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Weather based indices for forecasting foodgrain production in India

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ABSTRACT

Monthly (June-September) rainfall indices (RI) have been constructed for estimation of all-India annual foodgrain production index (PI) based on its relationship with subdivisional rainfall. The detrended production index has better relationship with the monthly RI than with the corresponding all-India monthly rainfall amounts. The PI also has a significant relationship with the Southern Oscillation Index (SOI). A regression model for estimation of the production index has been developed using the above weather indices. Similarly, the trend in the annual foodgrain production has been estimated by fitting an exponential equation to the foodgrain production series during the period of study (1953-2000). The study period has been divided in to two, 1953-92 for developing the model and 1993-2000 for verification. The above model is found to give the production estimates with reasonable accuracy, nearly eight months before the official final estimates become available.

Keywords: Rainfall indices, SOI, Foodgrain production estimation.

The rain dependent Indian agriculture is closely linked to the performance of summer monsoon (June-September), which produces 70-80% of the annual rainfall in most parts of the country. The summer monsoon rainfall is the main water resource for the *kharif* crops, which are cultivated over an extensive area in the country during this season. The *rabi* crops, which are raised during postmonsoon and harvested during early spring of the next year, also depend on the rainwater stored in lakes, reservoirs and rivers etc. during the preceding monsoon, since the winter rainfall is meager in most regions of India. There have been several studies linking the performance of summer monsoon with Indian annual foodgrain production (Mooley *et al.*, 1981a and 1981b; Mooley and Parthasarathy, 1982; Garnett and Khandekar, 1992; Parthasarathy *et al.*, 1988 and Gadgil, 1996). Attempts are being made in India to estimate the crop acreage and production using remote sensing data under the nationwide projects, Crop Acreage and Production Estimation (CAPE) and Forecasting Agricultural output using Space, Agrometeorology and Land based Observations (FASAL) funded by the Ministry of Agriculture.

Most of the short-term climate variability in the tropics is related to the ElNino/Southern Oscillation (ENSO) phenomenon, which influences/determines the location of tropical convection and ultimately changes the global atmospheric circulation. The Indian summer monsoon rainfall, which is the ultimate water resource for the agricultural production in India, is known to have significant relationship with the Southern Oscillation Index (SOI). One of the authors of this paper (Nageswara Rao, 1999) have evaluated the subdivisional composite mean rainfall during the positive and negative phases of SO. Besides rainfall, other weather parameters are affected-cloud cover reduces solar radiation, temperature and evaporation but increases humidity-all factors that influence plant growth and there have been several studies linking the agricultural production with SOI (Nicholls, 1985; Rimmington and Nicholls, 1993; Kuhnel, 1994; Phillips *et al.*, 1996; Meinke and Hammer, 1997; Hansen *et al.*, 1998 and Mjelde and Keplinger, 1998).

Any abnormality in the quantum and spread of monsoon rains can lead to substantial ups and downs in the agriculture production in India. Such fluctuations (Fig.2a) are evident even during the last 10 years when the country is considered to have received normal monsoon rainfall, consecutively since 1989. With fluctuations in foodgrain production and buffers being a small fraction of total production, the per capita availability also correspondingly fluctuates (Fig.2b). Though the current increasing trend in the national foodgrain production is considered satisfactory, the per capita availability of foodgrains per annum (Fig.2b) is still below the nutritional norm of 182.5 kg, except in two years (1991-92 and 1997-98). Therefore, advance estimates of foodgrain production are essential for evolution of mitigation measures to ensure greater food security in the country, as well as for planning the country's economy. Parthasarathy *et al.* (1988) have attempted to estimate the annual foodgrain production using all-India summer monsoon rainfall. Similarly, Arif (1988) and Parthasarathy *et al.* (1996) have made efforts to estimate the *kharif* foodgrains production from all-India monsoon rainfall. All these studies have attempted to relate the all-India annual foodgrain production with all-India summer monsoon rainfall amount. However, in the present study, an attempt has been made to obtain more accurate estimates of all-India annual foodgrain production well in advance of harvesting and compilation of the production statistics, from monthly (June-September) rainfall indices (RI) derived for the purpose based on the subdivisional rainfall and the Southern Oscillation Index (SOI), as parameters.

