Indian Journal of Agricultural Sciences **80** (7): 606–15, July 2010

Assessment of the influence of monsoon rain on rainy season rice (*Oryza sativa*) productivity over major rice growing states

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Received: 18 September 2009; Accepted: 29 April 2010

ABSTRACT

A study was conducted to understand the influence of monsoon rainfall on rice (*Oryza sativa* L.) productivity and also to quantify the contribution of monthly distribution of rainfall during monsoon period on rice productivity over the important rice growing states. The main rice growing season in the country is rainy (*kharif*) season in which farming operations start with onset of monsoon. About 84% of the country's rice crop is grown in this season. Eventhough, south-west monsoon strikes Kerala coast normally during the first week of June, the summer /pre-monsoon showers during May also have crucial role because the farmers' of eastern, coastal and peninsular region prepare their nursery during this time, so as to start main field preparation and transplanting with onset of monsoon. Assam receives 12.2% (280.2 mm) of its annual rainfall (2291.4 mm) during May, while Gujarat receives only 1.3% (9.3 mm). The rice crop continues to show an overall steady increase in productivity in all the states. The higher percentage of increase (140%) in triennium productivity was noticed in West Bengal, followed by Uttar Pradesh (127%). However a very low 26% increase in triennium productivity was observed in Maharashtra, followed by 34% increase in Bihar. Despite 56% rice area being under irrigation over India, 67% contribution of monthly rainfall during May–October to productivity variation indicate that the multiple regression equation could be used for estimating the productivity over India. In Haryana, rainfall distribution during May–October contributes only 3% to productivity variations while in Gujarat rainfall distribution during May–October explains 72% of productivity variations.

Key words: Crop productivity, Monsoon rainfall, Monthly rainfall anomaly, Productivity anomaly index, Rice growing environment, Technological trend

Rice (*Oryza sativa* L.) is a major foodgrain grown in about 42 million ha area under almost all climatic conditions in India with a production of 91.05 million tonnes (Economic Survey 2007). It is a staple food for 65 % of the population of India and constitutes 43 % of India's total food grain production. Of this, 80 % of the rice is cultivated during rainy (*kharif*) season. South-west monsoon rainfall (June to September) is the major source of water for rainfed agriculture. But its erratic distribution pattern—temporal as well as spatial—affect the rice growth and thereby production in one or other part of the region every year. Any aberrations of rainfall pattern, such as delay of monsoon, breaks in the monsoon activity, prolonged dry periods during the crop season and even continuous flooding also affect the production. It is estimated that the rice demand for India will be 100 and 140 million tonnes in 2010 and 2025, respectively (Mishra 2004). Tillering to flowering is the most critical stage when rice crop should not be subjected to any moisture stress. According to Jearakongman *et al*. (1995), grain yields were severely reduced when standing water disappeared for more than 20 days before anthesis, while the presence of standing water 20 days after anthesis resulted in the highest yields. Depending on climate, soils, cultivars and management practices, the total irrigation water requirement of the rice crop ranges from 450 mm in upland conditions to 1 300 mm in lowland conditions (Yoshida 1975, 1978; Doorenbos and Kassam 1979). Even though monsoon enters over the main lands of India through Kerala coast during the last week of May or first week of June, the pre-monsoon/summer showers during May are also crucial because for 20–30 days the crop is grown in nursery, so that it can be transplanted in puddled field after good initial monsoon showers. Similarly, the monsoon starts its withdrawal from the north-western part of the country from first September and it completely withdraws by 15 October.

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Hence, as far as rice crop is concerned, May–October rainfall is considered as the monsoon rainfall. Therefore, a thorough understanding of influence of monthly distribution of rainfall during May–October on *kharif* rice productivity variation can provide an opportunity to select suitable varieties and management practices to minimize the production losses. Hence, an investigation was undertaken to find out the quantitative assessment of influence of monthly rainfall on *kharif* rice productivity over important rice growing states of India.

MATERIALS AND METHODS

The monthly rainfall data during 1974–2005 of 14 important rice growing states was taken from the website of Indian Institute of Tropical Meteorology (www.tropmet.ac.in) and used in this study. They have considered 276 rain gauge stations spatially well distributed over these states for preparing area weighted data series on different time scales. The area, production and productivity of rainy (*kharif*) season rice over different states from 1974–75 to 2005–06 was taken from the Directorate of Rice, Ministry of Agriculture, Government of India and is available on-line at http://www.dacnet.nic.in. Since long-term productivity data is not readily available for Jharkhand, Chattisgarh and Uttarakhand, the analysis has been done for undivided Bihar, Madhya Pradesh and Uttar Pradesh. This study is restricted in respect to 14 major rice growing states only.

The production of rice depends on type of soil, seeds used, crop area, availability of irrigation facilities, fertilizers, pesticides and also on the government incentives to the farming sector during a year as well as on the meteorological parameters such as rainfall, temperature, relative humidity and solar energy. The non-meteorological parameters, i e the total technological inputs to the farming sector have been growing steadily and are difficult to quantify. Therefore, to know the pattern of trends and to quantify the growth rate of total technological inputs to the agricultural sector the actual productivity was fitted into an exponential curve as well as linear curve.

$$\text{The technological productivity } TP_i = a+b(x_i)$$

where TP_i is the technological productivity during the years i, i=1, 2, 3, … represent the years 1974 to 2005, b is the slope and a is the intercept and x_i = 1, 2, 3,… represent the years 1974 to 2005.

The exponential curve suggested by Neter *et al*. (1982) was used in this study.

$$\text{The Technological productivity } TP_i = ab^{xi}$$

where a and b are constants to be determined empirically and i = 1, 2, 3, … represent the years 1974 to 2005.

To normalize the productivity and rainfall data, the following indices were used.

