THE EFFECT OF SEASONAL VARIATION IN TEMPERATURE ON THE YIELD OF MAIZE IN THE WAIKATO AND GISBORNE REGIONS

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ABSTRACT

The correlation between regional, annual, yields of maize in Gisborne and Waikato and monthly temperatures, assessed as degree day sums, were examined by linear regression analysis.

Average yield for Gisborne over the past 20 years was found to have increased by 0.24 t/ha/annum due to improved technology. In the same time annual variations in temperature during vegetative growth (November to January), grain filling (February and March) and the whole growing period season accounted for 17, 36, and 47% respectively of the yield fluctuations about the technology trend. In the Waikato, for the past eight years of established production, annual variations in temperature during the same growth periods, accounted for 85, 0.003 and 67% of the yield variation. Equivalent percentages, for the same eight years in Gisborne, were 39, 59 and 81%.

The two regions have similar levels and patterns of seasonal temperatures. The relative unimportance of temperature during filling in determining Waikato yield as compared to Gisborne yield was considered to reflect the greater influence of moisture stress during filling on yield in the Waikato.

The mechanism of the temperature – yield response was considered. There was little evidence to support a restriction in kernel number formed under low spring temperatures. It was concluded that cool temperatures restricted vegetative growth and later, either directly or indirectly through reduced leaf area, restricted the rate of filling over a fixed filling period. The breeding of more cool tolerant hybrids was seen as the answer to improving the level and consistency of yield.

INTRODUCTION

Temperature exerts an influence on the rate of development and growth of annual crop plants throughout the life cycle. The total extent of seasonal growth is affected by temperature either indirectly through control of plant longevity or directly through the rate of growth. In reproductive crops temperature may influence grain yield through the accumulated effect on vegetative growth and the extent of the assimilate supply available for the developing grain. More specifically excessively low or high temperature at critical reproductive development stages may place irreversible limitations on the extent of grain development or sink size. Rarely, if ever though, does temperature act independently of other environment factors.

Identification and assessment of the temperature limitations of an environment to a crop can allow for improvement in yield through change in management, or more often through the selection and breeding of better adapted varieties. Study of the relationship between annual yield variation and the temperatures prevailing during different parts of the growing season can reveal when, and to what extent, temperature is limiting to yield. However, more specific studies, under controlled environments conditions, are often needed to reveal the mechanisms of such yield restraints.

An association observed between the decline in maize yield in the Waikato region in the three years 1975-77 and the occurrence of cooler than average spring temperatures prompted a closer study of the seasonal temperature-yield relationship. This paper reports on the relationship found for the two major production areas for maize in New Zealand, Waikato and Gisborne, and considers the possible mechanism of the temperature-yield effect.

METHODS

Local experiences, particularly in the Waikato, tell of the reductions in yield which can occur because of summer drought. Insufficient records of crop yields in relation to moisture stress were available to allow for adjustments to be made in regional yields and in this initial analysis of temperature the effect of drought on yield had to be ignored.

Assessment of temperature was made on a monthly basis using degree day sums calculated from daily maximum and minimum temperatures taken from a single meteorological station in each region. Two methods were used to calculate degree days:

1. The remainder system which assumes a linear relationship between maize growth and temperature in the range 10 to 30°C (Gilmore and Rogers, 1958). Degree days per month, DD_A, were calculated from daily maximum and minimum air temperatures using the formula:

$$DD_A = \sum \frac{(T_{max} - T_{min})}{2} - 10^\circ C$$

Temperatures below 10°C and above 30°C were entered as these values respectively.

2. The Ontario heat unit system (Brown, 1969) where the contribution of the maximum and minimum daily air temperatures are given as follows:

$$Y_{max} = 3.33\,(T_{max} - 10) - 0.084\,(T_{max} - 10)^2$$

$$Y_{min} = (T_{min} - 4.4)$$

and

$$DD_o = \sum \frac{(Y_{max} + Y_{min})}{2}$$

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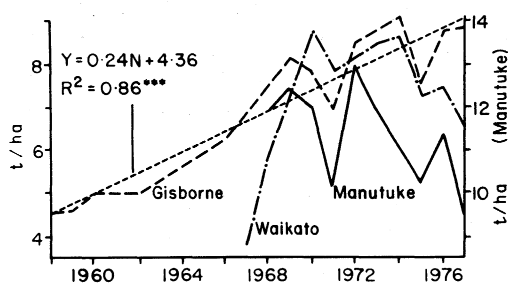
The annual, average yields (Y_A) for the Waikato region since 1967 and for 16 of the past 20 years of production in the Gisborne region, incorporating a variety of management practices, were available. In addition the annual, maximum yields from a rotation, rates of fertiliser trial run for the past 11 years on the Manutuke Research Station, Gisborne, were used as representative of a high level of management (Fig. 1). For the Waikato, only the eight years of data from 1970 could be used because there was insufficient long term data to correct for the rapidly rising yields, due to increased management skills gained, following the introduction of widespread maize cropping in 1966.

