-0.531	-0.569	1.558	1.488	1.403	1.551	1.379	1.476
Banana												
Precipitation	-0.839	-0.684	-0.520	-0.859	-0.747	-0.730	-1.273	-1.037	-0.789	-1.303	-1.132	-1.107
Temperature	4.694	4.649	4.486	4.722	4.204	4.551	6.010	5.952	5.743	6.045	5.383	5.827

Table 15 Impact of precipitation and temperature on covariance of selected crops

Crop Names	Paddy & Pulses	Intercept	Precipitation	Temperature	Time	D1	D2	D3	D4
Regression Coefficients		-0.404*	0.000	0.016*	0.001**	-0.051*	-0.018	-0.021*	-0.021
Standard Errors		0.216	0.001	0.008	0.000	0.028	0.020	0.012	0.029
R-Square	0.197								
Crop Names	Paddy & Groundnut	Intercept	Precipitation	Temperature	Time	D1	D2	D3	D4
Regression Coefficients		-1.033	-0.006	0.041	0.004***	-0.166	-0.075	-0.032	-0.221*
Standard Errors		0.883	0.006	0.033	0.002	0.121	0.080	0.046	0.118
R-Square	0.147								
Crop Names	Sorghum & Pulses	Intercept	Precipitation	Temperature	Time	D1	D2	D3	D4
Regression Coefficients		-0.122	0.000	0.005	0.000***	-0.019	0.003	-0.008	-0.011
Standard Errors		0.111	0.001	0.004	0.000	0.015	0.010	0.006	0.015
R-Square	0.148								
Crop Names	Maize & Cotton	Intercept	Precipitation	Temperature	Time	D1	D2	D3	D4
Regression Coefficients		2.591*	0.010	-0.103*	-0.008***	0.307*	0.282**	0.189**	0.469**
Standard Errors		1.413	0.008	0.057	0.002	0.160	0.132	0.096	0.182
R-Square	0.223								
Crop Names	Cotton & Groundnut	Intercept	Precipitation	Temperature	Time	D1	D2	D3	D4
Regression Coefficients		-0.726	-0.006*	0.031	0.001	-0.150**	-0.106**	-0.018	-0.116
Standard Errors		0.566	0.003	0.022	0.001	0.070	0.052	0.032	0.074
R-Square	0.169								
Crop Names	Chillies & Sugaracne	Intercept	Precipitation	Temperature	Time	D1	D2	D3	D4
Regression Coefficients		-31.075**	-0.427***	1.365**	0.057**	-3.515*	-4.959**	-5.675***	-3.410
Standard Errors		15.660	0.100	0.623	0.028	1.928	2.066	1.597	2.093
R-Square	0.215								

The projected values of precipitation and temperature were then plugged into the estimated production functions to project the productivities of the crops during 2020. The baseline productivities are the mean of the observed productivities for the 30 year period 1976-77 to 2005-06. Table 16 presents the influence of HADCM3A2a scenario on crop productivity and its variability. For each crop, the base line productivity, its coefficient of variation, climate change induced productivity, its coefficient of variation and percentage change in productivity due to climate change are presented. In view of similarity in discussion, we shall present the results for the linear form of the mean function only and these productivities have been used in the optimisation models.

Table 16 shows that the productivity of paddy may increase in all the zones except in Western region. Both North East and Cauvery Delta zones may experience an increase of 9.6% in productivity. This result is surprising because it is generally believed that increase in temperature due to climate change will normally reduce the productivity. But this result is in agreement with a similar finding reported for Tamil Nadu (ICAR,2008). As per the report, the productivity of paddy will increase up to 10% during Northeast monsoon period (September to December). This might be due to the positive effect of slight increase in temperature during this period and increase of 1 to 2 degree Celsius temperature