The productivity anomaly index (PAI) was taken as the percentage of the technological trend productivity (exponential or linear) to the actual productivity. The PAI for the ith year is

$$PAI_i = \frac{(P_i - TP_i)\times 100}{TP_i}$$

Where PAI_i is the *kharif* rice productivity anomaly index for the ith year, P_i is the actual productivity for the *i*th year and TP_i is the technological trend productivity for the i^{th} year.

The monthly rainfall anomalies during May–October were computed by taking the monthly rainfall in terms of percentage deviation from its mean. The monthly rainfall anomaly for any month is expressed as:

$$Ra_i = \frac{(R_i - R) - 100}{R}$$

Where Ra_i is the monthly rainfall anomaly for the ith year, R_i is the monthly rainfall for the ith year and R is the mean monthly rainfall. The influence of monthly rainfall during May to October was determined using simple correlations. Estimation equations for productivity anomaly of different states were developed by multiple regression statistics between anomalies of rainfall during May–October/June–September and productivity anomalies.

RESULTS AND DISCUSSION

Monthly rainfall characteristics

Normal monthly rainfall from May to October, monsoon season (June to September) and annual rainfall for major rice growing states are shown in Table 1. Eventhough, Southwest monsoon strikes the Kerala Coast normally during the first week of June, the summer/pre-monsoon showers during May are also crucial because the farmers' of eastern, coastal and peninsular region prepare their nursery during this time, so that they can start main field preparation and transplanting with the onset of monsoon. Assam receives 280.2 mm (12.2%) of its annual rainfall (2291.4 mm) during May while Gujarat receives only 9.3 mm (1.3%). Co-efficient of variation of more than 100% was noticed for Maharashtra and Gujarat. June and July constitute the main 'sowing window' for *kharif* rice over all major rice growing states. All the states except Punjab and Tamil Nadu receive more than 10% of annual rainfall during June. Similarly, co-efficient of variation is relatively less in all the states except Punjab, Tamil Nadu, Haryana and Gujarat. But as far as July is concerned all the states except Tamil Nadu, where north-east monsoon is predominant, receive 15–30% of its annual rainfall. Continuous and heavy rainfall during this period may hamper rice growth and even inundate the paddy fields on several days during July. The co-efficient of variation during August is below 50% in all the states except Tamil Nadu and gets more than 10% of its annual rainfall. As far as September is concerned, all the states except Kerala receive over 10% of annual rainfall and co-efficient of variation remains below 100%. Tamil Nadu receives highest rainfall

Table 1 Normal monthly rainfall and co-efficient of variation (CV) during May-October, monsoon season and annual rainfall over important rice growing states

State	May		June		July		August	
	Mean(mm)	CV(%)	Mean(mm)	CV(%)	Mean(mm)	CV(%)	Mean(mm)	CV(%)
West Bengal	176.2 (8.5)	31.0	346.7 (16.8)	20.1	505.1 (24.4)	14.2	394.7 (19.1)	25.9
Andhra Pradesh	45.5 (5.0)	93.3	97.8 (10.8)	39.6	152.2 (16.9)	41.5	158.3 (17.6)	36.5
Uttar Pradesh	20.9 (2.2)	69.8	113.3 (12.2)	49.3	278.7 (29.9)	30.2	252.7 (27.1)	29.5
Punjab	21.5 (3.2)	98.2	65.9 (9.7)	57.0	201.6 (29.7)	51.0	160.6 (23.7)	45.0
Orrisa	78.2(5.4)	92.2	215.5(14.9)	35.5	324.1(22.5)	29.1	368.0(25.5)	30.4
Karnataka	92.1(5.5)	73.6	418.5(25.0)	22.7	414.2 (24.8)	26.8	317.3(19.0)	28.5
Tamil Nadu	65.4(7.1)	71.5	46.4(5.0)	68.4	63.5 (6.9)	45.9	77.4(8.4)	41.8
Assam	280.2(12.2)	26.8	394.9(17.2)	24.8	449.2(19.6)	26.6	333.8(14.6)	27.5
Bihar	64.7(5.1)	47.3	193.3(15.2)	40.0	343.1(26.9)	23.2	291.2(22.9)	24.8
Haryana	24.6(4.1)	87.1	68.2(11.5)	50.6	183.6(31.0)	49.2	157.8(26.6)	51.4
Maharashtra	25.8(2.0)	122.4	288.7(22.0)	21.7	367.9(28.1)	24.5	300.5(22.9)	28.6
Madhya Pradesh	17.2(1.5)	86.0	176.1(15.4)	41.6	321.5(28.2)	22.4	342.4(30.0)	21.5
Gujarat	9.3(1.3)	188.3	122.4(17.7)	66.4	237.0(34.3)	48.2	191.7(27.8)	53.3
Kerala	224.7(8.2)	63.2	659.3(24.0)	28.2	562.3(20.5)	30.3	379.9(13.9)	30.4

State	September		October		Monsoon		Annual	
	Mean(mm)	CV(%)	Mean(mm)	CV(%)	Mean(mm)	CV(%)	Mean(mm)	CV(%)
West Bengal	347.9 (16.8)	29.5	137 (6.6)	55.8	1594.4 (77.0)	13.3	2069.5	12.0
Andhra Pradesh	152.2 (16.9)	43.9	153.5 (17.0)	46.2	560.5 (62.2)	23.6	901.8	14.8
Uttar Pradesh	176.0 (18.9)	42.6	28.1 (3.0)	117.3	820.7 (88.0)	19.2	932.8	17.2
Punjab	99.1 (14.6)	90.3	10.7 (1.6)	148.5	527.2 (77.6)	33.3	679.0	24.0
Orrisa	217.9(15.1)	32.5	108.2(7.5)	69.2	1125.4(78.1)	17.0	1441.9	17.5
Karnataka	182.0(10.9)	44.2	144.5(8.6)	46.6	1332.0(79.6)	18.7	1672.4	15.4
Tamil Nadu	121.2(13.1)	36.4	179.4(19.4)	36.8	308.5(33.4)	25.8	924.7	17.2
Assam	291.7(12.7)	29.5	153.2(6.7)	47.6	1469.7(64.1)	16.7	2291.4	13.3
Bihar	219.9(17.3)	35.5	71.9(5.6)	72.0	1047.6(82.3)	14.4	1273.5	13.7
Haryana	74.9(12.6)	77.8	8.6(1.5)	155.3	484.5(81.7)	32.9	593.1	26.9
Maharashtra	194.2(14.8)	48.5	83.0(6.3)	64.6	1151.3(87.8)	15.0	1310.8	14.5
Madhya Pradesh	174.4(15.3)	45.4	42.2(3.7)	68.0	1014.5(88.9)	15.8	1140.7	15.0
Gujarat	88.7(12.9)	87.2	21.3(3.1)	148.5	639.8(92.7)	34.0	690.1	30.9
Kerala	238.8(8.7)	58.2	297.6(10.9)	39.7	1840.4(67.1)	17.9	2742.4	12.8

