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A Curvilinear Study of Yield with reference to Weather—Sugarcane

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ABSTRACT. Method of successive graphic approximations has been used to examine the influence of prevailing weather on yield of sugarcane crop at Poona. The weather during the tillering phase alone accounts for about 50 per cent of the variations in yield. These factors, when combined with the weather factors of the elongation phase, can account for about 80 per cent of the variations. The weather of tillering phase appears to be more important in determining yield than the weather of the growth phase. The study also reveals the optimum value, if any, of a weather factor for yield. A technique has been suggested to predict yield in terms of the weather factors.

1. Introduction

Several authors have worked out prediction formulae for yield of crops in terms of the recognisable and measurable crop-characteristics. Keen (1940) worked out a linear regression for estimating the yield of wheat using the number of plants at the time of tillering and the height of the shoot at the time when the ears just emerge. Sarker *et al.* (1962) have worked a prediction formula for yield of sugarcane at Poona in terms of a set of constants called "growth constants" obtained from skew-logistic curve fitted to the periodic height measurements taken during the growth period of the crop. Gangopadhyaya and Sarker (1964 a) have used the curvilinear relations of yield of sugarcane with tillers, height and girth to predict the yield.

An alternative is to base the prediction formula of yield on the weather that the crop experiences during its life cycle. In the present study an attempt has been made to predict the yield of the sugarcane crop at Poona from the weather factors of the tillering and elongation phases. The study has been confined to the variety POJ-2878 of surgarcane only and the data utilised are those collected under the All India Co-ordinated Crop-weather Scheme—Sugarcane.

Sugarcane at Poona is planted by about the middle of January; the crop completes the tillering phase by the beginning of May; the elongation is over by the first week of November and the crop is harvested by the middle of January. As will be seen, prediction of yield in terms of the meteorological elements of the tillering phase can be given by the beginning of May. The forecast can then be bettered by taking into account the weather factors of the elongation phase. The final forecast thus can be given about two months and a half ahead of harvest.

2. Method of Analysis

The method adopted in the study is similar to what has been suggested by Ezekiel and Fox (1959) and used by Gangopadhyaya and Sarker (1964 a, 1964 b) in the study of yield and crop-characteristics and also in the study of effect of weather on growth.

If X_1 be the yield and X_2, X_3, X_4 etc the relevant meteorological factors upon which the yield depends, then our problem is to find out a regression equation of the type

$$X_1 = a + f_2(X_2) + f_3(X_3) + f_4(X_4) \qquad (1)$$

The expression $f_2(X_2)$ is a general function

TABLE 1

Meteorological factors of tillering phase and yield with estimates

Crop-year	Total rainfall (inches)	Daily average maximum temp. (°F)	Daily average minimum temp. (°F)	Total hours of sunshine	Yield (tons acre)	Estimated yield from weather factors of tillering phase	Estimated yield from weather factors of tillering and elongation phase
	X_2	X_3	X_4	X_5	X_1	X_1'	X_1''
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1947-48	1·04	95·5	64·7	565	58·3	53·0	55·3
1948-49	0·14	99·0	64·9	644	43·9	43·1	46·4
1949-50	0·19	100·1	68·1	561	46·6	36·5	44·1
1950-51	1·64	99·4	65·4	643	44·6	48·6	49·0
1951-52	0·00	95·8	65·2	565	38·3	46·3	38·7
1952-53	0·04	98·8	65·3	797	45·4	41·5	42·3
1953-54	0·00	99·3	67·8	850	33·4	34·6	34·4
1954-55	2·38	97·9	65·9	593	45·0	46·9	44·0
1955-56	1·87	97·3	63·2	779	49·2	46·4	49·8
1956-57	2·13	98·3	66·8	821	46·0	44·9	45·4
1957-58	0·40	96·3	63·5	339	37·3	35·1	39·1
1958-59	1·59	98·7	66·6	451	40·0	42·8	44·6
1959-60	2·76	99·2	63·9	637	40·6	40·6	41·5
1960-61	2·11	97·7	65·5	782	47·4	49·7	51·9

meaning any regular change in X_1 with changes in X_2 whether describable by a curve or a straight line.

It would have been ideal to find the partial regression curves $f_2(X_2)$ etc by fitting some mathematical expressions. But this has not been possible in view of the fact that there is no information, at present, as to the mathematical relation of yield with weather. Consequently the curves $f_2(X_2)$ etc have been found by the graphical methods of successive approximations. However, while drawing the free-hand curves the logical nature of the relation has to be kept in mind. This logical nature can be stated as follows—

Because yield should have an optimum value with respect to any weather factor with which it is related, each curve showing yield *versus* a weather factor should have a single maximum.

