Effect of timing and intensity of drought on the yield of Oats (*Avena sativa* L.)

R.J. Martin, P.D. Jamieson, R.N. Gillespie and S. Maley.

New Zealand Institute for Crop & Food Research Limited, Christchurch, New Zealand.

ABSTRACT

The response of oats (*Avena sativa* L.) to timing and intensity of drought was determined in a mobile rainshelter, which excluded rainfall during crop growth. Ten irrigation treatments subjected the crops to drought of varying duration at different stages during plant growth; the crops were otherwise fully irrigated. Oat grain yield generally increased linearly with cumulative water use, and decreased linearly as the maximum potential soil moisture deficit experienced during crop growth increased, regardless of the timing of drought. The exception to this was the no drought (fully irrigated) treatment, where lodging reduced panicle number and grain weight compared to early drought treatments. Drought affected yield mainly by reducing panicle and grain number, effects on grain weight were small. Relieving early drought through late irrigation led to more late tillers, more panicles, heavier grains, and later maturity. Full and late drought increased screenings.

KEY WORDS

Avena sativa L., drought, irrigation, oats, yield, screenings.

INTRODUCTION

A quantitative knowledge of the response of crops to drought stress is important for the management of both irrigated and dryland crops. Farmers who have irrigation can use the known responses to schedule irrigation timing and amount for maximum profit. Dryland farmers can use the knowledge as a guide to potential production, to maximise water use efficiency.

Yield response to drought stress can be quantified using maximum potential soil moisture deficit (PSMD) as the measure of stress (2, 8). Potential soil moisture deficit is readily calculated from potential evapotranspiration, rainfall and irrigation data and, because it is measured in mm, has practical meaning in that the deficit can be equated with irrigation applications (or lack of them). Responses to the potential deficit are given in terms of relative reduction in yield below the fully irrigated yield. The PSMD 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.

Oats (*Avena sativa* L.) are claimed to be sensitive to drought, particularly during anthesis and grain fill (1, 10), but to date the effect of drought has not been quantified. To clarify the effect of water stress on oat yield, we carried out an experiment in a rainshelter, where rainfall was excluded from experimental plots that were otherwise exposed to normal weather (4). The objective of the experiment was to quantify the influence of timing and intensity of drought on the yield and water use of oats, with a view to providing growers with a method for maximising profit.

MATERIALS AND METHODS

The rainshelter at Lincoln, Canterbury, New Zealand, is a mobile 55 m x 12 m greenhouse which automatically covers the experimental crop during rainfall, but is otherwise positioned some 50 m away (4). The soil is a deep (>1.6 m) Templeton sandy loam (*Udic Ustochrept*, USDA Soil Taxonomy) (7) with an available water holding capacity of c. 190 mm/m of depth.

`Drummond' oats (35 mg seed weight) were sown in rows 13 cm apart with an Amazone drill on 29 September 1998 at a seeding rate of 139 kg/ha, which achieved a plant population of 262 plants/m^2. Ten irrigation treatments were applied. These subjected the crops to drought of varying duration at different times during growth (Table 1). The experiment was a randomised complete block design with two replicates. Irrigations started as soon as the irrigation system was operational. This was on 3 November, when the soil moisture deficit to 1.5 m was 173 mm. Each plot had its own trickle irrigation supply, with emitters spaced 300 mm x 450 mm apart, and was watered weekly. All treatments scheduled for irrigation received the same amount of water, equal to the water use of the no drought (fully irrigated) treatment during the previous week. This was measured to 1.6 m by neutron probe and time domain reflectometry. The PSMD was calculated for each treatment by adding the maximum weekly Penman evapotranspiration from the no drought treatment to the irrigation deficit (the difference between the amount of water applied to the treatment and to the no drought control). The deficit was adjusted for different ground cover using the modified Penman model of Ritchie (9).

Table 1. Treatment number, timing of drought, start and end of drought periods, maximum potential moisture deficit, and date that maximum PSMD was reached.

