DOES CLIMATE CHANGE MAKE INDIAN AGRICULTURE MORE RISKY?

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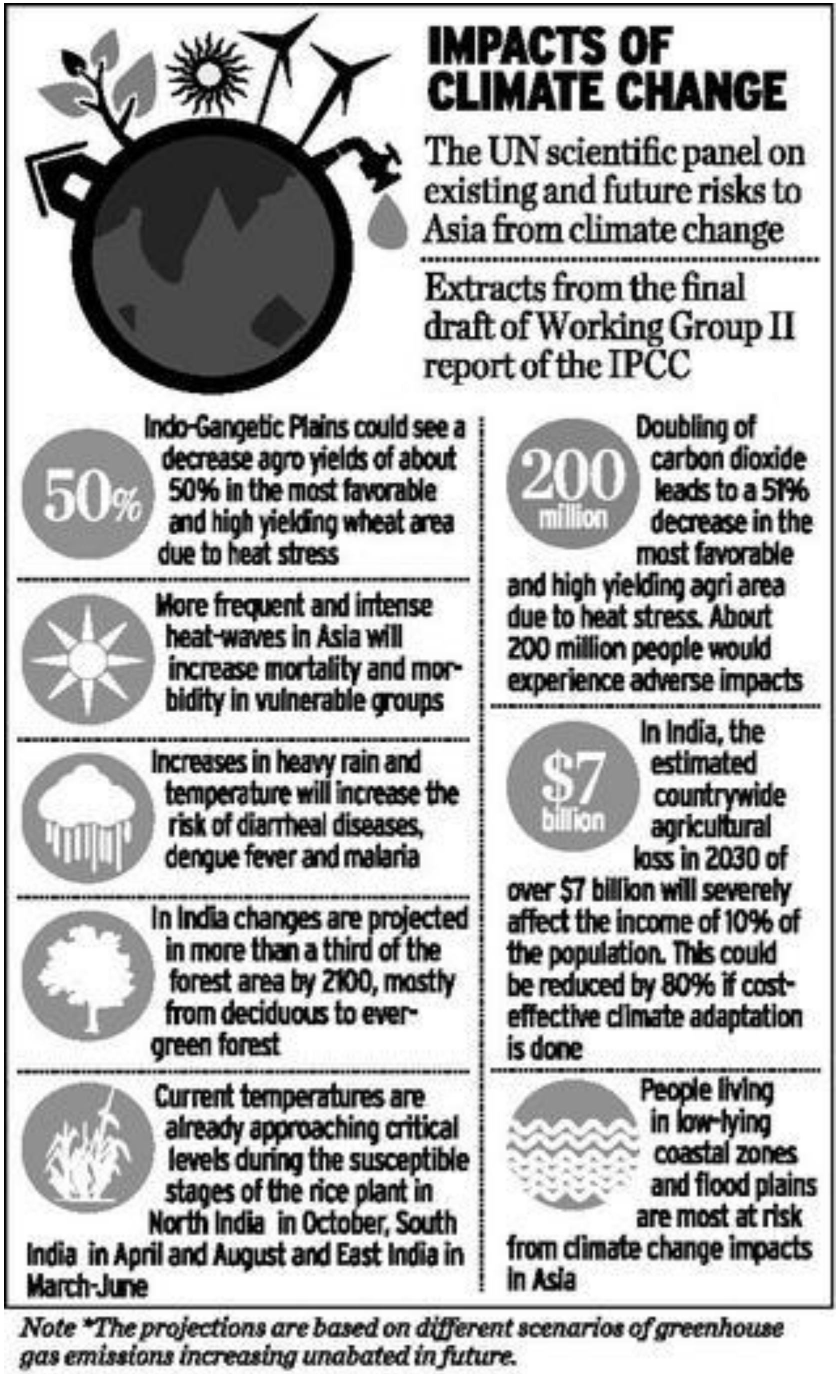
Climate Change and Developing Countries

- Though all countries affected by climate change, they are affected in different ways and to a different extent.
- Developing countries will be particularly badly hit, for three reasons:
  - geography (non-temperate latitudes)
  - greater dependence on agriculture
  - fewer resources implies greater vulnerability

Stern Review: The Economics of Climate Change (2006) p. 29



IPCC Working Group 2 Report (March 2014)

Warns of the risks the world will face if greenhouse gas emissions are not curtailed and countries do not adapt quickly enough.

For agriculture-dependent countries such as India, the report warns of ominous changes in crop yields. "With or without adaptation, climate change will reduce median yields by 0-0.2% per decade for the rest of the century, as compared to baseline without climate change."

The Economic Times, March 17, 2014

"Heavy rains, hailstorms take their toll on banking sector's profitability; Rs. 5,000 crores of crop loans expected to turn bad"

About 0.8 million hectares of farmland across 28 districts in Maharashtra has been hit by heavy rain and hailstorms over the past 10 days, according to state government officials. About 50,000 hectares of fruit crop, including grapes, oranges, bananas and pomegranates has been damaged, they said, adding that damage extends to wheat, jowar and cotton…

Climate Change and Asia

- **Effects of rising temperatures on Asia:**
  - declining crop yields; reduced fresh water supplies; rising sea-levels; increased floods, droughts and extreme weather events; biodiversity loss; higher risk of diseases
- **India-specific assessments:**
  - **NATCOM (2004):** General country-wide vulnerability assessment; post-2070 scenarios
  - **Indian Network for Climate Change Assessment INCCA (2010):** Finer-grained 4x4 assessment
  - 2030 time-horizon
  - 4 regions: Western Ghats, Himalayan Region, Coastal India, North-East
  - 4 sectors: Agriculture, Water, Forests, Human Health

e.g., for India…

- Global warming is real, but considerable uncertainty on ***specifics***
  - How much *average* temperature increase
    - When? In 2030, 2050, 2080, etc.?
    - Where? In Kashmir? In Karnataka?
  - How will a given *average* temperature increase occur?
    - Rise in maximum, minimum or the entire distribution?
    - More hot days, less cold days?
  - Same questions on rainfall, which may rise (or fall)
  - Impact uncertainties
    - More hot days bad in Rajasthan but not in Kashmir
    - More rain be good in Rajasthan but bad in Meghalaya

Expected Climate Change in India by 2030

- Regional climate models project by the 2030s, annual mean temperatures and summer monsoon rainfall both expected to increase on average:

  - increase in avg. surface temperature by 2-4 degrees C

  - changes in the **distribution** of rainfall (inter-temporal and spatial) during both monsoon and non-monsoon months:

    (decrease in number of rainy days by > than 15 days)

    (increase in intensity of rainfall by 1-4 mm/day)

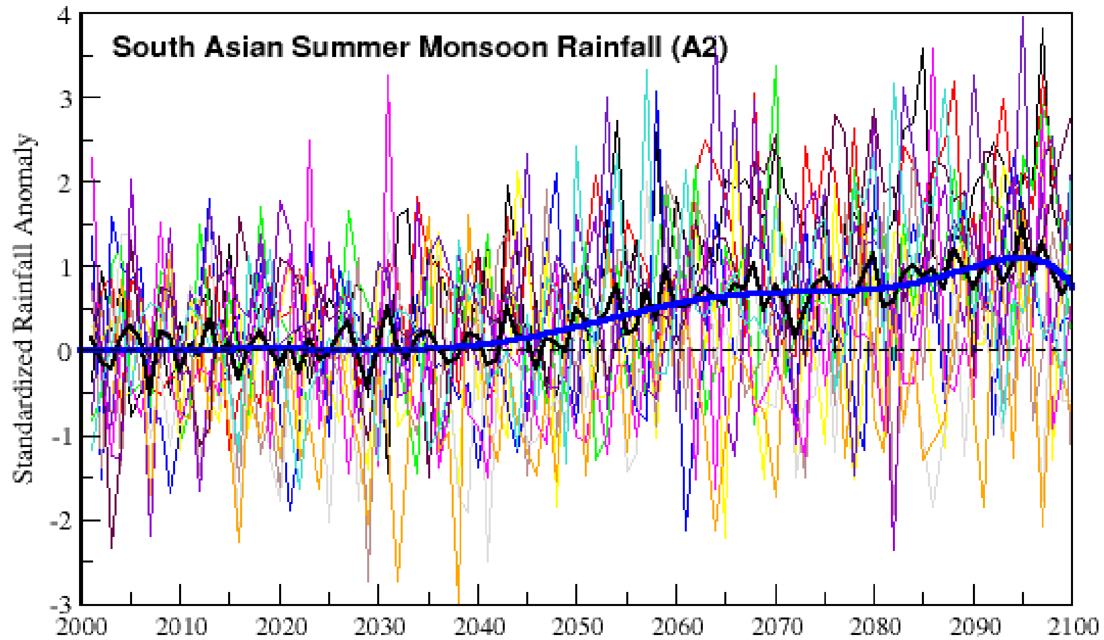
  - increase in the frequency and intensity of cyclonic storms