The numbers in parentheses indicate the per cent contribution to annual rainfall

of 19.4% of annual rainfall during October, but Punjab receives only 1.6% rainfall during this month. The co-efficient of variation for the rainfall is higher in almost all the states except southern states and Assam.

Kharif rice area, production and productivity trends

The state-wise area, production and productivity of *kharif* rice from 1974 to 2005 is depicted in Fig 1. All the states except West Bengal, Andhra Pradesh, Tamil Nadu, Bihar and Kerala, show an increasing trend in rice area and interestingly in the case of production only Kerala shows a decreasing trend. The regression equations show that the area increased significantly in Punjab, Haryana, Uttar Pradesh, Madhya Pradesh and Gujarat, while decrease of area was significant in Kerala. But as far as production is concerned, West Bengal, Uttar Pradesh, Punjab, Karnataka, Assam, Haryana, Madhya Pradesh and Gujarat show significant increase, while Kerala shows significant decrease in production. The rice crop continues to show an overall steady increase in productivity in all the states. The higher percentage of increase (140%) in triennium productivity ending 1976 to 2005 was noticed in West Bengal, followed by Uttar Pradesh (127%). However, a very low 26% increase in triennium productivity was observed in Maharashtra, followed by 34% increase in Bihar during the same period. It is clear that none of the states fall under the category of high productivity group (> 2 500 kg/ha) during the triennium ending 1976, while 5 states, viz West Bengal, Andhra Pradesh, Punjab, Karnataka and Haryana fall under this category during the triennium ending 2005. Similarly, none of the states fall under the category of very low productivity (< 1000 kg/ha) during the triennium ending 2005. This clearly shows the spreading of 'Green Revolution' to the entire India, even though at different rates.