MATERIALS AND METHODS

Monthly (June-September) rainfall series for all-India and 29 meteorological subdivisions (Fig.1) as estimated on the basis of 306 raingauge stations in India during 1953-2000 is extracted from the 'IITM Indian regional/subdivisional Monthly Rainfall data set', prepared by the Indian Institute of Tropical Meteorology, Pune, India. Monthly subdivisional rainfall for the year 2001 has been collected from NCMRWF, New Delhi. The monthly SOI (Tahiti minus Darwin sea level pressures) for the study period (1953-2000) have been extracted from the web, which are prepared by the Bureau of Meteorology, Australia. From these monthly SOI, the seasonal indices during winter (DJF) and spring (MAM) and the winter to spring seasonal pressure

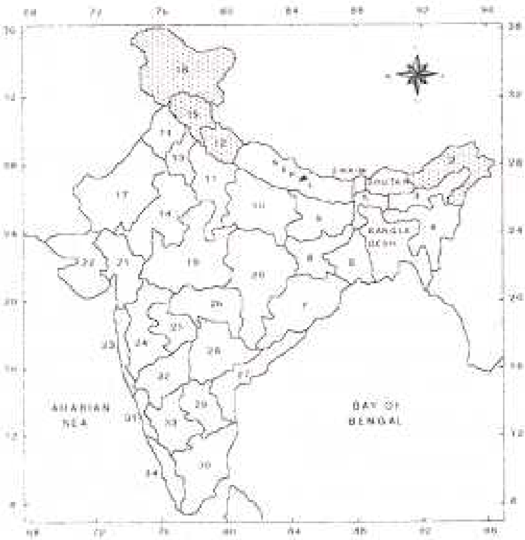

Fig. 1 : Meteorological subdivisions of India. Dotted hilly subdivisions are not considered in the study. (2.Arunachal Pradesh, 3.North Assam, 4.South Assam, 5.Sub-Himalayan West Bengal, 6.Gangetic West Bengal, 7.Orissa, 8.Bihar Plateau, 9.Bihar Plains, 10.East Uttar Pradesh, 11.West Uttar Pradesh, 12.West Uttar Pradesh Hills, 13.Haryana, 14.Punjab, 15.Himachal Pradesh, 16.Jammu and Kashmir, 17.West Rajasthan, 18.East Rajasthan, 19.West Madhya Pradesh, 20.East Madhya Pradesh, 21.Gujarat, 22.Saurashtra & Kutch, 23.Konkan & Goa, 24.Madhya Maharashtra, 25.Maratwada, 26.Vidarbha, 27.Coastal Andhra Pradesh, 28.Telangana, 29.Rayalaseema, 30.Tamilnadu, 31.Coastal Karnataka, 32.North Karnataka, 33.South Karnataka, 34.Kerala).

