

DROUGHT EFFECTS ON CANOPY DEVELOPMENT IN SWEET CORN

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Abstract

The response of sweet corn (hybrid 'Challenger') to timing and severity of drought was determined by subjecting a crop to six irrigation treatments using a mobile rainshelter: 1) no drought; 2) full drought; 3) moderate pre-silking drought; 4) severe pre-silking drought; 5) moderate post-silking drought; and 6) severe post-silking drought. Drought was quantified using the concept of potential soil moisture deficit (PSMD), which was calculated from climatic data. Drought reduced the fraction of radiation intercepted by reducing the rate of leaf expansion (hence maximum leaf size) and by hastening senescence. Despite the variable timing and severity of drought, each of these responses was described well using the average PSMD during the period of expansion or senescence for each leaf as an index of drought severity. Consequently, PSMD was a useful means of integrating the effects of water deficit into a simple model describing the effects of drought on the crop canopy.

Key words: Drought, potential soil moisture deficit, canopy development, radiation interception, leaf area index, rate of leaf expansion, senescence, Zea mays L., sweet corn.

Crop growth is related closely to the amount of radiation intercepted by the canopy (3,4). Drought may significantly reduce yield potential by reducing both the size and duration of the crop canopy, and hence both the fraction of radiation intercepted and the time over which interception occurs. Despite this fundamental influence of drought, there are few quantitative descriptions of the effects of water deficit on canopy development. In this paper we develop such a description for sweet corn (*Zea mays* L.) by using a simple concept to quantify drought (potential soil moisture deficit; PSMD) (2, 6), and then relating this drought index to key canopy performance variables measured in a sweet corn irrigation response experiment. The canopy characteristics [plant population, production rate and area of successive leaves on individual plants, loss of area caused by senescence and, hence, green leaf area index (LAI) and radiation interception] were the same as those defined in a maize canopy development model (5). By corollary, we show that the relationships can be used to determine the effects of rainfall or irrigation on canopy development at any time. In a companion paper (7) we demonstrate how these effects of drought on canopy development translate to water use, growth and yield.

Materials and methods

Sweet corn hybrid 'Challenger' was grown at 57,000 plants/ha in a mobile rainshelter at Lincoln, New Zealand (lat. 43°38'S, long. 172°30'E), where growing season temperature and solar radiation average ca 15°C and 18 MJ/m²/d, respectively. With the exception of water supply, crop husbandry was aimed at maximising yield. The rainshelter enabled complete control of crop water supply by covering the crop whenever it rained, while a drip irrigation system applied water to individual plots in precise volumes. By this means, six moisture stress regimes were applied in two replicates:

FI: fully irrigated - weekly irrigation to replace the previous week's water loss

FD: severe stress - no irrigation

MED: moderate early stress - no irrigation until 16 days pre-silking, then full irrigation

SED: severe early stress - no irrigation until silking, then full irrigation

MLD: moderate late stress - full irrigation until 19 days post-silking, then no irrigation

SLD: severe late stress - full irrigation until 21 days pre-silking, then no irrigation

When required, water was applied weekly in order to replace the previous week's loss, as measured from the FI treatment using neutron probe measurements of the soil water profile to 2 m depth. The time of tip appearance, full expansion and complete senescence of individual leaves on the main stem was

recorded twice-weekly, on five tagged plants/plot. In conjunction with measurement of individual leaf areas at 61 and 97 DAS, these data enabled us to calculate the development of green LAI on a daily basis. Radiation interception was calculated as an exponential function of LAI, using a radiation extinction coefficient of 0.4 (5). Thermal time was calculated as the average of daily maximum and minimum temperature, above a base of 8°C.

The severity of drought experienced by each treatment was calculated using the PSMD model of Penman (6), as applied by Jamieson *et al.* (2). In its simplest form, this method provides a continuous estimate of potential water deficit during crop growth by determining the balance between crop demand for water (potential ET) and water supply (rainfall and irrigation), as mediated by soil moisture content at sowing. The maximum PSMD (PSMD_{max}) recorded during the season has previously been shown to be significantly correlated with reduced yield (1).

Fig. 3-6 have been constructed using a family of curves. In Fig. 3, for example, each point represents the % reduction in rate of leaf expansion per mm average PSMD during the expansion of that leaf. This was determined for each point by regressing the relative rate of leaf expansion (cf. the fully-irrigated control) against the average PSMD during the expansion of that leaf. For each point then, the regression slope is equal to the value used in the solid line in Fig. 3. The r^2 for the regression slope for each point is shown as the hatched line in Fig. 3. Similar methodology was used to construct Fig. 4-6.