Table 16 Impact of HADCM3A2a scenario on productivity (tonnes/ha) of crops-linear mean function

	zone				
	North East	North West	West	Cauvery Delta	Southern
Crop : Paddy					
Baseline Productivity	2.77	2.96	3.51	2.61	2.46
CV (%)	21	25	21	28	27
CC Productivity	3.03	3.11	3.49	2.87	2.65
CV (%)	23	28	18	34	25
Change in Productivity (%)	9.6	4.8	-0.4	9.6	7.7
Crop : Sorghum					
Baseline Productivity	1.17	1.04	0.52	0.76	1.22
CV (%)	19	27	27	31	21
CC Productivity	1.16	1.09	0.50	0.75	1.25
CV (%)	19	30	19	33	22
Change in Productivity (%)	-0.8	5.0	-2.6	-1.3	2.0

Table 16 Impact of HADCM3A2a scenario on productivity (tonnes/ha) of crops: linear mean function (Contd...)

	zone				
	North East	North West	West	Cauvery Delta	Southern
Crop:Maize					
Baseline Productivity	1.56	1.55	1.30	2.03	1.79
CV (%)	24	25	18	30	30
CC Productivity	1.59	1.54	1.32	2.01	1.75
CV (%)	29	31	20	54	34
Change in Productivity (%)	1.6	-0.8	1.5	-0.9	-2.3
Crop:Cotton					
Baseline Productivity	2.04	1.83	2.36	1.70	1.29
CV (%)	35	26	31	27	21
CC Productivity	1.91	1.74	2.03	1.75	1.29
CV (%)	26	19	26	21	18
Change in Productivity (%)	-6.3	-4.9	-13.9	3.0	0.0
Crop:Chillies					
Baseline Productivity	1.03	0.64	0.78	0.71	0.65
CV (%)	28	48	59	38	47
CC Productivity	1.03	0.56	0.80	0.67	0.57
CV (%)	9	17	16	17	13
Change in Productivity (%)	-0.8	-12.4	2.3	-5.5	-12.8
Crop:Pulses					
Baseline Productivity	0.45	0.43	0.35	0.34	0.38
CV (%)	15	22	22	26	16
CC Productivity	0.41	0.41	0.33	0.30	0.36
CV (%)	18	22	22	31	16
Change in Productivity (%)	-8.8	-4.5	-7.7	-12.3	-5.8
Crop:Sugarcane					
Baseline Productivity	99.56	103.27	112.64	104.96	106.15
CV (%)	10	13	8	8	12
CC Productivity	101.63	103.46	106.06	101.29	107.19
CV (%)	10	9	9	10	10
Change in Productivity (%)	2.1	0.2	-5.8	-3.5	1.0
Crop:Groundnut					
Baseline Productivity	1.42	1.31	1.40	1.42	1.30
CV (%)	26	26	19	24	25
CC Productivity	1.39	1.35	1.31	1.42	1.40
CV (%)	14	15	17	13	15
Change in Productivity (%)	-1.8	2.8	-6.5	0.1	7.3
Crop:Banana					
Baseline Productivity	35.09	39.55	35.39	42.05	47.83
CV (%)	31	32	29	27	34
CC Productivity	45.15	44.78	44.65	45.34	46.06
CV (%)	21	22	22	20	16
Change in Productivity (%)	28.7	13.2	26.2	7.8	-3.7

may create a positive impact during 2020. It can be noticed that this increase in productivity may also be accompanied by increase in variability. For example, in North East and Cauvery Delta zones which are important regions for paddy production, the coefficient of variation will increase from 21% and 28% to 23% and 34% respectively.

In the case of sorghum crop, in all zones except in North West and Southern zones there will be decrease in productivity and the coefficient of variation may remain at the same level as that of base line values in these zones. In the case of maize most of the regions may register a slight marginal change in productivity with a significant increase in variation. For example, in the Cauvery delta zone, the mean productivity will decrease from 2.03 tonnes/ha to 2.01 tonnes per ha but the coefficient of variation will increase from 30% to 54%. Cotton crop may register a decrease in productivity with a reduction in variability. In North East, North West and Western zones there will be significant decline in productivity and in Western zone the productivity of cotton may fall by 13.9%. In Cauvery Delta zone there will be a marginal increase in productivity of 3% whereas in Southern zone there may not be any change in productivity.

