Yield variability in rainfed crops as influenced by climate variables

A micro level investigation into agro-climatic zones of Tamil Nadu, India

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Abstract

Purpose – This paper aims to explore the impact of climate change on yields and yield variances in major rainfed crops and measure possible changes in yields under projected climate changes in different agro-climatic zones of Tamil Nadu, India. Although many empirical studies report the influence of climate change on crop yield, only few address the effect on yield variances. Even in such cases, the reported yield variances were obtained through simulation studies rather than from actual observations. In this context, the present study analyzes the impact of climate change on crops yield and yield variance using the observed yields.

Design/methodology/approach – The Just-Pope yield function (1978) is used to analyze the impact of climate change on mean yield and variance. The estimated coefficient from Just-Pope yield function and the projected climatic data for the year 2030 are incorporated to capture the projected changes in crop yield and variances.

Findings – By the year 2030, the yield of pulses is estimated to decline in all the zones (Northeast, Northwest, Western, Cauvery delta, South and Southern zones), with significant declines in the

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Northeast zone (6.07 per cent), Cauvery delta zone (3.55 per cent) and South zone (3.54 per cent). Sorghum yield may suffer more in Western zone (2.63 per cent), Southern zone (1.92 per cent) and Northeast zone (1.62 per cent). Moreover, the yield of spiked millet is more likely to decrease in the Southern zone (1.39 per cent), Northeast zone (1.21 per cent) and Cauvery delta zone (0.24 per cent), and the yield of cotton may also decline in the Northeast zone (12.99 per cent), Northwest zone (8.05 per cent) and Western zone (2.10 per cent) of Tamil Nadu, India.

Originality/value – The study recommends introducing appropriate crop insurance policies to address possible financial losses to the farmers. Prioritizing area-specific stress-tolerant crop varieties without complementing yield would sustain crops cultivation further.

Keywords Climate change, Crop productivity, Just-Pope yield function,
Regional climate model simulation, Tamil Nadu (India)

Paper type Research paper

Introduction

The impact of climate change on human life and environment is an extensive area of research in the developing world. The consequences of marginal changes in global temperature and rainfall have far reaching ramifications, and not just on ecology; they can also affect many dimensions of human conditions, including agriculture, food security, nutrition and poverty, etc. Of these, agriculture is highly vulnerable to the changes in temperature and rainfall, as agricultural productivity depends on suitable climate phenomena (Downton and Miller, 1993).

The Intergovernmental Panel on Climate Change (IPCC) forecasts that during this century, there will be an increase in the average global surface temperature by 2.8°C, with best-guess estimates of the increase ranging from 1.8 to 4.0°C (IPCC, 2001, 2007). The impacts of climate change on agriculture require considerable attention, as climate change has been shifting the mean and variance of crop yield (IPCC, 2001, 2007; Reilly *et al.*, 2002). Several studies have found that changes in temperature and precipitation lead to reduction in crop yield and/or land values (Adams *et al.*, 1990; Reilly *et al.*, 2002; Deschenes and Greenstone 2007, McCarl *et al.*, 2008).

Further, Mearns *et al.* (1992), using GCMs (General Circulation Models)-derived climate change scenario, indicated that mean temperature effects dominate, resulting in increased yield variability and crop failures, because the magnitude of mean change is much greater than the magnitude of variance change. For all such experiments, the importance of considering not only mean but also variance change of climate variables in investigating the effect of climate change on crop yield has been confirmed. Moreover, Chen *et al.* (2004) used the Just-Pope stochastic production function on major crops in US agriculture and has reported that climate change affects both mean yield and yield variability.

In India, the southern region (Tamil Nadu) has been one of the region's most vulnerable to climate change (IPCC, 1998, 2001; Byravan *et al.*, 2010; Geethalakshmi *et al.*, 2011). Although many empirical studies have analyzed the impact of climate change on irrigated crops in general, very few studies have adequately addressed the effects on rainfed farming system. To note, an average, of 42 per cent of the total cultivated area in Tamil Nadu is found in a region where rainfed agricultural is both possible and common and where an agricultural labor force relies on rainfed farming for their livelihoods (Season and Crop Report, 2009-2010). In this context, the present study examines the potential impact of climate change on yield and yield variances in major rainfed crops in different agro-climatic zones of Tamil Nadu.

Data

District level yield data in sorghum (*Sorghum vulgare*), spiked millet (*Pennisetmtyphoides*), cotton (*Gyossiumspp*), groundnut (*Arachis hypogea*) and pulses (*family: Fabaceae*) for the period from 1980-1981 to 2009-2010 were collected from Season and Crop Report published annually by the Government of Tamil Nadu, India. Temperature (month-wise mean temperature during crop season) and rainfall (annual) data were obtained from Indian Meteorological Department (IMD). The predicted data on climate variables for 2030 were obtained from regional climate model simulation (RegCMs) developed by the Abdul Salam International Centre for Theoretical Physics (ASICTP), Trieste, Italy. District-level data were aggregated to reflect the average situation of the agro-climatic zones in which the districts are located.