Results

Estimates of potential water use agreed closely with water use measured in the FI treatment (Fig. 1). This confirmed the accuracy of the estimates of PSMD. The pattern of PSMD varied among treatments such that a wide range of deficits and times of maximum deficit occurred (Fig. 2). Although SED and MLD treatments attained a similar PSMD_{max}, this occurred at different stages of crop growth (600 and 925°Cdays, respectively).

Two measures of the PSMD level at which crop performance starts to be affected by drought were determined. The first was the critical value of PSMD_{max}, which was estimated to be 90 mm. This value was (a) the y-intercept above which drought-induced reductions occurred for most plant components when regressed against PSMD_{max}, and (b) the maximum PSMD attained in the FI treatment which was a fully but not excessively irrigated crop. The second measure was the critical average PSMD which was estimated to be 56 mm (the value for the FI treatment). It was the maximum value of the cumulative average of PSMD during the season, where cumulative average is defined as the mean of all PSMD values occurring up to any given point.

There was no effect of drought on leaf tip appearance, despite the fact that PSMD was as high as 200 mm before the emergence of the last leaf tip in the SED, SLD and FD treatments. Similarly, duration of leaf expansion was insensitive to drought, even though PSMD_{max} exceeded 250 mm during leaf expansion in treatments SLD and FD. Drought, therefore, reduced LAI by either reducing the rate of leaf expansion or by increasing the rate of leaf senescence.

Rate of leaf expansion was significantly reduced by drought and was related to the average PSMD during the expansion of each leaf ($r=0.95$; $P<0.001$) (Fig. 3). While the percentage reduction in rate of leaf expansion decreased exponentially with leaf number, the greatest absolute reductions occurred for the largest leaves (nos. 9-14). This resulted in significant reductions in the maximum size of each leaf. Again, the reduction in area per leaf was significantly related to the average PSMD occurring during leaf expansion, and the relative effect of drought on area per leaf declined exponentially with leaf number ($r=0.94$; $P<0.001$) (Fig.4).

Drought-induced reductions in maximum area per leaf resulted in diminished total leaf area. This effect was compounded by the fact that drought also reduced the duration of each leaf, and thereby increased the senesced fraction of total leaf area. The senesced fraction of total leaf area was significantly correlated with the cumulative average PSMD for the growth season, and the effect of drought increased exponentially with time ($r=0.99$; $P<0.001$) (Fig. 5). As a result, LAI and, therefore the fraction of radiation

intercepted, declined significantly with drought; the effects of PSMD declined exponentially with time ($r=0.99$; $P<0.001$) (Fig. 6).

The net effect of these changes in LAI was that cumulative radiation interception declined markedly with drought. As for green LAI, the relative influence of water deficit on cumulative radiation interception declined exponentially with time ($r=1.0$; $P<0.001$) (data not shown).

Discussion

We have shown that the PSMD approach quantifies drought in a way that can be used consistently to describe the response of canopy development to water deficit. The PSMD was a reliable index for describing the response of canopy development to drought at both the leaf and whole crop levels, and it was reliable over both short (10 day) and long (100 day) time-frames. The PSMD method has the advantage that it integrates the effects of timing and intensity of drought into a single index, and it facilitated a simple yet reliable analysis of the effects of drought on canopy performance and, hence, radiation interception.

For most variables, the relative response to drought declined with time. However, since later leaves were larger, the absolute impact of drought increased towards maturity. Analysis of this response using the PSMD model made it simple to interpret the manner in which drought reduced canopy development and radiation interception.

Early drought reduced radiation interception by decreasing the rate of leaf expansion and, consequently, the maximum area of individual leaves. Therefore, maximum LAI was reduced. Moderate late drought did not significantly reduce maximum LAI, and reduced radiation interception almost entirely by accelerating leaf senescence. Severe late drought reduced canopy growth through the two-fold effect of reducing maximum LAI and leaf senescence.

Since PSMD is measured in units of mm, our results can be inverted and used to describe the effects of irrigation on canopy growth and development. For example: at 800 °Cd days from sowing, the senesced fraction of leaf area increased 4% for every mm average PSMD above the critical level (Fig. 5). Alternatively, one can deduce that, at 800 °Cd days from sowing, every mm of irrigation up to the critical level would reduce the senesced fraction of leaf area by 4%.

Conclusions

Drought timing and severity can be simply, cheaply and continuously quantified using the PSMD index, which is calculated using standard meteorological data. The index can be used reliably to describe the effects of drought on a wide variety of canopy performance variables, at both the leaf and whole canopy levels. Using this approach we were able to explain how timing and severity of drought affected canopy development in sweet corn.

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