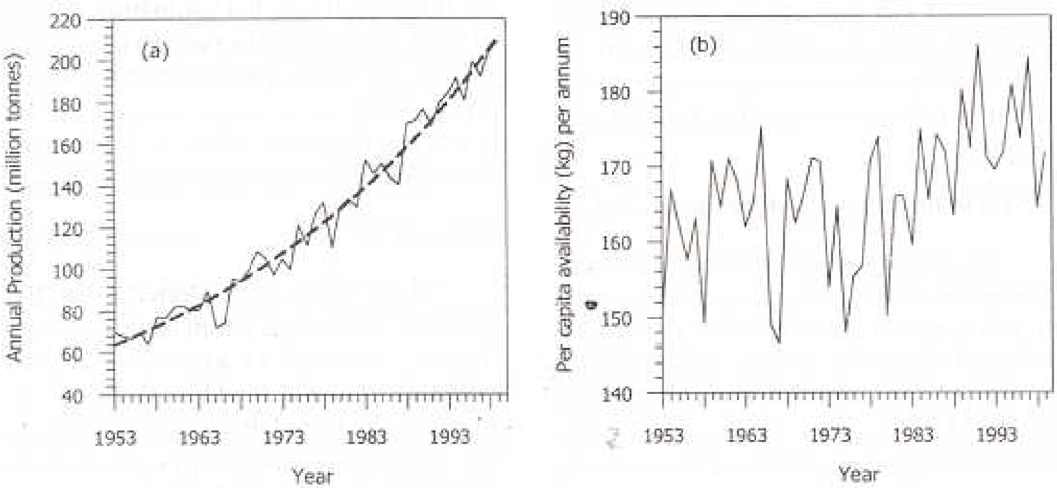

Fig. 2 : (a) All-India annual production and (b) per capita availability of foodgrains during 1953-2000.

tendency (MAM-DJF) are computed to represent SOI in the present study.

The annual production, which constitutes both *kharif* and *rabi* production of total foodgrains for the study period, from 1953-54 to 2000-01 are also extracted from the web, which have been prepared by the Directorate of Economics and Statistics, Ministry of Agriculture, Government of India, New Delhi. The entire study period has been divided into two parts, 1953-1992 for establishment of relationships through development of regression models and 1993-2000 for verification of the model estimates with actual data.

RESULTS AND DISCUSSION

The all-India annual foodgrain production series has two distinct components namely, (a) the trend component (Fig.2a) which can be attributed to non-meteorological factors such as, increased gross sown area, green revolution, improved technology and application of fertilizers, crop pest and disease control etc., and (b) the detrended production whose interannual variations are assumed due primarily to weather.

Trend in the annual foodgrain production

In order to find out the impact of climate variations on the foodgrain production, the trend component is to be removed from the original series by fitting various trend equations (Thompson 1969a, 1969b and 1970; Mooley *et al.* 1981a and 1981b; Parthasarathy *et al.*, 1988 and 1996). In the present study, the following exponential equation, which has been fitted to the annual foodgrain production series during 1953-2000, has been used to remove the trend component.

$$T = EXP(0.0256264 * YR) * 1.18E\text{-}020 \quad ......(1)$$

where, T is the trend component and YR is the year. The trend equation with a multiple correlation coefficient (MCC) of 0.94 is highly significant (at 0.001% level). The fitted trend curve is shown in Fig.2(a). The mean increasing trend in the annual foodgrains from the above equation during the period of study is found to be 3.12 million tonnes per year, while the mean annual foodgrain production is 125.1 million tonnes. Thus, the mean trend in the all-India annual foodgrain production during 1953-2000 is found to be 2.5% per year.

Detrended production index

As already mentioned, the detrended production is influenced by year-to-year weather variations. For estimating this, the actual foodgrain production (P) in each year during the study period (1953-2000) is expressed as a percentage of the corresponding trend value (T) to obtain the detrended production index (DPI) as follows:

$$DPI = (P/T)*100 \quad .... (2)$$

These DPIs are expected to be free form the technological trend and their year-to-year variations are assumed to be due primarily to weather and Fig.3 confirms the same in which the DPIs are plotted against the standardized anomalies of all-India summer monsoon rainfall. The figure clearly shows that whenever the rainfall anomaly is below -1.0 (above +1.0), the production index

Table 1 : Correlation coefficients of monthly subdivisional rainfall with all-India foodgrain production indices (PI) and with all-India summer monsoon rainfall (SMR) during 1953-92

June			July			August			September		
Subdiv. No.	DPI	SMR	Subdiv. No.	DPI	SMR	Subdiv. No.	DPI	SMR	Subdiv. No.	DPI	SMR
8	0.37'	0.43'	10	0.38'	0.37'	18	0.39!	0.36'	10	0.39'	NS
19	0.38'	0.41'	11	0.45'	0.46'	20	0.47s	0.37'	19	0.39'	0.61'
23	0.40'	NS	13	0.37'	0.29'	21	0.41!	0.48'	20	0.36'	0.52'
28	0.46'	0.45'	29	0.45'	0.44'				22	0.38'	0.61'
			30	0.38'	0.37'				23	0.44'	0.58'
									25	0.37'	0.39'
									31	0.44'	0.56'

