Water deficit effects on growth, water use and yield of sweet corn

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Abstract

The response of sweet corn (cv. Challenger) to timing and intensity of water deficit was determined in an irrigation experiment in the mobile rainshelter at Lincoln, Canterbury. Six irrigation treatments were applied so that plots experienced: 1) no drought; 2) full drought; 3) moderate pre-silking drought; 4) severe pre-silking drought; 5) moderate post-silking drought; or 6) severe post-silking drought. Actual soil moisture deficits were determined using weekly neutron moisture probe measurements, and drought was quantified using the concept of 'potential soil moisture deficit' (PSMD), as calculated from climate data. Drought responses of water use, yield and yield components were determined, and were highly correlated with maximum PSMD ($PSMD_{max}$). Crop water use was highest for the fully irrigated treatment (311 mm) and least for fully droughted plots (98 mm). The fresh biomass (FM) of harvestable ears (economic yield) decreased by 34 kg FM/ha per mm $PSMD_{max}$, largely through a decrease of 44 ears/ha per mm $PSMD_{max}$ and a decrease of 0.3 g FM/ear per mm $PSMD_{max}$. Mature crop biomass decreased by 27 kg DM/ha per mm $PSMD_{max}$, and this was a result of decreases in leaf (4 kg DM/ha per mm $PSMD_{max}$), stem (11 kg DM/ha per mm $PSMD_{max}$) and ear (12 kg DM/ha per mm $PSMD_{max}$) biomass. There was no evidence of different sensitivities to water deficit at any particular stage of crop development. Results are discussed with reference to their implications for efficient irrigation management of sweet corn.

Additional key words: *critical deficit, crop development, drought, financial cost, irrigation management*

Introduction

Sweet corn (*Zea mays* L.) is generally regarded as sensitive to water deficit (Evans *et al.* 1960; Braunworth and Mack 1987), and the need of sweet corn crops for water is often related to putative 'moisture-sensitive periods' (Stanberry *et al.* 1963; Andrew and Weis 1974; El-Forgany and Makus 1979). In many of the experiments which led to these perceptions, water deficit either was not measured quantitatively, or it was described in ways that could not be readily related to plant growth (Denmead and Shaw 1960; Claassen and Shaw 1970; Andrew and Weis 1974). Nevertheless, identification of genuine moisture-sensitive periods could have clear benefits for irrigation management of the crop. For example, sweet corn crops in Canterbury may be irrigated as many as seven times during the growing season and, with an average cost of over $100/ha per application (Burtt 1997), irrigation may comprise a significant proportion of the production costs. The number of irrigations, and therefore costs, could be reduced if irrigations could be targeted to coincide with moisture-sensitive periods. In addition, if the yield benefit associated with irrigation at a given time could be ascertained, the economic benefits (or costs) associated with irrigation could be determined.

The aim of the study described in this paper was to improve the approach used previously for irrigation scheduling of sweet corn by: (1) constructing a simple model which quantified the response of sweet corn yield to irrigation; (2) providing a method which can be used to determine dollar-value benefits and costs associated with irrigation at any stage of crop growth; and (3) constructing a simple model which explained the components of the yield response to water deficit, to facilitate incorporation of the effects of water deficit into predictive yield models.

Materials and Methods

Site

The experiment was performed in a cool-temperate climate at Lincoln, New Zealand (lat. 43° 38' S, long. 172° 30' E), where temperature and solar radiation during the sweet corn growing season average ca. 15°C and 18 MJ m^2/d (Wilson *et al.*, 1995). The soil is a deep (> 1.6 m) Templeton sandy loam (*Udic Ustochrept*) overlying sand, and has an available water-holding capacity of ca. 190 mm/m depth. Soil physical characteristics are described by Martin *et al.* (1992).

Crop culture

Sweet corn (cv. Challenger) was grown in rows 70 cm apart with 25 cm between plants within rows. On 30 October 1996, two seeds per position were sown using jab planters. Plots were thinned after emergence to give a uniform population of ca. 57,000 plants/ha. The area was divided into 12 plots each measuring 11.2 x 3.6 m. Rows were oriented east-west. Weeds were controlled effectively by a post-planting, pre-emergent application of a mixture of Cyanazine and Alachlor (2.5 and 7.0 L/ha, respectively). Fertiliser was applied twice to each plot through a trickle irrigation system: 200 kg/ha of 12:10:10 NPK was applied three weeks after sowing and was followed by 200 kg N/ha as urea ca. six weeks after sowing, giving totals of 224, 20 and 20 kg of N, P and K per ha, respectively.