Treatment No	Timing of drought	Start of Drought	End of drought	Maximum PSMD (mm)	Date of max. PSMD
1	No drought	Nil	Nil	173	3 Nov
2	Full drought	3 Nov	9 Feb	606	8 Feb
3	Early	3 Nov	23 Nov	256	23 Nov
4	Early	3 Nov	7 Dec	313	14 Dec
5	Early	3 Nov	21 Dec	375	21 Dec
6	Early	3 Nov	5 Jan	453	5 Jan
7	Late	9 Nov	9 Feb	556	8 Feb
8	Late	23 Nov	9 Feb	491	8 Feb
9	Late	30 Nov	9 Feb	402	8 Feb
10	Late	14 Dec	9 Feb	330	8 Feb

The crop was fertilised and sprayed to avoid any limitation to yield other than drought. The crop was 50% emerged by 8 October, and panicle emergence occurred in mid December. The crop was covered with bird netting 2 m above the ground from 4 December to maturity to prevent birds from eating the grain. Panicle numbers were determined on 0.1 m^2 quadrats taken weekly during growth. The full and late drought treatments matured first and were harvested on 9 February, when the plants had fully senesced. The heads of the no and early drought treatments were mature by 3 March, but stems, late tillers and some leaves were still green. At maturity, a 1 m^2 area was harvested by hand and the sample threshed in a Kurt Peltz mill. Grain yield and moisture content were determined and a subsample of the straw and chaff dried overnight for dry weight determinations. Grain weight and % screenings (2.4 mm screen) were determined on a grain subsample.

RESULTS

Grain yield was linearly related to both the water use over the growth of the crop and the maximum potential deficit for nine of the ten treatments (Figure 1). The exception was the lodged, no drought treatment 1, and also one of the plots in treatment 10. In both cases lodging soon after panicle emergence in the final harvest area reduced yield (Table 2). Excluding treatment 1, the regression equations were:

Grain yield = 3325 ($\pm$617.2) + 11.1 ($\pm$1.76) water use (r^2 = 0.85 (P<0.001), d.f. = 7)……..(1)
Grain yield = 12300 ($\pm$880) - 12.1 ($\pm$2.69) PSMD (r^2 = 0.74 (P<0.001), d.f. = 7)…………(2)

showing that 1 mm of water was required to produce 11 kg of grain, and 1 mm of deficit reduced yield by 12 kg/ha of grain, once the critical deficit of c. 200 mm was exceeded.

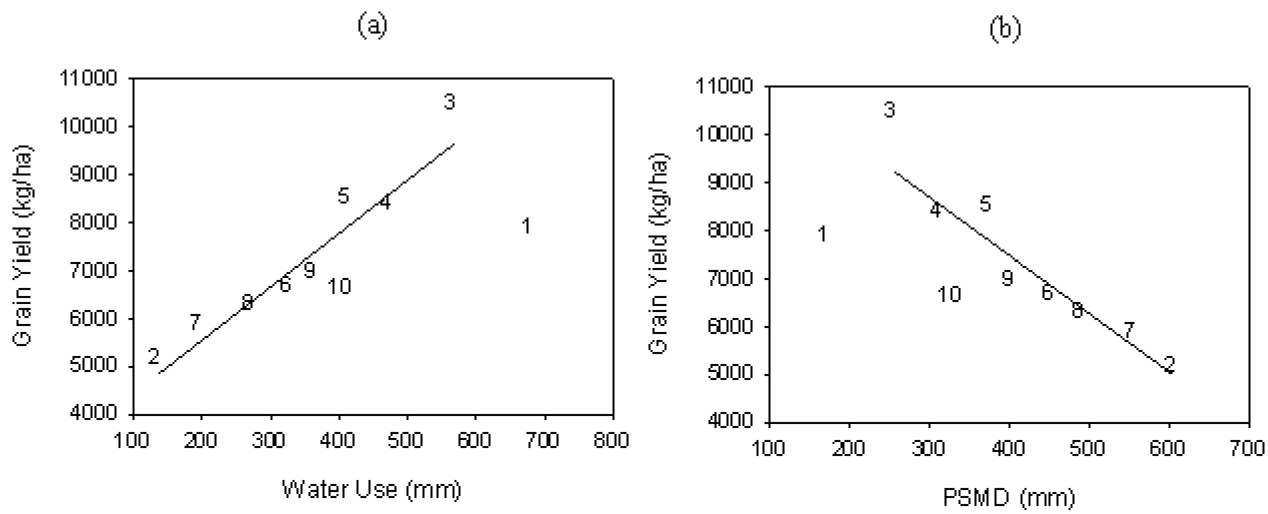

Figure 1. Relationship between grain yield and (a) crop water use (line from equation 1), and (b) potential soil moisture deficit (line from equation 2). Numbers are treatments from Table 1.