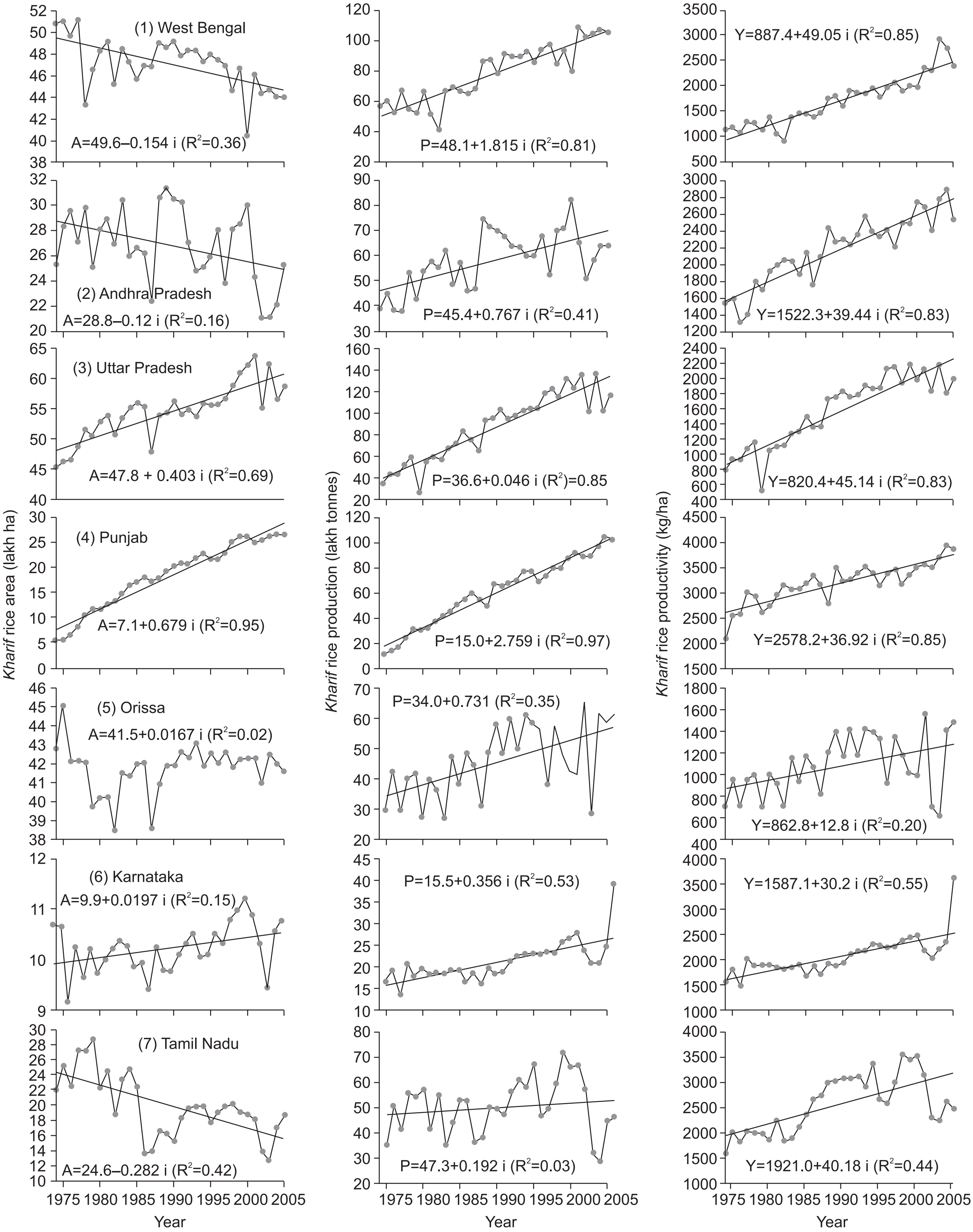
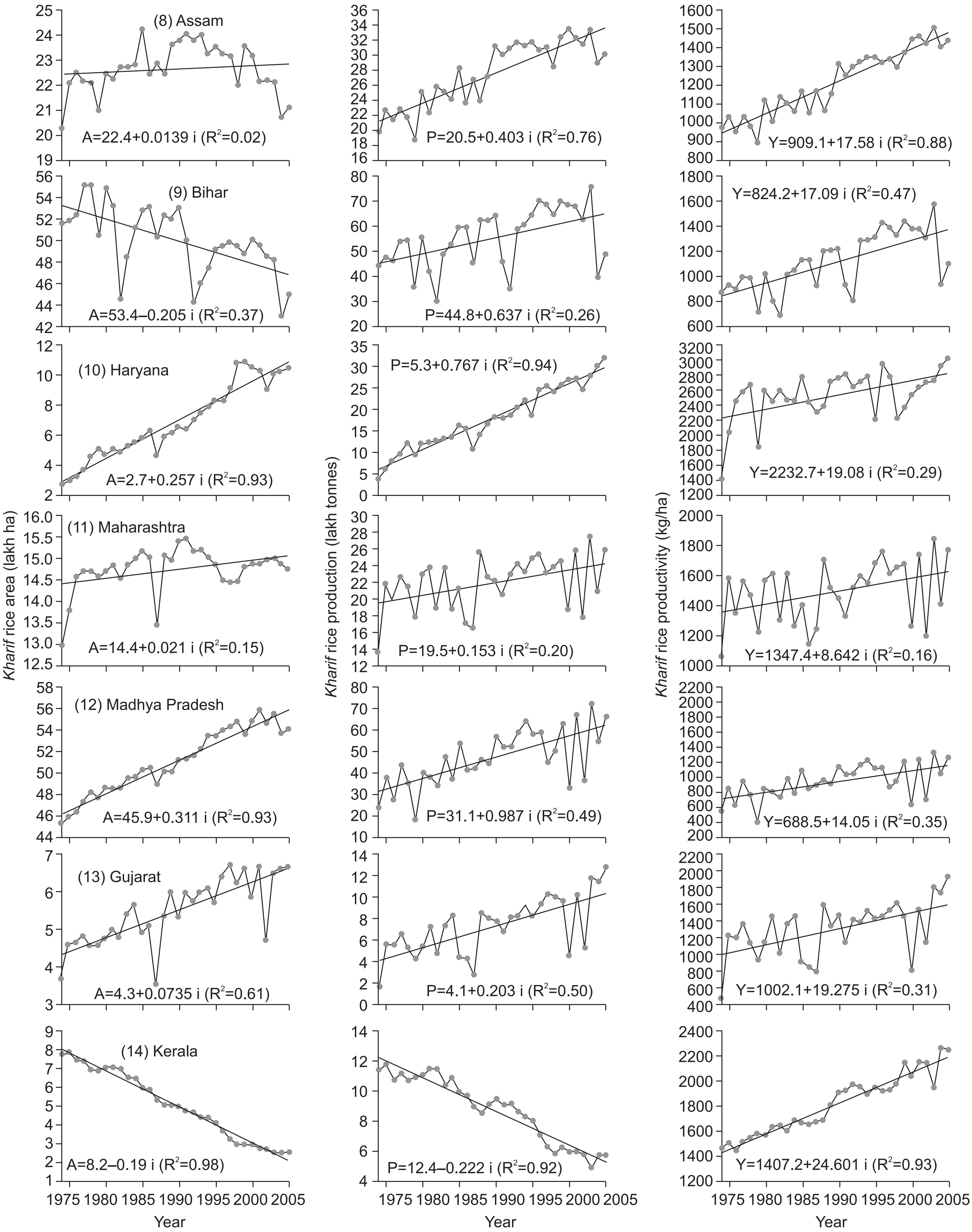


Fig 1 *Kharif* rice area, production and productivity during 1974–2005 over major rice growing states and its trends



(8) Assam
A=22.4+0.0139 i (R²=0.02)
P=20.5+0.403 i (R²=0.76)
Y=909.1+17.58 i (R²=0.88)
(9) Bihar
A=53.4–0.205 i (R²=0.37)
P=44.8+0.637 i (R²=0.26)
Y=824.2+17.09 i (R²=0.47)
(10) Haryana
A=2.7+0.257 i (R²=0.93)
P=5.3+0.767 i (R²=0.94)
Y=2232.7+19.08 i (R²=0.29)
(11) Maharashtra
A=14.4+0.021 i (R²=0.15)
P=19.5+0.153 i (R²=0.20)
Y=1347.4+8.642 i (R²=0.16)
(12) Madhya Pradesh
A=45.9+0.311 i (R²=0.93)
P=31.1+0.987 i (R²=0.49)
Y=688.5+14.05 i (R²=0.35)
(13) Gujarat
A=4.3+0.0735 i (R²=0.61)
P=4.1+0.203 i (R²=0.50)
Y=1002.1+19.275 i (R²=0.31)
(14) Kerala
A=8.2–0.19 i (R²=0.98)
P=12.4–0.222 i (R²=0.92)
Y=1407.2+24.601 i (R²=0.93)
Kharif rice area (lakh ha)
Kharif rice production (lakh tonnes)
Kharif rice productivity (kg/ha)
1975 1980 1985 1990 1995 2000 2005
Year

