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On the influence of weather on wheat yield at Dharwar

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ABSTRACT. A curvilinear regression study of weather factors with the wheat yield at Dharwar is made by the successive approximation technique developed by Ezekiel and Fox (1959). Various weather factors are tried and the following tentative conclusions are drawn.

An optimum of about 16° C minimum temperature, 29·3°C maximum temperature and 22° to 23°C mean temperature with 60 to 65 hours of bright sunshine per week and 50 to 60 per cent humidity appear to be the most favourable condition for wheat in Dharwar. An optimum total water requirement may be assessed as equivalent of 40 to 50 cm of rainfall during the period July to the end of the vegetative phase.

1. Introduction

Mallik *et al.* (1960) studied the crop weather relationships by simple correlation methods. Hooker (1907), Keen (1940) and Gangopadhyaya and Sarker (1963) have studied these relationship by partial correlation technique. Gangopadhyaya and Sarker (1964a, 1964b) have used the curvilinear technique for finding relationship between yield and crop characteristics and also between growth and meteorological factors in the case of sugarcane crop. We have used the same method to examine the influence of weather on wheat crop.

2. Data used

For a preliminary study of the relationship, yield data of wheat (NP-4) at the Government Experimental Farm, Dharwar (18° 27′N, 76°06′E) has been utilized as dependent factor. Data are available for 16 years from 1947-1948 to 1962-1963. Out of these, in 1948-49, the crop was affected badly by rust and in 1959-60 crop was damaged by rat-cut. These two years have been omitted and the remaining 14 years' data have been used.

Wheat is grown as Rabi crop in Dharwar. It is normally sown in the 43rd standard week (October end) and the vegetative phase continues up to the 50th week (2nd week of December). The crop is harvested by the 5th week (January end/February beginning) of the following year. The standard weeks are defined in the Agrimet. Technical Circular No. 50 and start with week No. 1 from 1 to 7 January of a year.

Gangopadhyaya and Sarker (1963) found the following weather parameters satisfactory in explaining the sugarcane height — (*i*) mean daily average minimum temperature, (*ii*) mean daily average maximum temperature, (*iii*) total rainfall and (*iv*) total hours of sunshine, during the elongation period. In the present analysis the same elements for the vegetative phase were first used. Vegetative phase is defined to cover the period from the date of sowing to the commencement of ear-emergence. However, it was seen that the rainfall of the vegetative phase alone does not appear to have much influence on wheat yield.

It will be clear that it is the total effect of the solar radiation and the total available water supply by way of rainfall during the period of the crop and the previous stored soil moisture that will effect the plant growth and yield. Based on this idea, the following factors were tried in the present analysis for study of the yield—weather relationship.

Average mean temperature, (Max. + Min.)/2, will represent, to an extent, the total net solar radiation, after allowing for cloudiness, etc and the air masses that were prevalent. The effect of mean maximum and mean minimum temperatures are also separately analysed. Stored water is not accounted for when the rainfall during vegetative phase only is considered. Gangopadhyaya and Sarker (1965) in their analysis of the influence of rainfall distribution on the yield of wheat, using Fisher's (1924) Response—Curve technique, have also found that pre-sowing rainfall is beneficent to the yield and that a little rainfall more than the normal during the germination period is expected to increase the yield substantially. Allen and George (1956) have also shown that in the case of wheat, which is grown as rain-fed crop, sub-soil moisture is an important factor. Therefore rainfall from previous July to the end of the vegetative phase has been used, on the assumption that this will be representative of the total water available and utilised by the crop. Average weekly total hours of bright sunshine has been utilised as another factor. To see if average humidity can replace the total weekly sunshine hours, an analysis using this factor in the place of sunshine hours is also tried.

The actual data used in this study are given in Table 1 together with the symbols (x_1, x_2, ...) used to designate them in the paper.