Table 2. Treatment number, lodge score (1 = vertical, 5 = horizontal), grain yield, grain weight, and percentage screenings of oats.

Treatment no	Lodge Score (%)	Grain yield (t/ha)	Grain no/m^2	Panicle no/m^2	Grain wt (mg)	% Screening
1	5.0	7.90	23200	345	34.7	9.2
2	1.5	5.19	14800	295	34.9	8.9
3	3.5	10.49	27300	489	39.2	6.5
4	1.5	8.39	22800	529	37.7	8.8
5	1.0	8.53	23600	449	37.1	10.0

6	1.0	6.67	17400	337	39.2	7.4
7	1.0	5.90	17800	296	33.1	33.7
8	1.0	6.32	19200	304	32.9	28.6
9	1.0	6.98	19900	325	35.0	21.1
10	2.5	6.63	20700	344	32.0	22.6
LSD (5%) (d.f.=9)	1.82	1.767	4680	60.5	3.31	4.44

Table 2 shows yield components that were significantly (P<0.05) affected by drought treatments. Grain yield was linearly related to grain number and panicle number:

Grain yield = -1138 ($\pm$459.8) + 0.408 ($\pm$0.0421) grain no (r^2 = 0.922 (P<0.001),d.f. = 8)……(3)
Grain yield = 1882 ($\pm$1038) + 14.58 ($\pm$2.801) panicle no (r^2 = 0.601 (P<0.001),d.f. = 8)……(4)

Differences in grain weight were not related to PSMD or to grain yield. Screenings were significantly (P<0.001) higher in the full and drought treatments compared to no and early drought.

DISCUSSION

We applied drought treatments commencing as much as 6 weeks apart, yet found no evidence of an effect of timing of drought stress on yield or associated characters. The linear relationship between grain yield and PSMD means that the effect of water stress can be easily quantified by using the relationship in Equation 2. Above a potential deficit of c. 250 mm on this soil, grain yield declined by 12 kg/ha for every mm increase in potential soil moisture deficit, irrespective of stage of growth. Growers can use this information to optimise irrigation of oats by calculating PMSD for crops using their own rainfall and

irrigation measurements and potential evapotranspiration published in the newspapers. The critical PSMD when grain yield starts to decline will change with different soil water holding capacities, but the rate of yield decline is unlikely to change (8).

The linear relationship between grain yield and PSMD for oats was similar to those for barley, maize, peas and wheat grown in this rainshelter (3, 5), and shows that, as for these crops, oat grain yield is not affected by timing of water stress, in contrast to the results reviewed by Brouwer & Flood (1) and Salter & Goode (10). The yield loss/mm of deficit in oats was higher than for peas (8 kg/ha/mm water), similar to maize (11 kg/ha/mm), but lower than barley (25kg/ha/mm) or wheat (21 kg/ha/mm) (3, 5). This suggests that, contrary to previous reports (1, 10), oats may not be more sensitive to than other cereals.

Although yield was not affected by timing of water stress, screenings were higher with late drought, when grains were filling. Therefore, irrigation timing may be critical to meet some crop quality requirements.

One difference with previous trials in the rainshelter (3, 5) was the reduction in yield of the no drought treatment, and one of the late drought treatments, caused by lodging. Lodging is a problem in oats, even in semi-dwarf cultivars like Drummond. A straw shortener and less nitrogen fertiliser may have reduced lodging, but both can lead to an increase in screenings (6).

CONCLUSIONS

There was no evidence that oat yield was more sensitive to drought stress at any particular growth stage. Hence oats should be watered on the basis of potential soil moisture deficit calculations (i.e. when it gets dry), not stage of crop development.

Some quality parameters were sensitive to timing of drought stress, and, in the case of screenings, irrigation should be continued until grain fill is completed.

Oats show a linear decline in yield with increasing potential soil moisture deficit above a critical deficit of c. 250mm, allowing the calculation of irrigation requirement or yield loss due to drought stress. At lower deficits, yield may also be reduced by lodging, and, in this situation, the crop will need to be managed to reduce lodging risk.

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