' — Significant at 5% ' — Significant at 1% ' — Significant at 0.1% NS — Not significant

Table 2 : Correlation coefficients of annual foodgrain PI with all-India monthly rainfall and monthly rainfall indices during 1953-92

Month/Season	All-India rainfall	Rainfall indices
June	0.37'	0.54'
July	0.46'	0.54'
August	0.54'	0.55'
September	0.57'	0.54'

— Significant at 1% — Significant at 0.1%

Table 3 : Regression equations for estimation of all-India annual foodgrain production index (PI) based on the data during 1953-92

Regression equations	R	R^2
A) Using monthly Rainfall Indices (RI) and SOI		
$PI = 72.88 + 0.039\,RI_{JUN} + 0.031\,RI_{JUL} + 0.027\,RI_{AUG} + 0.034\,RI_{SEP} + 0.141\,SOI$	0.83	0.68
B) Using all-India (AI) monthly rainfall amounts and SOI		
$PI = 55.96 + 0.050\,AI_{JUN} + 0.048\,AI_{JUL} + 0.066\,AI_{AUG} + 0.042\,AI_{SEP} + 0.137\,SOI$	0.75	0.57

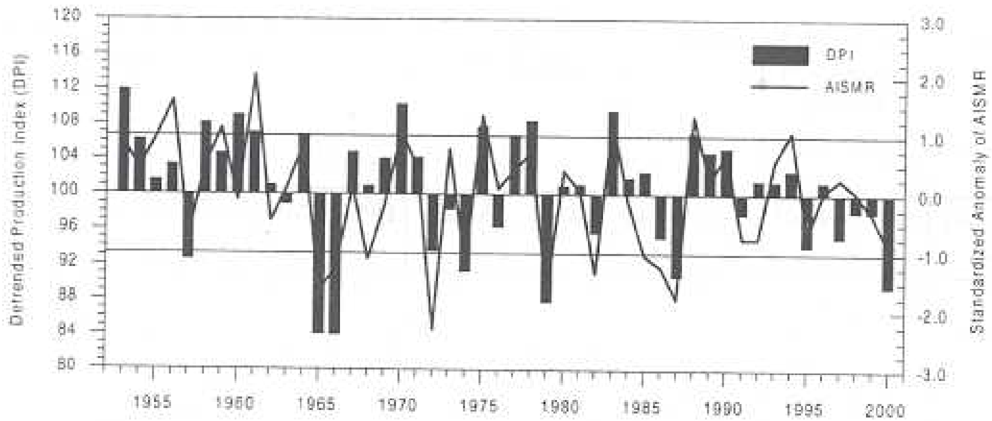

Fig. 3 : Variation of the detrended production index (DPI) of total foodgrains in India with the standardized anomaly of all-India summer monsoon rainfall (AISMR) during 1953-2000