HADCM3A2a scenario will produce a decrease in productivity of chilly crop. There may be a maximum reduction of about 12 to 13% reduction in productivity at North West and Southern zones but a significant reduction in variability is possible. For example, the coefficient of variation of the productivity of North West zone will drastically decrease from 48% to 17%. Similarly the productivity of pulses crop will decrease in all the zones with maximum reduction of 12.3% occurring at Cauvery Delta zone and the fluctuation in productivity may remain at the base line level.

Sugarcane may register marginal change in productivity and the maximum change will be a reduction of 5.8% productivity with a coefficient of variation of 9% in Western zone. Groundnut crop may experience very moderate changes in productivity. The maximum decline in productivity will be about 6.5% in Western zone and in Southern zone the productivity may go up by 7.3% and in all the zones there will be a significant reduction in coefficient of variation in productivity. Banana will have significant increase in productivities ranging from 7.8% to 28.7% and there will be significant reduction in the variability.

The impact of HADCM3 scenario can be analysed zone wise also. Table below presents a summary of the effect of climate change on the five zones. It provides the number of crops with increase/decrease in productivity. It shows that in western zone out of 9 crops, 6 crops will have decrease in productivity. Similarly North East and Cauvery Delta zones will have each 5 crops with decrease in productivity and southern zone will have equal number of crops in the two categories.

Number of Crops with	zone				
	NE	NW	W	CD	S
Increase in productivity	4	5	3	4	4
Decrease in productivity	5	4	6	5	4

To summarise, HADCM3 A2a scenario may have both positive and negative effects on crop productivities in all the five zones. It appears that slightly more number of crops will have decrease in productivity in all the zones. Further the variability in productivity may increases/decreases across crops and zones.

6. Optimum land area allocation using multi-goal-linear programming

The climate change induced productivities were used to allocate crop area to the nine competing crops to satisfy the objectives and constraints specified in Section 3. Tables 17 to 21 summarise the results for each objective. They provide the crop area and also increase/decrease in production.

i. Maximization of food grain production

a) Area

Table 17a. Optimal area ('000ha)

zone	Paddy	Cholam	Maize	Sugarcane	Cotton	Groundnut	Chillies	Banana	Pulses	Total
NEZ	691.5	0.0	0.0	0.0	0.0	259.7	38.7	0.0	0.0	990.0
NWZ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	512.2	512.2
WZ	250.0	0.0	0.0	0.0	77.7	0.0	0.0	0.0	0.0	327.7
CDZ	612.2	0.0	128.7	0.0	0.0	174.6	0.0	0.0	0.0	915.5
SZ	561.4	0.0	0.0	268.9	0.0	277.4	0.0	69.5	0.0	1177.2
Total	2115.1	0.0	128.7	268.9	77.7	711.7	38.7	69.5	512.2	3922.7

Table 17b. Shift in area ('000ha) allocation (optimal area-normal area)

zone	Paddy	Sorghum	Maize	Sugarcane	Cotton	Groundnut	Chillies	Banana	Pulses	Total
NEzone	120.3	-16.2	-5.9	-120.6	-11.3	-27.8	36.4	-11.1	-124.8	-161.0
NWzone	-119.6	-82.2	-48.3	-44.8	-28.3	-147.5	-5.2	-4.4	382.5	-97.8
Wzone	194.5	-119.5	-30.9	-42.2	64.2	-62.3	-2.9	-16.7	-63.7	-79.6
CDzone	126.8	-35.6	122.9	-22.1	-10.1	150.2	-2.0	-13.8	-128.8	187.4
Szone	66.0	-92.8	-58.5	232.2	-52.2	200.9	-53.9	39.7	-130.4	150.9
Total	388.0	-346.3	-20.6	2.5	-37.6	113.5	-27.8	-6.3	-65.3	0.0