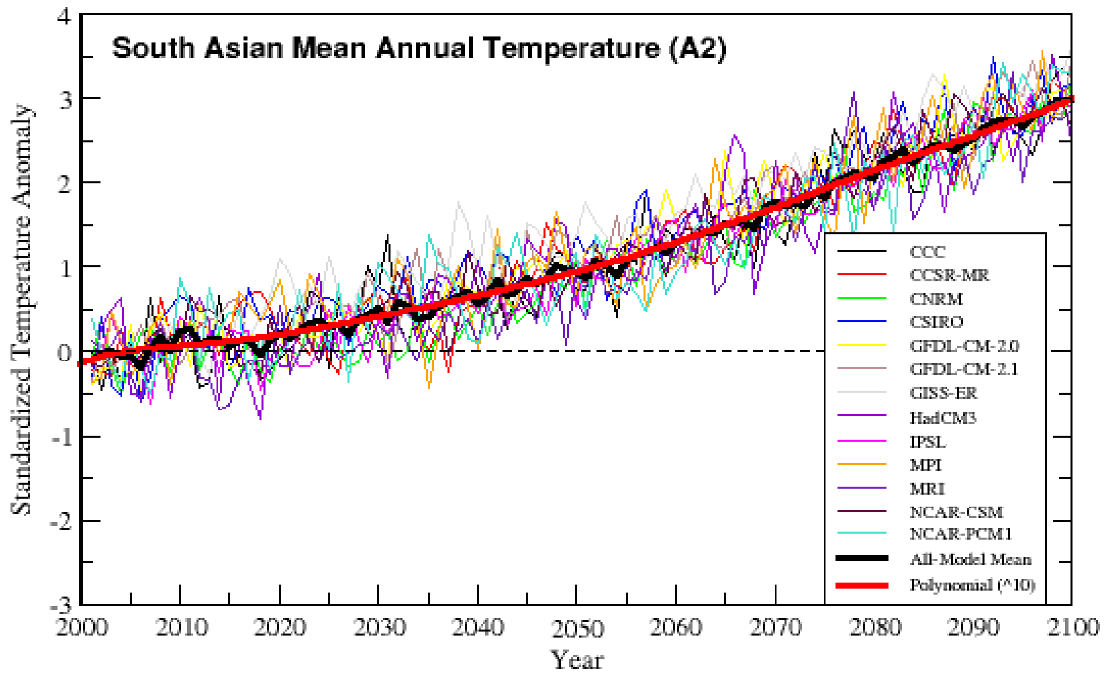
- Thus, medium-run projections for climate seem to indicate it will be warmer and wetter, **but with significant regional variation**

Future scenarios for summer monsoon rainfall and annual temperature over South Asia under A2 Scenario (High Emissions)

based on IPCC AR4 simulations of AOGCMs

(anomalies relative to current period)





Impact of Climate Change for India (INCCA 2010)

- **Agriculture**
  - Up to 50% reduction in maize yields
  - 4-35% reduction in rice yields (with some exceptions)
  - Rise in coconut yields (with some exceptions); reduced apple production
  - Negative impacts on livestock in all regions
- **Fresh water supply**
  - High variability predicted in water yields (from 50% increase to 40-50% fall)
  - 10-30% increased risk of floods; increased risks of droughts
- **Forests and natural ecosystems**
  - Shifting forest borders; species mix; negative impact on livelihoods and biodiversity
- **Human health**
  - Higher morbidity and mortality from heat stress and vector/water-borne diseases
  - Expanded transmission window for malaria

Regional Climate Change for India and its Impact

- Why of interest?
- Large country, diverse geography, climate, socioeconomic heterogeneity (3.3 million km^2, 28 states, 7 federal territories, 640 districts – 2011 census)
- Polity increasingly ‘federal’ in nature
- Makes little sense to focus on impacts at aggregate level when effects (and responses) are region specific

India’s Climate

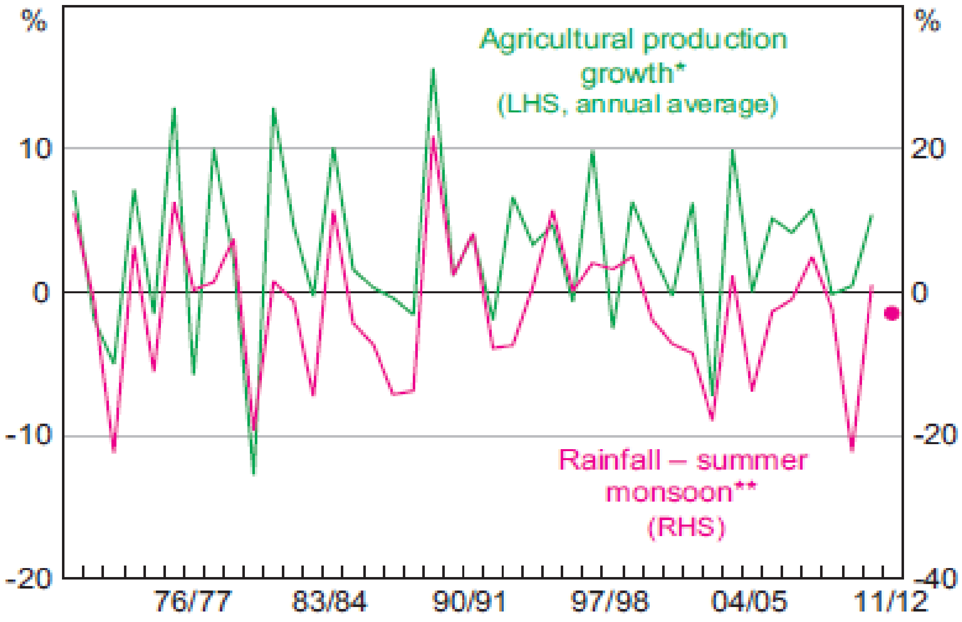
- India’s climate system -- unique features -- not well captured by global climate models (topography -- western and eastern Ghats, the central plateau and Himalayas)
- Dominated by summer (southwest) monsoon Jun-Sep (to a lesser extent winter or NE monsoon)
- Accounts for 80% of total rainfall – “Earth's most productive wet season”
- Quantity, temporal & spatial distribution of matter immensely – “the real Finance Minister” & “central bank governor”
- Only partially understood and notoriously difficult to predict.

Variability in Southwest Monsoon Rainfall

- Mean rainfall 848 mm and standard deviation 83 mm for the period 1871-2009.
- 23 deficient rainfall years and 20 excess rainfall years, slight negative trend of -0.4 mm per year, huge variability:
  - 1871-1920 deficient rainfall years > excess rainfall years
  - 1921-1960 deficient rainfall years < excess rainfall years
  - 1961-2009 deficient rainfall years > excess rainfall years
- **1951-2007:** extreme rainfall events and their intensity are increasing
  - alarming rise in intensity 1980 onwards (Uttarakhand floods – “Himalayan tsunami”)

Importance of Rainfall (Summer Monsoon)

- The summer monsoon is also the most economically important weather pattern.
- Agricultural production in India strongly correlated with summer monsoon rainfall
- Of total net sown area of 141 million hectares (Mha) in India, rain fed area is 85 Mha spread over 177 districts.



** Percentage deviation from long-run average

Modelling Impact of Climate Change (1)

- Many(!) studies have linked weather and climate to outcomes such as yields, land values, and farm profits.
- Agronomic studies focus on yields -- emphasise the dynamic physiological process of plant growth and seed formation (complex and dynamic in nature -- don’t easily fit in a regression framework).
- These phenological studies take production systems and nutrient applications as exogenous: no account for behavioural response on part of farmers. Nevertheless, these models are the predominant tool for evaluating likely effects of climate change on crop yields.