Figure 1: Annual Yield by Location



In the Gisborne region a rising level of yield, over the full 20 years of production, was discernable and attributed to the continued application of improved technology. This upward trend in yield was adjusted for by plotting the linear regression for yield by years and taking corrected yield (Yc) as the difference in annual yield from the regression line. The absence of any technological improvement trend in the Manutuke yields or over the last 8 years of production in the Waikato was notable and considered to be the result of the immediate application of the latest technology to research and a new area of production respectively while the movement into new practices in the traditional area of production, Gisborne, was slow.

The linear relationship between annual yield and the degree day sum for individual months or groups of months during the growing season November to March inclusive, was examined by regression analysis.

RESULTS

Waikato

Only the individual month of November gave good correlation between temperature (DD_A) and yield ($R^2 = 0.69^{**}$) but the combination of November with December improved the relationship ($R^2 = 0.77^{**}$). Use of DD_O values further strengthened the relationship ($R^2 = 0.84^{**}$) for the November-December period and with January included ($R^2 = 0.85^{**}$) emphasised the importance of temperature in the vegetative period of crop growth on yield in the Waikato. The yield relationship in each case was expressed as follows:

$$Y_A = 0.015\ DD_A + 1.92$$
$$Y_A = 0.015\ DD_O - 0.87$$

The relationship between yield and temperature (DD_A) predicts a rise in yield of 0.93 t/ha for each degree centigrade rise in the mean daily temperature during November and December. The same relationship determines the mean annual yield for the Waikato region over the past 20 years at 7.92 t/ha.

Gisborne

The uncorrected annual yield (Y_A) was significantly correlated with temperature (DD_A) for the February-March period only but the extent of the correlation was low (Table 1). Use of the corrected

TABLE 1: Extent and significance of linear relationship between Gisborne yield and temperature in 3 growth periods.

Assessment variates	Number years	Period NDJ	FM	NDJFM
$Y_A\ DD_A$	16	R^2= 0.14 NS	0.27*	0.19 NS
$Y_C\ DD_A$	16	0.17 NS	0.36*	0.47**
$Y_C\ DD_O$	16	0.21 NS	0.26*	0.31**
$Y_C\ DD_A$	14			0.69**

yield (Y_C) improved the yield-temperature relationship giving the best yield correlation with accumulated degree days (DD_A) for the total growing season, November to March. Removal of two outstanding data points from the analyses where low yield was associated with high temperatures, made a substantial improvement in the yield correlation with total degree days for the whole growing season. Either bad Northern Leaf Blight or drought could reasonably have accounted for the low yields in the high temperature situations but some record of either such event having occurred is needed to justify the exclusion of the data.

Variations in seasonal temperatures in the Gisborne region did not account as well for the variations in annual yield as in the Waikato. However, in the Gisborne region, in contrast to the Waikato, the emphasis for a temperature-yield effect was placed on temperatures prevailing during the grain filling rather than the vegetative growth period.

Comparison between localities

A comparison was made between the 8 years in common for the three locations (Table 2). The relationship between corrected yield for Gisborne and total degree days DD_A or DD_O, for the season was greatly improved with variations in annual temperatures accounting for 77 to 81% of the yield variation. The emphasis for the temperature-yield effect still remained in the grain filling period in contrast to the vegetative period for the Waikato. Manutuke, representing a high level of management for the Gisborne region, while showing a moderately good relationship between maximum yield and total season temperatures failed to define any one period as critical. Whether this result suggests that the effect of low temperatures can be overcome to some extent by high levels of fertiliser application is not clear.

The magnitude of the yield response was of a similar order in all three situations when the period

TABLE 2: Comparative extent and significance of linear relationship between yield and temperature for 8 years 1970-1977 in 3 locations.

Location	Assessment Variates		ND	NDJ	FM	NDJFM
Gisborne	$Y_C DD_A$	R^2=	0.39 NS	0.45 NS	0.59*	0.81**
Manutuke	$Y_M DD_A$		–	0.38 NS	0.37 NS	0.59*
Waikato	$Y_A DD_A$		0.77**	0.56*	0.04 NS	0.15 NS
Gisborne	$Y_C DD_O$	R^2=	0.40 NS	0.44 NS	0.58*	0.77**
Manutuke	$Y_M DD_O$		0.29 NS	0.38 NS	0.46 NS	0.65*
Waikato	$Y_A DD_O$		0.84**	0.85**	0.003 NS	0.67*

(Assessment Period: ND, NDJ, FM, NDJFM)

showing the highest level of correlation was considered (Table 3).

TABLE 3: Yield Response to temperature (t/ha/DD) for 3 locations.