TABLE 1

Crop Year	Duration of vegetative phase in standard weeks	Yield of wheat in kgm/hect. x_1	Total rainfall (mm) from July to the completion of vegetative phase x_2	Mean daily maximum temp. (°C) during vegetative phase x_3	Mean daily minimum temp. (°C) during vegetative phase x_4	Daily mean temp. (°C) during vegetative phase x_5	Average weekly total hours of sunshine during vegetative phase x_6	Mean daily humidity (%) during vegetative phase x_7
1947-48	44 — 50	1017	489·5	29·2	13·7	21·5	65·0	56
1949-50	42 — 50	1087	338·1	29·3	14·4	21·9	61·4	63
1950-51	43 — 50	856	634·1	29·3	13·3	21·3	65·5	51
1951-52	42 — 49	978	318·9	30·1	16·3	23·2	60·0	62
1952-53	43 — 49	1041	434·1	30·1	14·2	22·1	67·5	59
1953-54	45 — 52	734	690·6	29·6	12·4	21·0	71·5	52
1954-55	42 — 48	1382	482·0	29·2	14·9	22·1	58·7	65
1955-56	44 — 50	818	395·1	28·2	13·2	20·7	61·4	62
1956-57	44 — 51	505	607·4	27·9	15·1	21·5	51·2	71
1957-58	45 — 52	947	606·0	29·2	15·1	22·1	59·0	59
1958-59	42 — 48	1034	517·4	30·3	17·9	24·1	54·1	61
1960-61	42 — 48	790	360·1	29·6	17·1	23·3	50·3	67
1961-62	43 — 49	826	676·1	28·9	15·6	22·3	56·0	64
1962-63	42 — 49	856	559·5	29·4	16·4	22·9	50·2	71
1963-64	42 — 48	620	385·5	29·9	16·3	23·1	50·8	69

TABLE 2 — Analysis A

Details of analysis of four factors

The multiple regression equation with multiple C.C.

$$E(Y) = -0{\cdot}519x_2 - 12{\cdot}124x_3 + 78{\cdot}313x_4 + 22{\cdot}668x_6 - 980{\cdot}5$$

Multiple correlation coefficient = 0·569

	Residuals from			
Linear regression Z'	First approx. curve Z''	Second approx. curve Z'''	Third approx. curve Z''''	Final approx. curve Z'''''
+ 59	—184	— 67	—153	—110
+ 79	— 38	+112	+ 2	+ 28
— 6	— 33	+ 19	+ 1	+ 37
—148	— 41	— 12	— 22	— 6
— 30	— 56	— 29	— 54	— 26
—160	+232	— 41	+ 84	+ 73
+469	+133	+260	+109	+165
— 80	— 26	+ 86	— 12	+ 54
—204	+ 1	— 49	+ 35	— 47
+ 76	—165	— 45	—125	—108
+ 22	+117	+ 16	+124	+ 49
—163	+ 66	—150	— 20	— 59
+ 17	— 72	— 16	— 24	— 7
+ 6	+ 67	— 86	+ 51	— 35
S.S. 362978	168339	129830	81698	71693

TABLE 3 — Analysis B

Details of analysis of three factors with humidity

The multiple regression equation with multiple C.C.

$$E(Y) = 709{\cdot}3 - 0{\cdot}648\,x_2 + 56{\cdot}323\,x_5 - 11{\cdot}493\,x_7$$

Multiple correlation coefficient = 0·520

	Residuals from	
Linear regression Z'	First approx. curve Z''	Final approx. curve Z'''
+ 58	— 73	— 51
+ 87	+ 37	+ 76
— 56	+ 45	+ 56
—119	— 32	+ 35
+ 46	—151	—223
—113	+ 59	+ 41
+487	+317	+278
— 89	— 7	— 63
—206	—122	— 78
+ 64	— 75	—102
+ 4	+ 40	+ 83
—228	—133	— 98
+ 34	— 20	— 35
+ 35	+111	+ 86
S.S. 389118	189086	187003

3. Analysis

Curvilinear graphic regressions are fitted to the yield data of wheat using three different sets of independent factors. In analysis A, the independent factors used are — (1) total rainfall from July to the end of vegetative phase, (2) average maximum temperature during vegetative phase, (3) average minimum temperature during vegetative phase and (4) the average total weekly hours of bright sunshine, during vegetative phase.

In analysis B, the factors are—(1) the total rainfall from July to the end of the vegetative phase, (2) average mean temperature (Max. + Min.)/2, during the vegetative phase and (3) the average relative humidity during the same phase.

In analysis C, these are factors (1) and (2) of B above with (3) the average total weekly hours of bright sunshine during vegetative phase.

In all the three above analyses, the method of 'successive graphic approximations' has been followed to arrive at the final curvilinear regression curves. The conditions observed in fitting the curve to each function are—(*i*) The curve will have only one maximum, (*ii*) it might not rise at all or might rise slowly in the lower range, then more steeply and then taper off until the maximum is reached, (*iii*) after the maximum is reached, it might decline gradually or sharply and (*iv*) it might have utmost one point of inflexion on either side of the maximum.

The procedure indicated in Ezekiel and Fox (1959) had been used to arrive at the final approximation curves graphically.

Tables 2, 3 and 4 give the salient details of analysis A, B and C respectively. They give the multiple linear regression equation together with the multiple C.C., the residuals and the residual S.S. at each approximation.