Modelling Impact of Climate Change (2)

- Several economic studies use hedonic models to link land values to land characteristics, including climate, using reduced-form regression models (Mendelsohn et al. (1994); Schlenker et al. (2006); Ashenfelter and Storchmann (2006)). Also known as Ricardian approach -- for India -- Dinar et al. (1998) Kumar and Parikh (2001).
- One strength of Ricardian approach -- unlike crop simulation models it can account for whole agricultural sector rather than a single crop at a time. Can also account for behavioral response or adaptation.
- But typically cross-sectional, so omitted variable bias.
- Variant is to use net revenue or agricultural profits either in a cross-section or a panel dataset – Sanghi and Mendelsohn (2008), Deschenes and Greenstone (2007), Kelly et al. (2005)

Modelling Impact of Climate Change: Conceptual Framework

Optimization problem for a risk neutral farmer with opportunity cost π_0 is:

$$\max_{x(.)\geq 0} \pi(x(.), p, w, \theta)$$

$$\equiv p\big(Q(\theta)\big).q\big(\theta, x(\theta)\big) - w(\theta).x(\theta),$$

$$s.t. \pi \geq \pi_0$$

x is a vector of choice variables (inputs)

Q and q are market and farmer output vectors

p and w are output and input prices

θ timing and level of exogenous weather inputs

Applying the envelope theorem we can decompose the long run change in profit from a change in climate at the optimal decision vector x^*:

$$\left.\frac{\partial \pi}{\partial \theta}\right|_{x=x^*} = \frac{\partial p}{\partial Q}\frac{\partial Q}{\partial \theta} q(\theta, x^*(\theta)) + \left(\frac{\partial q}{\partial \theta} + \frac{\partial q}{\partial x^*}\frac{\partial x^*}{\partial \theta}\right) p(Q(\theta)) - \left(\frac{\partial w}{\partial \theta} x^*(\theta) + w(\theta)\frac{\partial x^*}{\partial \theta}\right)$$

The second term represents the contribution of climate change to profit through its effect on q the individual farmer's output. Further, crop output q is the product of acreage $a(\theta)$ and yield $y(\theta, x(\theta))$: $q(\theta) = a(\theta).y(\theta, x(\theta))$

$$\frac{\partial q(\theta, x(\theta))}{\partial \theta} = \frac{\partial a(\theta)}{\partial \theta}.y(\theta, x(\theta)) + \left(\frac{\partial y(\theta, x(\theta))}{\partial \theta} + \frac{\partial y(\theta, x(\theta))}{\partial x}\frac{\partial x(\theta)}{\partial \theta}\right) a(\theta)$$

Agriculture in India

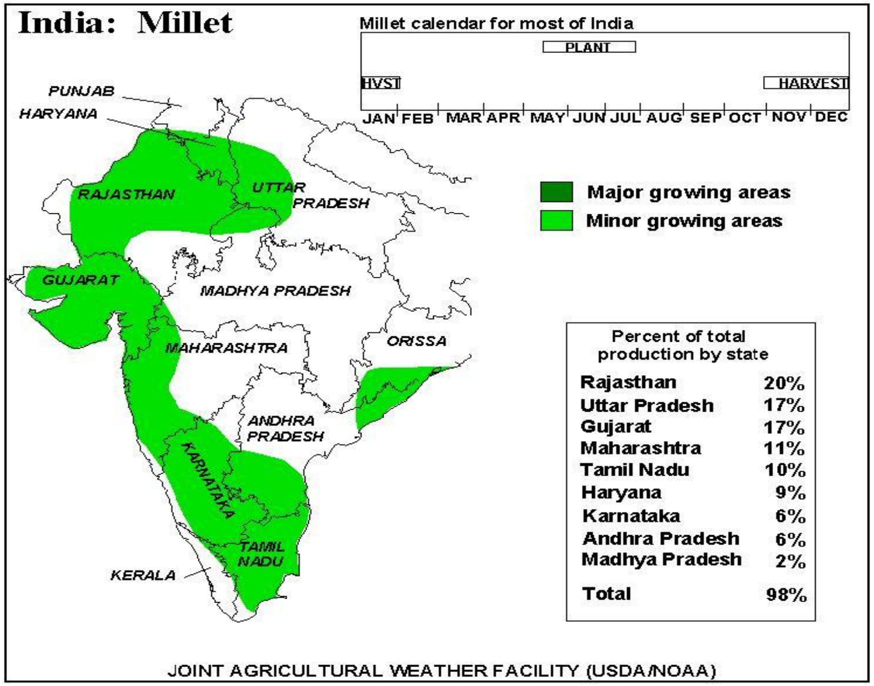
- Rice -- most important food crop in India accounting for 23.3% of gross cropped area and about 43% of total food-grain production, as well as 46% of cereal production.
- Rice (including paddy) ranked highest by value among all agricultural products in India with a total output of about $38.4 billion in 2010.
- Millets on the other hand are traditional ‘coarse cereals’ whose importance is more in terms of their role as a staple crop consumed by the poor.

Rice and Millets in India

- Three rice seasons —autumn (pre-*kharif*), winter (*kharif*) and summer (*rabi*)
- Winter or *kharif* rice (sown during Jun-Jul and harvested in Nov-Dec) is the main growing season -- 84% of the country’s rice crop
- *Bajra* (pearl millet) most widely grown millet followed by *Jowar* (sorghum)
- Because of their tolerance to difficult growing conditions such as drought, low soil fertility and high temperature, millets can be grown in areas where other cereal crops, such as rice or wheat would not survive

Millets in India

- *Bajra* (pearl millet) concentrated in Gujarat, Maharashtra and Rajasthan (70% of output)
- *Jowar* (sorghum) primarily grown in Maharashtra, Karnataka, Aandhra Pradesh (for almost 80% of output)
- Madhya Pradesh, Gujarat and Rajasthan other states producing *Jowar*



Areas Producing Millets

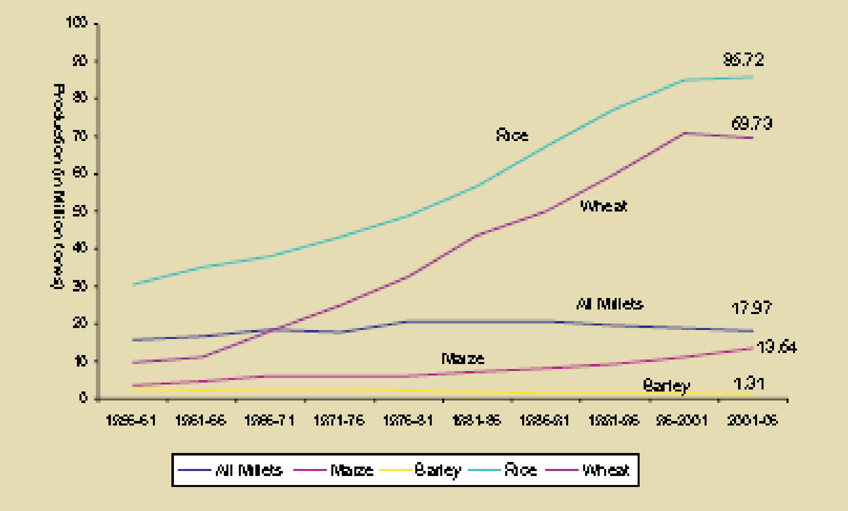
Table 2: Geographical spread of Sorghum, Pearl millet and Finger Millet in India.

Finger millet:	**Pearl millet:**	**Sorghum:**
Also known as Ragi or Mandwa is the most important small millet food crops of Southern Karnataka, Maharashtra, Uttaranchal, Tamil Nadu, Andhra Pradesh and Orissa, It is grown successfully in areas where rainfall is about 350 mm and temperatures more than 30° Celsius.	Also known as Bajra is a Kharif crop and is mainly grown in Rajasthan, Gujarat, Uttar Pradesh, Haryana, Andhra Pradesh, Tamil Nadu, Punjab and Maharashtra. The crop can do well in the areas with less than 350 mm annual rainfall and temperatures between 25° Celsius to 35° Celsius.	Also known as Jowar is perceived to be an important coarse-grained food crop, cultivated widely across Maharashtra, Madhya Pradesh, Uttar Pradesh, Haryana, Andhra Pradesh, Tamil Nadu, Karnataka and in parts of Rajasthan. The crop is hardy and cultivated in areas with rainfall beyond 350 mm.