3. Relation between yield and weather factors during tillering phase

The yield was first correlated with the meteorological factors of the tillering phase. On a preliminary examination it was found that maximum temperature, minimum temperature, sunshine and rainfall are the important factors for the yield. Accordingly, the yield was studied in relation to these factors. The relevant data are given in Table 1.

Utilising the above data and proceeding in the manner as outlined in Sec. 2, the relation of yield with the meteorological factors of tillering phase was found and are depicted in Figs. 1 to 4. These regression curves represent the relation between yield and each meteorological factor with the net variation associated with the remaining factors held constant. From these curves we can draw the following conclusions—

(*i*) Yield increases with rainfall so long as the rainfall is within 1·5″ and then decreases as the rainfall exceeds this value.

(*ii*) Yield decreases as the daily maximum temperature exceeds 95°F.

(*iii*) Yield increases with minimum temperature and then decreases when the minimum temperature exceeds 65°F, which is apparently the optimum value. Yield, however, remains constant when the minimum temperature exceeds 66·5°F.

(*iv*) The optimum value of sunshine period is about 700 hours for yield and the yield decreases as the sunshine period deviates from this value.

3.1. *Use of the curves for estimating yield*— From the set of curves in Figs. 1 to 4 a new set of curves can then be obtained to estimate yield. The yield has to be estimated from any one of the four meteorological factors and necessary corrections in estimates then have to be made for the remaining factors.

Here the estimate has been made for maximum temperature and corrections have been carried out for the remaining three factors. These curves are given in Figs. 5 to 8. The estimated yield is given by

$$X_1 = F_3(x_3) + f_2(x_2) + f_4(x_4) + f_5(x_5) \quad (2)$$

where F_3 (x_3) is the estimate of yield from maximum temperature and f_2 (x_2), f_4 (x_4), f_5 (x_5) are the corrections for rainfall, mimimum temperature and sunshine respectively.

The values so estimated along with the actuals are presented graphically in Fig. 23. They are also given in col. 7 of Table 1. It would be seen that all the estimates are within 10 per cent except two which are within 21 per cent. The correlation 0·71 between the estimates and the actuals suggests that about 50 per cent of the total variations in yield can be accounted for by the weather factors of the tillering phase itself.

The linear regression having multiple correlation of 0·43 could account for hardly 18 per cent of the variations.

4. Inclusion of the meteorological factors during the elongation phase

The next attempt was to correlate the yield with the weather factors of the growth phase alone. The linear multiple correlation was found to be only 0·286. Continuing the process of successive approximation upto the stage when the standard deviation of the residuals reduced to a minimum, the correlation of the estimates from the curvilinear relations with the actual yields worked out to 0·540. This would mean that hardly 29 per cent of the variations of yield could be accounted for by the weather of the growth phase, whereas the same during the tillering phase could account for about 50 per cent of the variations. Apparently, the weather during the tillering phase is more important in determining the yield than the weather of the growth phase. Also in the process of evaluating the relations, it was found that the effect of sunshine during the elongation phase on yield is negligible. Accordingly, it was omitted from further study. This is consistent with the finding by Gangopadhyaya and Sarker (1964 b) that sunshine of the growth phase does not practically have any effect on growth of sugarcane.

4.1. *Influence of the weather factors of tillering and elongation phases on yield* — In view of the discussion in the previous paragraph, the meteorological factors during the elongation phase were combined with those of the tillering phase to study their effects on yield. And as the sunshine of elongation phase does not have much effect on yield the factors considered are rainfall, maximum and minimum temperatures, sunshine of tillering phase and rainfall, maximum and minimum temperatures of the elongation phase. Proceeding exactly as before the effects of

