Indian J. Met. Geophys. (1971), 22, 47-58

551·509·3 : 633·18 (547)

Forecasting the yield of principal crops in India on the basis of weather – Paddy / Rice

J. C. DAS, A. K. MEHRA and M. L. MADNANI

Meteorological Office, Poona

(*Received 16 April 1970*)

ABSTRACT. By the method of regression analysis, forecast formulae have been evolved for forecasting yield of autumn paddy/rice in Mysore State using meteorological factors. The study reveals that there is increase in average yield per acre due to technology from early fifties. In Coastal Mysore, restricted rainy days during July to 15 September and frequency of occasions of drought and floods during August and September are the principal weather factors having significant effect on yield. The corresponding factor for Interior Mysore North is occasions of droughts during July to September. In the Interior Mysore South, June and September rainfall have significant effect on yield. By testing the formulae for the yields for 1965 to 1968, it is found that they agree well with the reported yields. All correlation coefficients obtained are significant at 0·1 per cent level.

1. Introduction

In an earlier paper* formulae were evolved for forecasting the yield of paddy in the State of Tamil Nadu, Kerala, Coastal Andhra Pradesh, portion of Andhra Pradesh and Sub-Himalayan portion of West Bengal. A similar study for forecasting the yield of Kharif (autumn) paddy/rice in the three sub-divisions of Mysore State is reported in the present paper.

2. Data

2.1. *Yield Data*

2.1.1. From the "Season & Crop Reports" published by the Government of Madras, Bombay and Mysore, districtwise yields per acre of rice/paddy were collected. For a few districts yield data were available from 1906, for some from 1916 and for the rest from 1941. The production figures for a few districts were not available for some years and those years, therefore, could not be included in the study.

2.1.2. By dividing the State into three sub-division, *viz.*, Coastal Mysore, Interior Mysore North and Interior Mysore South the yield of autumn rice/paddy per acre has been worked out by dividing the total yearly outturn of rice/paddy by the total rice/paddy acreage of that sub-division in that year. The yield per acre has been used as dependent variable in the study. While calculating the yield per acre the total outturn and the total acreage of both irrigated and unirrigated lands under rice/paddy are taken together as they are not given for a large number of years separately.

2.1.3. As the method of estimation of crop outturn and acreage differed from State to State and the districts now comprising Mysore State formed part of three different states for a large number of years, different yard-sticks were in use for the estimation of crop data in the past. However, from forties all the States adopted the technique of crop-cutting random sample surveys based on statistical considerations.

2.2. *Weather Data*

2.2.1. Precipitation and temperature data used in this study are available from a good network of stations in Mysore. Data on soil moisture, evapotranspiration etc are, however, available from a few stations and for short periods only. Hence, they could not be made use of in this study.

3. Technological Trend

3.1. Since 1950 crop yield per acre has shown gererally an upward trend due to important advances in the field of agricultural technology. Improved agronomic practices, *viz.*, Japanese method of cultivation, use of improved type of farm implements, control of diseases and pests by timely spraying, grow more food compaigns, use of hybrid seeds, use of chemical fertilizers, improved irrigational facilities etc, have resulted in this technological trend. This trend in crop yield has been noticed in each of the sub-divisions and is taken into account by introducing a suitable time scale linear variable in the regression study.

4. Analysis

4.1. Many factors had to be tried before finally chosing the combination of meteorological factors

*India met. Dep. Pre-published Sci. Rep., 120

MP)N)1DGOB—4

TABLE 1

Chart showing the independent variables used in the correlation analysis

Variables	Coastal Mysore	Interior Mysore North	Interior Mysore South
X_2	Restricted rainy days during 1 July to 15 September	Mean maximum temperature during July to September	September rainfall in inches
X_3	Occasions of drought and floods during Aug & Sep	X_2^2	June rainfall in inches
X_4	June rainfall	Occasions of drought during Aug & Sep	Occasions of drought during July and August
X_5	Mean maximum temperature during July and August	July rainfall	Mean maximum temperature during July and August
X_6	X_5^2	Square of June to August rainfall	X_5^2
X_7	Technological trend	Technological trend	Technological trend

TABLE 2

Regression equations developed including technological trend as independent variable