According to IMD (2011) report, Tamil Nadu is classified into eight agro-climatic zones, namely, Northeast, Northwest, Western, Cauvery delta, South, Southern, high precipitation and high altitude. Among the eight zones, we have focused on the first six zones of Tamil Nadu and have excluded high precipitation and hilly zones, which occupy less than 4 per cent of the geographic area. Zone-wise area of cultivation, production and productivity of major rainfed crops between the period from 2005-2006 to 2009-2010 is shown in Table I.

Crop area

The area of selected crops in different agro climatic zones shows that pulses and groundnut are the two major crops in all zones. In Southern (24.4 per cent), Northwest (20.1 per cent) and Cauvery delta (16.5 per cent) zones, maximum area falls under pulses, whereas in Northeast (20.1 per cent), Northwest (19.3 per cent) and Western (13.1 per cent) zones, maximum area falls under groundnut. Sorghum occupies the highest area in the Western zone (20.5 per cent), followed by the Northwest zone (14.2 per cent). Cotton and spiked millet occupies a smaller area compared to other crops. On an average, pulses and groundnut occupies 12 and 10 per cent of total cultivated area in Tamil Nadu.

Crop production

Production pattern shows that groundnut (57.2 per cent) is a predominant crop in the Northeast zone, followed by the Northwest zone (16.7 per cent) and South zone (11.3 per cent). Pulses (29.5 per cent) and cotton (38.5 per cent) are predominately grown in Cauvery delta zone. Sorghum (36.4 per cent) and spiked millet (31.2 per cent) are prevailing crops in the South zone than in any other regions.

Crop productivity

Productivity of selected crops in different agro climatic zones shows that the Northeast zone had maximum mean productivity of pulses (0.43 tons/ha) and groundnut (2.29 tons/ha). Productivity of spiked millet and cotton are high in the Western zone with 2.08 tons/ha and 2.74 bales/ha, respectively. The Southern zone had highest productivity of sorghum (1.27 tons/ha).

Table I. Area, production, productivities under major rainfed crops in different agro-climatic zones of Tamil Nadu (2005-2006 to 2009-2010)

Crops	Northeast zone	Northwest zone	Western zone	Cauvery delta zone	South zone	Southern zone	Tamil Nadu
Area (in ‘000 hectares)							
Sorghum (%)	13 (1.1)	59 (14.2)	65 (20.5)	63 (6.2)	69 (8.9)	11 (3.9)	278 (7.0)
Spiked millet (%)	22 (1.9)	3 (0.7)	1 (0.2)	7 (0.6)	17 (2.2)	15 (5.4)	64 (1.6)
Cotton (%)	17 (1.4)	26 (6.3)	14 (4.4)	23 (2.2)	24 (3.1)	17 (6.1)	120 (3.0)
Groundnut (%)	235 (20.1)	80 (19.3)	41 (13.1)	7 (0.7)	56 (7.2)	14 (5.2)	433 (10.9)
Pulses (%)	103 (8.8)	83(20.1)	37 (11.6)	166 (16.5)	52 (6.7)	67 (24.4)	508 (12.8)
Production (in ‘000 tons)							
Sorghum (%)	16 (6.3)	56 (22.5)	35 (14.3)	36 (14.4)	90 (36.4)	15 (6.1)	248 (100.0)
Spiked millet (%)	25 (27.6)	4 (4.7)	2 (1.7)	4 (4.4)	28 (31.2)	27 (30.5)	89 (100.0)
Cotton[a] (%)	12 (5.6)	54 (25.4)	13 (6.1)	82 (38.5)	34 (16.0)	18 (8.4)	213 (100.0)
Groundnut (%)	538 (57.2)	157.00 (16.7)	81 (8.6)	51 (5.4)	106 (11.3)	8 (0.9)	941 (100.0)
Pulses (%)	44 (22.7)	35.49 (18.1)	13.34 (6.8)	58 (29.5)	22 (11.1)	23 (11.7)	196 (100.0)
Productivity (in tons/ha)							
Sorghum	1.05	0.93	0.97	0.88	1.27	1.18	1.05
Spiked millet	1.11	1.44	2.08	1.67	1.66	1.87	1.64
Cotton[a]	2.23	2.29	2.74	2.18	2.37	2.18	2.33
Groundnut	2.29	1.96	1.95	1.91	1.91	1.70	1.95
Pulses	0.43	0.43	0.37	0.35	0.42	0.34	0.39

Notes: [a] In bales of 170 kg lint each; figure in parenthesis represent % to total
Sources: Season and Crop Report (2005-2006 to 2009-2010); Government of Tamil Nadu, India

Climate variables

Temperature

Descriptive statistics of temperature data from 1981 to 2010 for each zone is shown in Table II. It shows that the highest average temperature is recorded in the Southern zone (29.22°C), followed by Cauvery delta zone (28.96°C). Average temperature for all six zones is 28.65°C. The Northeast zone recorded high variability in temperature with a standard deviation of 2.58°C. While maximum temperature is recorded in the Southern zone (31.03°C), minimum temperature is observed in the Western zone (26.58°C) during the study period.