For making the results available in a conveniently and readily usable form, the final results are presented as follows. Expected values of the dependent variable (x_1) are tabulated corresponding to the values of the most important independent factor for selected intervals from the final partial regression curve and these are tabulated in cols. 1 and 2 of Tables 5, 6 and 7 and in graph I of figures 1, 2 and 3 respectively. The equation to work out these values is —

$$x' = f_2(x_2) - M_f\ (2) + M_1 \qquad (1)$$

where M_f (2) is the mean of all the values read from the final curve and M_1 is the mean of x_1s. For rainfed crops rainfall is the most important independent factor. This main curve gives the expected yield corresponding to any given rainfall when the other factors are kept constant.

TABLE 4

Analysis C

Details of analysis of three factors with sunshine

The multiple regression equation with multiple C.C.

$E(Y) = -0{\cdot}498\, x_2 + 97{\cdot}400\, x_5 + 5{\cdot}623\, x_6 - 912{\cdot}3$

Multiple correlation coefficient $= 0{\cdot}583$

Residuals from		
Linear regression Z'	First approx. curve Z''	Final approx. tion curve Z'''
+ 63	— 77	— 59
+ 75	— 79	+ 68
— 14	+ 78	+ 45
—148	— 42	— 58
— 38	—247	—110
—172	+198	+105
+465	+124	+196
— 48	— 38	— 63
—174	— 99	—101
+ 87	—119	— 49
+ 11	+208	+ 58
—174	+ 37	— 26
+ 28	— 75	+ 3
+ 32	+135	— 10
S.S. 351301	229496	95755

For the remaining independent factors, their effect is given as a correction to be made to the expected yield from (1) above for varying values of the particular independent factor. The formula to calculate these corrections is —

$$x_1' = f_3(x_3) - M_f\ (3) \qquad (2)$$

These corrections for the other factors are indicated in Tables 5, 6 and 7 and in the other graphs of Figs. 1, 2 and 3 for the respective factors.

To arrive at the expected yield in a given year when rainfall, temperature etc have stated values, the expected yield is read corresponding to the main factor and to this is added algebraically the corrections read for the other factors.

4. Conclusions

Analysis A gives an index of multiple correlation of 0·93 and accounts for 86 per cent of the variations in the wheat yield. In analysis B, the index of multiple correlation is 0·83 and the variance accounted for is 68 per cent. In C, they are 0·92 and 84 per cent respectively. One would conclude that the set of factors used in analyses A and C fit the observed wheat yield the best.

However, adjustments for degrees of freedom have to be made to get a correct indication as to

TABLE 5 — Final results of analyis A

Computed wheat yield for varying rainfall and corrections to this computed value for varying maximum temperature, minimum temperature and weekly total hours of sunshine

Rainfall (mm) (1)	Average yield (kgm/hect.) (2)	Maximum temp. (°C) (3)	Correction to expected yield (4)	Minimum temp. (°C) (5)	Correction to expected yield (6)	Weekly total hours of sunshine (7)	Correction to expected yield (8)
300	830	27·9	—179	12·2	—246	50·0	—235
350	920	28·0	—161	13·0	—211	52·5	—152
400	1005	28·5	— 64	14·0	— 66	55·0	— 60
450	1050	29·0	+ 44	15·0	+ 64	57·5	+ 20
500	1053	29·3	+ 71	16·0	+124	60·0	+ 65
550	1008	29·5	+ 53	17·0	+124	62·5	+105
600	880	30·0	— 37	18·0	+124	65·0	+115
650	775	30·3	— 81			67·5	+122
700	735					70·0	+122
						72·0	+122

TABLE 6 — Final results of analysis B

Computed wheat yield for varying rainfall and corrections to this computed value for varying mean temperature and daily mean humidity

Rainfall (mm) (1)	Average yield (kgm/hect.) (2)	Mean temp. (°C) (3)	Correction to expected yield (4)	Mean daily humidity (%) (5)	Correction to expected yield (6)
300	836	20·5	—240	50·0	+ 52
350	941	21·0	—145	52·5	+ 97
400	1051	21·5	— 50	55·0	+105
450	1056	22·0	+ 95	57·5	+ 92
500	1006	22·5	+105	60·0	+ 64
550	939	23·0	+ 60	62·5	+ 27
600	861	23·5	— 15	65·0	— 38
650	796	24·0	— 75	67·5	—113
700	736	24·2	— 95	70·0	—196
				72·5	—278

TABLE 7 — Final results of analysis C

Computed wheat yield for varying rainfall and corrections to this computed value for varying mean temperature and weekly total hours of sunshine