Name of sub-division	Number of years data used for correlation study	Regression equations	Coefficient of multiple correlation	Standard error of estimate	Percentage total variation in yield accounted for by the regression equation
Coastal Mysore	49	$X_1' = -32295 \cdot 96 + 6 \cdot 01 X_2$ (3·40) $- 32 \cdot 69 X_3 - 1 \cdot 46 X_4$ (4·14) (3·16) $+ 2336 \cdot 23 X_5 - 41 \cdot 16 X_6$ (2·06) (2·06) $+ \cdot 67 X_7$ (4·49)	0·8952	27·4	80·1
Interior Mysore North	53	$X_1' = -69537 \cdot 02 + 4704 \cdot 24 X_2$ (3·75) $- 78 \cdot 31 X_3 - 64 \cdot 26 X_4$ (3·74) (9·32) $+ 25 \cdot 47 X_5 - .40 X_6 + \cdot 81 X_7$ (3·56) (2·16) (8·20)	0·9241	49·9	85·4
Interior Mysore South	24	$X_1' = -62153 \cdot 87 + 51 \cdot 49 X_2$ (4·21) $+ 59 \cdot 93 X_3 - 42 \cdot 89 X_4$ (2·42) (2·19) $+ 4599 \cdot 71 X_5 - 83 \cdot 57 X_6$ (1·75) (1·76) $+ \cdot 76 X_7$ (9·51)	0·9674	84·5	93·6

Note—The *t—test* for each coefficient, taken as the ratio of the coefficient estimate to its standard error, is shown below each coefficient.

which give the best result. Examination is also made to find out whether the relationship between yield and chosen weather parameters is linear or curvilinear by plotting the chosen weather parameters against the yield. When the graph shows that a parabola would fit better, the squared term of the parameter chosen is introduced in the correlation analysis as second parameter for temperature or rainfall.

4.2. The formulae developed for forecasting the yield of rice in these sub-divisions of Mysore along with the corresponding coefficients of multiple correlation, the standard error of estimates and the percentage of total variation of yield accounted for by the regression are given in Table 2. The parameters which are used in forecasting for each sub-division are shown in Table 1. It will be seen that the weather factors used vary from sub-division to sub-division. Even in case of the same factors the contributions are different in the different sub-divisions.

4.3. *t-test*

By applying *t-test* for each coefficient (taken as the ratio of the coefficient estimate to its standard error), the significance of each individual parameter was tested. Except two, all partial regression coefficients of the independent parameters are significant at 5 per cent level. Some are significant even at 0·1 per cent level. In order to find the maximum effect of temperature on the yield of crop, two parameters significant at 10 per cent level are used in the case of Interior Mysore South. The test values of each coefficient are given in Table 2.

4.4. *Durbin-Watson test*

To ascertain whether the parameters used in multiple correlation analysis are serially correlated or not, Durbin-Watson tests were also performed. The statistics used is, $d = \frac{\Sigma(\triangle Z)^2}{\Sigma Z^2}$

where, ΣZ^2 is the sum of squares of the residuals from the regression and $\triangle Z$ is the successive differences of residuals ($\triangle Z_r = Z_{r+1} - Z_r$). The values of d are given in Table 3. It will be seen that there is no significant serial correlation positive or negative at 1 per cent level, according to Durbin-Watson test (1951) and Theil-Nagar test (1961).

4.5. *Independence of successive operations*

The independence of successive observations of each of the parameters has been tested by Neumann Ratio (the ratio of the mean square successive differences to the variance—Hart 1942). These values are given in Table 4. None of the values of Neumann ratio for the independent variables except technological trend are significant even at 5 per cent level. The test also shows that the yield has definite trend. The independent variables used in the study may be regarded as independent.

4.6. *F-test*

The significance of the net correlation obtained has been tested by partitioning the total sum of the squares. The analysis of variance and the corresponding F values are given in Table 5. It is remarkable that all F values are significant even at 0.1 per cent level.

5. Discussion

5.1. *Coastal Mysore*

5.1.1. This sub-division consists of North and South Kanara districts of Mysore State. The district-wise yield figures of rice for these districts were available from 1916 to 1964.

5.1.2. By plotting the yearly yield per acre (Fig. 1), it is noticed that the yield shows technological trend from 1953. In the regression analysis technological trend was, therefore, introduced as one of the variables.

5.1.3. Rainfall and temperature data used for the study are those of Mangalore, Karwar and Honavar observatories.

5.1.4. The following parameters were chosen finally as factors for the correlation study—

(*i*) Total number of restricted rainy days from 1 July to 15 September (X_2) (Restricted is used in the sense that rainfall of 5 cm or more in 24 hours followed by any rain next day has been counted as one).