Location	Variates	b Value	Period
Gisborne	$Y_C DD_A$	0.009	NDJFM
Manutuke	$Y_M DD_A$	0.014	NDJFM
Waikato	$Y_A DD_A$	0.015	ND
Gisborne	$Y_C DD_O$	0.006	NDJFM
Manutuke	$Y_M DD_O$	0.009	NDJFM
Waikato	$Y_A DD_O$	0.015	ND

The difference in the growth period during which yield was most affected by temperature for two regions whose seasonal temperature patterns are very similar was of particular interest (Table 4). The explanation must surely relate to crop moisture supply. The deep alluvial soils of the Gisborne region have a much greater water holding capacity than the lighter, shallower, soils of the Waikato. If the Waikato crops suffer more from moisture stress in the summer period when filling it would account for lack of response to high temperatures in the February-March period compared with the Gisborne crops.

TABLE 4: Monthly mean daily temperatures for Gisborne and Waikato.

Location		Month N	D	J	F	M
Manutuke	(G)	15.1°C	16.9	17.9	18.3	16.5
Rukuhia	(W)	14.8	16.7	18.0	18.4	17.0

DISCUSSION

Comparison with similar overseas studies

Analysis of seasonal yield variation in relation to mean monthly temperature rather than degree day variation together with variation in rainfall have been made for the cornbelt states of the USA covering periods of 30 to 50 years (Wallace, 1920; Rose, 1936; Runge and Odell, 1958; Thompson 1969). Higher yields are recorded with increased mean monthly temperatures in the range 19 to 22°C during the 30 day period after emergence. The magnitude of the response, operating over a higher temperate range, is only one third of that determined for the Waikato for the November-December period. Yield is also responsive to increased temperatures up to 24°C in the period 50 days before to 30 days after anthesis and to higher temperatures if adequate water is available. In this analysis so far the effect of February temperatures, 0-30 days after anthesis, has not been partitioned off from that of March, 30-60 days after anthesis. In general though there is ample support for the relationships calculated and some suggestion that the high average annual yields recorded in both Waikato and Gisborne compared with those in the U.S. cornbelt are because average daily temperatures in the 30 day period either side of anthesis, unlike those in the cornbelt, are never excessive.

The possible nature of the response to temperature

The reduction in yield with low temperatures during the vegetative period in the Waikato could be the result of a limitation to the extent of vegetative growth, crop leaf area and later the rate at which assimilate is available to fill the grain during a relatively fixed length of time between mid silk and maturity. Alternatively, lower temperatures could reduce the sink size by reduction in the kernel numbers per plant.

Low temperatures during the vegetative growth phase reduce plant height, leaf number and leaf area and result in a lower leaf area index at silking (Cooper and Law, 1978; Iremiren and Milbourn, 1978). Whether bigger plants at flowering result in higher yield is debatable. In Kenya, where the energy input per unit leaf area is high, plant size at flowering is unrelated to final plant grain yield (Hawkins and Cooper, 1979). However, in a situation such as the Waikato where the energy input per unit area is substantially lower the reduction in leaf area through reduced plant growth in the vegetative stage maybe of importance.

The maximum weight of the maize kernel is limited so that regardless of how favourable conditions are for filling the number of kernels available may limit yield. (Duncan, 1975). However, it is considered in the USA, that the kernel size x number limitation is rarely reached (Shaw, 1976). Kernel number could be restricted at the cob initiation stage 30 days after emergence or at pollination. High temperature can affect pollination and kernel set but usually the environmental restriction is moisture stress (Shaw, 1976). On the other hand the developing cob meristem is accepted as being determinate and the potential kernel number unaffected by environment (Duncan, 1975; Iremiren and Milbourn, 1978). An increase in yield as a result of higher temperatures at the cob initiation stage and a higher kernel number per cob has been recorded (Cooper and Law, 1978). The difference found though was considered to be the effect of temperature on the number of viable kernel sites rather than on the total number formed.

Consideration of these possible effects of low, early season, temperatures on final grain yield tend to favour an overall reduction in crop vegetative growth as the limiting factor. The difference in the growth stage of the crop at which yield was most closely related to temperature in the two locations which have a similar level and pattern of seasonal temperature support this interpretation. Changes in kernel number during cob initiation because of temperature should operate equally in the two locations. If such an effect occurred it could not be readily compensated for by favourable conditions in the February-March period. There would appear to be a compensatory effect operating against low November-December temperatures in the Gisborne region which could effectively be a higher grain filling rate because the response to increased temperature is not limited by insufficient moisture.

CONCLUSION

The study currently favours improvement in the consistency of annual yield through the selection of genetic material showing greater early season cool tolerance. The possibility of a temperature effect on sink size through a restriction in kernel number needs further consideration. The monitoring of the variations in crop leaf area, grain weight and the proportion of the total kernels filled across environments and years would give an insight into the mechanism of the temperature restriction on yield. Closer study of the interaction of temperature with moisture in relation to crop yield is desirable to assess the limitations of the environment for maize in the major production areas and in new areas of production.

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