DROUGHT EFFECTS ON WATER USE, GROWTH AND YIELD OF SWEET CORN

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Abstract

The responses of sweet corn to timing and severity of drought were examined by subjecting a crop to six irrigation treatments in a rainshelter. Drought was quantified using the concept of 'potential soil moisture deficit' (PSMD), which was calculated from climatic data. Responses to drought were correlated strongly with the maximum PSMD ($PSMD_{max}$) experienced by the crop. Total water use declined by 0.6 mm/mm $PSMD_{max}$, from 310 mm for the fully irrigated crop to 100 mm with no irrigation. Mature crop biomass decreased by 27 kg/ha/mm $PSMD_{max}$, radiation use efficiency by 0.12%/mm $PSMD_{max}$, and fresh mass of harvestable ears (economic yield) by 34 kg/ha/mm $PSMD_{max}$. Drought timing did not affect the response for economic yield. PSMD quantifies drought in a way that describes crop responses consistently and, since it is expressed in units of mm, it can be used directly to optimise irrigation management decisions to maximise yield.

Key words: Drought, potential soil moisture deficit, water use, biomass production, yield, Zea mays L., sweet corn.

In a companion paper (6) we showed that potential soil moisture deficit (PSMD) (3, 4) was a simple and reliable index for quantifying the effects of drought on canopy development in sweet corn (Zea mays L.). As PSMD increased, the size and duration of the crop canopy, and hence the fraction of radiation intercepted, decreased. In this paper we describe how these effects translated to effects on water use, growth and yield by relating reductions to maximum PSMD during crop growth, in the same manner as in previous analyses of grain yield responses to water deficit (2).

Previous research on sweet corn has focussed on yield sensitivity to drought at particular stages of crop development (1, 5, 7). In most cases, drought timing and severity were not quantified adequately and the mechanisms of the drought effects were not determined. In our analysis, we examine how drought affected the crop's utilisation of intercepted radiation by determining the effects of PSMD on water use and radiation use efficiency (RUE). We also determine the effects of water deficit on total biomass production, economic yield (harvestable ears), and yield components.

Materials and methods

Sweet corn hybrid 'Challenger' was grown and subjected to six irrigation treatments as described in the companion paper (6). For each treatment, water use was determined from weekly neutron probe measurements of the soil water content profile to 2 m depth. At harvest maturity (72% kernel moisture content), total crop biomass was measured by harvesting a sample of ten plants per plot and weighing them after drying to a constant mass at 80^{o}C in a fan-forced oven. RUE was calculated by dividing total crop biomass by the total amount of radiation intercepted by the canopy throughout crop growth. Daily intercepted radiation was calculated using values of radiation interceptance calculated as described previously (6) and daily incident radiation was obtained from a weather station about 200 m from the experiment site. The fresh mass of harvestable ears, number of ears, and mean fresh mass per ear were measured on a sample of 20 plants per plot at harvest maturity. Ears were deemed to be 'harvestable' (suitable for processing) if they were greater than 20 cm long. The severity of drought experienced by the crop in each treatment was calculated using the PSMD model as described in the companion paper (6).