(*ii*) Number of occasions of drought and floods during August and September (X_3). The occasions of droughts are defined as—When there is no day of rainfall more than 2·5 mm within a continuous period of 10 to 14 days, it has been taken as an occasion of drought marked by dummy figure 1. Similar occasions of —

(a) 15-17 days	dummy figure 2		
(b) 18-21 ,,	,,	,,	4
(c) 22-24 ,,	,,	,,	6
(d) 25-28 ,,	,,	,,	8

TABLE 3

Results of Durbin-Watson and Theil-Nagar Tests

Sub-division	Number of years of data used	$d=\frac{\Sigma(\triangle Z)^2}{\Sigma Z^2}$	According to Durbin-Watson test at 1% level		According to Theil-Nagar test at 1% level
			d_L	d_u	
Coastal Mysore	49	1·67	1·12	1·64	1·64
Interior Mysore North	53	1·69	1·17	1·64	1·64
Interior Mysore South	24	2·01	·64	1·79	1·77

TABLE 4

Neumann Ratio

Sub-division	No. of years of data used	Significant values at 5% level	Neumann ratio for variables						
			X_1 (Yield)	X_2	X_3	X_4	X_5	X_6	X_7 (Trend)
Coastal Mysore	49	1·57	·95	1·67	1·91	1·71	1·73	1·67	·02
Interior Mysore North	53	1·59	1·04	1·68	1·63	1·75	1·65	1·68	·01
Interior Mysore South	24	1·41	·46	2·12	2·21	1·93	2·37	1·89	·02

TABLE 5

Analysis of Variance

Met. sub-Div.	Variance due to factors	S. S.	D. F.	M. S.	F calculated	F Table at 0·1% level
Coastal Mysore	Regression	276830·31	6	46138·38	28·25	4·70
	Residual	68581·35	42	1632·88		
	Total	345411·66	48			
Interior Mysore North	Regression	1437186·00	6	239531·00	44·80	4·61
	Residual	245894·49	46	5345·53		
	Total	1683080·49	52			
Interior Mysore South	Regression	2373455·40	6	395575·90	41·34	6·56
	Residual	162664·35	17	9568·49		
	Total	2536119·75	23			

The occasions of floods defined as (*a*) 5 cm or more rainfall consecutively for three days or more; (*b*) 15 cm or more of rainfall consecutively for two days or more; (*c*) 20 cm or more of rainfall in a single day.

(*iii*) Rainfall during June (X_4)

(*iv*) Mean maximum temperature for July and August (X_5)

(*v*) Square of the mean maximum temperature of July and August (X_6).

5.1.5. The regression formula between yield and the parameters X_2 to X_6 mentioned in para 5.1.4. was worked out. The multiple coefficient is ·84 and accounts for 70·6 per cent of total variation in yield. By adding the factor technological trend (X_7) the multiple correlation coefficient becomes 0·90 (Table 2).

5.1.6. The following observations on the regression equation given in Table 2 for Coastal Mysore are of interest—

(*i*) The precipitation received in June is greater than is needed for rice production. Higher yields are generally associated with less than normal rainfall in this month.

(*ii*) Absence of rain continuously for 18 days or more during August and September affects the yield significantly. Three or more number of occasions of flood during these two months are also harmful for the crop.

(*iii*) Higher yields of rice have been associated with more number of restricted rainy days during the period 1 July to 15 September.

(*iv*) Near normal maximum temperature during July and August appears to be favourable for higher yield of rice.

(*v*) *The annual increase in yield due to technological trend is about 9 lb per acre from 1953 onwards.*

5.1.7. The reported rice yields of Coastal Mysore and those estimated from the regression equation are given in Table 6 and shown graphically in Fig. 1. In 90 per cent of the years, the estimated yield lie within 5 per cent of the reported yield; only in 5 per cent cases they lie within 5 to 10 per cent of the reported yield. The difference between the estimated and the reported yield is

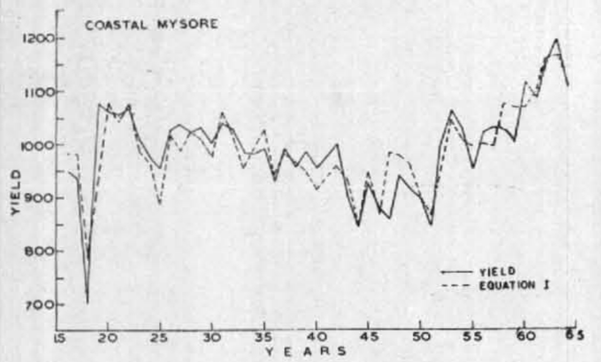

Fig. 1

about 11 per cent in 1918 and 13 per cent in 1947. The lowest yield year was 1918.

5.2. *Interior Mysore North*

5.2.1. This sub-division consists of Bidar, Gulbarga, Raichur, Bijapur, Dharwar and Belgaum districts of Mysore State. The districtwise yield figures of rice for the different districts available for 53 years from 1906 to 1964 have been used for the study.

5.2.2. By plotting the yield figures for each year against the corresponding years in a graph, it is noticed that the effect of technological trend is present from 1948 onwards. This effect is taken into account by introducing technological trend as a separate time scale variable.

5.2.3. The rainfall data of Bidar, Gulbarga, Raichur, Bijapur, Gadag, Belgaum, Yadgir, Ilkal, Athni, Lingsugur and Haveri and the temperature data of Bidar, Gulbarga, Raichur, Bijapur (Gadag) and Belgaum were analysed.