Table 2 Linear and exponential technological trend equations for *kharif* rice productivity (kg/ha) and its regression co-efficient for different rice growing states

State	Linear	Exponential
West Bengal	TP_{ti}= 887+(49.1*ti) ; R^2=0.85*	TP_{ti} = 1006.93(1.02944)^{ti} ; R^2=0.86 *
Andhra Pradesh	TP_{ti}= 1522+(39.4*ti) ; R^2=0.83*	TP_{ti} = 1555.96(1.00193)^{ti} ; R^2=0.79 *
Uttar Pradesh	TP_{ti}= 820+(45.1*ti) ; R^2=0.83*	TP_{ti} = 868.96(1.033)^{ti} ; R^2=0.74 *
Punjab	TP_{ti}= 2578+(36.9*ti) ; R^2=0.74*	TP_{ti} = 2594.18(1.0121)^{ti} ; R^2=0.71 *
Orissa	TP_{ti}= 863+(12.8*ti) ; R^2=0.44*	TP_{ti} = 862.98(1.0113)^{ti} ; R^2=0.16 *
Karnataka	TP_{ti}= 1587+(30.2*ti) ; R^2=0.55*	TP_{ti} = 1636.82(1.0139)^{ti} ; R^2=0..62 *
Tamil Nadu	TP_{ti}= 1921+(40.2*ti) ; R^2=0.44*	TP_{ti} = 1923.09(1.0166)^{ti} ; R^2=0.48 *
Assam	TP_{ti}= 909+(17.6*ti) ; R^2=0.88*	TP_{ti} = 928.966(1.01496)^{ti} ; R^2=0.86 *
Bihar	TP_{ti}= 824+(17.1*ti) ; R^2=0.46*	TP_{ti} = 835.60(1.0157)^{ti} ; R^2=0.44 *
Haryana	TP_{ti}= 2233+(19.1*ti) ; R^2=0.29*	TP_{ti} = 2197.86(1.0083)^{ti} ; R^2=0.27 *
Maharashthra	TP_{ti}= 1347+(8.6*ti) ; R^2=0.16*	TP_{ti} = 1339.67(1.0058)^{ti} ; R^2=0.14 *
Madhya Pradesh	TP_{ti}= 688+(14.0*ti) ; R^2=0.35*	TP_{ti} = 682.34(1.0163)^{ti} ; R^2=0.30 *
Gujarat	TP_{ti}= 1002+(19.3*ti) ; R^2=0.31*	TP_{ti} = 984.02(1.0158)^{ti} ; R^2=0.26 *
Kerala	TP_{ti}= 1407+(24.6*ti) ; R^2=0.92*	TP_{ti} = 1435.49(1.0137)^{ti} ; R^2=0.94 *
India	TP_{ti}= 1065+(30.1*ti) ; R^2=0.88*	TP_{ti} = 1099.01(1.0203)^{ti} ; R^2=0.86 *

*P=0.05

Table 3 Linear correlatin co-efficient 'r' between monthly rainfall anomaly and productivity anomaly index for important rice growing states and India

State	Correlation co-efficient 'r' between productivity anomaly index (PAI) and rainfall during					
	May	June	July	August	Sept	Oct
West Bengal	–0.093	0.265	–0.173	0.040	0.072	0.220
Andhra Pradesh	–0.022	0.184	0.245	0.152	0.183	–0.068
Uttar Pradesh	–0.220	0.194	0.161	0.402*	0.332	0.183
Punjab	0.248	0.024	–0.149	–0.156	–0.580**	0.056
Orissa	0.116	0.354*	0.414*	0.116	0.223	–0.075
Karnataka	–0.062	0.173	0.508**	–0.101	0.215	0.158
Tamil Nadu	–0.193	–0.082	0.143	0.092	0.082	–0.154
Assam	0.027	0.273	–0.304	–0.147	–0.205	–0.141
Bihar	0.171	0.369*	0.225	0.089	0.322	0.365*
Haryana	0.006	0.023	0.112	0.104	0.089	0.009
Maharashtra	–0.297	–0.217	0.453**	0.017	0.572**	0.164
Madhya Pradesh	–0.028	0.238	0.578**	0.241	0.543**	0.444*
Gujarat	–0.240	0.295	0.560**	0.390*	0.619**	0.078
Kerala	0.486**	0.313	0.102	–0.191	–0.143	0.229
India	0.053	0.487**	0.631**	0.198	0.391*	0.315

**P=0.01, *P=0.05

Relation between monthly rainfall anomaly during monsoon season and productivity anomaly index