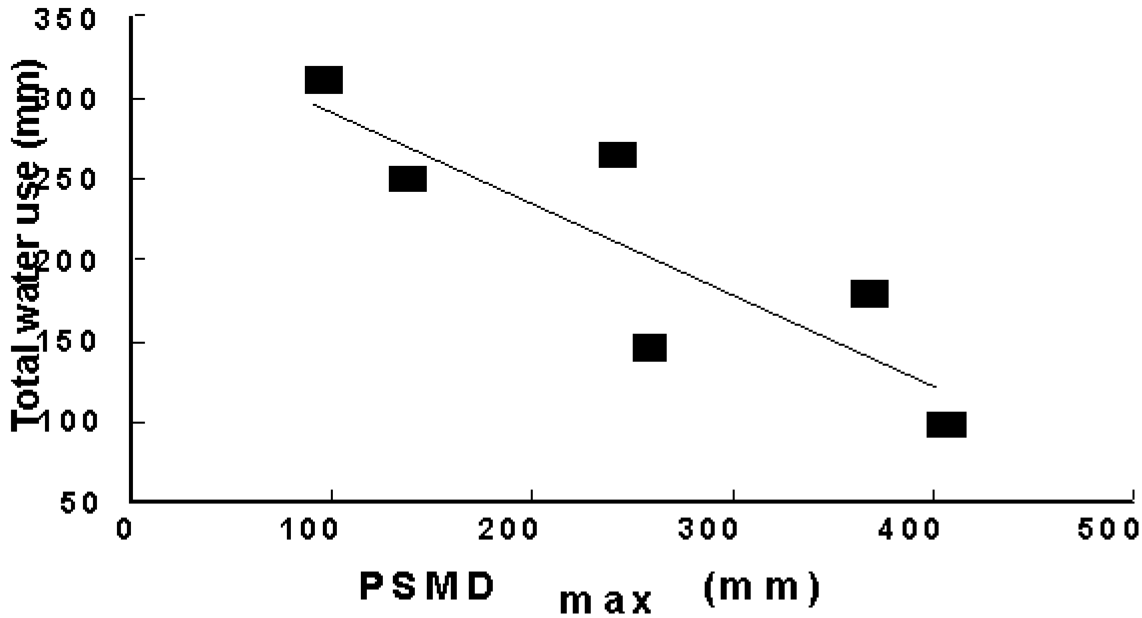

Figure 1

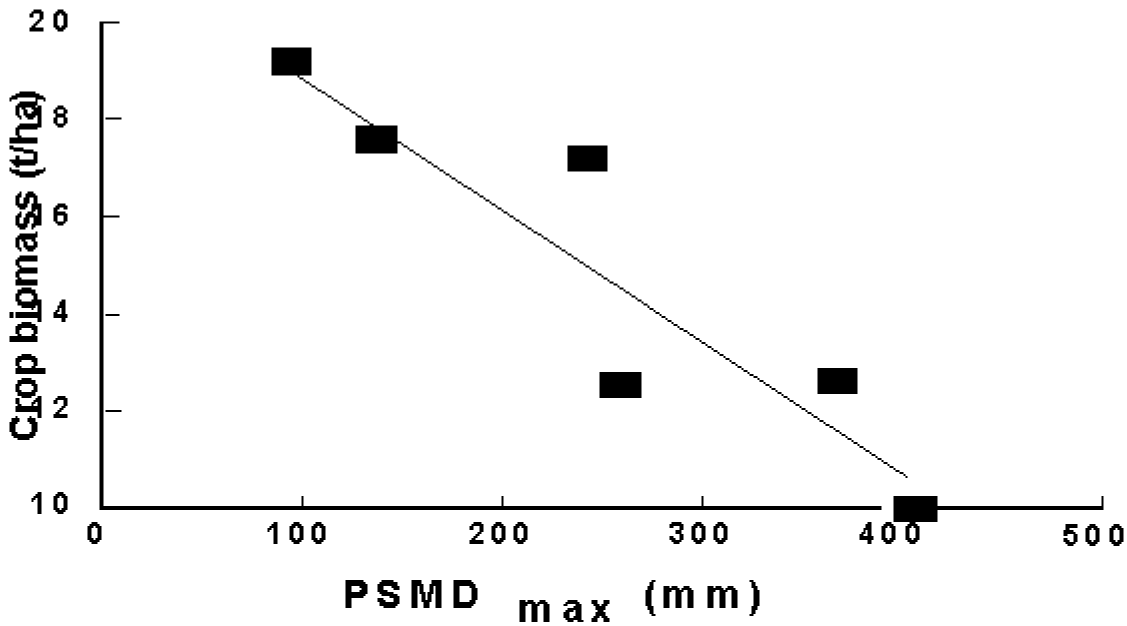

Figure 2

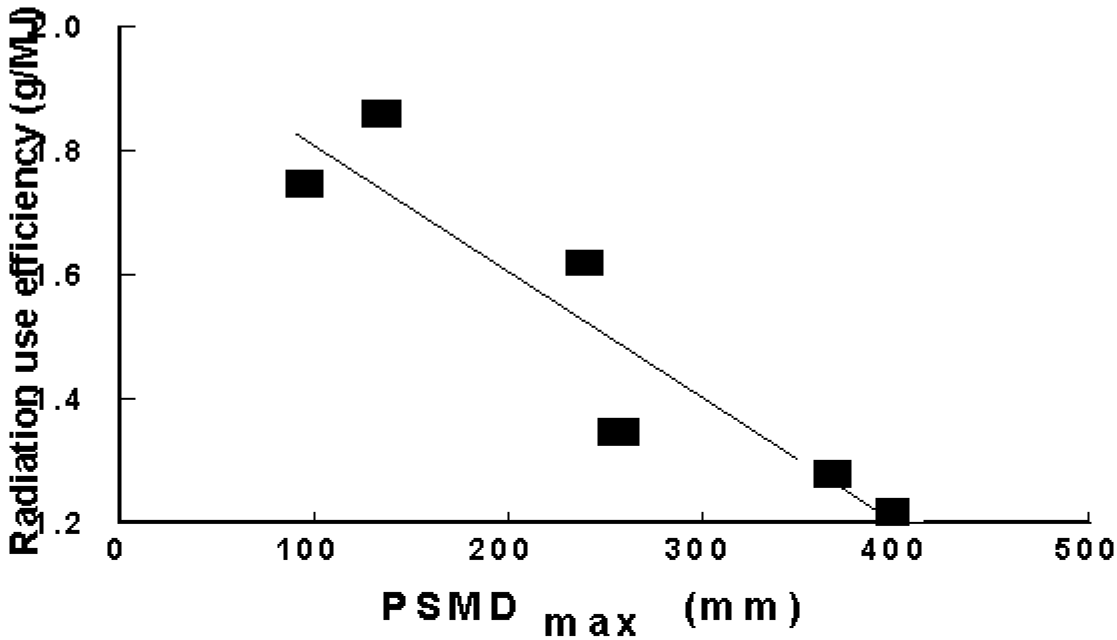

Figure 3

Results

There was a strong correlation between total water use from plant emergence to harvest and crop biomass at harvest maturity (r=0.99; P<0.001), and both declined linearly as the maximum PSMD experienced by the crop during the growing season ($PSMD_{max}$) increased. Water use declined by 0.6 mm/mm $PSMD_{max}$, from 310 mm for the fully irrigated crop to 100 mm for the unirrigated crop (Fig. 1). Biomass decreased by 27 kg/ha/mm $PSMD_{max}$ from about 19 to 10 t/ha (Fig. 2).

Crop biomass was related closely to the total amount of radiation intercepted (r=0.94; P.<001) and, consequently, RUE also decreased linearly as $PSMD_{max}$ increased (Fig. 3). The decrease was 0.2 g/MJ/100 mm $PSMD_{max}$.

Harvestable ear fresh mass (ie. economic yield) declined linearly by 34 kg/ha/mm $PSMD_{max}$, from about 28 to 16 t/ha (Fig. 4). There was a strong linear relationship between harvestable ear fresh mass and crop biomass (r=0.88; P<0.01).

The number of harvestable ears was particularly sensitive to drought (Fig. 5). There were about 76,000 harvestable ears/ha in the fully irrigated treatment, and this number was reduced by about 15,000 in the least severe drought treatment (132 mm $PSMD_{max}$). The re- duction of ear number beyond this level of water deficit was much smaller, with a linear decline of about 20 ears/mm $PSMD_{max}$.

In contrast to ear number, the mean fresh mass per harvestable ear was quite insensitive to mild levels of drought; there was no significant reduction until $PSMD_{max}$ exceeded 250 mm (Fig. 6). However, beyond this level it declined by over 50 g/mm $PSMD_{max}$.