5.2.4. The following factors were finally chosen for the regression equation —

(*i*) July to September mean maximum temperature in Centigrades (X_2).

(*ii*) Square of July to September mean maximum temperature (X_3).

(*iii*) Occasions of drought during August and September (X_4). The occasions of drought are defined below—

When there is no day of rainfall more than 2·5 mm within a continuous period of 8-10 days it has been taken as an occasion of drought marked by dummy figure 1. Similar occasions of—

(a) 11-14 days dummy figure 2

(b) 15-17 „ „ „ 4

TABLE 6

Reported and expected rice yield of Coastal Mysore (lb per acre)

Year	Reported yield	Expected yield	Year	Reported yield	Expected yield	Year	Reported yield	Expected yield
1916	950	981	1932	1027	1021	1948	940	979
1917	935	981	1933	983	951	1949	914	957
1918	700	788	1934	981	985	1950	895	893
1919	1075	1055	1935	990	1023	1951	844	863
1920	1060	1079	1936	939	928	1952	997	950
1921	1056	1042	1937	990	982	1953	1061	1043
1922	1065	1074	1938	955	962	1954	1025	1008
1923	1005	988	1939	988	947	1955	950	994
1924	972	961	1940	953	913	1956	1020	997
1921	953	881	1941	987	938	1957	1030	993
1926	1027	1016	1942	997	957	1958	1026	1073
1927	1036	989	1943	900	929	1959	1004	1068
1928	1025	1024	1944	848	843	1960	1114	1065
1929	1032	1009	1945	928	947	1961	1083	1095
1930	1000	974	1946	878	867	1962	1152	1158
1931	1040	1060	1947	857	983	1963	1194	1163
						1964	1100	1102

TABLE 7

Reported and expected rice yield of Interior Mysore North (lb per acre)

Year	Reported yield	Expected yield	Year	Reported yield	Expected yield	Year	Reported yield	Expected yield	Year	Reported yield	Expected yield
1906	750	831	1921	791	803	1936	646	647	1951	869	975
1907	967	887	1922	600	614	1937	645	632	1952	685	632
1908	638	577	1923	709	785	1938	623	631	1953	771	916
1909	858	845	1925	918	985	1939	701	735	1954	838	934
1910	930	880	1926	917	908	1940	717	745	1955	786	916
1911	644	607	1927	723	704	1941	634	688	1956	790	821
1913	676	624	1928	877	841	1942	724	683	1958	1327	1197
1914	883	883	1929	726	697	1944	656	714	1959	1284	1072
1915	968	945	1930	611	634	1946	833	776	1960	936	956
1916	814	832	1932	905	919	1947	763	741	1961	1120	994
1917	791	812	1933	996	848	1948	805	860	1962	1216	1235
1918	428	423	1934	755	612	1949	785	874	1963	970	1031
1919	692	705	1935	587	618	1950	1066	998	1964	1098	1168
1920	801	771									

(c) 18-21 days dummy figure 6
(d) 22-24 ,, ,, ,, 8
(e) 25-28 ,, ,, ,, 11
(f) > 28 ,, ,, ,, 14

(*iv*) July rainfall in inches (X_5)

(*v*) Square of June to August rainfall (X_6).

5.2.5. The multiple correlation was then calculated between yield and parameters X_2 to X_6. It was found to be $0 \cdot 80$ accounting for 64 per cent of total variation in yield. A regression equation with these factors and technological trend mentioned in para 5.2.2 gave a multiple coefficient of $0 \cdot 92$. The formula is given in Table 2.

5.2.6. The following points are observed from the regression equation for Interior Mysore North—

(*i*) More than normal rainfall in July is usually conducive for greater yield. *Increase in yield for every additional inch of rainfall is about 25 lb per acre.*

(*ii*) The rainfall received during June to August is greater than is needed for growing rice in this region. Higher yields are associated with less than normal rainfall in this period.

(*iii*) The absence of rain continuously for 18 days or more during August and September have substantial adverse effect on the yield as in Coastal Mysore. *The yield may decrease even to the extent of 500 lb per acre, if the drought condition persists for more than 28 days.*

(*iv*) For higher yield of rice, the mean maximum temperature during July to September should be near about 30°C.

(*v*) *The annual increase in yield due to technological trend is found to be about 18 lb per acre from 1948 onwards.*

5.2.7. The yields estimated with the help of the regression equation developed for Interior Mysore North are given in Table 2. The corresponding reported yields are given in Table 7 and are presented graphically in Fig. 2. In 87 per cent of the years the estimated yields lie within 10 per cent of the reported yield and in 50 per cent of the years within 5 per cent of the reported yield.