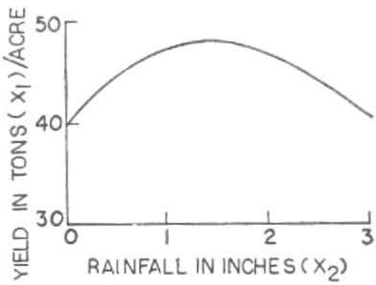


Fig. 1

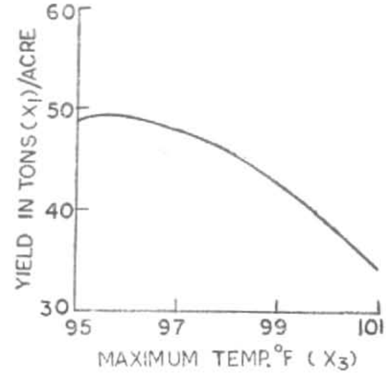


Fig. 2

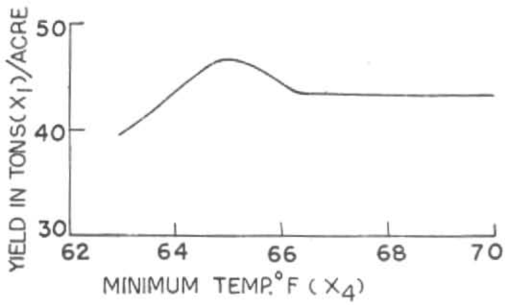
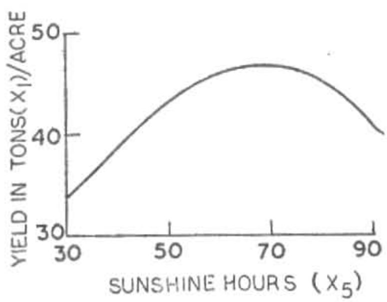


Fig. 3



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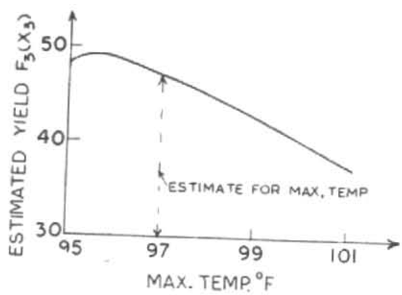


Fig. 5

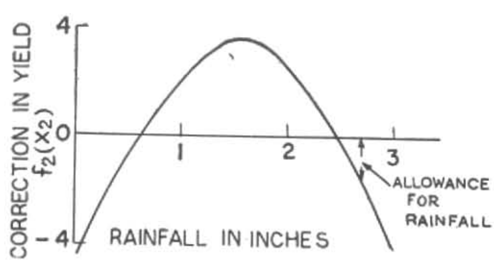


Fig. 6

these factors on yield were found and are given in Figs. 9 to 15. These can be described as follows—

(*i*) The optimum value of rainfall during the elongation phase for yield is about 18″. The yield decreases as the rainfall exceeds this value and remains practically constant as the rainfall exceeds 24″ (Fig. 13).

It should, however, be kept in mind that the sugarcane crop at Poona is irrigated. The relation of yield with rainfall might have been quite different had the crop been entirely rain-fed.

(*ii*) The yield is indifferent to maximum temperature of the growth phase so long as it is within 85°F after

