Responses of barley, wheat and maize to drought in a cool temperate climate

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Summary. The response of three grain crops to drought was determined in a series of experiments in a mobile rainshelter at Lincoln, Canterbury, New Zealand. For winter wheat and spring barley the critical potential soil moisture deficit (D_r) above which yield was affected was independent of drought timing, but was much smaller for barley than wheat. Both crops showed similar yield responses to drought above their Dr. In contrast, Dr for maize increased as the season progressed, and yield was much less sensitive to drought once D_r was exceeded. Yield response was mostly associated with grain number in wheat and barley, and with grain size in maize.

Introduction

In contrast to much of Australia, Canterbury, in the South Island of Ncw Zealand, has a cool temperate climate. The region is a major producer of wheat and barley with an expanding area of maize. Although the climate is wel1 within the normal range for barley and wheat crops, it is marginal for maize (13). A feature of the climate is recurrent and variable drought. with summer potential evapotranspiration approximately twice the mean rainfall. Supply of water is often the limiting factor in grain yield. Several experiments in New Zealand have investigated the response of grain crops to drought, but the results were often inconclusive due to the occurrence of untimely rainfall (2, 4, 7). Consequently, a series of experiments was conducted in the 55 m x 12 m Crop & Food Research rainshelter at Lincoln (8) to define the sensitivity of grain crops to variable droughts at different times in the growing season. This paper compares the responses of spring barley, maize and winter wheat to imposed drought of varying times and intensities.

Methods

The rainshelter is on a deep (>1.6 m) Templeton sandy loam soil with an available water holding capacity of about 190 mm per metre of depth. The experimental area is divided into 24 3.6 x 5 m plots, each with its own metered trickle irrigation supply. All crops were grown after at least 3 years of mown ryegrass/white clover pasture.

The crops were 'Triumph' barley *(Hordeum vulgare L.),* sown on 7 September 1988, population 300 plants/m^2; the hybrid maize cultivar $1^3$3902' *(Zea mays L.),* sown on 6 November 1990 with seeds 0.15 m apart in rows 0.75 m apart; 'Batten' wheat *(Triticum aeslivum L.),* sown on 8 June 1991, population 300 plants/m^2. Sufficient fertiliser was applied to each crop so that water deficit provided the only limitation to growth, and a prophylactic fungicide and insecticide programme ensured that no disease was present. Weed control was good in all experiments.

Treatments were designed to impose droughts of varying severity at different times during the growth of each crop. Each experiment contained a control treatment which was irrigated every week with sufficient water to replace the amount used in the previous week, based on a water balance calculation using the soil moisture content measured to 1.6 m depth with a neutron probe and in the upper 0.2 m either gravimetrically (barley) or by TDR (maize and wheat). In the barley and maize experiments, droughts were imposed with common starting times early (from planting) and in the middle (from about two weeks before anthesis and silking respectively) of the growing season; late droughts were imposed for differing periods before a common end (harvest). In the wheat experiment droughts were imposed either for different periods from planting or for different periods before harvest. Drought severity was adjusted by varying drought duration from 2 to 8 weeks in the barley, from 2 to 10 weeks in the maize, and from 5 to 18 weeks in the wheat. The wheat experiment had additional treatments of no irrigation, and a half irrigation treatment which was irrigated every second week with the amount of water applied to the control treatment that week. Plots scheduled for irrigation were watered weekly, with the same amount of water as the control treatment.

Drought response was calculated using the drought response model of Penman (10) and expanded by French and Legg (5). The model, which was shown to have a sound theoretical basis by Monteith (9). has the advantage that the potential soil moisture deficit (D_p) is readily calculated from potential evapotranspiration, rainfall and irrigation data, and responses are given in terms of reductions in yield below the fully irrigated yield. It produces two meaningful numbers: a critical deficit beyond which yield is reduced, and a reduction in yield per unit of potential deficit when the critical deficit is exceeded.

Potential evapotranspiration was calculated by the method of Ritchie (12), from the control treatment. Meteorological data came from a weather station within 300 m of the experiment site, and leaf area index (LAI) measurements which were made from destructive sampling throughout the growing season in all experiments. Extinction coefficients (k) for net radiation (Re) interception were set at 0.45 for the barley and wheat (6) and 0.4 for the maize (R. Muchow, pers. comm. 1990). Drought severity (Dpmax) was quantified as the maximum value of Dp.

Grain yield and its components were determined at harvest from approximately I m2 samples from each plot in the wheat and barley, and from 20 plants per plot in the maize experiment.

Results and discussion

Ranges of Demi, achieved in each experiment were 75 - 330 mm in the barley, 100 - 340 mm in the maize, and ax)-510 mm in the wheat (Fig 1). Although the corresponding yield range in the barley and wheat experiments was quite wide (3.5 - 9.2 and 3.6 - 9.8 t/ha respectively), in the maize experiment it was narrow (9.6 - 12.0 t/ha). There was a considerable difference in the expression of yield variation between crops. The barley was the only crop in which there was a clear effect of drought timing on yield components. Nevertheless, overall in the barley and wheat most of the variation was associated with grain number per unit area (r2=0.93 and 0.95 respectively). In the maize, however, most of the yield variation was associated with kernel mass (r2=0.61). The variation in grain number in the wheat was best accounted for by the number of surviving tillers (r2=0.83). although early drought in particular tended to reduce grains per ear. In the barley, variations in grain number were associated xx ith both tiller numbers and grains per ear.