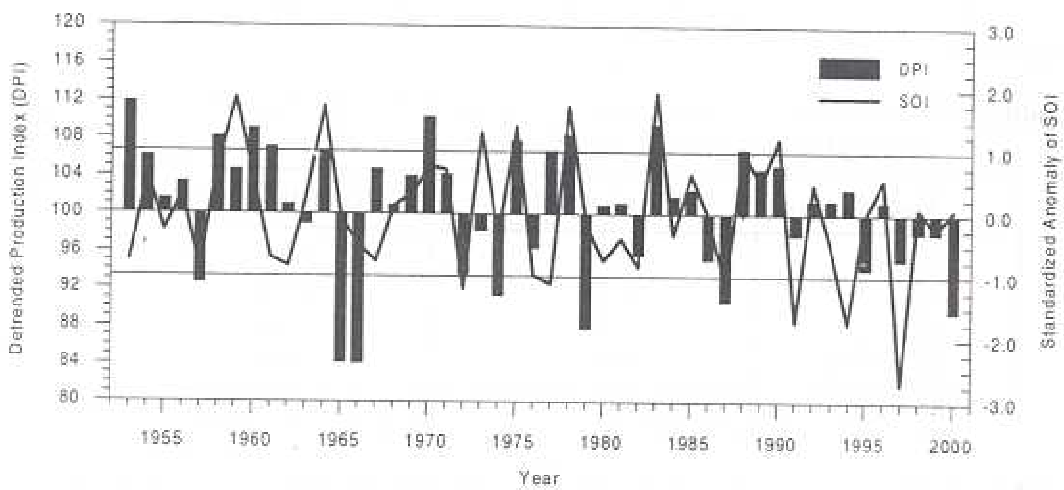

Fig. 4 : Same as Fig. 3, but with the standardized anomaly of Southern Oscillation Index (SOI).

is below (above) the normal value of 100.

Construction of rainfall indices (RI)

Earlier studies have attempted to relate the detrended PI with all-India monsoon seasonal rainfall alone (Parthasarathy *et al.*, 1988 and 1996). However, the Indian summer monsoon rainfall is known to have significant variations in space and time, and the crop production depends on the magnitude, as well as the distribution of monsoon rains in space and time. Hence, the monthly subdivisional rainfall (June-September) and the SOI have been considered for correlating with DPI.

Results showed that the DPI has significant correlations in respect of some specific subdivisions in each month (Table 1). Surprisingly, the meager rainfall in July in Subdivision No.30 (Tamilnadu), which is dominated by the winter monsoon, also has shown significant correlations with all-India annual foodgrain production index. First, such subdivisions having highly significant (1%) correlations with annual DPI during 1953-92 (model development period) have been identified (Table 1). Monthly rainfall indices (RI) are then constructed from the area-weighted rainfall of these subdivisions, as follows:

$$RI = \sum Ai\ Ri / \sum Ai \qquad \ldots\ldots\ldots\ (3)$$

where Ai is the area and Ri is the rainfall of the subdivisions that have shown significant relationship with the annual DPI.

Incidentally these subdivisions (except one each in June and September) have also shown significant correlations with the all-India monsoon seasonal rainfall (Table 1). In this connection, it may be mentioned that Joshi *et al.*, (1981) and De and Joshi (1996) have identified the clusters of subdivisions having a fair degree of homogeneity in the rainfall series by using contingency indices.

Development of model for estimation of production index

The detrended all-India annual foodgrain production indices (DPI) evaluated in the study are found to have better correlation with the monthly subdivisional area-weighted rainfall indices (RI) than with the corresponding all-India monthly rainfall amounts, except in September (Table 2). The DPI also has shown a correlation of 0.48 (significant at 1% level) with SOI during 1953-92. This positive relationship of DPI with SOI is evident from Fig.4, which shows that during the years with positive (negative) SOI anomaly, the DPI is above (below) 100, in general. In view of the significant relationship of DPI with both RIs and SOI, a multiple regression equation (Eq.A in Table 3) has been finally developed for estimation of all-India annual foodgrain production index (PI) from monthly rainfall indices (RI) and SOI. For purposes of comparison, a similar regression equation (Eq.B) using all-India monthly rainfall amounts and SOI also has been developed (Table 3). It is evident that the regression model based on the monthly rainfall indices (RI) and SOI accounts for higher variance (68%) in the annual foodgrain production index than that based on the all-India monthly rainfall amounts and SOI, which accounts for only 57% of variance (Table 3). In this connection, it may be mentioned that a regression equation reported by Parthasarathy *et al.* (1988) with all-India monsoon seasonal rainfall amounts alone for the period 1961-84 could account for a variance of 67% in the annual foodgrain production as against 81% explained by computations using the present model based on monthly RIs and SOI for the corresponding period.