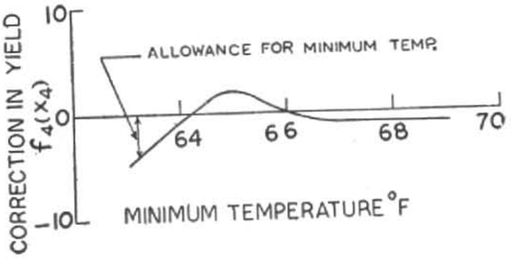


Fig. 7

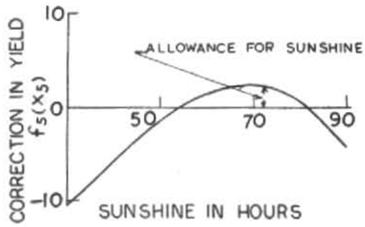


Fig. 8

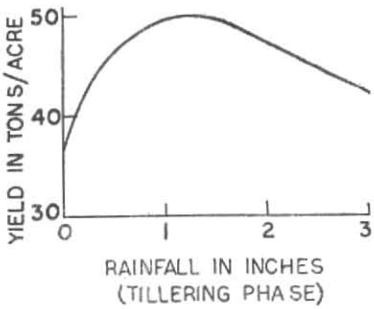


Fig. 9

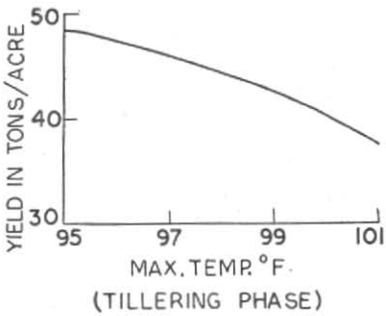


Fig. 10

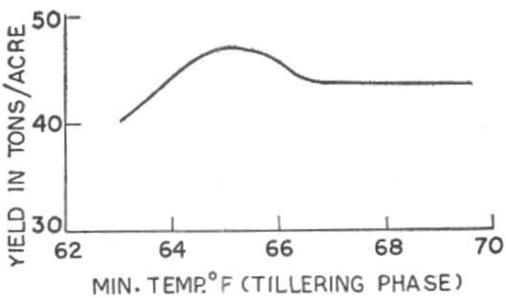


Fig. 11

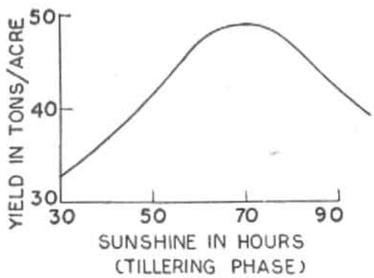


Fig. 12

which the yield increases and again decreases as the temperature exceeds 87°F. Apparently, the optimum day temperature during the elongation phase is 87°F (Fig. 14).

(*iii*) The optimum value of night temperature during the growth phase is about 68·5°F and the yield decreases as the minimum temperature deviates from this value (Fig. 15).

A comparison of Figs. 9 to 12 with Figs. 1 to 4 would reveal that the relations of the weather factors of the tillering phase with yield as found in Sec. 3 do not modify when they are considered along with the weather of the growth phase. Accordingly, the inferences drawn in Sec. 3 as to the relation of weather of tillering phase with yield, will hold good also when the weather factors of elongation phase are included.

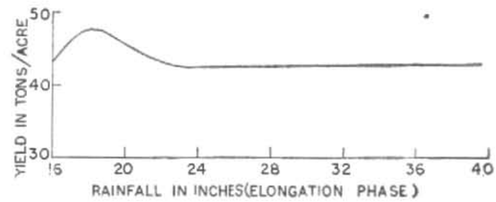
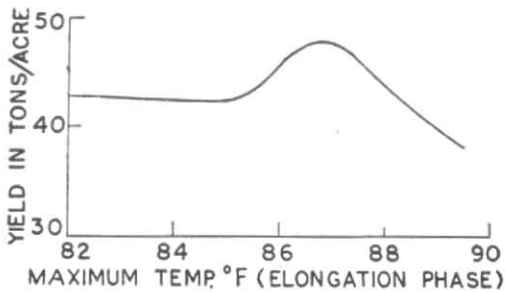


Fig. 13



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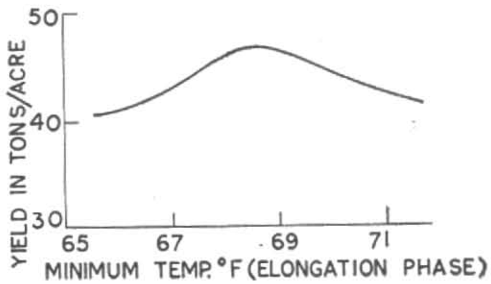


Fig. 15

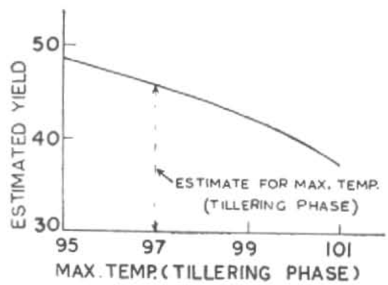


Fig. 16

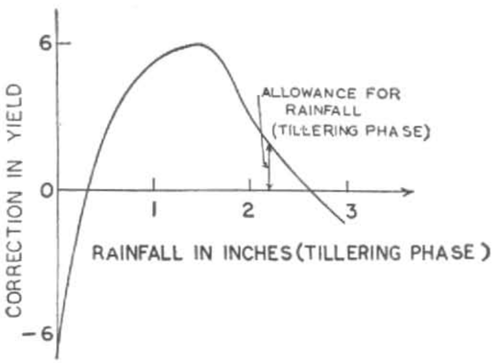


Fig. 17

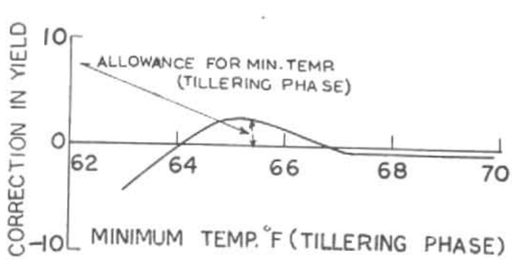


Fig. 18

4.2. *Estimates of yield*—From the curves in Figs. 9 to 15, the curve for estimating yield with respect to one factor, *e.g.*, maximum temperature of tillering phase (Fig. 16) and the correction curves for the remaining six factors (Figs. 17 to 22) have been obtained by proceeding as in Sec. 3.1.