5.3. *Interior Mysore South*

5.3.1. This sub-division covers Bangalore, Kolar, Tumkur, Mysore, Mandya, Hassan, Shimoga, Chikmagalore and Bellary districts of Mysore State. The districtwise yield figures of paddy for the districts included in the study were available from 1941 to 1964 only. So in the correlation study the data for 24 years have only been used.

5.3.2. Noting a gradual rise in the yield figures from 1950 onwards, this increasing trend due to technology is taken into account by introducing a separate time scale variable.

5.3.3. For the study the rainfall figures of Kadur, Kolar, Shimoga, Hassan, Mysore, Tumkur, Chitaldrug, Bellary, Bangalore and Mandya and the monthly mean maximum and minimum temperatures of Bellary, Chitaldrug, Hassan, Bangalore and Mysore were used.

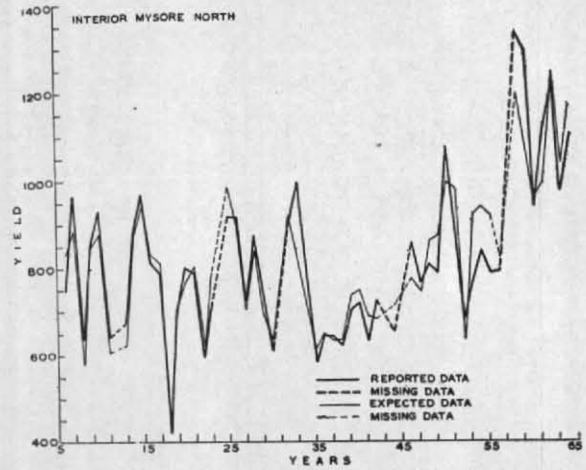

Fig. 2

5.3.4. After a large number of trials, the following weather factors were chosen as independent variables —

(*i*) September rainfall in inches X_2

(*ii*) June rainfall in inches X_3

(*iii*) Number of occasions of drought in July and August X_4. The occasions of drought are defined as below —

When there is no day of rainfall more than 2·5 mm within a continuous period of 10-14 days, it has been taken as an occasion of drought marked by dummy figure 1. Similar occasions of —

(a) 15-17	days	dummy figure 2
(b) 18-21	,,	,, ,, 4
(c) 22-24	,,	,, ,, 6
(d) 25-28	,,	,, ,, 8
(e) > 28	,,	,, ,, 10

(*iv*) July and August mean maximum temperature X_5.

(*v*) Square of July and August mean maximum temperature X_6.

5.3.5. When the regression equation was worked out with the five independent variables mentioned in para 5.3.4 and the yield, multiple correlation was found to be 0·77 and accounts for 59·4 per cent of total variation in the yield. The final equation has been worked out by adding technological trend as one of the factors. Details are presented in Table 2.

5.3.6. The conclusions arrived at from the regression equation obtained for Interior Mysore South are as follows —

(*i*) More than normal rainfall in June is helpful in increasing the yield per acre.

TABLE 8

Reported and expected rice yield of Interior Mysore South (lb per acre)

Year	Reported yield	Expected yield	Year	Reported yield	Expect ed yield
1941	1200	1258	1953	1530	1555
1942	1324	1312	1954	1450	1550
1943	1232	1217	1955	1921	1743
1944	1355	1336	1956	1789	1705
1945	1192	1098	1957	1750	1705
1946	1407	1452	1958	1945	1907
1947	1364	1422	1959	2055	2082
1948	1293	1288	1960	1685	1731
1949	1208	1216	1961	2037	1967
1950	1112]	1325	1962	1795	1890
1951	1510	1481	1963	1887	1963
1952	1423	1274	1964	2309	2296

Increase in yield for every additional inch of rainfall in June is about 60 lb per acre.

(*ii*) Absence of rain continuously for 18 days or more during July and August affect the yield appreciably. *The yield decreases by 250 lb per acre, if the drought condition persists for more than 28 days.*

(*iii*) For better yield of rice the mean maximum temperature during July and August should be nearly normal.

(*iv*) More than normal rainfall in September is also conducive for better yield of rice. *Increase in yield for every additional inch of rainfall in September is about 51 lb per acre.*

(*v*) *The annual increase in yield due to technological trend is found to be about 45 lb per acre from 1950 onwards.*

5.3.7. The reported yield and the yield estimated by the regression equation developed are given in Table 8, and are presented graphically in Fig. 3. In 84 per cent of the years, the estimated yield differs from the reported yield by less than 5 per cent only. It is also observed that the estimated yields differ from the reported yield by more than 10 per cent in 8 per cent of the years and by 5 to 10 per cent in 8 per cent of the years.