In the barley, early drought had a substantial effect on grain number, with a clear negative linear relationship between grain number and D_{pmax}. However, although the grain number of the middle and late treatments was reduced with respect to the control, grain number was constant at about I 5,000/m2 across the middle drought treatments, and at about 20,000/m^2 across the late drought treatments. There was a linear reduction in mean grain mass with increasing D_{emax} (r^2=0.74), which was independent of drought timing. This meant that yield reductions from early drought were mostly associated with reductions in grain number, in middle drought treatments from a combination of reduced grain mass and grain number, but in late drought treatments mostly from reductions in grain mass.

A notable contrast between the barley and wheat crops was in the production of very small or empty grains (screenings). In the wheat, screenings were low at between 0.7 and 4.5%. However, in the barley, late drought produced up to 41% screenings. One response of barley to drought during grain filling appears to be the preferential filling of some grains at the expense of others which are not filled at all. Hence screenings in barley were excluded from the analysis.

For each experiment, simple linear models were fitted by least squares to the yield and Dpmax data (Fig. I). These models defined the critical deficit (D_r) above which yield was affected by drought, and the slope of the yield/Dpmax curve above this deficit. Spring barley yield appeared quite sensitive to drought as Dr was less than the Dome, experienced by the control treatment (ie <75 mm). In contrast, winter wheat was unaffected by drought until D_{pmax} exceeded 262 mm. This difference reflected the greater rooting depth and thus the amount of water available to the winter - compared with the spring-sown crop when drought was imposed. Neutron probe measurements showed that the barley extracted most of its moisture from depths of less than I m, whereas the wheat crop was able to extract substantial water from between 1.0 and 1.5 m depth. However, once, D_r was exceeded, the barley and wheat crops showed a similar rate of decline in yield (-25 and -21 kg/(ha mm) respectively) as D_{pmax} increased (Fig. I). Evidence that the timing of drought had any effect on yield response was not strong, as all barley or wheat treatments were described by the same linear model. However, grain yield in the barley middle drought treatments may have responded less to increasing drought than the other treatments (Fig. I). Barley experiencing drought at this time may be able to increase the amount of stem and leaf carbon partitioned to the grain to partially compensate for reduced assimilation (3).

A similar experiment in the UK (3) also showed that barley had a small D_c, but the yield response beyond D_e was much less (-8.0 kg/ha/mm) than in the Lincoln experiment. The response relative to the maximum yield in the UK crop (5.6 t/ha) was -0.14%/mm. compared with -0.27%/mm at Lincoln.

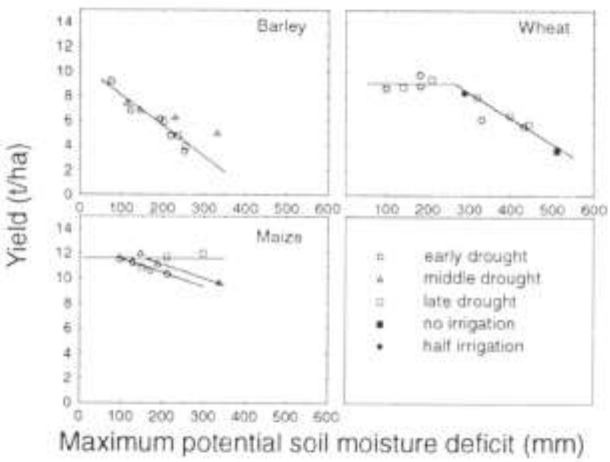

Figure 1. The response of grain yield to maximum potential soil moisture deficit for the three crops.

The relative value of wheat yield response to drought has been reported at about -0.3%/mm in mid-Canterbury (I) and the UK (5). This is slightly larger than the value obtained at Lincoln (-0.2Ic/c/mm). However, compared with the Lincoln data, in these experiments either maximum yields were much lower (3.5 - 4.0 t/ha; 1), or variability about the response was large (5).

A model assuming a single value for 13, indicated that maize yield and D_{pmax} were unrelated (r2=0.13). However, a linear model allowing different values of 13_q but restricting the slope of the response to a constant value (Fig. I) had an r^2 of 0.81. The values Of I), were 97 mm for early drought and 157 mm for mid drought, significantly different at P.0.05. Late droughts were insufficiently large to cause any yield response. Once D_c was exceeded, the maize yield showed a substantially smaller sensitivity to drought than wheat or barley, both in absolute (-I I kg/ha/mm) and relative terms (-0.09%/mm). The relative value is considerably smaller than the 0.25%/mm obtained by analysing data from a warmer, less marginal climate (I I). The cool, marginal climate of Canterbury reduced both the severity of drought and the yield response of maize to it.

Although wheat response to drought appeared similar in the New Zealand and the UK, the response of barley was much greater in the warmer New Zealand environment. In contrast, the maize response in New Zealand (a relatively cool environment for this crop) was much smaller than for a crop grown in a much warmer environment (11). The reasons for these results are unclear, especially as the variations in the ambient vapour pressure deficit among these locations suggests the differences in response should be in the opposite sense, because D_{pmax} is proportional to the difference between the actual and potential evapotranspiration (9). Hence these differences in response require further investigation.

ConclusionS

The model used in this analysis provides a good description of the response of grain crops to drought in terms of easily understood numbers with a clear practical application. The reasons for the large differences in crop responses from those measured in cooler (barley) and warmer (maize) environments arc unclear. It is apparent that drought responses in one environment cannot be assumed to be the same in another, even when differences in vapour pressure deficit are taken into account.

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