Rainfall (mm) (1)	Average yield (kgm/hect.) (2)	Mean temp. (°C) (3)	Correction to expected yield (4)	Weekly total hours of sunshine (5)	Correction to expected yield (6)
300	822	20·5	—229	50·0	—197
350	917	21·0	—149	52·5	—142
400	987	21·5	— 74	55·0	— 77
450	1032	22·0	+ 41	57·5	+ 33
500	1057	22·5	+106	60·0	+ 91
550	982	23·0	+ 96	62·5	+108
600	882	23·5	+ 71	65·0	+ 93
650	802	24·0	+ 39	67·5	+ 63
700	752	24·2	+ 21	70·0	+ 33
				72·5	+ 3

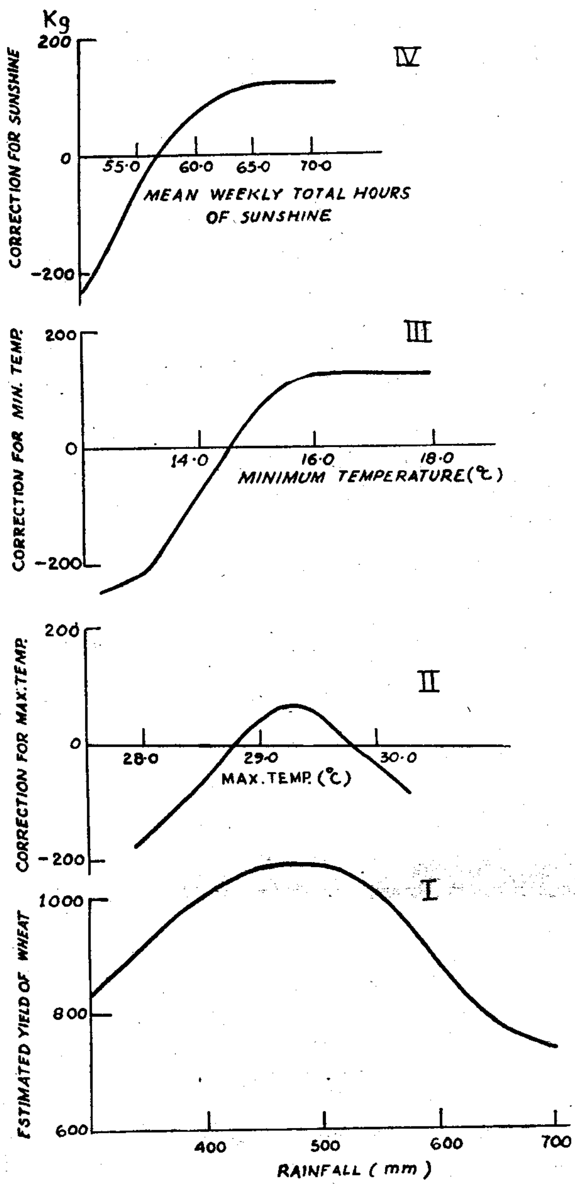

Fig. 1. Final results of Analysis A

(Index of multiple correlation — 0·927)

which of the three sets of curvilinear regressions fit the observed data best. Any reduction in the unadjusted standard error, or the residual sum of squares, is only a fictitious improvement in accuracy, as with additional variables or by employing a higher degree curve, more degrees of freedom are used up. This is particularly relevant in the case of small samples. But for regression curves determined by graphic processes, no exact estimation of the degrees of freedom used up is possible. For the type of curves which has been defined for this study, if we assume that an average of three degrees of freedom is used up by each factor, the analysis in Table 8 will give the