Verification of model performance

Annual foodgrain PIs have been estimated from Eq.A (Table 3) for the periods, 1953-1992 (development period) and

Table 4 : Actual and estimated annual production of foodgrains during the verification period 1993-2000 and for 2001-2002

Year	Model estimates			Actual	
	Production index (PI)	Trend value (million tonnes)	*Production (P) in million tonnes	Production (million tonnes)	Deviation (%)
1993-94	100.5	179.0	180.0	184.3	-2
1994-95	104.2	183.7	191.5	191.5	0
1995-96	93.7	188.5	176.6	180.4	-2
1996-97	97.4	193.3	188.3	199.4	-6
1997-98	97.4	198.4	193.2	192.4	0
1998-99	98.9	203.5	201.2	203.6	-1
1999-00	99.9	208.8	208.6	208.9	0
2000-01	93.9	214.2	201.0	196.1	2
2001-02	95.9	219.8	210.9	211.3	0

* Eight months before the official final estimates

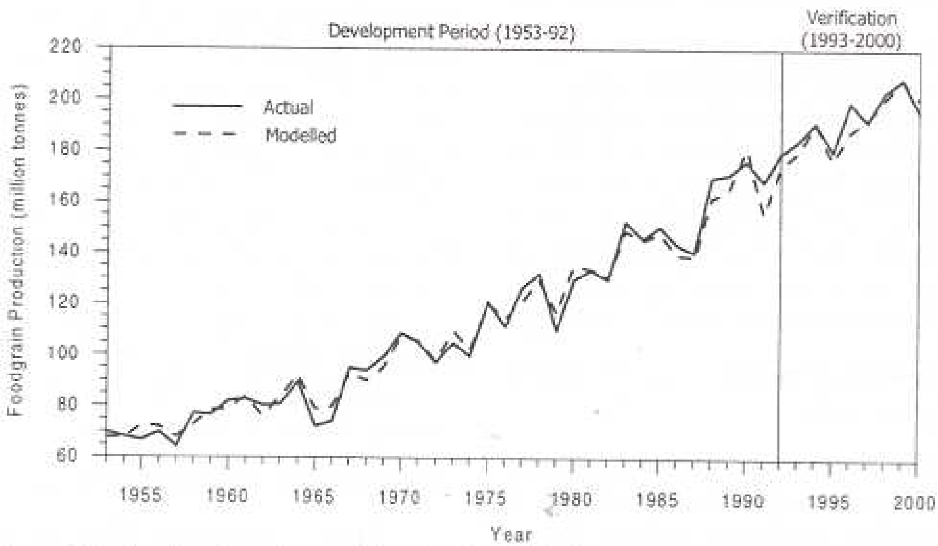

Fig. 5 : Actual and estimated annual production of foodgrains in India during model development (1953-92) and verification (1993-2000) periods

1993-2000 (verification period). The trend component of the foodgrain production, in each year during the above periods is also estimated from the fitted trend equation (Eq.1). The estimated production indices (PI) are then converted into annual productions (P) using the corresponding trend values (T) with Eq.2. The actual (compiled by the Directorate of Economics and Statistics, Government of India) and estimated productions of all-India annual foodgrains (Fig. 5) thus evaluated show that the modeled production is in close agreement with the actual values during both the development and verification periods. The percentage deviations of the production estimates from their actual values during the verification period (Table 4) varied from 2% to +2%, except in one year (1996-97).

Model application for the year 2001-2002 gave rise to a production index of 95.9 that is nearly 4% lesser than the normal production index (100). Based on the estimated PI and trend (Table 4), the all-India annual (*kharif* and *rabi*) foodgrain production for 2001-2002 was worked out as 210.9 million tonnes in October 2001, compared to the official final estimate of 211.3 million tonnes released in June 2002. Thus, the present model facilitates estimation of the all-India annual foodgrain production by October itself, nearly eight months before the official final estimates generally become available.

CONCLUSIONS

The present study shows that the regression model based on the weather indices i.e., monthly rainfall indices (RI) and Southern Oscillation Index (SOI) gave more accurate estimates of annual foodgrain production than those based on the all-India monsoon seasonal rainfall amounts alone. Based on the monthly rainfalls (June to September) of some specific subdivisions and SOI, the above model predicts the annual (*kharif* and *rabi*) foodgrain production in India by October, significantly in advance of the official final estimates are available.

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REFERENCES

Arif, R.R. 1988. *Kharif* production and monsoon rainfall: An empirical study, *Reserve Bank of Ind. Occa. Papers*, 9(4): 375-93.