Source: http://milletindia.org/statusofmillets.asp

Trends in Area & Production: Major Food Crops

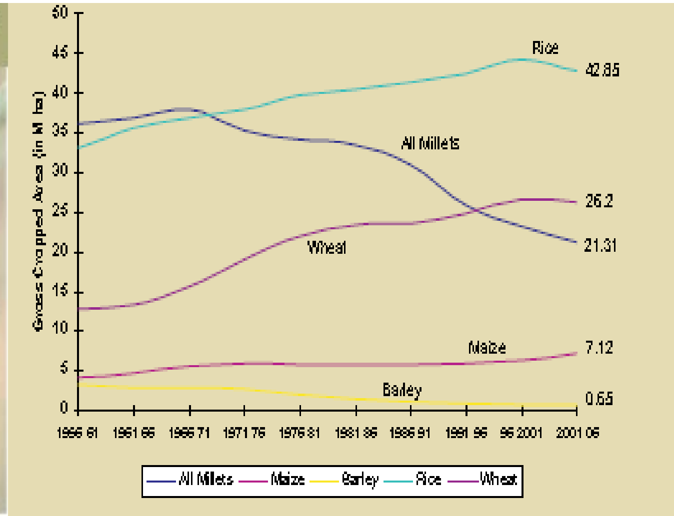
Production



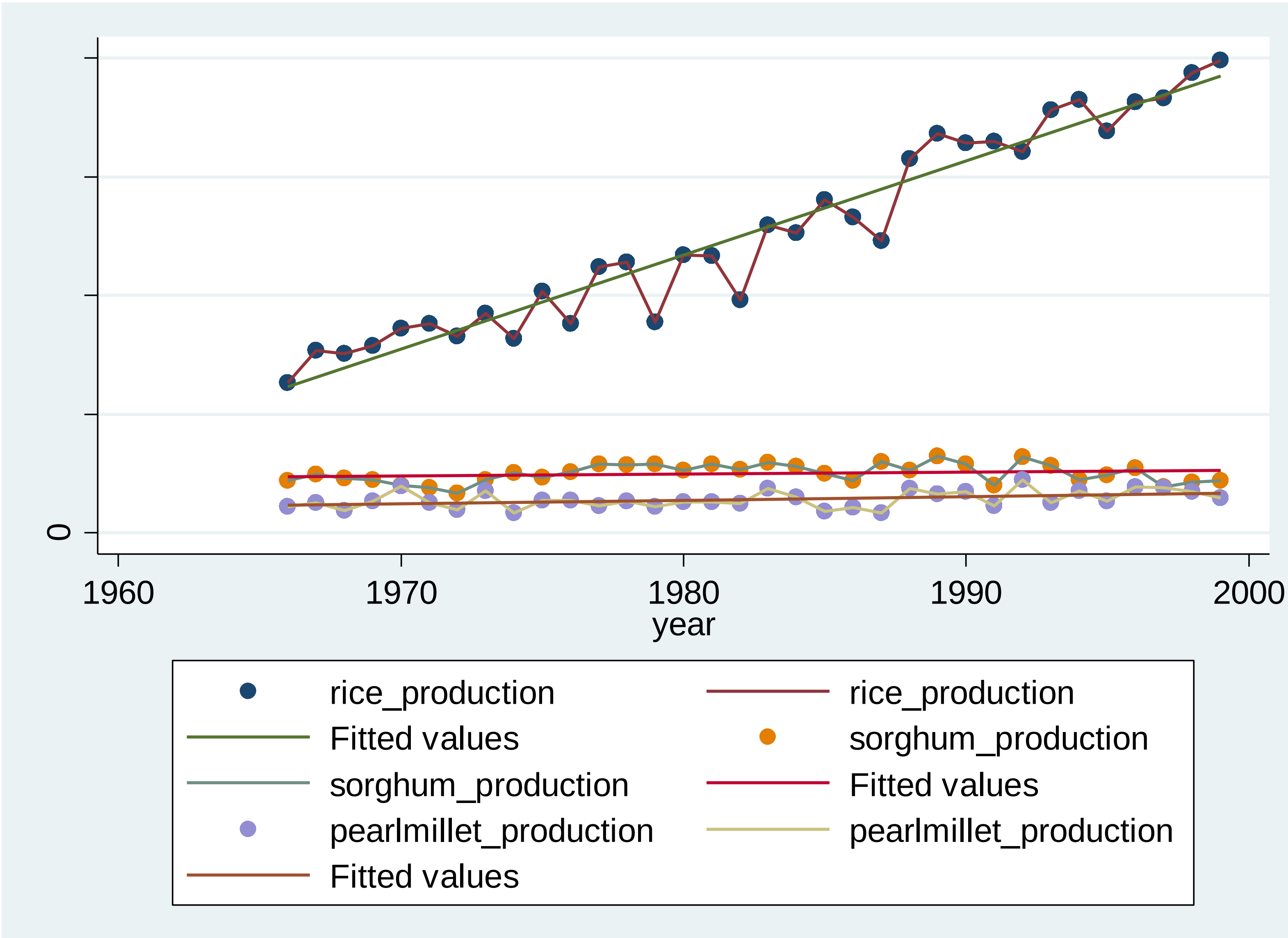
Crops	1966-71	1971-76	1976-81	1981-86	1986-91	1991-96	1996-01	2001-06	%
All Millets	18.41	17.87	20.7	20.89	20.78	19.69	18.68	17.97	[-]2.4
Rice	38.09	42.94	48.86	56.53	67.15	77.33	85	85.72	[+]125
Wheat	18.1	25.17	32.88	43.37	49.92	60.12	70.61	69.73	[+]285

Area

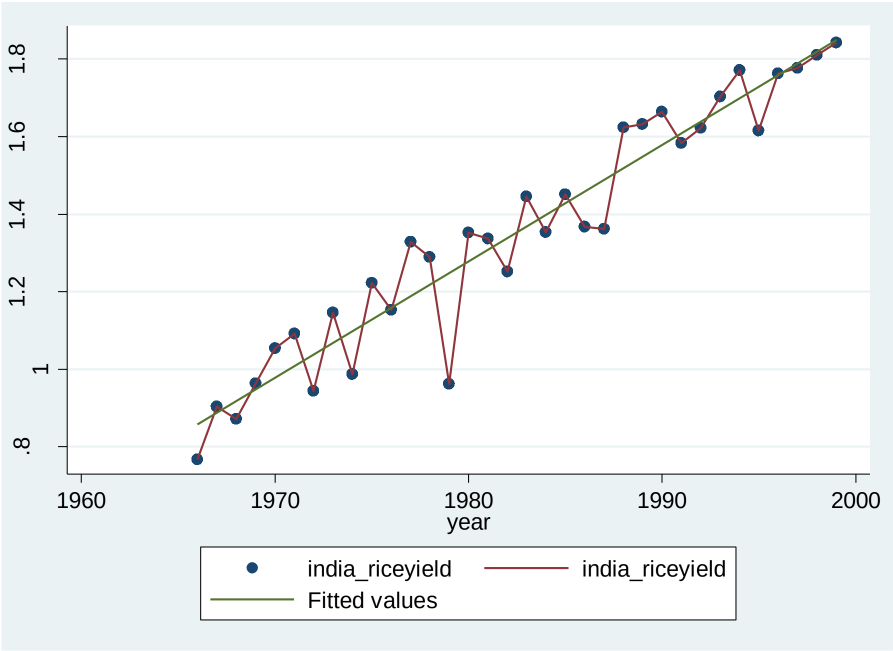
Crops	1956-61	1961-66	1966-71	1971-76	1976-81	1981-86	1986-91	1991-96	96-2001	2001-06
Millets	36.2	36.81	37.89	35.27	34.16	33.39	30.88	25.9	23.17	21.31
Rice	33.14	35.63	36.79	38.02	39.77	40.5	41.31	42.53	44.31	42.85
Wheat	12.84	13.33	15.73	19.13	21.89	23.39	23.59	24.74	26.67	26.2
Cereals	89.65	93.29	98.89	100.95	103.58	104.54	102.7	100.04	101.29	98.13
Gross Cropped Area	150.51	156.89	161.73	166.54	171.32	176.77	179.49	186.01	189.67	185.71