Precipitation

Descriptive statistics on precipitation from 1981 to 2010 is presented in Table II. The Northeast zone had highest mean annual precipitation of 1,091 mm with a standard deviation of 217 mm, followed by the Cauvery delta zone with mean annual precipitation of 979 mm and highest deviation of 221 mm. The Western zone had the lowest mean precipitation (690 mm) with standard deviation of 181 mm. Average precipitation of all zones together is 880 mm.

Methodology

Literature survey revealed three major approaches to measure the sensitivity of agricultural production to climate change:

1. agro-economic methods (AEMs);
2. cross-sectional methods (CSMs); and
3. agro-ecological zone (AEZ) methods.

The AEM begins with a crop model that has been calibrated with carefully controlled agronomic experiments in greenhouse (Adams *et al.*, 1998; Kumar and Parikh, 2001; Parry *et al.*, 2004). Limitations of this method are that it is lab oriented, time consuming and uncertainty in the functional forms. In CSM, also known as Ricardian method, farm performances are examined across climatic zones (Mendelsohn *et al.*, 1996; Benhin, 2006;

Table II. Descriptive statistics of the temperature and precipitation in different zones of Tamil Nadu (1980-1981 to 2009-2010)

Zones	Northeast zone	Northwest zone	Western zone	Cauvery delta zone	South zone	Southern zone	Tamil Nadu
Temperature (in °C.)							
Mean	28.60	28.18	27.98	28.96	28.93	29.22	28.65
SD	2.58	2.19	2.02	2.26	2.17	1.97	2.20
Maximum	29.20	30.44	28.99	29.97	29.74	31.03	29.89
Minimum	27.88	26.64	26.58	28.08	28.23	27.65	27.51
Precipitation (in mm)							
Mean	1090.57	819.40	690.43	979.59	937.62	762.67	880.05
SD	216.53	125.33	180.67	220.53	155.53	128.58	171.20
Minimum	720.43	534.77	430.25	593.32	611.92	547.00	572.95
Maximum	1,641.93	1,169.22	1,097.85	1,564.10	1,383.40	1,049.87	1,317.73

Source: IMD (1980-1981 to 2009-2010)

Deressa and Hassan, 2009). CSMs underestimate damages and overestimate benefits by holding prices constant. The third approach to measure the impact of climate change utilizes AEZ (FAO, 1996). The main advantage associated with the AEZ 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 (FAO, 1996). The AEZ modeling/Just-Pope yield function is widely used in agricultural production analysis (Chen *et al.*, 2004; McCarl *et al.*, 2008; Carew *et al.*, 2009; Ranganathan, 2009). Just-Pope yield function gives a simple specification of output or yield attributes with associated production risk (mean-variance), where input affects both expected yield and its variance. It is important to understand the marginal effects of input on crop yield and variance. Hence, the present study used Just-Pope yield function to assess the climate change effects on crop yield and variance.

Just-Pope yield function

Just and Pope (1978) developed a stochastic production function specification that allows explicit estimation of the effect of independent variables on the probability distribution of output. An added advantage of this approach is that it does not impose dependence between an item's effect on yield variability and its effect on mean yield. Just and Pope (1978,1979) described both maximum likelihood (1978) and feasible generalized least squares (sFGLS) (1979) procedures for estimating the function. The other advantage is that the function is a sum of two components, one relating to the output level and the other relating to the variability in output. This specification allows an econometrician to differentiate the impact of inputs on output and risk, and has sufficient flexibility to accommodate both positive and negative marginal risks with respect to inputs. In addition, Just-Pope function shows that ignoring risk in the production function can lead to wrong inferences on the technology coefficients and, in particular, can produce standard errors that are misleading by indicating much greater precision in estimation than is, in fact, obtained. However, Just-Pope yield function suffers from the following drawbacks:

- The model is limited to the first two moments of the output distribution.
- Input levels are likely to be endogenous in the production function.
- Risk preferences are not identified (Antle, 1983; Antle and Capalbo, 2001).

To overcome these drawbacks, the study used the estimation method similar to McCarl *et al.* (2008) which has been explained below.

Just and Pope (1978) yield function is specified as:

$$y_{it} = f(X_{it}, \beta) + h(X_{it}, \delta)\omega_{it} \tag{1}$$

where Y_{it} is the yield of a given crop, $f\,(X_{it}, \cdot\, \beta)$ is an average production function and X is a set of explanatory variables (climate, location and time period). The functional form $h\,(X_{it}, \cdot\, \delta)$ for the error term is an explicit form for heteroskedastic errors, allowing estimation of variance effects. Estimates of the parameters of $f\,(X_{it}, \cdot\, \beta)$ give the average effect of the independent variables on yield, while $h(X_{it}, \cdot\, \delta)$ gives the effect of each independent variable on the variance of yield. The interpretation of the signs on the parameters of $h\,(X_{it}, \cdot\, \delta)$ is straight forward. If the marginal effect on yield variance of any independent variable is positive, then the increase in that variable increases the standard deviation of yield, while a negative sign implies a decrease of yield variance. FGLS is used to estimate the function. The fundamental procedure of Just-Pope yield function is:

- estimate the model by ordinary least squares (OLS) and obtain residuals;
- regress the logarithm of squared residuals against *X* as independent variables;
- obtain the predicted values of those residuals, which are calculated as the antilogarithm of the predictions from the second step, and this is consistent estimates of the variances; and
- estimate the original model by weighted least squares (WLS) using the squared root of the variance predictions as weights.