6. Remarks

6.1. The percentage total variation in yield accounted for by each factor for the different subdivisions is given in Table 9. 'Restricted rainy

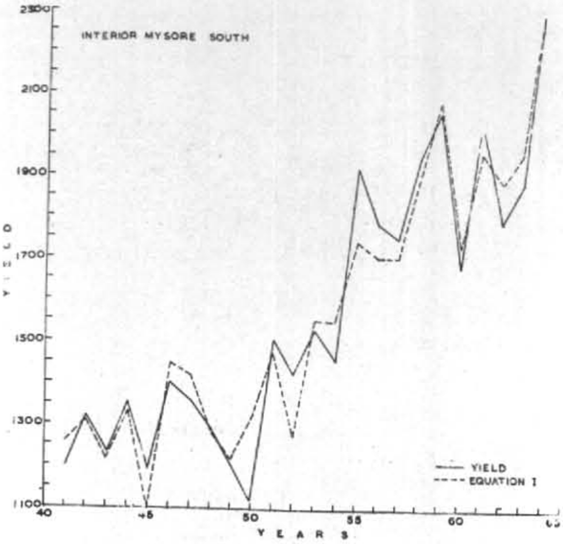

Fig. 3

days' during July to 15 September and occasions of 'drought and floods' during August and September are the principal weather factors which account for the variations in yield in Coastal Mysore. For Interior Mysore North, the corresponding factors are occasions of drought and mean maximum temperature during July to September. Rainfall during June and September and occasions of drought are the principal factors which account for most of the variations in yield in Interior Mysore South.

6.2. In order to see how the multiple correlation changes if the effect of technological trend is removed, the regression equations have been recalculated after removing the technological trend first. These are presented in Table 10. It is found that there is no significant change in the regression coefficients but there is decrease in the magnitude of multiple correlation. As a result, the estimated yields obtained by these equations agree in the same way as they do when the regression equations have been developed by introducing technological trend as a separate independent variable in the correlation analysis. This shows that the regression equations given in Table 2 may be used with confidence for forecasting yield.

6.3. The method of estimation of yield of autumn rice in Mysore underwent a change from 1951. But it is evident from Figs. 1-3 that no sharp discontinuity exists between the yields prior to 1951 and post 1951. So no adjustment has been made in the yield of earlier years to make them comparable with yield of years commencing from 1951.

TABLE 9

Percentage variation in yield accounted for by each independent variable

Sub-division	X_2	X_3	X_4	X_5	X_6	Trend	Total percentage accounted
Coastal Mysore	36·0	25·2	6·8	*	2·6	9·5	80·1
Interior Mysore North	*	9·2	48·0	5·4	2·4	20·4	85·4
Interior Mysore South	22·0	20·4	11·3	*	6·4	34·3	93·6

*Parabola fitting

TABLE 10

Regression equations developed after removing the trend

Sub-Div.	Number of years of data used for correlation study	Regression equation	Coefficient of multiple correlation	Percentage variation in yield accounted for by the regression equation
Coastal Mysore	49	$\text{Yield} = -32457{\cdot}77 + \underset{(3\cdot46)}{6{\cdot}02X_2} - \underset{(4\cdot36)}{32{\cdot}63X_3} - \underset{(3\cdot29)^*}{1{\cdot}45X_4} + \underset{(2\cdot09)}{2347{\cdot}41X_5} - \underset{(2\cdot10)}{41{\cdot}36X_6}$	·8521	72·6
Interior Mysore North	53	$\text{Yield} = -69647{\cdot}87 + \underset{(3\cdot83)}{4711{\cdot}49X_2} - \underset{(3\cdot83)}{78{\cdot}43X_3} - \underset{(9\cdot59)}{64{\cdot}17X_4} + \underset{(3\cdot63)}{25{\cdot}45X_5} - \underset{(2\cdot17)}{{\cdot}39X_6}$	·8719	76·0
Interior Mysore South	24	$\text{Yield} = -62413{\cdot}65 + \underset{(4\cdot71)}{51{\cdot}47X_2} + \underset{(2\cdot50)}{60{\cdot}04X_3} - \underset{(2\cdot31)}{42{\cdot}87X_4} + \underset{(1\cdot80)}{4618{\cdot}38X_5} - \underset{(1\cdot81)}{83{\cdot}90X_6}$	·8462	71·7

*The *t-test* for each coefficient, taken as the ratio of the coefficient estimate to its standard error, is shown below each coefficient

6.4. The regression formulae have been recalculated by using post 1951 yield data only. They are presented in Table 11. There is no appreciable change in net multiple correlation but the regression coefficients and the value of the test of significance have changed.

