Drought effects on biomass production in barley

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Theory

Stresses experienced by crops affect final biomass yield by influencing the rate and duration of growth. Daily growth rate (C) is the product of the amount of photosynthetically active radiation (PAR) intercepted (Q) and the radiation use efficiency (A). Biomass (B) at any time is then the time integral of the growth rate from crop emergence (Monteith, 1977).

$$B = \int C dt = \int A Q dt \qquad (1)$$

Q varies with incident radiation (Q_o) and the proportion intercepted. The latter depends on leaf area index (LAI) according to Beer's law:

$$ln\ (1 - Q/Q_o) = -k\text{LAI} \qquad (2)$$

where k is an extinction coefficient. Most of the published literature (e.g., Legg et al., 1979) shows that A is conservative, and that variation in biomass production is associated mainly with changed LAI, and therefore Q. However, severe stress, or stress at particular stages of growth, may reduce the growth rate by reducing both LAI and A. The purpose of this short report is to examine the effects of water stress on biomass production in a barley crop, in terms of changes in LAI, Q and A. The analysis assumes that k stays constant, an assumption supported by data from the experiment.

Experimental

A "Triumph" barley crop was sown within and alongside the 54.5 x 12 m mobile rainshelter on the Crop & Food Research station at Lincoln on 7 September 1988. The sowing rate was 188 kg/ha. The crop emerged on 20 September and established a plant population of 291±6 plant/m^2. Fertilizer applications were 100 kg/ha 15% potassic superphosphate (P:K:S, 6:15:7) applied at sowing, and 50 kg N/ha in the form of ammonium sulphate applied a week after emergence.

Good weed and disease control was achieved through the use of standard herbicide and fungicide applications. The crop was divided into 24 plots within the shelter, each 3.6 x 5 m and with its own trickle irrigation supply (Jamieson et al., 1995). A randomised complete block design with 2 replicates of 12 treatments was used. In the control treatment, irrigation was applied every week according to a water balance calculation based on weekly soil moisture profile measurements. These were measured to 1.5 m depth using a combination of gravimetric (for near surface) and neutron probe techniques. Remaining treatments were divided into 3 categories: 4 early (before anthesis), 4 middle (around anthesis) and 3 late (during grain fill) dough treatments, where irrigation applications were withheld for varying durations. Except during their assigned drought periods, plots were irrigated each week with the same volume as the control treatment. Two 0.1 m^2 samples were taken from each plot every fortnight until anthesis, and thereafter at approximately 4 day intervals. LAI and dry biomass were measured each time. LAI and corresponding Q/Q_o measurements were made just before ear emergence and the results use in equation 2 to determine the value of k. Q/Q_o measurements were made with a line quantum sensor. Maximum potential soil moisture deficit (D_{pmax}), calculated from potential evapotranspiration and irrigation amounts, was used as a drought severity index (French and Legg, 1979; Jamieson et al., 1995).

Soil moisture deficits

D_{pmax} ranged from 75 mm in the control treatment to 332 mm in the most severe middle drought treatment. The highest values of D_{pmax} in the most severe early and late drought treatments were 252 and 255 mm respectively (Jamieson et al., 1995). These deficits caused substantial variations in total biomass yield at harvest, with a maximum of 16.5t/ha in the control treatment, to a minimum of 8.7t/ha in the most severe of the early drought treatments. Middle and late drought treatments showed similar relationships of total biomass

to drought severity (-103±0.32 g/m^2/mm D$_{pmax}$, r^2=0.63, P<0.05). However, the yield reduction response to the early drought treatments was four times greater (-4.21±0.59 g/m^2/mm D$_{pmax}$, r^2=0.94, p<0.01).

Extinction coefficient

A regression of 1n (*1 -Q/Q$_o$*) on LAI was forced through the origin to give a value for *k* of 0.47±0.02 (r^2=0.89), indistinguishable from the value of 0.46±0.007 found by Thorne *et al.* (1988) for winter wheat crops. Although early drought treatments were under considerable stress when the measurement was made, there was no evidence the *k* was any different for them.

Biomass

In the dynamics of biomass production, the most obvious effect of drought was on LAI. The middle and late drought treatments caused accelerated leaf senescence and early maturity. In the early treatments, the rate of LAI increase was slower during drought and reached much lower maxima. This was compensated for by a flush of late tillers initiated at about the time irrigation commenced. It resulted in longer persistence of leaf area, and delayed maturity. The delay was linearly related to D$_{pmax}$ (r^2=0.99).

Radiation use efficiency

The slopes of regressions of *B* on accumulated *Q* (equation 2) were compared to test the constancy of *A* and to identify departures in linearity of the relationships. There was no evidence of any nonlinearity in any of the relationships of *B* with *Q*. In the middle and late drought treatments, the regression slopes equations were all statistically similar to the slope for the control treatment (mean 2.28±0.05 g/MJ). Therefore, in these cases, biomass variation was associated only with changes in *Q*. In contrast, except for the least severe treatment, the regression slopes for the early drought treatments were significantly smaller than that for the control, with the most severe drought treatment having its slope reduced by half. The decreased value of *A* persisted, despite the commencement and continuation of irrigation. Moreover, *A* reduced linearly with increasing D$_{pmax}$ (r^2=0.98). Hence in the early drought treatments, reductions in both interception (*Q*) and radiation use efficiency (*A*) were responsible for the reduced biomass

yield. Comparison of the effects using equation 1 showed that the contribution of reduced *A* was substantially larger than from reduced *Q*. Increased duration associated with late tiller formation largely compensated for reduced interceptance, but the treatments still produced less biomass than the control.

Conclusion

We conclude that drought stress can reduce biomass yield through effects on both radiation interception, by reducing LAI, and radiation use efficiency. The relative influences depended on the timing of stress. Severe early drought is not often experienced in the field, which may explain why reports of changes in *A* of the magnitude reported here are unusual.

References

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