The estimated yields from these curves together with the actuals are presented graphically in Fig. 23. They are also given in col. 8 of Table 1. It would be seen from the table that the estimates are all within 10 per cent except one which is 11 per cent from the actual and that most of the estimates

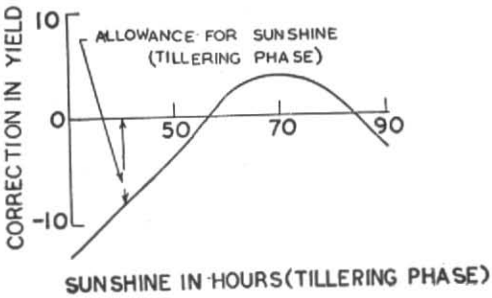


Fig. 19

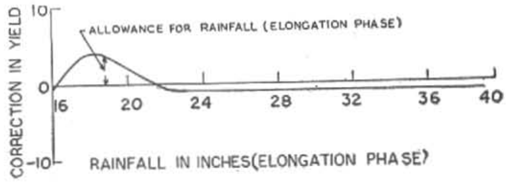


Fig. 20

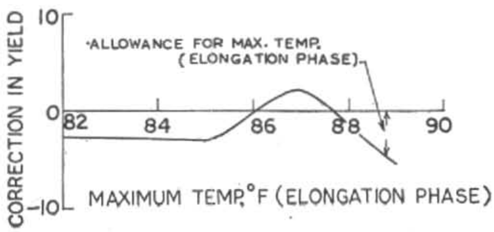
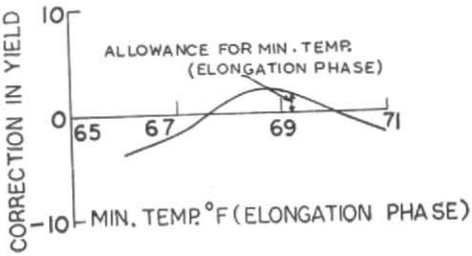


Fig. 21



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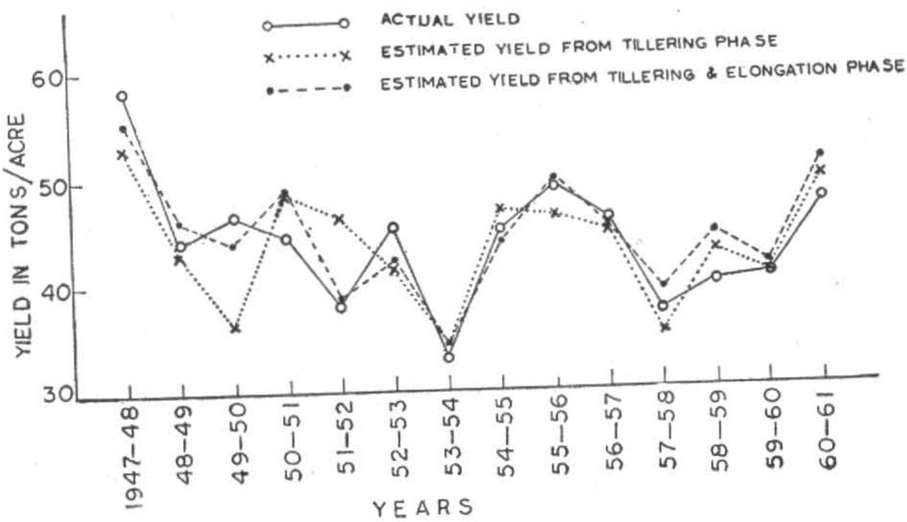

Fig. 23

are within 5 per cent. The correlation of the estimates with the actuals works out to be 0·899. This would mean that about 80 per cent of the total variations in yield can be accounted for by the weather prevailing during the tillering and elongation phases of the crop. The weather during tillering phase could account for 50 per cent of the variations. A comparison of the two estimates from the graphs in Fig. 23 suggests that the inclusion of the weather factors of the elongation phase definitely improves the estimates.

5. Conclusion

The present study of yield in relation to weather has brought out how the yield of sugarcane is related to the meteorological factors prevailing during the different phases. The study has also revealed the optimum values of the different weather factors for yield.

Apart from the above relations of yield with weather factors, the study has a forecasting value. As has been seen in Secs. 3 and 4, the crop planted in January and to be ready for harvest by next January can be predicted in early May fairly accurately by taking into consideration the weather experienced upto that stage. The forecast can then be further modified in early November by taking into account the weather that prevails during the growth phase. The prediction curves (Figs. 16 to 22), with a large series of data, will be very useful to be used as working tools for predicting yield of sugarcane about a period of two months and a half ahead of harvest.

6. Acknowledgements

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