This study used the fixed effects model to estimate unit-specific effect for each zone. Moreover, the fixed effects model does not require the restrictive assumption that the zone-specific effects is independent of the included covariates as the random effects model does. Zonal dummies were included in the regression to capture zone-specific effects that are invariant over time. This procedure was applied in all first-stage OLS estimations, variance estimations and in second-stage WLS estimations.

The linear climate variables and the interactions of regions with temperature and precipitation were also included, as their effects may not be uniform across zones. Also, the Just-Pope yield function was used with additional specifications like added acreage, annual precipitation and mean temperature during crop growing season, standard deviation of temperature and precipitation intensity (the ratio of highest monthly precipitation to the yearly total precipitation). The precipitation ranges from 1/12 (uniformly intense) to 1 (one month gets all yearly rain). Zonal dummies are exogenous variables. Linear and quadratic trends were included to incorporate the effect of technological change. The linear mean function *f* (X, β) is:

$$\begin{aligned} f(X;\beta,d) = {} & \beta_0 + \beta_{1Acreae} + \beta_{2Precipitation} + \beta_{3Temperature} + \beta_{4SD-temperature} \\ & + \beta_{5Precipitation\ Intensity} + \beta_{6trend} + \beta_{7trend^2} + \sum_{i-1}^{i-R-1} T_iD_i \\ & + \sum_{i-1}^{i-R-1} P_iD_i + \sum_{i-1}^{i-R-1} d_iD_i \end{aligned} \tag{2}$$

where T_iD_i are temperature interaction dummies, P_iD_i are precipitation interaction dummies and diDi ($i = 1, 2 \ldots$) are zone-specific dummies taking Values 1 and 0.

The variance function $\sigma^2\omega$ ln h^2 (x, δ, η) with $\sigma^2\omega = 1$ was assumed to have the following semi-log form:

$$\begin{aligned} \ln h^2(X;\beta,\eta) & = (\delta X + \eta D) \\ & = \Big\{ \delta_0 + \delta_{1Acreae} + \delta_{2Precipitation} + \delta_{3Temperature} + \delta_{4SD-temperature} \end{aligned}$$

$$+ \delta_{5Precipitation\ Intensity} + \delta_{6trend} + \delta_{7trend^{2}} + \sum_{i-1}^{i-R-1} Ti\eta_i$$

$$+ \sum_{i-1}^{i-R-1} Pi\eta_i + \sum_{i-1}^{i-R-1} \eta_i Di \Big\} \qquad (3)(3)$$

where, (ln $h^2[x, \delta, \eta]$) logarithm of squared residuals from first stage OLS is a dependent variable, and independent variables are same as first stage OLS. The basic assumption of Just-Pope yield function is that the included variables are stationary. Accordingly, before estimating the model, panel unit root test was performed to test the stationary of dependent (yield) and independent variables (acreage, rainfall and temperature).

Panel unit root test

Just-Pope yield function can be estimated from the panel data relating annual yield to exogenous variables. The deterministic and stochastic trends in variables can introduce spurious correlations between the variables, because the errors in the data-generating processes for different series might not be independent (Granger and Newbold, 1974). Further, correlations might be detected between variables even though they are increasing for different reasons and in increments that are not correlated (Banerjee *et al.*, 1993). For these reasons, it is important to test stationarity.

The stationary time series are integrated at order zero or $I(0)$. Regressions on stationary variables may fulfill the basic conditions, and inferences on a deterministic time trend can be made safely. If the stationary time series are found to be I(1), the particular time series must be differenced before being included in the Just-Pope yield function. Any data set with a time period of 20 years or more should be tested for its time series properties before being used in empirical models that assume stationary variables. Practitioners have tested for unit roots and used differencing or other filtering techniques to make the variables stationary. The objective is to test whether a given series is non-stationary for all the individual units (ϕ_i for zone). It is assumed that the series follow a general panel data model structure (for *i* zones and *t* periods):

$$Y_{it} = (1 - \phi_i)\mu_i + \phi_i y_{i,t-1} + \varepsilon i_{it}, \qquad (4)$$

$$\mathrm{i} = 1, \ldots, \mathrm{N}; \quad \mathrm{t} = 1, \ldots, \mathrm{T}$$

where Y_{it} represents the variable to be tested, μ_i is a zone-specific constant, ϕ_i is a zone specific parameter and ε_{it} is an error term. This equation can be shown as:

$$\Delta Y_{it} = \alpha_i + \phi_i y_{i,t-1} + \varepsilon i_{it}, \qquad (5)$$

It is important to test whether $\varphi_i = 1$ for all i, which is equivalent to the null hypothesis of panel unit root $H0$: $\beta_i = 0$ for all i.