7. Formulae for interim forecasts of crop yield

The formulae developed for forecasting paddy/rice yield of Mysore State may be used for issuing interim forecasts during the progress of the crop season itself by slightly modifying these formulae. The formulae will have to be modified by using the average value of the parameters for the periods for which the actual weather parameter will not be available. The formulae thus modified for different sub-divisions for different periods of crop growth are given in Table 12. The yields have been estimated by these equations and compared with the reported yields. They are presented graphically in Figs. 4, 5 and 6. It will be noticed that the estimated yields lie within 10 per cent of actual yield in 90 to 95 per cent of the years in Coastal Mysore and 80 to 85 per cent of the years in case of Interior Mysore South. As September rainfall is very important for crop and varies widely, interim forecasts may be made with modified regression equations with 50 to 55 per cent success in Interior Mysore North.

8. Varification of yield forecasts and their limitations

8.1. The yield figures for 1965-1966 to 1967-1968 have been used to verify the correctness of the forecast formulae developed. The yields for

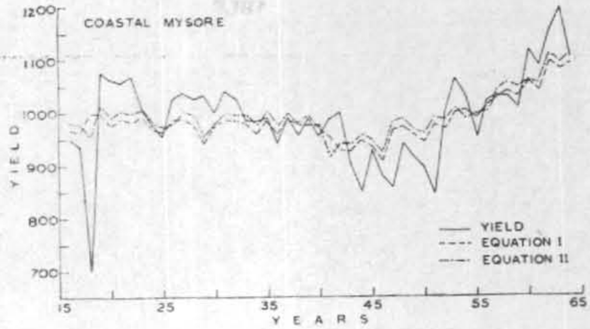

Fig. 4

TABLE 11

Regression equations developed with yield data from 1951

Name of sub-div.	No. of years of data used for correlation study	Regression equation*	Coefficient of multiple correlation	Percentage total variation in yield accounted for by regresssion Eq.
Coastal Mysore	14	$X'_1 = 572\cdot 59 + \underset{(\cdot 73)}{3\cdot 65X_2} - \underset{(1\cdot 22)}{23\cdot 44X_3} - \underset{(1\cdot 92)}{2\cdot 88X_4} - \underset{(\cdot 10)}{\cdot 02X_5} + \underset{(\cdot 98)}{\cdot 54X_6} + \cdot 53X_7$	·9038	81·7
Interior Mysore North	13	$X'_1 = -128952\cdot 42 \times \underset{(1\cdot 35)}{8557\cdot 53X_2} + -\underset{(1\cdot 34)}{140\cdot 90X_3} - \underset{(1\cdot 94)}{72\cdot 74X_4} + \underset{(1\cdot 90)}{62\cdot 83X_5} - \underset{(\cdot 66)}{\cdot 54X_6} + \underset{(1\cdot 87)}{1\cdot 04X_7}$	·9058	82·0
Interior Mysore South	14	$X'_1 = -6516\cdot 84 + \underset{(4\cdot 14)}{74\cdot 05X_2} + \underset{(1\cdot 59)}{68\cdot 79X_3} - \underset{(2\cdot 67)}{74\cdot 62X_4} + \underset{(\cdot 53)}{545\cdot 67X_5} - \underset{(\cdot 52)}{9\cdot 58X_6} + \underset{(3\cdot 65)}{\cdot 52X_7}$	·9617	92·5

**t—test* values for each coefficient is shown below the coefficient

TABLE 12

Modified formulae for issuing interim forecast

Name of Met. sub-div.	Modified formulae	For issuing forecasts in the first week of
Coastal Mysore	$X_1(\text{estimated}) = 1030\cdot 08 - 1\cdot 46X_5 + \cdot 67X_7$	July
Do.	$X_1(\text{estimated}) = -32104\cdot 38 + 2336\cdot 23X_4 - 1\cdot 46X_5 - 41\cdot 16X_6 + \cdot 67X_7$	September
Interior Mysore North	$X_1(\text{estimated}) = 603\cdot 46 + 25\cdot 47X_2 + \cdot 81X_6$	August
Do.	$X_1(\text{estimated}) = 695\cdot 46 + 25\cdot 47X_2 + \cdot 81X_6 - \cdot 40X_7$	September
Interior Mysore South	$X_1(\text{estimated}) = 1156\cdot 66 + 59\cdot 93X_2 + \cdot 76X_7$	July
Do.	$X_1(\text{estimated}) = -61924\cdot 23 + 59\cdot 93X_2 - 42\cdot 89X_3 + 4599\cdot 71X_4 - 83\cdot 57X_6 + \cdot 76X_7$	September