The *kharif* rice productivity were fitted into exponential as well as linear curve and its regression co-efficients are shown in Table 2. It is noticed that all the states except Maharashtra and Orissa, the productivity fitted linearly as well as exponentially at 95 % significant level. But the correlation co-efficient 'r' higher for exponential fitting for West Bengal, Karnataka, Tamil Nadu and Kerala, while it is higher for linear fitting for all the other states as well as for the entire India. The productivity anomaly was computed based on high correlation co-efficient. The observations on the relation between monthly rainfall anomaly during May–October and productivity anomaly for different states indicated that no uniform relation exists between monthly rainfall during May–October and productivity for all the states. This may be due to two reasons; one is the difference in per cent of irrigated area as well as the irrigation facilities created in these states and the other is the variation of crop growing period in these states. Since monsoon normally hits the Kerala coast around first June and covers the entire country during second/third week of July. It starts retrieving from first September from the extreme north-western part of the country (north-western Rajasthan) and withdraws from the country completely by 15 October. This large-scale variation reflects in the crop growing period under rainfed situation over the country. The linear correlation co-efficient between monthly rainfall anomaly and productivity anomaly index for important rice growing states and India as a whole are given Table 3. It indicated that May rainfall is more important and crucial and significant for Kerala based on the rainfall received in the form of pre-monsoon /summer showers for nursery raising and field preparation so that they will start transplanting with onset of monsoon rains. As far as June rainfall is concerned, eastern states, i e Bihar and Orissa show highly significant relation. Moreover, these rainfed states experience the fluctuations in onset of monsoon as well as the occurrence of floods which affect the rice nursery and transplanting. July rainfall is most crucial for Orissa, Karnataka, Maharashtra, Madhya Pradesh and Gujarat, while August is crucial for Uttar Pradesh. September rainfall is also more significant for Punjab, Maharashtra, Madhya Pradesh and Gujarat and this may be due to coincidence of grain-filling /milking stage of the rice crop with this period, in which adequate moisture supply is very much essential. But due to delayed sowing; it may extend the moisture critical stage to October in Bihar and Madhya Pradesh and this may be the reason for the significant correlation between October rainfall anomaly and productivity anomaly. However, July rainfall is more significant as far as productivity of India as a whole is considered, followed by June. The relation between productivity anomaly and monthly rainfall anomaly indicates that out of 32 years considered for analysis, 14 years fall under the negative productivity anomaly as far as India as a whole is concerned. Out of these 14 years (1974, 76, 79, 81, 82, 84, 86 ,87, 95, 98, 2000, 02, 04 and 05), May rainfall anomaly for 5 years falls under deficient, June rainfall anomaly for 3 years falls under deficient, while excess rainfall anomaly is noticed during 3 years. However, deficient rainfall occurred continuously for June and July in 1987, but its productivity anomaly reached to –7.9, which is not the maximum productivity anomaly. Maximum productivity anomaly of –17.9 occurred in 1979 and interestingly all the monsoon months (June to September) fall under the category of normal rainfall, while May and October had deficit rainfall anomaly. This highlights the importance of May and October rainfall to productivity. The state-wise frequency of deficit productivity anomaly years and extreme deficit years and corresponding monthly rainfall anomalies are shown in Table 4. It indicates that in almost 40–45% of the years in all the states except Bihar and Gujarat, the productivity anomaly indices fall in the negative side. Frequency of productivity anomaly indices below –15.0 show large spatial variations between the states. Orissa shows maximum number (10 years) of extreme productivity deficit years, followed by Bihar and Tamil Nadu (7 years each). The corresponding monthly rainfall anomalies during the extreme deficit years for different states reveal the following observations.

West Bengal: During 1981 due to excess rainfall during July and deficit rainfall during September and October leads the extreme productivity anomaly, while during 1982 due to deficit rainfall during May and August to October are the main reasons for the deficit productivity anomaly.

Andhra Pradesh: Both extreme deficit productivity years shows normal total rainfall during June to September while due to alternate deficit and excess rainfall months may be the reason for low productivity during 1976.

Uttar Pradesh: Due to deficient rainfall during June and scanty rainfall from August to October resulted more than 50 % deficit in productivity in 1979 and due to continuous deficit rainfall during August and September and excess rainfall during October might be resulted in deficit in productivity in 2004.

Punjab: Excess rainfall during August-September and the deficit rainfall during May-June resulted multiple crop failure in 1974.

Orissa: Out of 10 extreme deficit productivity years, 7 (1974, 76, 79, 87, 96, 2000 and 02) years fall under the category of deficit monsoon years. But in 1999 and 2003, due to excess rainfall during September-October resulted low productivity. Even though the monsoon during 1982 is normal, its deficit during July, September and October and excess rainfall during August might have influenced the final productivity.

Karnataka: Excess rainfall during October and deficit rainfall during July and September resulted poor crop growth and deficit productivity.

Tamil Nadu: Out of 7 extreme deficit productivity years, 3 years (1979, 82 and 92) fall under the category of deficit monsoon years and one (1983) excess monsoon year. Even though the remaining 3 years fall under the category of normal monsoon year, the deficit during May, July, September and October and excess during August in 1982, excess rainfall during September-October in 1999 and 2003 have resulted negative productivity anomalies.

Bihar: Out of 7 extreme deficit productivity years, 3 years (1979, 82 and 92) fall under the category of deficit monsoon years and 4 years (1981, 91, 2004 and 2005) fall under the normal monsoon year. Moreover, these 3 deficit monsoon years, the rainfall distribution is so erratic and at least 3 months during May-October received deficit rainfall. In 1981, excess rainfall during July and deficient rainfall during June, in 1991, deficient rainfall during May and July and scanty rainfall during October, in 2004, deficient rainfall during July and September and in 2005, deficient rainfall during July and September and excess rainfall during August and October might have influenced the final productivity.

Haryana: Out of 4 extreme deficit productivity years, 2 years (1974 and 79) fall under the category of deficient monsoon years and 2 years (1995 and 98) under the excess category.

Table 4 State-wise frequency of productivity anomaly and monthly rainfall anomalies during extreme productivity anomaly indices years (< – 15.0)