This study performed two types of panel unit root tests. First test assumes an alternative hypothesis that the series is stationary for some individuals and not stationary for others: $H1$: $\beta_i < 0, i = 1, \ldots, N_1, \beta_i = 0, i = N_1 + 1, \ldots, N$ (Im *et al.*, 2003). In the second test, the alternative hypothesis is that the series is stationary for all the individuals, say $H1$: $\beta_i < 0$, $i = 1, \ldots, N$ (Levin *et al.*, 2002). Both tests allow the inclusion of lags of ΔY_{it} into the null hypothesis, which makes the test robust for serially correlated errors. Also, the test in Im *et al.* (2003) has a “degraded” version that is robust when the disturbances are correlated cross-sectionally. In that case, the model structure is specified as follows:

$$\Delta\hat{Y}_{it} = \hat{\alpha}_i + \beta_i\hat{y}_{i,t-1} + \varepsilon i_{it}, \tag{6}$$

where the (^) above the variables indicates that the cross-sectional mean was subtracted from each variable. All the tests explained above are distributed standard normal under the null hypothesis. Those are lower tail tests; thus, the null hypothesis is rejected at a 95 per cent confidence level.

Projection of impact of climate change

The mean precipitation and temperature for the period from 1980-1981 to 2009-2010 for each zone constitute the baseline climate scenario. To project the mean and variance of crop productivity due to climate change by 2030, the projected climate variables (temperature and precipitation) generated by the RegCM4 model from the RegCMs were then plugged into the estimated production function.

Estimation (2010)

$$\begin{aligned}\hat{Y}_t = {} & \hat{\beta}_0 + \hat{\beta}_1 A_t + \hat{\beta}_2 P_t + \hat{\beta}_3 T_t + \hat{\beta}_4 SD - T_t + \hat{\beta}_5 PI_t + \hat{\beta}_6 t_t + \hat{\beta}_7 t_{2t} \\ & + \hat{\beta} T_i D_t + \hat{\beta} P_i D_t + \hat{\beta} d_i D_t\end{aligned} \tag{7}$$

The projected climate variables were plugged into equation (7) to get equation (8) to assess the projected future climate change’s impacts on crop yield.

Projection (2030):

$$\begin{aligned}\hat{Y}_{t+1} = {} & \hat{\beta}_0 + \hat{\beta}_1 A_{t+1} + \hat{\beta}_2 P_{t+1} + \hat{\beta}_3 T_{t+1} + \hat{\beta}_4 SD - T_{t+1} + \hat{\beta}_5 PI_{t+1} \\ & + \hat{\beta}_6 t_{t+1} + \hat{\beta}_7 t_{2t+1} + \hat{\beta} T_i D_{t+1} + \hat{\beta} P_i D_{t+1} + \hat{\beta} d_i D_{t+1}\end{aligned} \tag{8}$$

Subtracting equation (8) from equation (7), we obtain equation (9), which is the change in yield (ΔY) between estimated yield ($\hat{Y}_t$) and projected yield ($\hat{Y}_{t+1}$) due to climate change:

$$\Delta Y = \hat{Y}_{t+1} - \hat{Y}_t \tag{9}$$

A similar procedure was followed for variance function to project the variance in crop productivity due to climate change.

Results and discussion

Panel unit root test

The Im–Pesaran–Shin (IPS) test is the same as the Levin – Lin – Chu unit root **(LLC)** test, but the alternative hypothesis is more flexible. It states that at least one of the series is stationary but not necessarily all. The results of the LLC and IPS tests are reported in Table III. Both LLC test and IPS test results indicate that all the variables are statically significant; thus, the null hypothesis can be rejected, as the included variables are stationary.

Impact of climate change on crop yield

The final estimates of the parameters of stochastic production function are presented in Table IV, where the models were estimated by the FGLS method and the standard errors were adjusted appropriately to account for the first-stage variation. The functional form for the average yield equation is linear for both the independent and the dependent variables; meanwhile, the variance equation is linear for the independent variables, but the dependent variable appears logarithmically to assure positive predicted variances. The space constraints, the coefficients for the individual zonal dummies, are not described herein.

The estimated results showed that weather-related variables have significant influence on yields of sorghum, spiked millet, cotton, groundnut and pulses. This suggests that holding acreage, other involved variables and the coefficient for precipitation are significantly positive for sorghum, spiked millet, cotton and pulses. A higher amount of total annual precipitation would increase the yields of the above crops, meanwhile it does not, significantly, affect the groundnut yield. Ranganathan, (2009) has also recorded similar results that higher amount of annual precipitation had significant and positive effect on yield of sorghum, cotton, groundnuts and pulses. The parameter for precipitation intensity is negative for all selected crops and significantly influences the yield of spiked millet, cotton and pulses, suggesting that greater intensity of precipitation (high amount of rain in short period) had adverse effect on yields. This result suggests that precipitation intensity is also a greater concern along with annual amount of precipitation. Studies also confirm that the precipitation intensity is an important factor while considering precipitation impact on crop yield (Selvaraju, 2003; Kumar *et al.*, 2004, McCarl *et al.*, 2008, and Barnwal and Kotaniy 2010).