The above tables show that in order to achieve maximum food grain (which includes paddy, sorghum, maize and pulses) production, total paddy area in the five zones should be increased from the 1727 '000ha to 2115.1 '000ha, an increase of 388 '000 ha. This increase can be achieved by increasing the paddy area in North East zone by 120.3 '000ha, Western zone by 194.5 '000ha, Cauvery Delta zone by 126.8 '000ha and Southern zones area by 66.0 '000 ha. Also the current paddy area in North Western zone should be reduced by 119.6 '000 ha. Also area under sorghum should be completely removed and area under maize should be reduced by 20.6 '000 ha. There should be a reduction in pulses area by 65.3 '000 ha. In order to main at least the normal level of production of other crops (viz., sugarcane, cotton, chillies, groundnut, chillies and banana), area under sugarcane has to be increased by 2.5 '000 ha, area under groundnut should be increased by 113.5 '000ha ha whereas areas under cotton, chillies and banana should be respectively reduced by 37.6 '000ha, 27.8 '000 ha and 6.3 '000 ha. Of course there is no change in the total area under all crops. Thus the above analysis implies reallocation of existing crop areas only without requiring additional crop area.

With this reallocation, the optimum production of each crop and change in production can be worked out and they are presented in the following tables:

b) Production

Table 18a. Optimum production (in kilotons)

zone	Paddy	Sorghum	Maize	Sugarcane	Cotton	Groundnut	Chillies	Banana	Pulses	Total
NEZ	2098	0	0	0	0	362	40	0	0	2499
NWZ	0	0	0	0	0	0	0	0	212	212
WZ	873	0	0	0	158	0	0	0	0	1031
CDZ	1754	0	258	0	0	248	0	0	0	2260
SZ	1489	0	0	28823	0	388	0	3203	0	33903
Total	6214	0	258	28823	158	998	40	3203	212	39906

Table 18b. Change in production (kilotons) (optimum production – normal production)

	Paddy	Sorghum	Maize	Sugarcane	Cotton	Gnut	Chillies	Banana	Pulses
NEzone	371	-17	-9	-12852	-19	-162	38	-403	-51
NWzone	-359	-73	-62	-4725	-45	-212	-3	-177	159
Wzone	664	-40	-44	-4901	137	-94	-2	-605	-21
CDzone	666	-19	250	-2365	-17	202	-2	-581	-34
Szone	236	-94	-96	24843	-57	267	-30	1767	-54
Total	1577	-243	39	0	0	0	0	0	0

The above analysis shows that with reallocation of land area, the production of paddy can be increased from the current level of 4637 kilotons to 6214 kilotons tonnes, an increase by 1577 kilo tons. There won't be any sorghum production and maize production will go up by 39 kilotons and all other crops will maintain their current level of production. Finally the total food grain production will go up from the current level of 5311 kilotons to 6685 kilotons.

ii. Maximization of paddy production

For this objective, the production of all other crops is maintained at least at their current level. The optimal area under each crop and the change from normal area are summarized in the tables below:

a) Area

Table 19a Optimal area ('000ha)

zone	Paddy	Sorghum	Maize	Sugarcane	Cotton	Groundnut	Chillies	Banana	Pulses	Total
NEzone	647.8	0.0	0.0	0.0	0.0	322.6	38.7	0.0	0.0	1009.2
NWzone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	512.2	512.2
Wzone	230.8	0.0	0.0	0.0	77.7	0.0	0.0	0.0	0.0	308.5
CDzone	554.6	0.0	109.3	0.0	0.0	251.7	0.0	0.0	0.0	915.5
Szone	507.2	195.0	0.0	268.9	0.0	136.6	0.0	69.5	0.0	1177.2
Total	1940.4	195.0	109.3	268.9	77.7	710.9	38.7	69.5	512.2	3922.7

Table 19b Shift in area ('000ha) (optimal area – normal area)

zone	Paddy	Sorghum	Maize	Sugarcane	Cotton	Groundnut	Chillies	Banana	Pulses	Total
NEzone	76.6	-16.2	-5.9	-120.6	-11.3	35.1	36.4	-11.1	-124.8	-141.8
NWzone	-119.6	-82.2	-48.3	-44.8	-28.3	-147.5	-5.2	-4.4	382.5	-97.8
Wzone	175.3	-119.5	-30.9	-42.2	64.2	-62.3	-2.9	-16.7	-63.7	-98.8
CDzone	69.1	-35.6	103.5	-22.1	-10.1	227.3	-2.0	-13.8	-128.8	187.4
Szone	11.9	102.2	-58.5	232.2	-52.2	60.1	-53.9	39.7	-130.4	150.9
Total	213.3	-151.3	-40.1	2.5	-37.6	112.7	-27.8	-6.3	-65.3	0.0