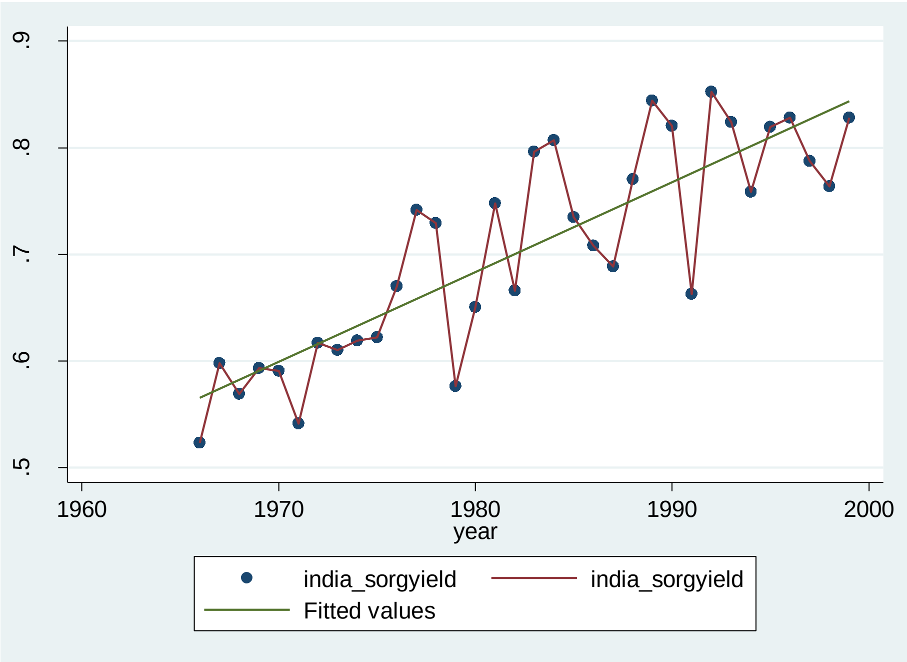


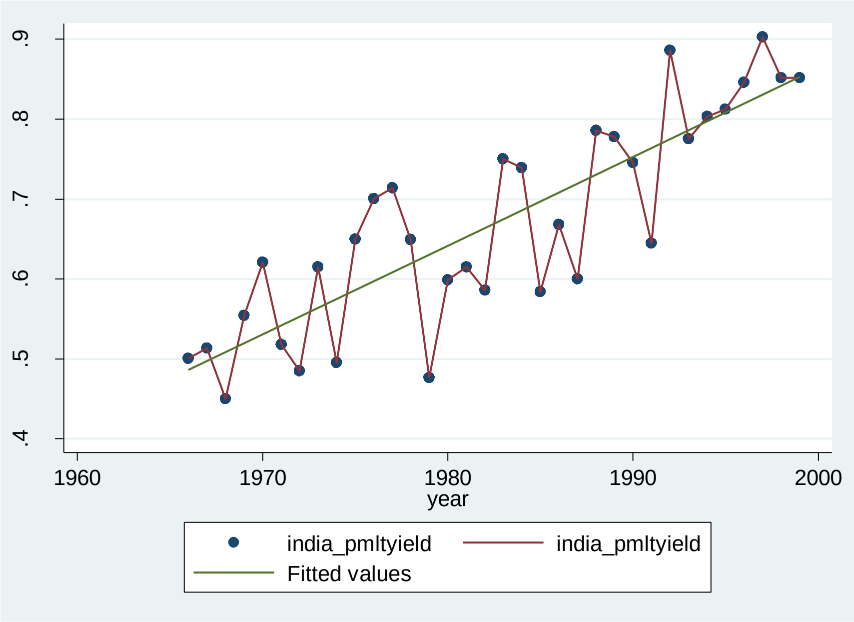
Trends in Production: Rice, Pearl Millet and Sorghum (000 tons)



Trends in yields







Yield Patterns in India

- Yields have increased for all three crops
- Maximum increase can be seen in rice yields (agricultural inputs like fertilizer, irrigation and HYV)
- Greater variability in yields of sorghum and pearl millet (coarse cereals -- mainly rain fed)

Agricultural Data

- Data on agricultural variables are for 1966-1999 from ICRISAT VDSA (Village Dynamics in South Asia) Apportioned Meso database. This is district level data

- **Dependent Variable**: **yield** (tons of output per hectare), for each of the three crops (area is gross cropped area (GCA) in each district accounting for multiple cropping)

- **Agricultural Controls**
    - district-wise consumption of fertilizer (tons of nitrogen, phosphate and potash fertilizers used)
    - gross irrigated area under each of the three crops for multiple cropping)
    - district wise gross area under HYV for each crop

- Did not use **labour** unlike other studies – entails too much interpolation

Agriculture data

- Fertilizer consumption (available at district level for all crops combined) -- weighted by ratio of area under that crop in that district.

- Irrigation (and HYV) variables created by taking ratio of gross irrigated area / area under HYV to gross cropped area for each crop.

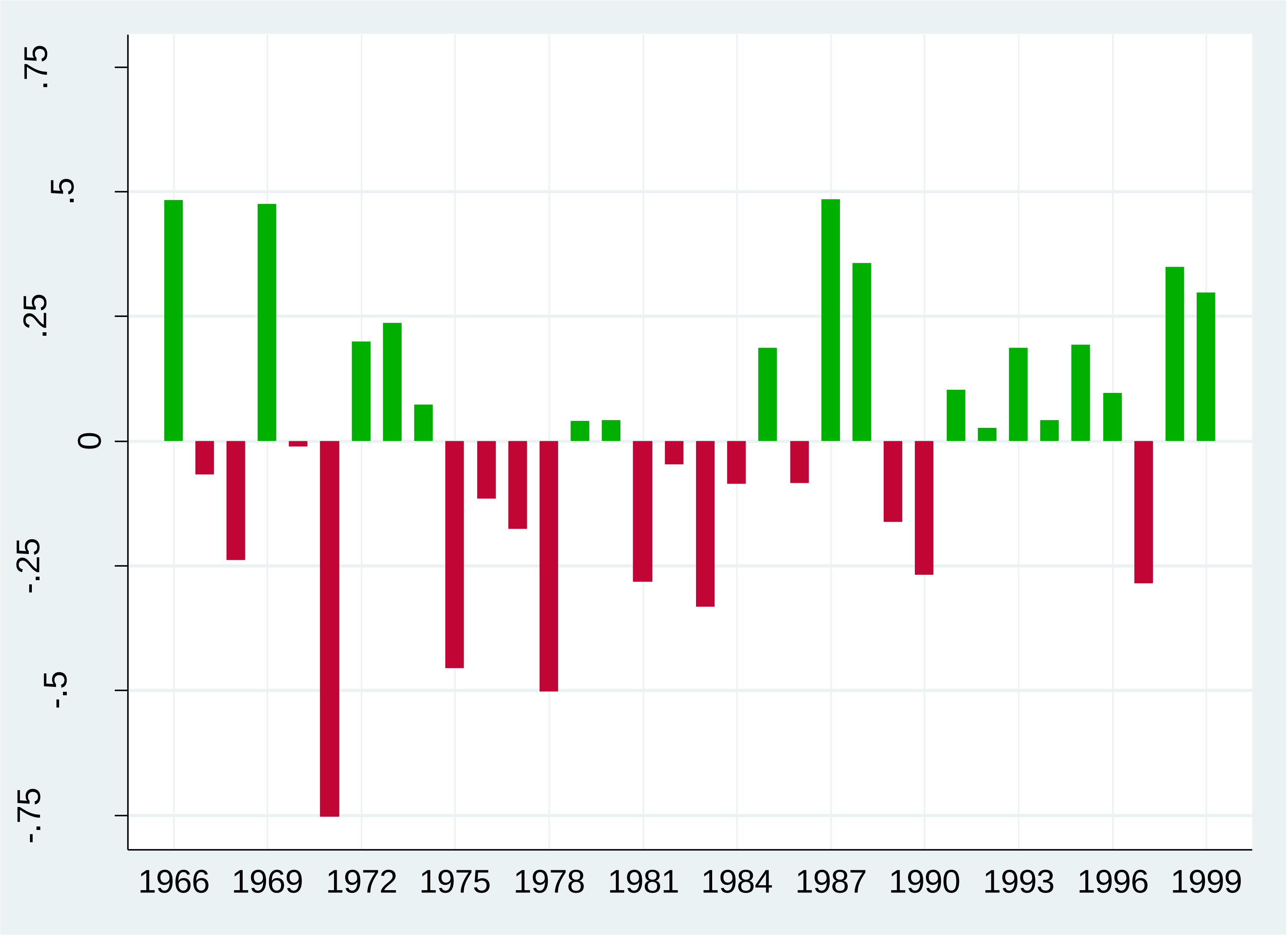
Climate data

- Publicly available Climate Research Unit (CRU) TS2.1 dataset (Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK).
- Consists of interpolated (on 0.5 degree latitude-longitude grid) global monthly data on variables such as rainfall and temperature from 1901 to 2002. The CRU data was transformed to the district level by simple linear averaging from the gridded data of the CRU dataset, by Indian Meteorological Department.
- Temperature: Average of monthly maximum temperature(^{o}C)
- Rainfall: Monthly precipitation in mm