Table III. Results of Levin–Lin–Chu and Im–Pesaran–Shin unit root tests:

Particulars	No. of panels	No. of periods	Yield (kg) *t*-value	Area (ha) *t*-value	Temperature (° C) *t*-value	Precipitation (mm) *t*-value
Levin – Lin – Chu test						
Sorghum	6	30	−2.45***	−2.14***	−4.20***	−4.66***
Spiked millet	6	30	−5.24***	−1.92**	−5.22***	−4.48***
Cotton	6	30	−2.64***	−2.33***	−4.29***	−4.72***
Groundnut	6	30	−1.97**	−1.73**	−4.53***	−4.38***
Pulses	6	30	−2.67***	−3.79***	−3.65***	−4.02***
Im – Pesaran – Shin test (W-t-bar statistic)						
Sorghum	6	30	−2.62***	−1.77**	−4.44***	−5.23***
Spiked millet	6	30	−4.15***	−1.77**	−4.96***	−4.997***
Cotton	6	30	−3.71***	−2.50***	−5.52***	−4.987***
Groundnut	6	30	−3.06***	−1.79**	−5.64***	−4.57***
Pulses	6	30	−3.04***	−2.62***	−5.75***	−4.725***

Notes: *, **, ***Significant at the 10%, 5% and 1% levels, respectively; time trend is included

Table IV. Yield mean regression second-stage WLS with predicted standard deviation as weight

Independent variables	Sorghum Coefficient	Sorghum Standard error	Spiked millet (cumbu) Coefficient	Spiked millet (cumbu) Standard error	Cotton Coefficient	Cotton Standard error	Groundnut Coefficient	Groundnut Standard error	Pulses Coefficient	Pulses Standard error
Acreage (ha)	−0.00**	0.00	0.01*	0.00	0.00	0.00	−0.00***	0.00	0.00	0.00
Precipitation (mm)	3.68***	0.78	0.12**	0.05	0.28*	0.15	0.07	0.43	0.18**	0.08
Mean Temp °C	−79.19	54.26	−36.59	97.47	53.41**	27.23	−209.7***	74.69	5.98	25.08
SD–temperature	−77.45	68.48	−8.54	115.36	−9.63	44.03	−0.33	88.65	−9.12	29.83
Precipitation intensity	−12.68	13.86	−6.01*	3.53	−4.84***	1.66	−7.89	5.14	−4.06***	1.70
Trend	−8.09***	3.22	50.80***	17.32	−36.9***	5.11	66.62***	12.01	9.32**	4.27
Trend ^2	0.06	0.33	−0.69	0.52	1.65***	0.15	−1.25***	0.36	−0.28*	0.14
Temperature × D1[b]	−11.13	14.10	4.61	24.37	17.87**	7.14	16.60*	9.07	4.83	4.85
Temperature × D2	−10.80	16.14	26.82	23.34	10.16	7.42	6.86	19.71	10.40*	5.69
Temperature × D3	−12.1***	13.58	7.30	20.73	22.9***	7.31	10.81	18.09	8.36	4.94
Temperature × D5	−17.51	15.94	11.75	24.27	16.67*	9.50	11.20	19.32	8.18	5.56
Temperature × D6	−14.33	18.17	27.79	17.63	1.42	6.66	7.72	17.66	4.43	4.26
Precipitation × D1	0.83***	0.32	0.13	0.60	−0.46***	0.18	0.06	0.48	−0.05	0.12
Precipitation × D2	0.76	0.62	−0.24	0.60	−0.11	0.19	0.00	0.49	−0.17	0.14
Precipitation × D3	0.87**	0.38	0.32	0.68	−0.54**	0.22	0.05	0.53	−0.19	0.15
Precipitation × D5	0.70	0.54	0.21	0.73	−0.56**	0.28	0.38	0.54	−0.16	0.17
Precipitation × D6	0.55*	0.34	−0.32	0.52	−0.09	0.18	0.07	0.47	−0.10	0.12
Constant	−129.19	1,597.13	2,480.62	2,986.38	−1,338.1*	742.30	7,074.0***	2,260.40	105.46	744.40
Number of observations	180		180		180		180		180	
F (22,157)	8.92		4.89		34.50		22.32		3.02	
Prob>*F*	0.000		0.000		0.000		0.000		0.0001	

Notes: *, **, ***Denotes significance at the 10, 5 and 1% levels, respectively; [a] dependent variables: yearly average crop yield (kg) by zone and independent variables: crop acreage, yearly amount of precipitation, yearly standard deviation of temperature and precipitation intensity; [b] regional interaction dummies: D1–Northeast zone, D2–Northwest zone, D3–Western zone, D4–Cauvery delta zone, D5–South zone, D6–Southern zone