The analysis of the shifts in area shows that in order to have maximum paddy production, there should be an overall increase of 213.3 '000 ha of area under paddy. To achieve this, area under paddy in all zones except north western zone wherein the productivity is low should be increased. Areas under other crops except sugarcane and groundnut have to be decreased. Of course these are net changes. The optimum production and the change from normal production are presented in the next two tables:

b) Production

Table 20a. Optimum production (in kilotons)

zone	Paddy	Sorghum	Maize	Sugarcane	Cotton	Groundnut	Chillies	Banana	Pulses
NEZ	1965	0	0	0	0	450	40	0	0
NWZ	0	0	0	0	0	0	0	0	212
WZ	806	0	0	0	158	0	0	0	0
CDZ	1589	0	219	0	0	357	0	0	0
SZ	1346	243	0	28823	0	191	0	3203	0
Total	5706	243	219	28823	158	998	40	3203	212

Table 20b. Change in production (in kilotons)

zone	Paddy	Sorghum	Maize	Sugarcane	Cotton	Gnut	Chillies	Banana	Pulses
NEZ	239	-17	-9	-12852	-19	-74	38	-403	-51
NWZ	-359	-73	-62	-4725	-45	-212	-3	-177	159
WZ	597	-40	-44	-4901	137	-94	-2	-605	-21
CDZ	500	-19	211	-2365	-17	311	-2	-581	-34
SZ	93	149	-96	24843	-57	70	-30	1767	-54
Total	1069	0	0	0	0	0	0	0	0

So there can be a net increase of 1069 kilotons of paddy due to optimum allocation. There will not be any change in the production of other crops.

iii. Minimum agricultural area needed for normal production

The problem of finding the minimum agricultural area needed to produce at least the current level of production assumes special importance in the context of change in productivity and gradual decline in cropped area over years due to urbanization and other factors. On one hand these factors try to reduce the total production and on the other hand population explosion demands increased production. In order to meet these two opposing forces, a balance must be struck. One way of achieving this is to find what should be the minimum cropped area needed for meeting the required level of production and how much excess area is used or available now. Table 21 below presents the optimisation results. The normal levels of productions of the nine crops are set as the target levels.

Table 21a Optimal area ('000ha)

zone	Paddy	Sorghum	Maize	Sugarcane	Cotton	Groundnut	Chillies	Banana	Pulses	Total
NEzone	556.0	0.0	0.0	0.0	0.0	85.0	38.7	0.0	0.0	679.7
NWzone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	512.2	512.2
Wzone	190.4	0.0	0.0	0.0	77.7	0.0	0.0	0.0	0.0	268.1
CDzone	433.4	0.0	109.3	0.0	0.0	372.9	0.0	0.0	0.0	915.5
Szone	393.3	195.0	0.0	268.9	0.0	250.5	0.0	69.5	0.0	1177.2
Total	1573.1	195.0	109.3	268.9	77.7	708.3	38.7	69.5	512.2	3552.8

Table 21b Surplus area used for normal production (normal area-optimal area)

zone	Paddy	Sorghum	Maize	Sugarcane	Cotton	Groundnut	Chillies	Banana	Pulses	Total
NEzone	15.2	16.2	5.9	120.6	11.3	202.5	-36.4	11.1	124.8	471.3
NWzone	119.6	82.2	48.3	44.8	28.3	147.5	5.2	4.4	-382.5	97.8
Wzone	-134.9	119.5	30.9	42.2	-64.2	62.3	2.9	16.7	63.7	139.2
CDzone	52.1	35.6	-103.5	22.1	10.1	-348.5	2.0	13.8	128.8	-187.4
Szone	102.0	-102.2	58.5	-232.2	52.2	-173.9	53.9	-39.7	130.4	-150.9
Total	154.0	151.3	40.1	-2.5	37.6	-110.1	27.8	6.3	65.3	369.9

Negative sign indicates deficiency

The total crop area needed in all the five zones for producing the normal production is 3922.7 '000 ha and the optimization results show that it is possible to generate the same production with 3552.8 '000ha only and so there is an excess of 369.9 '000 ha of land currently used. The results also show that except for groundnut and sugarcane, areas under all crops are used in excess.