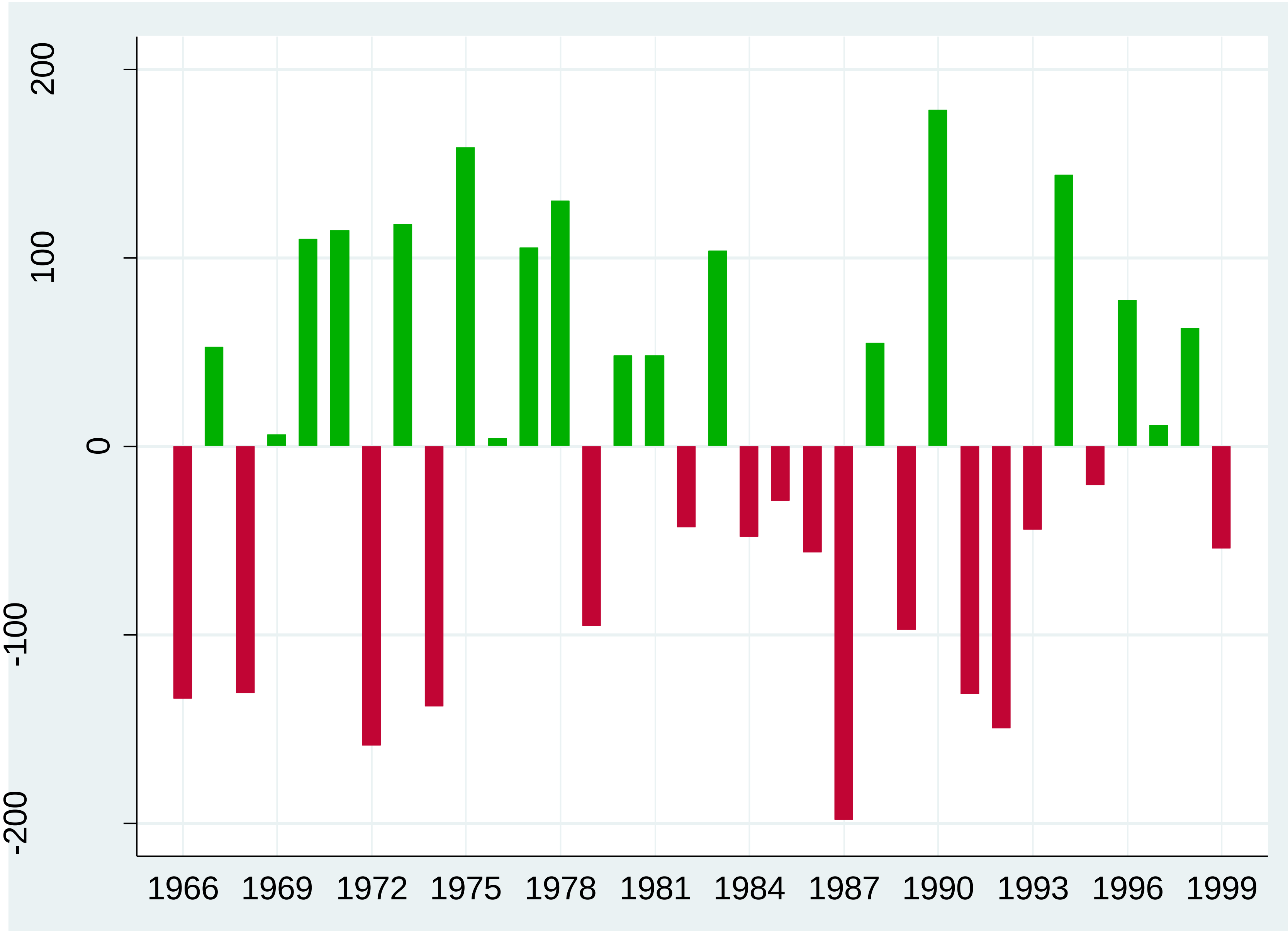
Climate Anomalies

- *Anomaly* -- departure from a reference value or long-term average
- Actual measurement (daily, monthly, annual) -- *weather*
- To capture *climate change* we need to use anomalies
- Anomalies are calculated by subtracting long term average from the absolute values of the variable
- Can also use standardized anomalies -- eliminate scale effects and take account of the likelihood that for some regions variability may be large compared to mean

All India Maximum Temperature Anomalies



All India Rainfall Anomalies



Districts in India (increasing…)

Year	No. of Districts
1971	356
1981	412
1991	466
2001	593
2011	640
Current	671 (avg. size 5,000 sq km)

- District boundaries of ICRISAT data are as of 1966 (n = 311)
- District boundaries for climate data are as of 2002
- Climatic variables have been approximated from the district which got the most area of the parent district (provided it was more than 50% of the total area of the parent district)

Summary Statistics

Variable	Unit	Rice				Sorghum (*Jowar*)				Pearl Millet (*Bajra*)			
		Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Yield (production/ area)	tons/ hectare	1.36	0.79	0.01	5.54	0.72	0.41	0.00	9.84	0.69	0.48	0.00	16.86
Area	000 hectare	140.32	164.65	0.01	1106.65	67.37	112.13	0.01	836.70	57.05	112.85	0.01	1174.00
Production	000 tons	205.02	276.04	0.01	2418.93	45.55	78.80	0.01	692.20	29.38	51.84	0.01	456.00
fertilizer consumption	tons/ hectare	47.85	49.55	0	408.22	42.62	44.77	0.00	301.60	46.41	45.73	0.00	257.97
Irrigation	proportion (0 to 1)	0.10	0.14	0	0.74	0.00	0.01	0.00	0.09	0.00	0.01	0.00	0.14
HYV use	proportion (0 to 1)	0.10	0.14	0	0.89	0.02	0.05	0.00	0.50	0.02	0.05	0.00	0.67
Minimum temperature	C	24.26	1.70	17.82	28.79	24.18	1.70	17.82	28.61	24.38	1.69	17.88	28.79
Maximum temperature	C	32.78	2.46	22.52	39.70	32.84	2.51	22.52	39.70	33.21	2.48	22.59	39.70
Rainfall	millimeters	1030	447	87	3664	962	422	49	3664	895	393	49	3596

Methodology

- The regression equations that are typically estimated:

$$\mathbf{Yield_{it} = \alpha_i + \gamma_t + X_{it}'\beta + \sum \sigma^* f\,(W_{it}) + \mu_{it}}$$

- α_i is *district-level fixed effects* -- useful in capturing *time-invariant unobserved heterogeneity* across districts and γ_t *refer to the year-level fixed effects* which control for annual differences in yield common to all districts (Deschenes & Greenstone 2007)
- X_{it} refer to district and year-specific agricultural variables, whereas W_{it} refers to climatic/weather variables
- In the presence of serial autocorrelation (the outcomes are correlated across years for a given district) and cross-sectional dependence (the outcomes are correlated across districts in a given year), along with heteroscedasticity, FGLS with fixed effects was found appropriate
- But FGLS produces overly optimistic standard error estimates. Moreover, estimates feasible only if N<T, which is not the case here. To correct for this, panel-corrected standard error (PCSE) estimates are obtained, where the parameters are estimated using a Prais-Winsten (or OLS) regression

An extension

- Production function estimation using the **stochastic production function** approach- Just and Pope (1978) and Just and Pope (1979).
- Differentiates impact of inputs on output (or yield) and risk
- The general form of stochastic production function is

$$= \quad (\quad) + h \, (\quad)* \quad ,$$

- The parameter estimation of ( ) provides the impact of explanatory variables on mean yield while h( ) offers their effect on the variability of yield

$$y = f(X, \beta) + \mu = f(X, \beta) + h(X, \alpha)\varepsilon$$

- 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 (Chen et al. 2004).