Likewise, an increase in temperature had a significant positive influence on cotton yield, which is contradictory to the findings of Ranganathan (2009) that temperature had significant negative influence on cotton yield. Hence, a debatable result was estimated and reported for cotton with respect to temperature in Tamil Nadu. The other variable, increases variability in temperature (SD temperature), had no significant effect on the yield of selected crops. The variable "temperature" should be understood as the effect of temperature for the base zone (central region of the study area – Cauvery delta zone), while the coefficients for all of the interaction terms reflect the differences between the temperature effects over a given zone with respect to the Cauvery delta zone. Positive (negative) sign indicates a beneficial (harmful) effect of higher temperature on crop yield. As one could observe, in the Northeast zone, an increase in temperature had a significant positive effect on yield of cotton and groundnut and, in Northwest zone, had a significant positive effect on yield of pulses. In the Western zone, an increase in temperature had a significant negative effect on sorghum yield and a significant positive effect on cotton yield. In the Southern zone, higher temperature had significant positive effect on cotton yield.

Similarly, an interaction between precipitation and zones were also included in the analysis. Higher precipitation had a significant positive impact on the yield of sorghum, but had significant negative impact on cotton in the Northeast zone. In the Western zone, higher precipitation had positive influence on sorghum yield, while it had negative impact on cotton. In the Southern zone, higher rainfall had a significant negative impact on cotton. Finally, the linear time trend is positive and significant for spiked millet, groundnut and pulses, whereas it had negative effect on yield of sorghum and cotton, and the quadratic time trend is negative for both groundnut and pulses but positive for cotton. The time trend may serve as a proxy for the non-stochastic portion in the variation in the yield such as advances in agricultural technology. It means that the technological progress was consistently positive for spiked millet, groundnut and pulses, while sorghum and cotton were sporadic during the study period.

The variability in crop yield indicates the risk in crop yield due to climate variables. Table V shows the regression results of variance of residuals from the first stage OLS. Regarding the variance equation, a positive coefficient implies a higher yield variance. Higher precipitation had negative influence on variances in sorghum and spiked millet, and in groundnut, higher the temperature, higher was the variance in groundnut yield. The interaction dummies between temperature and zone indicated that higher temperature increased the variance of groundnut in the Northeast zone and would increase the yield variance of spiked millet in the Northwest zone. In the Southern zone, the higher temperature decreased the variance of sorghum yield. The precipitation intensity increased the variance in spiked millet yield, and precipitation interaction dummies indicated that higher precipitation significantly decreases the variance of spiked millet yield in the Northwest zone. In the Southern zone, higher precipitation significantly decreased variance in sorghum yield.

Projection of crop yield and yield variability due to climate change

The likely impacts of future climate changes were predicted with the parameters estimated from the Just-Pope yield function, and the results are given in Table VI. By the year 2030, the productivity of pulses likely to decline in all zones with maximum reduction in the Northeast zone (6.07 per cent), followed by Cauvery delta (3.55 per cent)

Table V.
Log-yield variance–regressions

Independent variables	Sorghum Coefficient	Sorghum Standard error	Spiked millet (cumbu) Coefficient	Spiked millet (cumbu) Standard error	Cotton Coefficient	Cotton Standard error	Groundnut Coefficient	Groundnut Standard error	Pulses Coefficient	Pulses Standard error
Acreage (ha)	−0.00	0.00	0.00	0.00	0.00	0.00	−0.00	0.00	0.00	0.00
Precipitation (mm)	−0.00**	0.00	−0.00*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean temperature °C	0.90	0.69	0.36	0.42	−0.59	0.52	0.64**	0.32	0.75	0.55
SD–temperature	−0.11	0.48	0.33	0.55	−0.66	0.64	−0.31	0.63	−0.27	0.67
Precipitation intensity	0.02	0.03	0.06**	0.03	0.03	0.04	−0.05	0.03	0.02	0.04
Trend	0.13**	0.07	−0.02	0.08	−0.34***	0.09	−0.00	0.09	0.08	0.09
Trend ^2	−0.00**	0.00	0.00	0.00	0.01***	0.00	0.00	0.00	−0.00	0.00
Temperature X D1[b]	0.05	0.08	−0.12	0.10	−0.00	0.11	0.23*	0.13	0.04	0.12
Temperature × D2	0.08	0.09	−0.18*	0.11	0.08	0.13	0.09	0.13	−0.05	0.14
Temperature × D3	0.07	0.08	0.01	0.10	0.01	0.11	0.13	0.11	0.05	0.12
Temperature × D5	0.05	0.09	−0.07	0.10	0.02	0.12	0.07	0.11	−0.00	0.13
Temperature × D6	0.20**	0.08	0.00	0.09	0.09	0.10	0.02	0.10	0.08	0.12
Precipitation × D1	−0.00	0.00	0.00	0.00	0.00	0.00	−0.00	0.00	−0.00	0.00
Precipitation × D2	−0.00	0.00	−0.01**	0.00	−0.00	0.00	0.00	0.00	0.00	0.00
Precipitation × D3	−0.00	0.00	−0.00	0.00	−0.00	0.00	−0.00	0.00	0.00	0.00
Precipitation × D5	−0.00	0.00	0.00	0.00	−0.00	0.00	−0.00	0.00	0.00	0.00
Precipitation × D6	−0.01**	0.00	0.00	0.00	−0.00	0.00	0.00	0.00	−0.00	0.00
Constant	31.62***	11.39	−1.12	12.91	30.18**	15.413	−8.006	15.28	−14.14	16.19
Number of observations	180		180		180		180		180	
F (22,157)	1.33		1.26		2.55		1.13		0.99	
Prob>*F*	0.18		0.22		0.00		0.33		0.47	