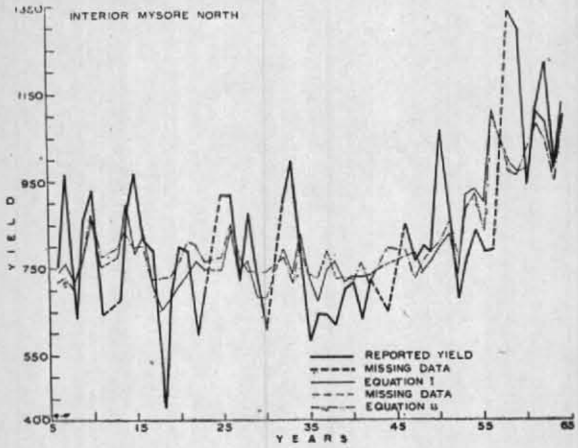

Fig. 5

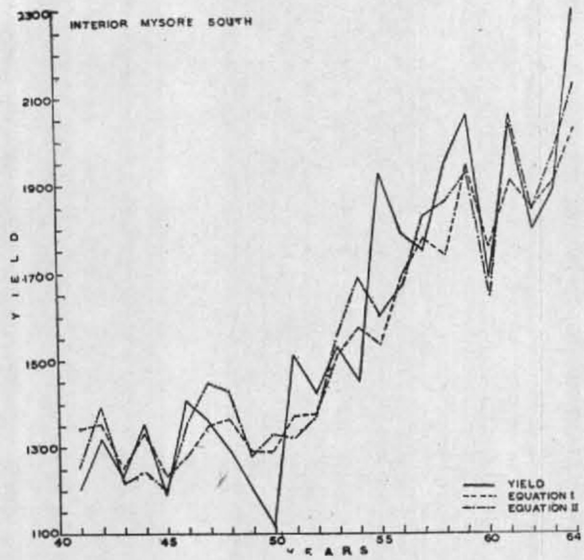

Fig. 6

TABLE 13

Reported and estimated rice/paddy yields for years not included in this study(lb/acre)

Sub-division	Year	Reported yield	Yield estimated by equations in Table 2	Yield estimated by equations in Table 12	Difference between (3)&(4) (%)	Difference between (3) & (5) (%)
Coastal Mysore	1965	1175	1189	1208	1	3
Do.	1966	1205	1197	1080	1	10
Do.	1967	1209	1183	1073	2	11
Do.	1968	1216	1201	1380	1	14
Interior Mysore North	1965	975	1071	1056	9	8
Do.	1966	1111	1100	1245	1	1
Do.	1967	1365	1272	1202	7	13
Do.	1968	892	937	1100	5	23
Interior Mysore South	1965	1910	1819	1843	5	3
Do.	1966	2223	2121	1910	5	14
Do.	1967	2206	2024	1902	9	14
Do.	1968	2826*	2479	2236	14	21

*Provisional yield figure based on preliminary data

these years have been estimated by two sets of equations developed and presented in Table 13. For the set using longer series of data, the agreement is remarkable in Coastal Mysore where estimated yields are within 2 per cent of the reported yields in all the four years. In Interior Mysore North, the agreement is within 8 per cent in all the years. In Interior Mysore South, the difference is within reasonable limits during 1965-1967. In 1968, the provisional yield figure is seen to be 14 per cent more than the estimated yield.

8·2. Agreement with the yields estimated by the equation developed with shorter series of data is somewhat satisfactory for 1965-66 only. For other years they are out by more than 10 per cent.

8·3. On scrutinizing the provisional production figures of different districts for 1968, it is noticed that there is a sharp increase in the production in Tumkur, Shimoga, Mysore, Mandya and Hassan districts. If the provisional production figure is finally confirmed, then the sharp increase may be due to the rapid increase in the acreage of areas sown with hybrid seeds. After getting confirmation from the State Authorities, the regression equation developed for Interior Mysore South will have to be recalculated by using a different technological trend variable.

8.4. The forecast formulae presented in this paper will have to be constantly reviewed because the technology may change substantially the yield due to (*i*) more land being sown with seeds of hybrid variety, (*ii*) improved irrigation facilities and (*iii*) use of more fertilizers.

9. Conclusions

By using the furmulae developed, the overall estimate of production of food crops in Mysore State will become available well before the harvest. The final forecast can be issued for each division on 1 October.

Acknowledgement — The authors express their most grateful thanks to Shri K. N. Rao, Deputy Director General of Observatories (Climatology and Geophysics,), Poona, Shri M. Gangopadhyaya, Director of Agricultural Meteorology, Poona under whose guidance the work was done. Shri C.J. George, Meteorologist also helped the authors by offering valuable suggestions for improving the work. The computations were done on IBM 1620 computer at the Institute of Tropical Meteorology, Poona and CDC 3600 at T.I.F.R., Bombay.

REFERENCES

Durbin, J. and Watson, G. S.	1951	*Biometrika*, **38**, p. 159.
Hart, B. I.	1942	*Anu. Math. Statistic*, **13**, p. 445.
Theil, H. and Nagar, A. L.	1961	*J. Am. statist. Ass.*, **56**, p. 793