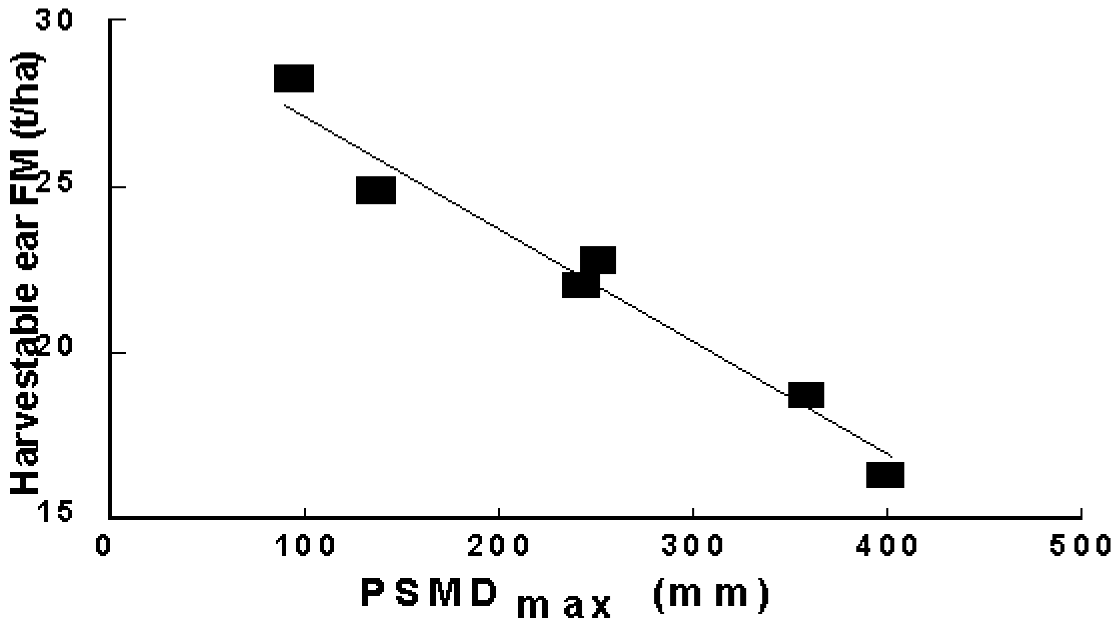

Figure 4

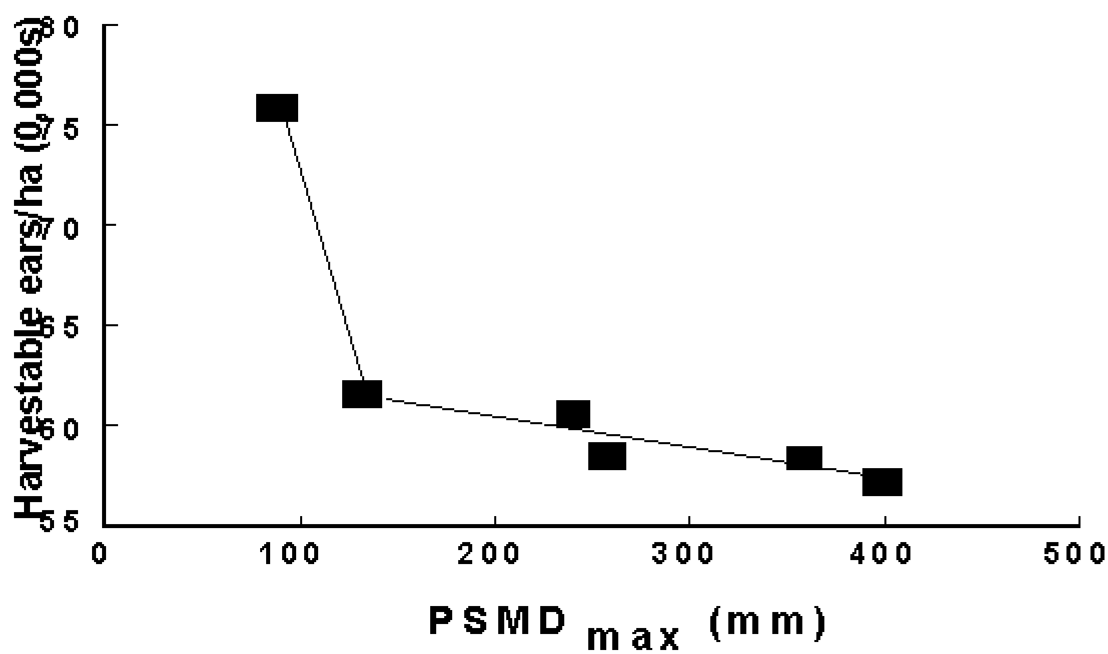

Figure 5

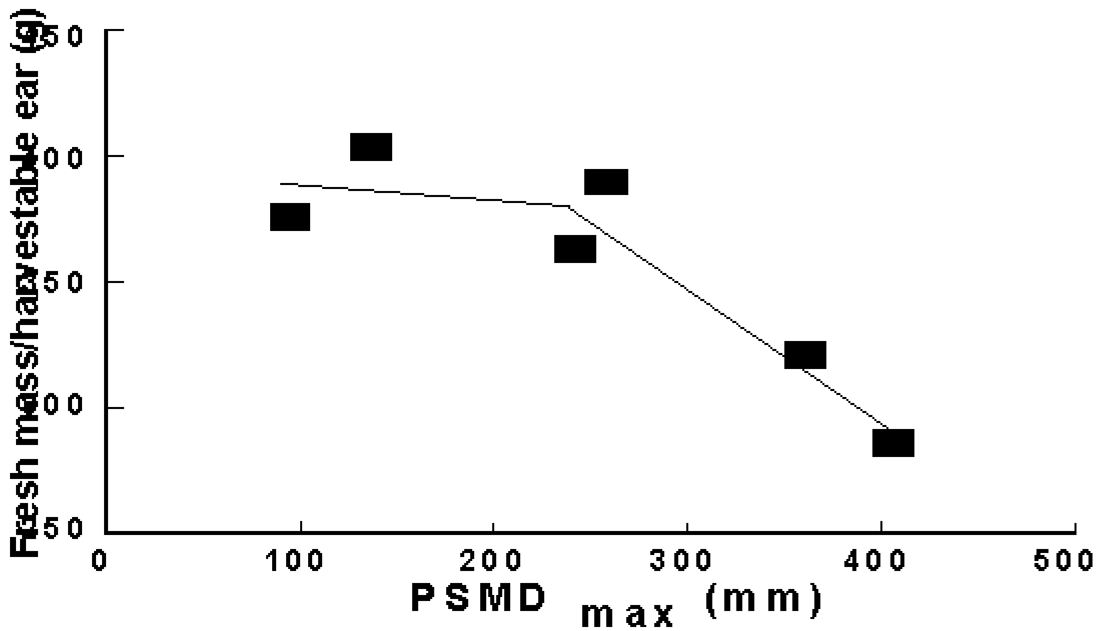

Figure 6

Discussion

The results confirmed our earlier conclusion that PSMD is useful for quantifying drought in a way that can be used consistently to describe crop responses to water deficit (6). Even though there was a range of timings and severities of $PSMD_{max}$ among the treatments, water use, biomass production, RUE and economic yield all declined linearly as $PSMD_{max}$ increased. The linear responses indicated that the primary response was to drought severity. In the case of economic yield, there was little or no effect of drought timing (Fig. 4). The close relationship showed clearly that yield was equally sensitive to drought at any time during crop development. There were yield reductions in all treatments where $PSMD_{max}$ exceeded the fully irrigated value of 100 mm, regardless of when the maximum occurred. Even the mildest $PSMD_{max}$ value of about 130 mm, which occurred early in crop development, was sufficient to reduce yield significantly. The two middle drought treatments with $PSMD_{max}$ values of about 250 mm had similar yields even though they occurred at very different stages of crop development (6). Our results mean that, to achieve maximum economic yield, sweet corn crops should be irrigated whenever necessary to avoid exposure to $PSMD_{max}$ values exceeding the level where yield reductions start to occur (about 100 mm in our experiment).

As well as the response to drought severity, there was an effect of drought timing on water use, biomass production and RUE, particularly for the two middle drought treatments (Fig. 1, 2 and 3). One treatment experienced its $PSMD_{max}$ late in crop development. As a result, its leaf canopy was largely unaffected by drought (6) and so it had high water use, biomass and RUE. In contrast, the other treatment experienced its $PSMD_{max}$ much earlier in crop development. Consequently, the production and activity of its leaf canopy were reduced substantially, as indicated by its lower water use and RUE (Fig. 1 and 3), and its biomass was much lower.

The PSMD index was useful for analysing how water deficit reduced the economic yield of sweet corn. The primary effect was to reduce crop biomass. This occurred because of lower radiation interception (as described previously (6)) and RUE. The reduction in RUE was related strongly to the reduction in water use ($r=0.88$; $P<0.01$). This suggests that stomatal closure was largely responsible for the lower RUE, although some reduction in water use can be attributed to reduced canopy size and duration (6).

Drought reduced both the number and mass of harvestable ears, but the two yield components responded differently. Ear number was sensitive to mild drought, apparently because many potentially harvestable ears were reduced below the 20 cm minimum length, but was stable as drought became more severe. On the other hand, the size of harvestable ears was quite insensitive to drought except when it became severe. These contrasting responses affected the balance between the yield components. They meant that, for a given level of drought occurring at different times, reductions in one yield component were balanced by increases in the other so that yield remained constant.

Conclusions

Using PSMD to quantify drought was a simple and reliable way to analyse the response of water use, growth, yield and yield components of sweet corn to water deficit. Since it is expressed in units of mm, PSMD can be used directly to optimise irrigation management decisions by assessing the response of yield and its components to various quantities of water or, conversely, the likely yield loss if irrigation is delayed.

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