Soil temperature affects growth and development of maize

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Introduction

It is widely understood that temperature has a major influence on crop development (Warrington and Kanemasu, 1983), and it is usually implicitly assumed that crop development rate is driven by air temperature because the latter is a good guide to meristem temperature. When the apical meristem is underground, however, it is perhaps more logical to assume that development rate responds to soil temperature at meristem depth. Here we examine the effects of soil temperature on development of maize. Soil temperature has two major implications for maize growers in cool-temperate climates such as New Zealand, where the meristem may be underground for extended periods. First, because thermal time is usually calculated using air temperatures the heat units available for growth may often be underestimated. Second, factors that reduce soil temperature may markedly reduce crop development rate and, potentially, yield.

Materials and Methods

On 13 November 1997, maize (Pioneer hybrid 3730) was hand planted at Hastings, New Zealand, to give a final population of 89,000 plants/ha. Immediately following sowing, plots received one of three temperature treatments, designed to alter soil temperature with only minimal impact on air temperature: 1) a surface layer of transparent polythene sheeting, to increase soil temperature; 2) a 5 cm thick surface layer of barley straw, to reduce soil temperature and 3) an unmodified soil surface. These treatments will subsequently be referred to as 'warm', 'cool' and 'normal', respectively. Treatments were applied in four fully randomised complete blocks, in plots of 8.4 x 9 m. Temperatures were measured hourly using three thermistors in each plot: one remained at 5 cm below the soil surface, one remained at 30 cm above the soil surface, and the other was moved weekly to the level of the meristem (which was determined by weekly dissection). Plant development was assessed by twice-weekly measurements on five tagged plants per plot.

Results

Soil temperature was effectively modified using polythene sheeting and straw mulch. Up to the time of meristem emergence, the average daily temperature at meristem depth in the normal treatment was 20.0°C. For the warm and cool treatments it was 25.2 and 18.3°C, respectively.

Warm soil reduced the time to crop emergence by approximately 1 day for every 1°C rise in average soil temperature at meristem depth (R^2 = 0.92), such that emergence occurred after 14, 10 and 6 days in the cool, normal and warm treatments, respectively.

For all treatments, meristem emergence from the soil surface occurred when the plant had either six fully expanded leaves, or 10 leaf tips had appeared. For crop emergence, the time from sowing to meristem emergence declined markedly with increased soil temperature. Time to meristem emergence declined by 2.8 days for every 1°C rise in average soil temperature at meristem depth. Time to silking declined significantly in the warm (67 days after sowing [DAS]) compared with the cool treatment (84 DAS), as did time to physiological maturity (124 and 142 DAS, warm and cool, respectively).

Thermal time calculated from air temperature (°A d) was not consistently related to crop development stage for the different soil temperature treatments, but the inclusion of soil temperatures in the thermal time calculation (°SA d) markedly improved the relationship between thermal time and crop development.

Air temperature was a poor predictor of rate of leaf tip appearance, and was not consistently related to tip appearance rate when soil temperature varied: paired t-tests indicate that time of leaf tip appearance (°A d) differed significantly ($P<0.001$) among soil treatments. By contrast, when soil temperatures until meristem emergence were used to calculate thermal time there was no significant difference in the rate of development amongst the treatments and the combined index (°SA d) described all treatments (41 °SA d per leaf tip) with great reliability (R^2 = 1.0; $P<0.001$).

Similarly, the time of full expansion of successive leaves was not consistently related to °A d, with paired t-tests showing significant differences ($P<0.001$) in time of full leaf expansion amongst soil treatments. The inclusion of soil temperature in the thermal time calculation markedly improved the prediction of time of full leaf expansion (pooled $R^2 = 0.97$; $P<0.001$).

Inclusion of soil temperature in the calculation of thermal time also markedly improved the consistency of prediction of time to meristem emergence and silking. When only air temperature was used, the thermal time required to reach meristem emergence declined from 456 °A d in the cool treatment to 248 °A d in the warm treatment, but when the combined index was used there was no significant difference between the two treatments (489 and 452 °SA d). Similarly, thermal time to silking differed markedly between the cool (861 °A d) and warm (640 °A d) treatments when only air temperature was used, but did not differ significantly when the combined index was used (887 and 840 °SA d).

Discussion

The results from this study clearly demonstrate that soil temperature determines the rate of maize development while the meristem is underground. For treatments differing in soil temperature, thermal time calculated from air temperature was not a reliable predictor of crop development rate, as shown previously for wheat (Jamieson *et al.*, 1995). It was only when soil temperature up to time of meristem emergence was included in thermal time calculations that the rate of crop development could be predicted with confidence.

The results from this study also suggest that factors that reduce soil temperature, such as mulching (Fortin and Pierce, 1990; Fortin *et al.*, 1994) and minimum tillage (Swan *et al.*, 1987), will also slow early development. In cool regions, this tends to reduce yields by reducing leaf area index (Bollero *et al.*, 1996), as well as by reducing stand establishment by making seedlings more susceptible to disease (Schultz and Bateman, 1969).

Analysis of potential yields using a maize growth model (Wilson *et al.*, 1995) suggests that yield declines by approximately 0.17 t/ha per °C decrease in soil temperature (10-18°C range) up to time of meristem emergence. This corresponds closely with the experimental estimates of (Bollero *et al.*, 1996) (0.14 t/ha), which were obtained for soils with average temperatures of c. 17-25°C.

Conclusions

Maize development is controlled by soil temperature while the meristem is underground, which in this instance was until the crop had six fully expanded leaves or 10 leaf tips. Consequently, factors that reduce soil temperature will retard crop development for up to 25% of the crop's life, and this may reduce yield. Furthermore, to maximise the reliability of predictions of crop phenology (particularly in cool-temperate environments), we recommend that soil temperatures be included in calculation of thermal time up to time of meristem emergence.

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References

Bollero, G.A., Bullock, D.G. and Hollinger, S.E. 1996. Soil temperature and planting date effects on corn yield, leaf area, and plant development. *Agronomy Journal* ***88***, 385-390.

Fortin, M.-C. and Pierce, F.J. 1990. Development and growth effects of crop residues on corn. *Agronomy Journal* ***82***, 710-715.

Fortin, M.-C., Pierce, F.J. and Edwards, M. 1994. Corn leaf area response to early season soil temperature under crop residues. *Agronomy Journal* ***86***, 355-359.

Jamieson, P.D., Brooking, I.R., Porter, J.R. and Wilson, D.R. 1995. Prediction of leaf appearance in wheat: a question of temperature. *Field Crops Research* ***41***, 35-44.

Schultz, F.A. and Bateman, D.F. 1969. Temperature response of seeds during the early phases of germination and its relation to injury by *Rhizoctonia solani*. *Phytopathology* ***59***, 352-355.

Swan, J.B., Schneider, E.C., Moncrief, J.F., Paulson, W.H. and Peterson, A.E. 1987. Estimating corn growth, yield, and grain moisture from air growing degree days and residue cover. *Agronomy Journal* ***79***, 53-60.

Warrington, I.J. and Kanemasu, E.T. 1983. Corn growth response to temperature and photoperiod. II. Leaf initiation and leaf-appearance rates. *Agronomy Journal* ***75***, 755-761.

Wilson, D.R., Muchow, R.C. and Murgatroyd, C.J. 1995. Model analysis of temperature and solar radiation limitations to maize potential productivity in a cool climate. *Field Crops Research* ***43***, 1-18.