State	No of deficit productivity anomaly years	No of years having productivity anomaly < –15.0	Productivity anomaly	
			Year	Productivity anomaly
West Bengal	14 (1979,81, 82, 86, 87,90, 95, 98,99,2000, 02,05)	2 (1981,82)	1981	–18.6
			1982	–31.2
Andhra Pradesh	15 (1974,75,76,77,79,84,86,91,95,96,97,98,99,2002,05)	2 (1976,77)	1976	–20.5
			1977	–17.0
Uttar Pradesh	15 (1974,76,79,80,81,82,83,84,86,87,98,2000,02,04,05)	2 (1979,2004)	1979	–53.7
			2004	–19.3
Punjab	13 (1974,75,76,79,80,88,95,96,98,99,2000,01,02)	1 (1974)	1974	–20.8
Orissa	13 (1974, 76,79,81,82,84,87,96,98,99,2000,02,03)	10 (1974, 76,79, 82, 87,96, 99, 2000, 02,03)	1974	–20.7
			1976	–22.0
			1979	–26.8
			1982	–27.9
			1987	–22.7
			1996	–21.3
			1999	–15.3
			2000	–18.3
			2002	–43.5
			2003	–51.3
Karnataka	15 (1974,76,82,83,85,86,87,88,89,90,97,2001,02,03,04)	1 (2002)	2002	–16.4
Tamil Nadu	15 (1974,76,77,79,79,80,82,83,84,95,96,2002,03,04,05)	7 (1974,82,83,2002,03, 04,05)	1974	–18.5
			1982	–16.9
			1983	–16.3
			2002	–25.6
			2003	–28.6
			2004	–17.7
			2005	–23.8
Assam	15 (1976,78,79,81,84,86,88,89,96,97,98,99,2002,04,05)	Nil		
Bihar	9 (1979,81,82,87,91,92,2002,04,05)	7 (1979,81,82,91, 92, 2004,05)	1979	–24.2
			1981	–17.7
			1982	–30.8
			1991	–18.6
			1992	–31.4
			2004	–31.8
			2005	–20.5
Haryana	13 (1974,75,79,86,87,88,95,98, 99,2000,01,02,04)	4 (1974,79,95,98)	1974	–36.7
			1979	–21.1
			1995	–16.1
			1998	–17.4
Maharashtra	12 (1974,79,82,84,85,86,87, 90,91,2000,02,04)	5 (1974,86,87, 2000,02)	1974	–21.7
			1986	–22.0
			1987	–15.8
			2000	–20.0
			2002	–25.0
Madhya Pradesh	15 (1974,76,78,79,81,82,84,86,87,89,97,98,2000,02,04)	6 (1974,76,79,97,2000,02)	1974	–23.8
			1976	–17.4
			1979	–50.5
			1997	–18.6
			2000	–42.7
			2002	–38.7
Gujarat	10 (1974,79,82,85,86,87,91,99,2000,2002)	6 (1974,85,86,87,2000,02)	1974	–52.6
			1985	–25.1
			1986	–30.4
			1987	–36.6
			2000	–46.8
			2002	–26.0
Kerala	14 (1976,77,80,83,85,86,87,88,94,96,97,98,2000,03)	Nil		
India	14 (1974,76,79,81,82,84,86,87,95,98,2000,02,04,05)	1 (1979)	1979	–17.8

Figures in parentheses indicate years

Maharashtra: Out of 5 extreme deficit productivity years, only one year (1986) fall under the category of deficient monsoon years. However, due to erratic distribution of rainfall during May –October, particularly during May–June and September–October, which coincides with the sowing/ transplanting and ripening/harvesting stage of the crop.

Madhya Pradesh: All the extreme deficit productivity years, the rainfall pattern is so erratic and out of 6 extreme deficit productivity years, 3 years (1974, 79 and 2002) fall under the category of monsoon deficit years. The remaining 3 years show different explanation for productivity loss. In 1976, due to deficient rainfall during June and scanty rainfall

Table 5 Regression equations for eastimating productivity anomaly index using June–September and May–October monthly rainfall anomaly indices and its regression co-efficient for important rice growing states of India