Model

The basic specification is:

$$y = f(X) + u = f(X) + [h(X)]^{\frac{1}{2}}\varepsilon \ , E(\varepsilon) = 0 \ \ E(\varepsilon^2) = 1$$

The functions of *f* and *h* will be written as function of parameters

$$y = f(X,\beta) + h(X,\alpha)^{1/2}\varepsilon$$

- *y* measure of output (or yield)
- X a vector of inputs
- *f(.)* production function relating *X* to output/yield, β is the vector of estimable parameters
- h(X,α) risk function associated with X such that *h* is the yield variance
- ε is random shock distributed with mean zero and unitary variance
- α is a vector of estimable parameters associated with risk function

Literature for India (1)

- **Lahiri -Roy** (1985) -- supply response of rice yield -- all India. Postulate *gamma distribution* for effect of rainfall on yield (right skewed and bounded at zero), i.e., less rainfall is worse than too much. With spread of HYVs since mid 1960s, Indian agriculture became more rainfall dependent esp. since water requirement has gone up and the spread of irrigation has not kept pace
- **Kanwar** (2006), **Auffhammer et al.** (2012) extend this type of work-- look at supply response using state-level panel datasets, again find that rainfall matters considerably for supply response. [Problem: the need to aggregate rainfall and other weather data (there are several observation stations in a state) to one value at the state or national level.]
- **Guiteras** (2009) examines impact of temperature and rainfall on combined yield (in money terms) for five major food and one cash crop (rice, wheat, jowar, bajra, maize & sugarcane). Finds climate change could reduce yields in the medium- and long-run

Literature for India (2)

- **Kumar and Parikh** (2001), **Kumar** (2009) estimate impact of climate change on net agricultural revenue per hectare (revenue minus cost of labour and fertiliser, normalised by area). Use net revenue instead of land prices as is norm in Ricardian approach.
- **Fishman** (2011) -- district-level panel. Examines impact of intra-seasonal variability of rainfall on yields. Aims to capture adaptation (through expansion of irrigation) to climate change. Finds irrigation useful in protecting yields against irregularities in rainfall, but not useful against higher temperatures. This limits efficacy of irrigation as an adaptation mechanism.

Literature for India (3)

- **Krishnamurthy** (2012) – district-level panel -- ***quantile regression*** to estimate the impact of climate change on yields of rice and wheat. Suggests both Ricardian and panel data approaches inadequate--assume covariates (weather variables, agricultural controls, etc.) only affect mean yield and not conditional distribution of yield.
- **Gupta et al.** (2014) – district level panel – rice, millets

	Impact of climate/weather	Controls	Districts and Time period	Crops Considered	Predictions for Yields
Kumar and Parikh (2001)	Temperature-negative Rainfall-negative	Bullocks, tractors, population density, literacy rate	271 districts, 1956- 1999	Net revenue from all crops grown in a district	2 C temp rise & 7% increase in rainfall → 8% loss in net revenue
Guiteras (2009)	Temperature-negative Rainfall-positive	Proportion of crop irrigated, under HYV	218 districts, 1960-99	Gross revenue from Rice, Wheat, Jowar, Bajra, Maize, Sugar (**combined**)	Medium-Run: 4.5-9% decline Long-run: 25%
Fishman (2011)	Temperature-negative Rainfall-positive	Proportion of crop irrigated	580 districts, 1970-2004	Rice and Wheat	Negative impact
Krishnamurthy (2012)	Temperature-negative Rainfall-positive	Proportion of crop irrigated	580 districts, 1971-2005	Rice and Wheat	Wheat: 11% decline, Rice: Very moderate reductions
Gupta et al. (2014)	Temperature – negative (for rice only) Rainfall – positive (all 3 crops)	Proportion of crop irrigated, HYV, fertiliser use	311 districts 1966-1999	Rice, Pearl Millet (*Bajra*), Sorghum (Jowar)	

Production function and risk (1)

	Estimation method	Region	Crops	Weather Variables	Controls	Results
Chen et al. (2004)	MLE	United States	corn, soybean, wheat, sorghum and cotton yields	Avg. Temp. for growing season and annual total rainfall	acerage harvested, trend, random effects	mean yield increase with rainfall and decline with warming, impact on variance varies with crops
Mc. Carl et al. (2008)	FGLS	United States	corn, soybean, wheat, sorghum and cotton yields	Mean and variance of avg. temp. for growing season and total precipitation, precipitation intensity index, Palmer drought severity index	interaction between regions and weather conditions, fixed effects	increase in precipitation intensity and drought severity reduces yields and increases variability

Production function and risk (2)

	Estimation method	Region	Crops	Weather Variables	Controls	Results
Isik et al. (2006)	MLE	Idaho state of US	wheat, barley, potato and sugar beet	Avg. Temp. for April to Nov. and total annual precipitation	impact estimated on mean, variance and covaraince of yields	rainfall mainly reduces mean variance of yields and also covariance of crop yields, warming increases the covariance of crop yields
Cabas et al. (2010)	FGLS	Ontario province of Canada	corn, soybean and winter wheat	temp., precipitation, CV of both, length of growing period	input change, area change, fixed effects	yield variance remains unexplained, timing of heat pattern and precipitation matters

Production function and risk (3)

	Estimation method	Region	Crops	Weather Variables	Controls	Results
Kelbore et al. (2013)	MLE	Ethiopia	teff, wheat and maize	*belg*rainfall, *kiremt* rainfall	Interaction of rainfall with region dummies, random effects	impacts vary with season and region
Kotani et al. (2013)	FGLS	Nepal	rice and wheat	average and standard deviation of temperature and rainfall for each growing season	dummy for low, mid and high altitude, fixed effects, trend	variability of climate reduces yields, rest impcts vary across altitudes and seasons
Sarker et al. (2013)	FGLS	Bangladesh	Aus rice	avg. max. and min. temp., total rainfall	district specific fixed effects	yield variability increased max. temp. increase and decreased with minimum temperature and rainfall increase

Panel-unit root tests

- Fisher type Dicky-Fuller panel unit root test is employed.
- This test does not require the dataset to be balanced and the alternative hypothesis would allow some groups to have unit roots while others may not.
- The results revealed that all the variables except HYV are stationary.
- First differencing is used for HYV input variable to make it stationary.

Estimation

- With reference to the Just and Pope production function, in our study *y* is crop yield and **X** is a vector of climate and other control variables
- Fixed effects model estimated using district dummies
- A time dummy for each year
- The linear production function
- Method of estimation: Three step Feasible Generalized Least Square (FGLS) estimation

Three Step FGLS

- Step I: Run ordinary least square regression on independent variables which include district specific dummies and get the residuals which are a consistent estimator of μ.

- Step II: The natural log of squared residuals are regressed against **X.** Results of this stage represent "yield variability" regression and the coefficients are consistent estimates of α.

- Step III: use the squared root of antilogarithm of the predictions from the second stage as weights for the WLS (Weighted Least Squares) estimation for the mean yield equation. The final result represents "mean yield" regression and the coefficients in this final step are consistent estimators of β and are asymptotically efficient under a broad range of conditions and the whole procedure corrects for the heteroscedastic disturbance term.

Results for Rice (1)

Number of observations	8217				R-squared	0.8544
F(298, 7918)	155.88				Prob > F	0
Mean Yield	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer	0.004685	0.000	29.98	0.000	0.004	0.004
Irrigated area	1.207	0.087	13.93	0.000	1.037	1.377
Area under HYV	0.57106	0.049	11.54	0.000	0.474	0.668
Temp	0.018	0.009	1.86	0.063	-0.001	0.038
Rainfall	0.00015	0.000	10.13	0.000	0.000	0.000
Number of observation	8214				R-squared	0.1574
Wald chi2(293)	2058.16				Prob > chi2	0
Yield Variance	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Temp	0.204	0.078	2.51	0.012**	0.044	0.356
Rainfall	-0.0001	0.0001	-0.81	0.419	-0.0003	0.00015

Results for Rice (2)

Number of observations	8217				R-squared	0.8522
F(296, 7920)	154.26				Prob > F	0
Mean Yield	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer	0.004782	0.000	30.43	0.000	0.004	0.005
Irrigated area	1.166	0.087	13.38	0.000	0.996	1.338
Area under HYV	0.5694413	0.049	11.44	0.000	0.472	0.667
Number of observation	8214				R-squared	0.1574
Wald chi2(293)	2058.16				Prob > chi2	0
Yield Variance	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Temp	0.204	0.078	2.51	0.012**	0.044	0.356
Rainfall	-0.0001	0.0001	-0.81	0.419	-0.0003	0.00015

Results for Sorghum (1)