7. Linking the results of optimisation with per capita food grain availability in 2021 and 2026

Food security implies a state of affairs in which every human being can have access to sufficient nutritious food to maintain a happy and healthy living. This is possible only if food production keeps pace with population. But natural resources such as arable land and fresh water for production are fixed. Further about 43% of the population of the world depends on agriculture and this sector dominates economies of 25% of the world's countries. The problem becomes more significant in the context of climate change which threatens to decrease agricultural production. Hence an estimate of food grain availability when crop production is limited by climate change will help policy makers not only to identify the quantum of gap between supply and demand but also to take appropriate steps to fill the gap.

Projected population of Tamil Nadu

Fig.7 presents the population trend of Tamil Nadu. The projected population for the year 2021 and 2026 are given in Table 22. The food grain production and crop area required to meet the three objectives are as given in Table 23.

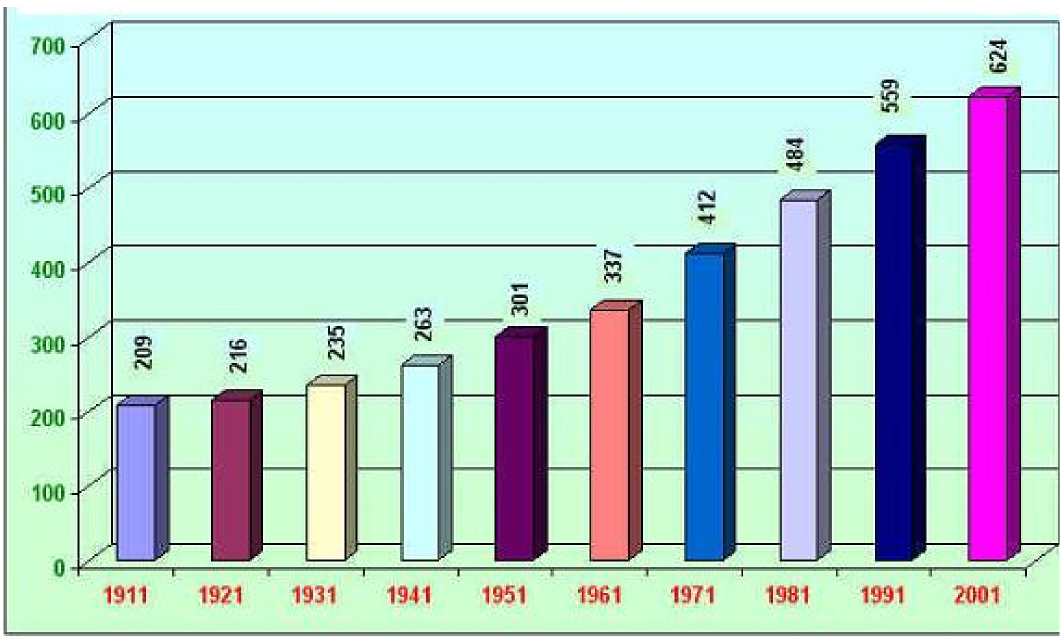

Fig.7 Decennial growth of population in Tamil Nadu (persons in lakhs)

Table 22. Population Projection (in '000) for Tamil Nadu for 2021 and 2026

Sex	Year	
	2021	2026
Male	35482	35931
Female	35383	35920
Total	70865	71859

(Source: Census of India 2001 – Population projection for India and States 2001-2026, Exhibit 3.4: Population projection for Tamil Nadu state)

Table 23. Food grain production (tonnes) under three goals

Goal	Paddy	Sorghum	Maize	Pulses	Total Food Grain	Crop Area Required ('000ha)
Max Food Grain	6214091	0	258467	212242	6684800	3922.7
Max Paddy production	5705563	242999	219407	212242	6380211	3922.7
Min Agrl.Area	4636648	242999	219407	212242	5311296	3552.8

With these data available, the projected food grain availability per capita per day can be worked out and the results are presented in Table 24.