Notes: *, **, *** Denote significance at the 10, 5 and 1% levels, respectively; [a] dependent variables: logarithm of squared residuals from first-stage OLS, independent variables: crop acreage, yearly amount of precipitation, yearly standard deviation of temperature and precipitation intensity; [b] regional interaction dummies: D1–Northeast zone, D2–Northwest zone, D3–Western zone, D4–Cauvery delta zone, D5–South zone, D6–Southern zone

Table VI. Percentage change in mean yield and standard deviation–projections for 2030

Crops	Northeast zone	Northwest zone	Western zone	Cauvery delta zone	South zone	Southern zone
Mean yield changes						
Sorghum	−1.62	4.67	−2.63	−1.23	4.45	−1.92
Spiked millet	−1.21	0.76	0.05	−0.24	−0.08	−1.39
Cotton	−12.99	−8.05	−2.10	10.17	13.52	4.82
Groundnut	−1.07	1.59	−2.19	0.40	3.94	4.97
Pulses	−6.07	−2.30	−1.45	−3.55	−3.54	−1.61
Standard deviation changes						
Sorghum	1.06	−1.45	−0.65	−0.37	−0.44	−3.18
Spiked millet	−3.86	−3.38	−5.08	−3.95	−2.29	−6.64
Cotton	3.71	0.88	2.24	−3.14	2.18	3.23
Groundnut	−3.19	−1.43	−0.32	−1.88	−1.02	2.86
Pulses	0.92	8.24	2.79	2.66	2.66	−3.59

and South (3.54 per cent) zones. A similar projected results for the year of 2070 and 2100 was reported in IARI (2012). Palanisami *et al.* (2009) has also reported that consequently overall production in Tamil Nadu may decrease between 9 to 22 per cent for the selected crops by 2020. The variation of pulses yield is also likely to increase at the maximum level compared to baseline values. The productivity of sorghum would decrease more in the Western zone (2.63 per cent), Southern zone (1.92 per cent) and Northeast zone (1.62 per cent). Cotton crop may register a decrease in productivity with a reduction in variability, whereas in the Northeast, Northwest and Western zones, there would be a significant decline in cotton productivity to an extent of nearly 12.99, 8.05 and 2.10 per cent, respectively, whereas in the Cauvery delta zone, South zone and Southern zone, there would be a significant increase in productivity of 10.17, 13.52 and 4.82 per cent, respectively. Groundnut productivity would decline maximum about 2.19 per cent in the Western zone, and in Southern zone, the productivity would increase up to 4.97 per cent. The variation in groundnut yield would be minimum when compared with baseline. The projected result also reliable with past studies (Ranganathan, 2009), by the year 2020, the yield of sorghum is expected to decline in the Northeast zone (0.8 per cent), Western zone (2.6 per cent) and Cauvery delta zone (1.3 per cent). Similarly, cotton yield in the Northeast zone (6.3 per cent), Northwest zone (4.9 per cent) and Western zone (13.9 per cent) is also on the downward trend. In the Southern zone, the yield of groundnut may also decline by 3.7 per cent.

Conclusion

Climate change leads to increases in temperature and changes in precipitation. These changes have a considerable impact on agricultural production, as all agricultural operations rely on climate variables. In this study, the impact of climate change on agriculture was quantified by using the Just-Pope yield function. The results showed that the increase in temperature has a significant positive influence on cotton and a significant negative influence on groundnut yield. On the other hand, the increase in the precipitation has significant positive influence on sorghum, spiked millet, cotton and pulses. Precipitation intensity has a negative influence on all selected crops. Likewise, an increase in precipitation intensity increases yield variance in spiked millet. While an increase in temperature increases the variance in groundnut yield, an increase in precipitation decreases yield variability in sorghum and spiked millet; thus, changes in climate variables caused different effects on different crops. By 2030, pulses productivity would decline in all the six zones, and four zones would experience decrease in productivity of sorghum (Northeast, Western, Cauvery delta and Southern zones) and spiked millet (Northeast, Cauvery delta, South and Southern zones). Similarly, in three zones (Northeast, Northwest and Western zones), there would be a decrease in cotton productivity. Whereas two zones (Northeast and Western zones) will experience decreases in groundnut productivity. This study recommends the adoption of appropriate crop insurance scheme to reduce the possible financial losses to the farmers and to mitigate the uncertainty and risk associated with yield variability. Developing stress-tolerant, crop varieties need to be prioritized by the breeders to reduce climate vulnerability while maintaining optimum crop yield. The government policies should ensure that farmers have better access to affordable or subsidized inputs and credits to increase their ability and flexibility to change production strategies.

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