De, U. S. and Joshi K. S. 1996. A climatological-cum-statistical analysis of monthly rainfall in the meteorological subdivisions of India. In: *Advances in Tropical Meteorology, Meteorology and National Development* (Ed. R .K. Dutta), Concept Publishing Co., New Delhi, pp. 384-393.

Gadgil, S. 1996. Climate change and agriculture An Indian Perspective. In: *Climate variability and Agriculture* (Eds. Y.P. Abrol, S. Gadgil and G.B.

Pant), Narosa Publishing House, New Delhi, pp. 1-18.

Garnett, E. R. and Khandekar, M. L. 1992. The impact of large-scale atmospheric circulations and anomalies on Indian monsoon droughts and floods and on world grain yields - a statistical analysis. *Agric. Forest Meteorol.*, 61 (1-2): 113-128.

Hansen, J. W., Hodges, A. W. and Jones, J.W. 1998. ENSO influences on agriculture in the Southeastern U.S., *J. Climate*, 11: 404-411.

Joshi, K. S., Vaidya, D. V. and De, U. S. 1981. An objective aid to forecasting weekly rainfall over India. *Vayu Mandal*, 11: 19-22.

Kuhnel, I. 1994. Relationship between the Southern Oscillation Index and Australian sugarcane yields. *Aust. J. Agric. Res.*, 45: 1557-1568.

Meinke, H. and Hammer, G. L. 1997. Forecasting regional crop production using SOI phases: a case study for the Australian peanut industry. *Aust. J. Agric. Res.*, 48: 789-793.

Mjelde, J.W. and Keplinger, K. 1998. Using the Southern Oscillation to forecast Texas winter wheat and sorghum crop yields. *J. Climate*, 11: 54-60.

Mooley, D. A., Parthasarathy, B. and Munot, A. A. 1981a. Large scale droughts over India and their impact on economy during the period 1871-1978. *Ann. Nat. Assoc. Geogr. Ind.*, 2, pp. 17-26.

Mooley, D. A., Parthasarathy, B., Sontakke, N. A. and Munot, A. A. 1981b. Annual rainwater over India, its variability and impact on the economy. *J. Climate*, 1: 167-186.

Mooley, D. A. and Parthasarathy, B. 1982. Fluctuations in deficiency of summer monsoon over India and their effect on economy. *Arch. Meteorol. Geophys. Bioklimatol.*, Ser. B., 30: 383-398.

Nageswara Rao, G. 1999. Variations of the SO relationship with summer and winter monsoon rainfall over India: 1872-1993. *J. Climate*, 12: 3486-3495.

Nicholls, N. 1985. Impact of the Southern Oscillation on Australian crops. *J. Climatol.*, 5: 553-560.

Parthasarathy, B., Munot, A. A. and Kothawale, D. R. 1988. Regression model for estimation of Indian foodgrain production from summer monsoon rainfall. *Agric. Forest Meteorol.*, 42: 167-182.

Parthasarathy, B., Rupa Kumar, K. and Munot, A. A. 1996. Relationship between Indian summer monsoon rainfall and *Kharif* foodgrain production. In: *Advances in Tropical Meteorology, Meteorology and National Development* (Ed. R .K. Dutta), Concept Publishing Co., New Delhi, pp. 291-297.

Phillips, J., Cane, M. A. and Rosenzweig, C. 1996. ENSO, seasonal rainfall patterns and maize yield variability in Zimbabwe. *Agric. Forest Meteorol.*, 90: 39-50.

Rimmington, G. M. and Nicholls, N. 1993. Forecasting wheat yields in Australia with the Southern Oscillaton index, *Aust. J. Agric. Res.*, 44: 625-632.

Thompson, L. M. 1969a. Weather and technology in the production of corn in the U.S. corn belt. *Agron. J.*, 61: 453-456.

Thompson, L. M. 1969b. Weather and technology in the production of wheat in the United States. *J. Soil Water Conserv.*, 24: 219-224.

Thompson, L. M. 1970. Weather and technology of soybeans in central United States. *Agron. J.*, 62: 232-236.