Table 24a. Food grain availability (in gms) per capita per day in 2021

Objective	Paddy	Sorghum	Maize	Pulses	Total Food Grain
Max Food Grain	240.2	0.0	10.0	8.2	258.4
Max Paddy production	220.6	9.4	8.5	8.2	246.7
Min Agrl.Area	179.3	9.4	8.5	8.2	205.3

Table 24b. Food grain availability (in gms) per capita per day in 2026

Goal	Paddy	Sorghum	Maize	Pulses	Total Food Grain
Max Food Grain	236.9	0.0	9.9	8.1	254.9
Max Paddy production	217.5	9.3	8.4	8.1	243.3
Min Agrl.Area	176.8	9.3	8.4	8.1	202.5

The current level of food grain availability, assuming a population level of 651.35 lakhs works out 223.4 gms which includes 195 gms of paddy, 10.2 gms of sorghum, 9.2 gms of maize and 8.9 gms of pulses. The results presented in Table 24 show that the decrease in per cap food grain availability during 2026 as compared to that of 2021 will range from 3.5 gms to 2.8 gms for the three goals. Fig.8 provides a comparison of projected food grain availability under different goals. It shows that the per capital food grain availability under maximum food grain/maximum paddy production will be higher than the current level and also that obtained by minimizing agricultural area. Thus optimal land allocation will ensure increased food grain availability even under increased population explosion and changes in crop productivities due to climate change.

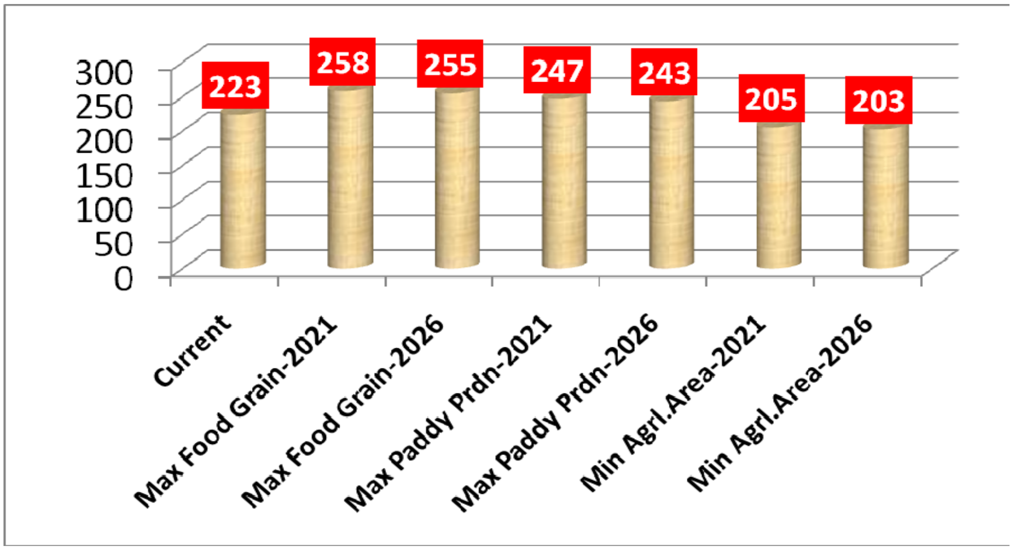

Fig.8 Per-capita per day food grain availability(in grams) under different goals

8 Conclusions

Climate change induces increase in the temperature and changes in precipitation. These changes will have wide impact on agricultural production in terms of average yield and yield variability because all agricultural operations are climate dependent. This paper presents a framework for quantifying the impact of climate change on the mean and variance of productivities of crops simultaneously. Specifically it employs econometric modelling to estimate stochastic production functions. The estimated production functions and their parameters are then used to estimate the change in agricultural production in Tamil Nadu. Further, it uses the climate change induced productivities to find optimum land allocation for crop mix to meet maximum food production. Lastly, it provides a link between the projected food grain production and population for the year 2021. Thus this paper provides a complete modelling framework to resilience of agriculture from the impact of climate change.