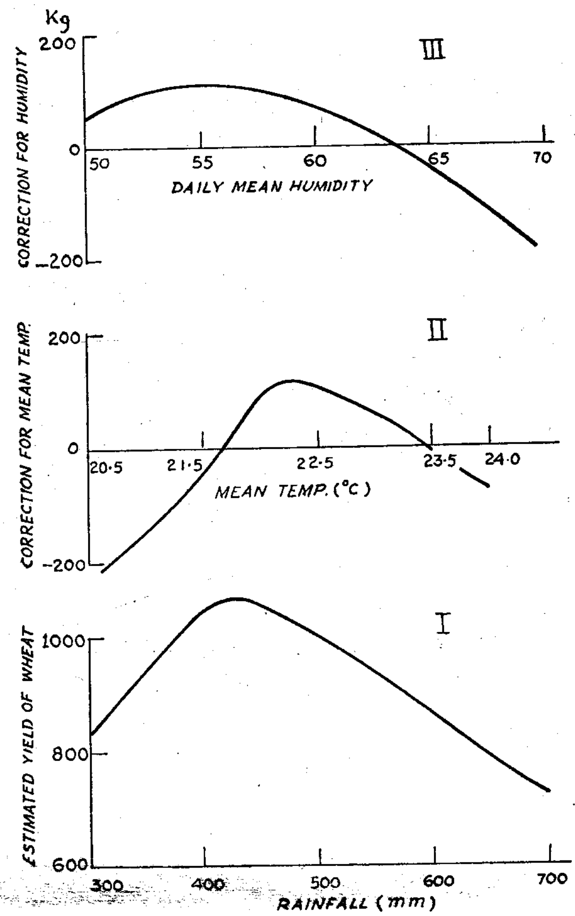

Fig. 2. Final results of Analysis B

(Index of multiple correlation — 0·825

estimate of standard error (S.E.) for the three curvilinear studies.

The values of the S.E. as well as of the variance indicate that the three factors chosen for B and C explain the wheat yield much better than the four factors used in A. As between B and C, C is better than B. This brings out the salient fact that bright sunshine is an important factor in the production of wheat.

Optimum values from the final curves

(*i*) *Rainfall* — Analysis B gives an optimum July to end of vegetative phase rainfall to be 40 to 45 cm. A and C places the optimum 45 and 50 cm. We may tentatively fix the optimum total water requirement at equivalent of 40—50 cm of rainfall during this period.

(*ii*) *Temperature* — A gives an optimum minimum temperature of about 16°C and a maximum of above 29·3°C. B and C show an optimum mean temperature of 22 to 23°C.

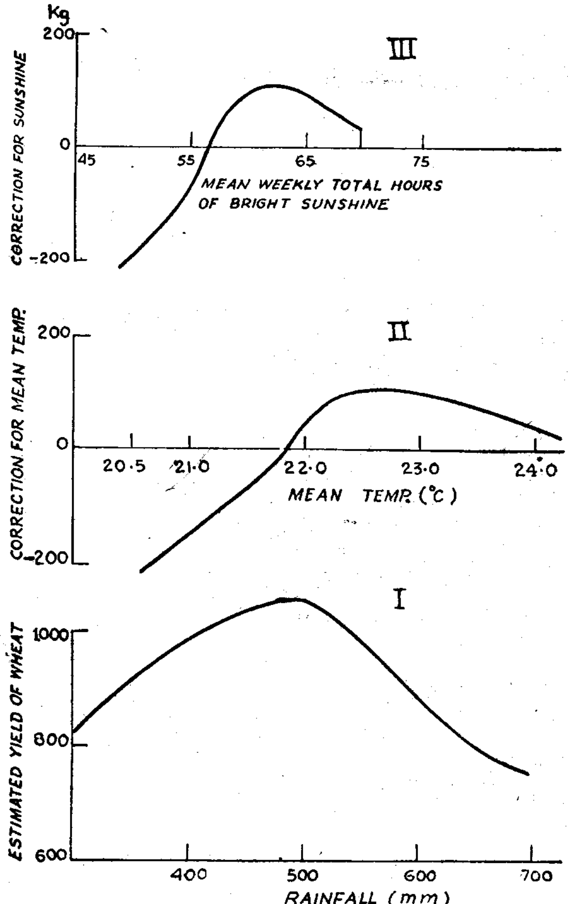

Fig. 3. Final results of Analysis C
(Index of multiple correlation — 0·917)

(*iii*) *Sunshine* — An average weekly total of 65 hours of bright sunshine per week during the vegetative phase is shown to be most conducive to a good yield from A. Analysis C shows that

TABLE 8

Regression	Residual S.S.	D.F.	Variance	S.E. kgm/hect.
A	71683	1	71683	267·7
B	187003	4	46751	216·2
C	95755	4	23939	154·7

60 to 65 hours of bright sunshine per week is optimum for a good yield. An average weekly total of more than 60 hours of bright sunshine may be tentatively fixed as the optimum value.

(*iv*) *Humidity* — The optimum humidity would appear to be near about 55 per cent.

Remarks

The data are only of 14 years and the above analysis is, therefore, tentative. It cannot stand any further statistical refinements and none is attempted in this study.

Since completing the paper, data for the year 1963-64 have become available. Wheat yields have been calculated based on each one of the three analyses A, B and C and are given below along with the actual yield.

Calculated yield (kgm/hect) A	B	C	Actual (kgm/hect)
883	905	860	620

It may be mentioned that during this year the crop suffered due to 'seedling death'. Five out of six plots were affected.

Hence no specific conclusion can be drawn.

5. Acknowledgement

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