Treatments

Six water deficit treatments were imposed with a drip irrigation system (described by Martin *et al.*, 1990). A mobile rainshelter (12 x 55 m) covered the plots automatically whenever rainfall occurred. The treatments were fully randomised in two blocks and were designed to subject the crop to varying degrees of stress at different stages of crop development:

FI:	fully irrigated - weekly irrigation to replace the previous week's water loss
FD:	severe drought - no irrigation
MED:	moderate early drought - no irrigation until 16 days pre-silking, then full irrigation
SED:	severe early drought - no irrigation until silking, then full irrigation
MLD:	moderate late drought - full irrigation until 19 days post-silking, then no irrigation
SLD:	severe late drought - full irrigation until 21 days pre-silking, then no irrigation

Drip irrigation was supplied weekly to each plot via emitters spaced 300 x 450 mm apart, and irrigation volume was measured using a flow meter connected to the main line. The previous week's water loss or actual evapotranspiration (E) was defined as :

$$E = I + \Delta \mathrm{SM},$$

where I was the amount of irrigation applied in the previous week and ΔSM was the change in soil moisture content of the profile over the week, assuming runoff and drainage were negligible. As defined here the term E was identical to actual weekly water use defined below.

Soil moisture measurements

Soil moisture content was measured weekly using TDR (time domain reflectometry) for the top 0.2 m and the remaining depth was measured with a neutron probe at 0.2 m intervals to a depth of 2 m. Actual soil moisture deficit and actual water use (WU) were determined from these measurements.

Potential soil moisture deficit

Potential soil moisture deficit (PSMD) was calculated using standard meteorological data, as described by Jamieson *et al.* (1995a). This method estimated the difference between the theoretical crop demand for water (potential ET) and the supply of water (rainfall and irrigation; N.B., rainfall = 0 under the rainshelters), plus any soil moisture deficit present at the start of measurements. The maximum PSMD ($\mathrm{PSMD}_{\max}$) during the season has been correlated linearly with yield in a several crops (Baird *et al.*, 1987; Jamieson *et al.*, 1995b).

Plant measurements

Biomass of stem, leaf, husk and ear, and yield components (number of harvestable ears, total kernel biomass and ear biomass) were measured on 20 plants per plot at maturity. Fresh weights (FM) were recorded and plant material was dried in a forced-ventilation oven (80°C) until constant weight (DM) was attained.

Results

Water use (WU) for each treatment was generally linear with time ($r>0.90$; $P<0.0001$) from the start of water use measurement (48 days after sowing [DAS]) to maturity (143 DAS) (Fig. 1). Total WU was significantly ($P<0.001$) higher for the fully irrigated treatment (FI; 311 mm) than the others. Moderate early (MED) and moderate late drought (MLD) treatments used a similar quantity of water (250 and 265 mm, respectively), whereas WU for severe early (SED) and severe late drought (SLD) treatments differed by ca. 30 mm (147 and 180 mm, respectively). Fully droughted (FD) sweet corn used only 98 mm of water from 48 DAS to maturity (Fig. 1). Other than a few data points at the start, WU (measured) and the potential ET (calculated) were virtually identical.

The PSMD for the FD treatment increased steadily throughout the experiment, and attained a maximum value of 403 mm (Fig. 2). For the fully irrigated treatment (FI) PSMD increased linearly to 42 DAS and thereafter was maintained between 53 and a maximum of 90 mm by weekly irrigations. The 'serrated' profile of PSMD for the irrigated treatments was characteristic of the effects of regular irrigation: watering resulted in a sudden decrease in PSMD followed by a less rapid increase as water was used at a slower rate during the week following (Fig. 2). PSMD for the MED treatment increased linearly to 54 DAS and was thereafter maintained below a maximum of 132 mm by weekly irrigations. The SED and MLD treatments attained a very similar maximum PSMD (254 and 237 mm, respectively), although the timing of the maximum differed markedly. For the SED treatment, PSMD increased linearly to 97 DAS and attained its maximum shortly afterwards, whereas the MLD treatment was irrigated until 91 DAS, and did not attain its $PSMD_{max}$ until maturity (143 DAS) (Fig. 2). The SLD treatment was irrigated until 55 DAS, but not thereafter, and attained its $PSMD_{max}$ of 363 mm at maturity (Fig. 2).