Number of observations	7466				R-squared	0.6639
F(292, 7173)	48.52				Prob > F	0
Mean Yield	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer	0.000619	0.000	5.14	0.000	0.0003	0.0008
Irrigated area	1.133106	0.593	1.91	0.056	-0.0295	2.2957
Area under HYV	0.466067	0.072	6.40	0.000	0.3233	0.6087
Temp	0.016548	0.008	2.06	0.039	-0.0008	0.0322
Rainfall	0.000034	0.000	2.56	0.010	8.19e-06	0.0006
Number of observation	7465				R-squared	0.1563
Wald chi2(289)	2657.77				Prob > chi2	0
Yield Variance	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Temp	0.1438	0.084	1.70	0.089*	-0.0217	0.30948
Rainfall	0.0001	0.0001	1.06	0.290	-0.0001	0.00041

Results for Sorghum (2)

Number of observations	7466				R-squared	0.6638
F(290,7175)	48.84				Prob > F	0
Mean Yield	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer	0.000632	0.000	5.24	0.000	0.004	0.000
Irrigated area	1.043601	0.592	1.76	0.078	-0.117	2.204
Area under HYV	0.488423	0.072	6.75	0.000	0.346	0.630
Number of observation	7465				R-squared	0.1563
Wald chi2(289)	2657.77				Prob > chi2	0
Yield Variance	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Temp	0.1438	0.084	1.70	0.089*	-0.0217	0.30948
Rainfall	0.0001	0.000	1.06	0.290	-0.0001	0.00041

Results for Pearl Millet (1)

Number of observations	6577				R-squared	0.7040
F(284, 6292)	52.69				Prob > F	0
Mean Yield	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer	0.000915	0.000	6.44	0.000	0.0006	0.0011
Irrigated area	0.215957	0.482	0.45	0.655	-0.7302	1.1621
Area under HYV	0.162025	0.083	1.93	0.053	-0.0023	0.3263
Temp	-0.028283	0.009	-3.14	0.002	-0.0459	-0.1062
Rainfall	0.000449	0.000	2.89	0.004	0.0001	0.0000
Number of observation	6572				R-squared	0.2472
Wald chi2(277)	1.85e+07				Prob > chi2	0
Yield Variance	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Temp	0.0571	0.0917	0.62	0.533	-0.1226	0.23696
Rainfall	-0.0003	0.0001	2.14	0.032*	0.0003	0.00062

Results for Pearl Millet (2)

Number of observation	6577				R-squared	0.7022
F(284, 6294)	52.64				Prob > F	0
Mean Yield	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer Consumption	0.001	0.000	6.86	0.000	0.001	0.001
Irrigated Area	0.147	0.482	0.31	0.760	-0.798	1.09
Area under HYV	0.186	0.083	2.20	0.026	0.0217	0.350
Number of observation	6572				R-squared	0.247
Wald chi^2 (277)	1.85e+07				Prob > chi^2	0
Yield Variance	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Temp	0.05714	0.0917	0.62	0.533	-0.122	0.236
Rainfall	0.00032	0.0001	2.14	0.032*	0.000	0.000

Results for Rice with anomalies (1)

Number of observations	8217				R-squared	0.8568
F(298, 7918)	159.04				Prob > F	0
Mean Yield	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer	0.005	0.000	29.990	0.000	0.004	0.005
Irrigated area	1.215	0.085	14.220	0.000	1.047	1.382
Area under HYV	0.553	0.049	11.330	0.000	0.458	0.649
Temp anomaly	0.011	0.004	2.560	0.010	0.003	0.019
Rainfall anomaly	0.039	0.004	11.200	0.000	0.032	0.046
Number of observation	8214				R-squared	0.1646
Wald chi^2 (296)	2109.86				Prob > chi^2	0
Yield Variance	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer	0.004	0.001	3.120	0.002	0.001	0.006
Irrigated area	-1.917	0.581	-3.300	0.001	-3.056	-0.778
Area under HYV	0.577	0.383	1.510	0.131	-0.173	1.327
Temp anomaly	0.063	0.034	1.840	0.065	-0.004	0.130
Rainfall anomaly	-0.060	0.029	-2.080	0.037	-0.116	-0.004

Results for Rice with anomalies(2)

Number of observation	8217				R-squared	0.8544
F(296, 7920)	160.02				Prob > F	0
Mean Yield	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer Consumption	0.005***	0.000	30.170	0.000	0.004	0.005
Irrigated Area	1.153***	0.087	13.290	0.000	0.983	1.323
Area under HYV	0.571***	0.049	11.650	0.000	0.475	0.667
Number of observation	8214				R-squared	0.1589
Wald chi^2 (293)	2116.56				Prob > chi^2	0
Yield Variance	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Temp anomaly	0.051	0.034	1.500	0.133	-0.016	0.118
Rainfall anomaly	-0.095***	0.029	-3.320	0.001	-0.151	-0.039

Results for Sorghum (1)

Number of observation	7466			R-squared		0.665
F(292, 7173)	48.75			Prob > F		0
Mean Yield	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer Consumption	0.001	0.000	5.570	0.000	0.000	0.001
Irrigated Area	1.160	0.582	1.990	0.046	0.019	2.301
Area under HYV	0.494	0.075	6.570	0.000	0.346	0.641
Temp anomaly	0.007	0.003	1.960	0.050	0.000	0.013
Rainfall anomaly	0.007	0.003	2.310	0.021	0.001	0.012
Number of observation	7465			R-squared		0.1568
Wald chi^2 (292)	2608.22			Prob > chi^2		0
Yield Variance	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer Consumption	0.004	0.001	2.990	0.003	0.001	0.006
Irrigated Area	-3.732	5.856	-0.640	0.524	-15.209	7.745
Area under HYV	1.385	0.770	1.800	0.072	-0.125	2.895
Temp anomaly	0.059	0.037	1.600	0.110	-0.013	0.131
Rainfall anomaly	0.014	0.031	0.450	0.655	-0.047	0.075

Results for Sorghum (2)

Number of observation	7466			R-squared		0.663
F(290, 7175)	48.68			Prob > F		0
Mean Yield	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer Consumption	0.001***	0.000	5.300	0.000	0.000	0.001
Irrigated Area	0.907	0.596	1.520	0.128	-0.261	2.075
Area under HYV	0.475***	0.072	6.570	0.000	0.333	0.617
Number of observation	7465			R-squared		0.1544
Wald chi^2 (289)	2827.36			Prob > chi^2		0
Yield Variance	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Temp anomaly	0.057	0.037	1.570	0.116	-0.014	0.129
Rainfall anomaly	0.016	0.031	0.500	0.616	-0.046	0.077

Results for Pearl Millet (1)

Number of observation	6577				R-squared	0.4609
F(284, 6292)	18.94				Prob > F	0
Mean Yield	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer Consumption	0.001	0.000	4.710	0.000	0.001	0.002
Irrigated Area	0.431	0.840	0.510	0.608	-1.215	2.077
Area under HYV	0.178	0.148	1.200	0.230	-0.113	0.468
Temp anomaly	0.005	0.006	0.730	0.463	-0.008	0.017
Rainfall anomaly	0.016	0.005	2.840	0.005	0.005	0.026
Number of observation	8217				R-squared	0.594
Wald chi^2 (297)	77801.33				Prob > chi^2	0
Yield Variance	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer Consumption	0.006	0.001	8.310	0.000	0.005	0.007
Irrigated Area	1.232	4.787	0.260	0.797	-8.150	10.614
Area under HYV	-2.279	0.919	-2.480	0.013	-4.080	-0.479
Temp anomaly	-0.019	0.024	-0.820	0.414	-0.065	0.027
Rainfall anomaly	0.028	0.020	1.350	0.178	-0.013	0.068

Results for Pearl millet (2)

Number of observation	6577				R-squared	0.4613
F(282, 6294)	19.12				Prob > F	0
Mean Yield	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Fertilizer Consumption	0.001***	0.000	4.620	0.000	0.001	0.002
Irrigated Area	0.246	0.838	0.290	0.769	-1.397	1.889
Area under HYV	0.202	0.150	1.340	0.179	-0.093	0.497
Number of observation	8217				R-squared	0.5913
Wald chi^2 (294)	83921.8				Prob > chi^2	0
Yield Variance	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Temp anomaly	-0.029	0.024	-1.230	0.219	-0.075	0.017
Rainfall anomaly	0.070***	0.020	3.420	0.001	0.030	0.110

Conclusion

- Since rice appears to be temperature sensitive in terms of variance of yield, so there should be a shift towards coarse cereals which are less variable in warmer conditions.

- Though increase in rainfall increases all the crop yields it must be noted yields decrease with decrease in rainfall. Since rainfall is highly variable yields will fluctuate.

- Agricultural inputs like fertilizer, irrigation and HYV could improve yields but at times could also make the crop sensitive to climatic variation increasing the variance of crop yields.