State	Regression equations	
	June–September	May–October
West Bengal	$PAI=0.647+0.140RA_{Ju}–0.162RA_{Jl}+ 0.0548RA_{Au} +0.00315RA_{Sp}$ (R^2=0.12)	$PAI=0.608–0.0659RA_{My}+0.155RA_{Ju}–0.112RA_{Jl}+ 0.0541RA_{Au} +0.0271RA_{Sp}+0.0345RA_{Oc}$ (R^2=0.17)
Andhra Pradesh	$PAI=-0.130+0.0328RA_{Ju}+0.0423RA_{Jl}+ 0.0132RA_{Au}+0.0253RA_{Sp}$ (R^2=0.12)	$PAI=–0.129+0.00512RA_{My}+0.0341RA_{Ju}+0.0446RA_{Jl}+ 0.0122RA_{Au}+0.0260RA_{Sp}–0.00179RA_{Oc}$ (R^2=0.12)
Uttar Pradesh	$PAI=-0.780+0.0341RA_{Ju}+0.0655RA_{Jl} + 0.168RA_{Au}+0.0905RA_{Sp}$ (R^2=0.29)	$PAI=–0.813–0.0145RA_{My}+0.0442RA_{Ju}–0.0461RA_{Jl} +0.151RA_{Au}+0.0851RA_{Sp}+0.0176RA_{Oc}$ (R^2=0.31)
Punjab	$PAI=-0.0300-0.000548RA_{Ju}-0.00750RA_{Jl} - 0.00269RA_{Au}-0.0441RA_{Sp}$($R^2$=0.34)	$PAI=–0.0389+0.00257RA_{My}+0.000112RA_{Ju}–0.00883RA_{Jl}– 0.000896RA_{Au}–0.0442RA_{Sp}–0.00250RA_{Oc}$ (R^2=0.35)
Orissa	$PAI=0.508+0.116RA_{Ju}+0.257RA_{Jl}+0.142 RA_{Au}+0.175RA_{Sp}$ (R^2=0.29)	$AI=0.93+0.0618RA_{My}+0.0959RA_{Ju}+0.345RA_{Jl}+0.132RA_{Au} +0.255RA_{Sp}+0.116RA_{Oc}$ (R^2=0.42)
Karnataka	$PAI=0.0337+0.101RA_{Ju}+0.213RA_{Jl}–0.0688 RA_{Au}+0.0288RA_{Sp}$ (R^2=0.32)	$PAI=0.0294–0.00225RA_{My}+0.100RA_{Ju}+0.213RA_{Jl}– 0.0672RA_{Au}+0.0284RA_{Sp}+0.00180RA_{Oc}$ (R^2=0.32)
Tamil Nadu	$PAI=1.149–0.0249RA_{Ju}+0.0315RA_{Jl}+ 0.0439 RA_{Au} +0.0351RA_{Sp}$ (R^2=0.04)	$PAI=1.138–0.0464RA_{My}–0.0386RA_{Ju}–0.0100RA_{Jl}+0.0413 RA_{Au}+0.0570RA_{Sp}–0.0235RA_{Oc}$ (R^2=0.09)
Assam	$PAI=0.164+0.0853RA_{Ju}–0.0678RA_{Jl}– 0.0392RA_{Au}–0.0268RA_{Sp}$ (R^2=0.27)	$PAI=0.172+0.0494RA_{My}+0.108RA_{Ju}–0.0752RA_{Jl}– 0.0656RA_{Au}–0.0185RA_{Sp}+0.00694RA_{Oc}$ (R^2=0.32)
Bihar	$PAI=–0.0294+0.195RA_{Ju}+0.185RA_{Jl}–0.0102 RA_{Au}+0.197RA_{Sp}$ (R^2=0.41)	$PAI=–0.0313–0.0189RA_{My}+0.181RA_{Ju}+0.150RA_{Jl}– 0.00109RA_{Au}+0.218RA_{Sp}+0.0755RA_{Oc}$ (R^2=0.54)
Haryana	$PAI=–0.0834–0.00595RA_{Ju}+0.0234RA_{Jl}+0.0221 RA_{Au}+0.00545RA_{Sp}$ (R^2=0.02)	$PAI=–0.0789+0.0129RA_{My}–0.00948RA_{Ju}+0.0318RA_{Jl} +0.0232RA_{Au}+0.00820RA_{Sp}–0.000380RA_{Oc}$ (R^2=0.03)
Maharashtra	$PAI=0.0946+0.00558RA_{Ju}+0.119RA_{Jl}–0.0360RA_{Au} +0.128RA_{Sp}$ (R^2=0.39)	$PAI=–0.109–0.0319RA_{My}+0.0644RA_{Ju}+0.156RA_{Jl}+ 0.0162RA_{Au}+0.0983RA_{Sp}+0.0354RA_{Oc}$ (R^2=0.45)
Madhya Pradesh	$PAI=–0.0888+0.339RA_{Ju}+0.462RA_{Jl}+ 0.253 RA_{Au}+0.218RA_{Sp}$ (R^2=0.66)*	$PAI=–0.0812–0.0258RA_{My}+0.0671RA_{Ju}+0.391RA_{Jl}+ 0.234RA_{Au}+0.208RA_{Sp}+0.0490RA_{Oc}$ (R^2=0.70)*
Gujarat	$PAI=0.830+0.0639RA_{Ju}+0.233RA_{Jl}+0.136 RA_{Au}+0.0801RA_{Sp}$ (R^2=0.69)*	$PAI=0.846+0.0124RA_{My}+0.0817RA_{Ju}+0.270RA_{Jl}+0.153 RA_{Au}+0.0692RA_{Sp}+0.0241RA_{Oc}$ (R^2=0.72)*
Kerala	$PAI=0.0926+0.0400RA_{Ju}+0.0153RA_{Jl}–0.0217 RAAu–0.00308RA_{Sp}$ (R^2=0.17)	$PAI=0.180+0.0274RA_{My}+0.0454RA_{Ju}+0.0167RA_{Jl}– 0.0106RA_{Au}+0.000382RA_{Sp}–0.0000243RA_{Oc}$ (R^2=0.40)
India	$PAI=–0.0241+0.179RA_{Ju}+0.194RA_{Jl}–0.0749 RAAu+0.0847RA_{Sp}$ (R^2=0.62)*	$PAI=–0.0118+0.0116RA_{My}+0.167RA_{Ju}+0.207RA_{Jl} +0.125RA_{Au}+0.0454RA_{Sp}+0.0496RA_{Oc}$ (R^2=0.67)*

PAI, Productivity anomaly index; RA_{My} – RA_{Oc}, rainfall anomaly index during May–October; **P*=0.05

during October in 2000 due to deficient rainfall during August–September and scanty rainfall during October might have resulted productivity loss, while interestingly even with normal rainfall during May–October resulted poor productivity shows the need of in-depth small temporal study.

Gujarat: All the extreme deficit productivity years, the monsoon rainfall was deficient or scanty.

India: Eventhough, with normal total monsoon rainfall as well as normal distribution during June–September in 1979, extreme deficit productivity was occurred. However, the deficient rainfall during May and October might have affected the productivity.

The important aspect emerged out from these observations highlight different reasons for productivity anomalies pertaining to different states as well as for different years and it is also evident that both excess rainfall as well as deficit rainfall during the critical period has equally influenced the productivity variations.

Productivity estimate equations for rice growing states

The multiple regression equations for productivity anomaly versus monthly rainfall anomaly during May–October and June–September were developed and are shown in Table 5. It is observed that the multiple correlation co-efficients during May–October were higher compared to June–September rainfall for all the states as well as for the whole India. Despite 56% rice area being under irrigation over India, 67% contribution of monthly rainfall during May–October to productivity variation indicates that the multiple regression equation could be used for estimating the productivity over India. But the per cent area under irrigation in rice growing states varies from 4.6% in Assam to 99.9% in Haryana. Andhra Pradesh, Punjab and Tamil Nadu have more than 90% and Uttar Pradesh and Karnataka have more than 70% irrigated area. This might be the reason for the large variation of multiple correlation co-efficients between productivity and rainfall anomalies during May–October over these states. In Haryana, rainfall distribution during May–October contributes only 3% to productivity variations, while in Gujarat rainfall distribution during May–October explains 72% of productivity variations. Even with these large internal differences, these equations could be used for estimating the productivity, so that planners and policy makers can make arrangement to activate their machinery for successful procurement as well as to manage other development/ management issues. Since the moisture sensitive phenophases of rice crop is limited to 1–2 weeks, it is necessary to analyze the weekly/biweekly rainfall to capture and quantify the impact of deficient/excess rainfall on productivity. Another aspect is that there is large-scale variation of rainfall within the state and hence future research work should focus on smaller grid areas – perhaps at district level.

ACKNOWLEDGEMENTS

We are grateful to ICAR for permitting the study leave for the first author to carry out this study. We are also grateful to Department of Atmospheric Sciences, CUSAT for providing infrastructural facilities to carry out this study.

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