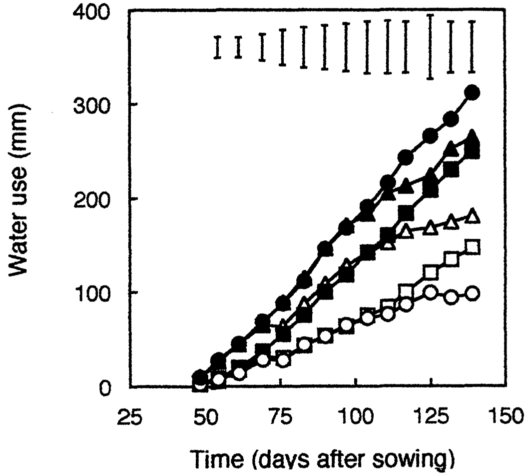

Figure 1. **Water use in sweet corn cv. Challenger under different drought inducing irrigation regimes as described in the text. ● FI; ○ FD; ■ MED; □ SED; ▲ MLD; △ SLD. Data are presented from the start of water measurement (48 DAS) to harvest ripeness. Bars are l.s.d$_{(0.05)}$ of means for each measurement time.**

The critical $PSMD_{max}$ was attained at 90 mm, found by regressing yield on $PSMD_{max}$ to determine the level which described the greatest percentage of the yield variation. This statistically-determined critical deficit was very close to the available water content of the soil to 1 m depth (95 mm, or 50% of 190 mm), and suggests that the latter quantity may provide a good approximation of the critical deficit for use by growers.

Total ear fresh biomass (FM) was reduced significantly by water deficit (52 kg FM/ha per mm $PSMD_{max}$; r=0.98; P<0.0001) (Fig. 3). Harvestable ear FM was also reduced, but less severely (34 kg FM/ha per mm; r=0.95; P<0.0001), indicating that water deficit reduced the yield of non-harvestable (non-economic) ears. Indeed, as $PSMD_{max}$ increased from 90 (FI treatment) to 403 mm (FD treatment) the biomass of non-harvestable ears decreased from 5.45 to 0.43 t FM/ha.

This response was largely due to the effects of water deficit on ear number (Fig. 4). The total number was reduced by 148 ears/ha for every mm of $PSMD_{max}$ above 90 mm (r=0.87; P<0.001), whereas harvestable ear number was reduced by only 44 ears/ha per mm $PSMD_{max}$ (r=0.68; P<0.01). Therefore, the number of non-harvestable ears decreased as the severity of water

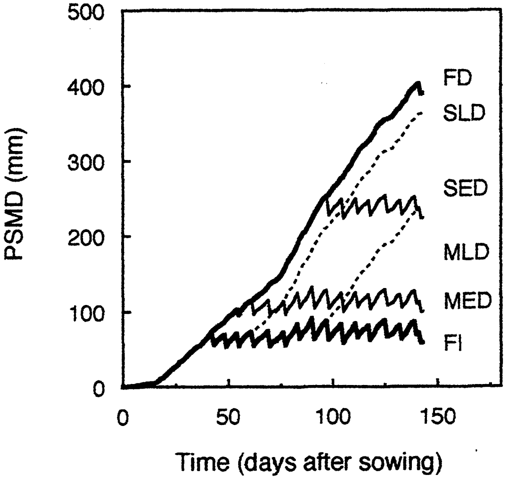

Figure 2. **The development of drought (PSMD = potential soil moisture deficit) under different irrigation regimes as described in the text.**

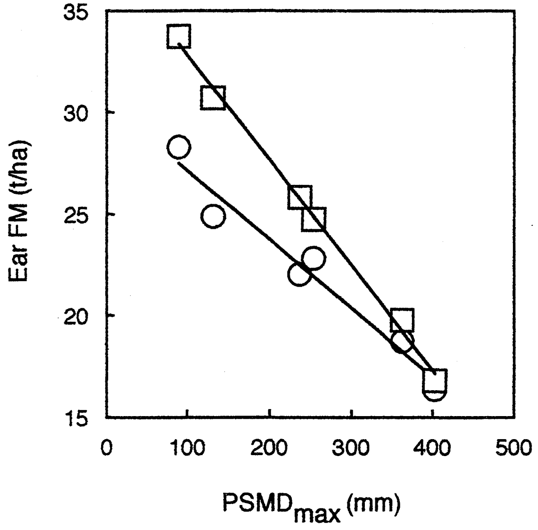

Figure 3. The effect of PSMD$_{max}$ on ear fresh mass in sweet corn cv. Challenger. (☐ total ears; ○ harvestable ears).

deficit increased, by 104 ears/ha per /mm PSMD$_{max}$ (r=0.83; P<0.001) (data not shown).