The study shows that precipitation and temperature have varying effect on productivity and variability of crops. Trend has positive impact on paddy, maize, pulses, sugarcane, groundnut and banana for the two alternative functional forms of the mean function whereas for the other three crops, viz, sorghum, cotton and chillies it has negative impacts.

Similarly the climate variables have different impact on risk in crop productivity. For paddy, sorghum, pulses and banana, under both forms of mean function, precipitation is a risk decreasing climate variable whereas temperature is a risk increasing input. The two climate variables are risk increasing inputs for maize and for cotton they are risk decreasing inputs. For chillies, precipitation increases the variability in productivity whereas temperature decreases the variability. For sugarcane, temperature decreases risk while precipitation decreases variability in groundnut productivity.

HADCM3A2a scenario of climate change will have modest impacts in crop productivities across the five zones of Tamil Nadu. zones where traditionally paddy is cultivated, may witness modest increase in productivity accompanied by increase in variability also. Other crops except banana may have decrease in productivity in most of the zones. There is no uniformity in changes in their variability across the five zones.

With climate change induced productivities, it is possible find out optimum allocation of crop area for meeting multiple objectives. When land is the only constraint, food grain production can be increase by 26% without decrease in the outputs of other crops, by optimally reallocating the crop area. To achieve this, total area under paddy, sugarcane and groundnut have to be increased while areas under the remaining crops may have to be decreased. This will not result in demand for additional agricultural area.

When the objective is to produce maximum paddy without reduction in the production levels of all other crops, it is possible to increase the production by 23% of the current level with productivity of all crops governed by climate change. To achieve this, area under paddy in all zones except north western zone wherein the productivity is low should be increased by 12.4% and area under other crops have to be modified and there will not be any net change in agricultural area and it will remain at the current level only.

Total agricultural area can be brought down by 9% without change in current level of production of all crops when productivities are dictated by climate change and land is the only constraint. This will involve decrease in area under all crops except sugarcane and groundnut.

Estimation of food grain availability is an important step towards food security with increase in population. The present study provides a link between food grain availability per capita per day with projected population of Tamil Nadu for 2021 and 2026. It shows that optimal land use planning can overcome the negative effects of climate change and population increase.

As stated in the next section, the results of the present study have limitations. With constraints on other resources for agriculture, there will be changes in total production and area under crops. Nevertheless, this study provides a framework for future studies on optimum land use planning in the context of climate change.

9 Limitations of the Study

The present study and the results reported have certain limitations. The area and production of crops which have been collected from various issues of *Season and Crop Report* of government of Tamil Nadu are available annually and not for each season except for paddy. Hence it was not possible to estimate season wise productivities (which would have been more useful) of crops due to climate change and the productivities reported are average productivities during the year. So there will be a difference in the estimated productions. Second, the results of multi-goal linear programming model suffer due to non-inclusion of constraints on resources like water, labour etc. In the absence of good estimation for the availability of these resources due to climate change, it was assumed that *status quo* availabilities of all resources will continue in future period, viz., 2010-20039 also. Probably when constraints on these resources are included in the model, there will be decrease in area and production. This issue can be taken up in future studies. Third, the variability in productivities of crops estimated via Just-Pope production function has not be incorporated in the linear programming models. When they are included, it is possible to compute not only the mean production but also its variance. This issue can be solved by formulating risk optimisation models like expected value-variance model of Markowitz or Freund's (Freund,1956) M-V model, MOTAD model of Hazell (Hazell,1971) or Tauer's (Tauer,1983) Target MOTAD model etc. This will also be taken up in future studies.

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