Water deficit also influenced ear FM by reducing the average size of both harvestable and non-harvestable ears (Fig. 5). Harvestable ear FM declined by 0.3 g FM/ear per mm PSMD$_{max}$ (r=0.80; P<0.001), which was sufficient to reduce ear FM from a maximum of 404 to 286 g FM/ear in the FD treatment (Fig. 5). It should be noted, however, that FM of harvestable ears was quite insensitive to mild levels of water deficit; there was no significant reduction until PSMD$_{max}$ exceeded 250 mm, but beyond this level it declined by over 0.5 g FM/ear per mm PSMD$_{max}$.

Kernel FM by contrast was very responsive to water deficit. It was reduced by 16 kg/ha per mm PSMD$_{max}$ (r=0.93; P<0.001) (Fig. 6). This was sufficient to reduce 'canning yield' from 15.0 t/ha in the FI treatment to 9.5 t/ha in the FD treatment.

Mature crop biomass decreased by 27 kg DM/ha per mm PSMD$_{max}$ (r=0.79; P<0.01), as a result of reductions in dry biomass for each of stem (11 kg DM/ha per mm PSMD$_{max}$; r=0.58; P<0.05), leaf (4 kg DM/ha per mm PSMD$_{max}$; r=0.85; P<0.001) and ear (12 kg DM/ha per mm PSMD$_{max}$; r=0.97; P<0.0001) (data not shown).

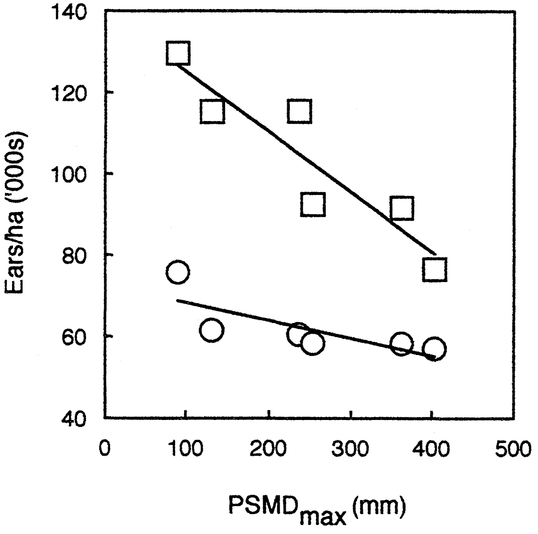

Figure 4. The effect of PSMD$_{max}$ on ear number in sweet corn cv. Challenger. (☐ total ears; ○ harvestable ears).

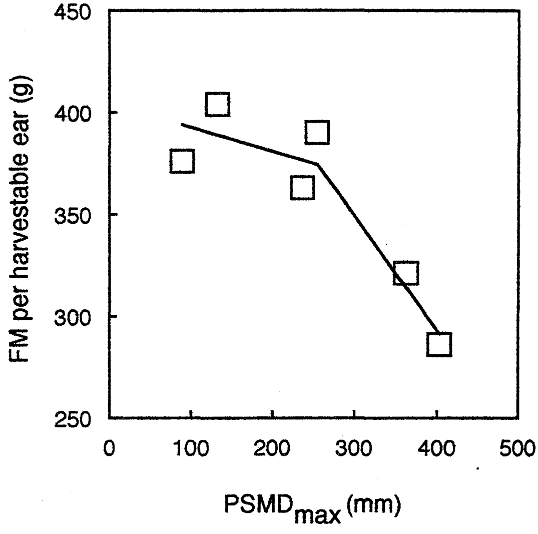

Figure 5. The effect of PSMD$_{max}$ on fresh mass per harvestable ear in sweet corn cv. Challenger.

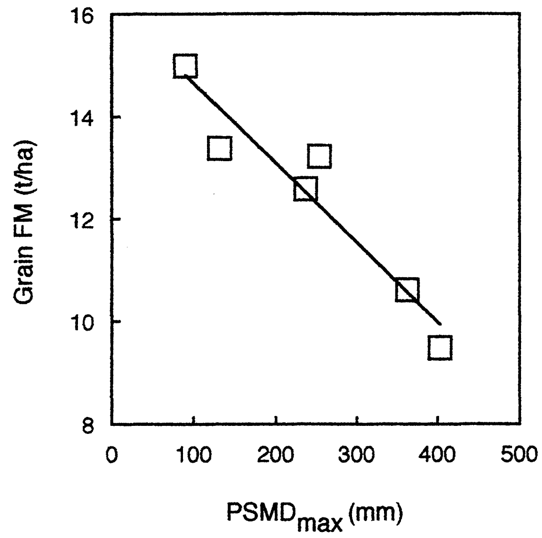

Figure 6. The effect of $PSMD_{max}$ on grain fresh mass in sweet corn cv. Challenger.

Discussion and Conclusions

The results from this study demonstrate the utility of the PSMD model for describing the response of sweet corn to irrigation. This simple model enabled us to: (1) define the critical PSMD for Challenger sweet corn on this soil type (90 mm); (2) describe the responses to water deficit of sweet corn yield and its components; (3) show the yield benefit (if any) to be gained by irrigation at any stage throughout the season; (4) show that sweet corn yield is reduced by water deficits at any stage of development, provided deficits are greater than the critical water deficit, and (5) show that this yield reduction is a linear response to $PSMD_{max}$ for $PSMD_{max}$ > critical PSMD.

Growers can use this approach to make informed decisions about when to irrigate, how much water to apply, and the economic costs or benefits of irrigation. They can assess the profitability of irrigating at any time during the season or, conversely, the yield and financial losses resulting from delayed irrigation. For example, suppose the $PSMD_{max}$ is allowed to reach 140 mm at any stage, i.e., 50 mm greater than the 90 mm critical level. This would cause a yield loss of 1.7 t/ha, because our results showed that harvestable ear yield declines by 34 kg/ha for every mm of $PSMD_{max}$ greater than 90. If the sweet corn is worth $148/t, this equates to a financial loss of $252/ha. Assuming the variable cost of applying 50 mm of water is $100/ha (Burtt 1997), the economic benefit from irrigating in time to avoid the damaging deficit would be $152/ha.

The model has several other consequences for sweet corn irrigation management:

1. No additional yield increase will occur in response to any extra water applied once $PSMD_{max}$ is less than 90 mm (i.e., there is no benefit from over-irrigation).
2. The maximum PSMD experienced by a crop during the season is the event that sets the upper limit to final yield. Therefore, there is no point in irrigating to maintain a low PSMD if a large deficit has already occurred. For example, if PSMD reached 200 mm early in the season due to delayed irrigation, there is no point in subsequent watering to maintain PSMD near 90 mm. Once the maximum of 200 mm has been reached, subsequent irrigation management should aim to maintain PSMD above 200 mm for the rest of the season to avoid further yield reduction.

3. These rules apply at all stages of crop development because there was no evidence of any periods of particular vulnerability to water deficit. This was clear from the simple linear relationship between $PSMD_{max}$ and yield. The fact that it integrates the effects of crop development stage and water deficit is one of the most useful features of the PSMD approach to irrigation scheduling. This helps to simplify irrigation management, because decisions can be based only on the value of $PSMD_{max}$ without any need for empirical or other modifications during the growing season.

In addition to its utility for irrigation scheduling, the PSMD model can be used to help interpret results of field experiments. Where water deficit is likely to have occurred, analysis of yield results by regression against $PSMD_{max}$ may make it possible to compare and apply results across sites and years. The fact that $PSMD_{max}$ can be related to a range of agronomic traits makes it useful for incorporation into models which predict the response of sweet corn growth and yield to water deficit. For example, in this case it was possible to partition the significant relationship between biomass and $PSMD_{max}$ into significant relationships between $PSMD_{max}$ and each of ear, leaf and stem biomass. At a higher level, the relationship between harvestable ear FM and $PSMD_{max}$ was the result of equally strong relationships between

$PSMD_{max}$ and each of the grain, husk and rachis in response to water deficit (16, 13 and 5 kg FM/ha per mm $PSMD_{max}$, respectively; $r>0.9$; $P<0.0001$). PSMD therefore quantifies water deficit in a way that has high agronomic relevance.

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