Research Note

Water Stress and Seed Yield in Perennial Ryegrass (*Lolium perenne* L.) Grown in Pots

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ABSTRACT

Climate change predictions indicate that drought-events will become more frequent in the major seed-growing areas of New Zealand. In order to provide information to assist in irrigation-scheduling in perennial ryegrass (*Lolium perenne* L.), individual plants were grown in 4 litre pots filled with a 4:1 mix of soil:gravel. Pots were maintained at approximately 90 % field capacity except during one of four stages of plant development: stem elongation, head emergence, anthesis or seed-fill. At each stage soil moisture was depleted to 90 % (control), 70, 60, 50, 40 or 30% of field capacity by withholding watering. These soil moistures were maintained for 1 day after the desired level had been reached during stem elongation and head emergence, and for 5 days during anthesis and seed-fill. Increasing moisture stress at stem elongation was associated with a reduction in reproductive tillers and seed yield was significantly reduced at soil moisture depletions to 50% of field capacity or lower. Moisture stress at anthesis (at 70, 40 and 30% field capacity) and at seed fill (at 70 % field capacity) also reduced seed yield, but moisture stress during head emergence had no effect on seed yield. Although soil moisture depletion decreased the rate of leaf photosynthesis, the effect was not related directly to seed yield.

Additional index words: **irrigation, moisture stress, photosynthesis, ryegrass, seed yield.**

EXPERIMENTAL AND DISCUSSION

Most grass seed produced in New Zealand is grown in the drought-prone, east coast regions of Canterbury and North Otago (Seed Statistics, 1995); climate-change predictions for these regions indicate that the incidence of droughts will increase (N. Cherry, Lincoln University, pers. comm., 1997). Although 50 % of growers on the Canterbury Plains have irrigation systems (Rolston, Rowarth, DeFilippi and Archie, 1994), water requirements exceed supply; seed growers thus have limited irrigation ability. This means that they must ration their water, using it on susceptible and high value crops as appropriate. Soil moisture depletion during the growing season reduces seed yield in herbage seed crops (Lambert, 1967; Hebblethwaite, 1977; Guy, Archie and Rowarth, 1990). However, the sensitive stages for water stress, and what constitutes a water stress, have yet to be defined for perennial ryegrass (*Lolium perenne* L.) seed crops.

In the past, growers have tended to irrigate grass seed crops according to a cereal schedule. However, a recent study at AgResearch Lincoln indicated that water use by ryegrass was double that of wheat (*Triticum aestivum* L.), reflecting the greater dry matter production of the ryegrass crop (Rowarth, Archie and Rolston, unpublished). Furthermore, as growers use more nitrogen in an attempt to increase yields (Rowarth, 1997), water use increases (Cookson, Rowarth and Cameron, 1997).

In general, irrigation extends the period of reproductive development and increases seed yield (Lambert, 1967; Hebblethwaite, 1977; Guy *et al.,* 1990; Rolston *et al.*, 1994). Water deficit before stem elongation can reduce head numbers, thereby decreasing seed yield (Hebblethwaite, 1977). After stem elongation, a water deficit of less than 100 mm has little effect on floret site utilisation (FSU; the number of seeds as a percentage of numbers of florets) (Hebblethwaite, 1977) and seed yields of over 2000 kg ha^{-1} can be obtained (Rolston *et al.*, 1994). Moisture stress after anthesis reduces thousand seed weight (Lambert, 1967), probably due to a reduction in photosynthetic area and capacity. Excess water, however, can increase vegetative tillers (Hebblethwaite, 1980), which have been reported to be a stronger assimilate sink than reproductive tillers. Assimilate partitioning away from the developing seeds causes increased abortion and reduces seed yields in *Lolium multiflorum* Lam. (Griffith, 1992). However, recent studies with perennial ryegrass (Warringa and Kreuzer, 1996) indicate no major effect of competition between growth of vegetative tillers after anthesis and seed development. The difference in conclusions may be due to

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Accepted for publication 8 October,1997.

species differences or to differences in growing conditions before anthesis (although both experiments were in glasshouses) affecting storage of mineral nutrients and water soluble carbohydrates.

The experiment reported here was established in an attempt to identify stages of development in perennial ryegrass during which moisture stress would have a detrimental effect on physiological activity, and to examine the consequent effects on seed yield.

Individual plants of perennial ryegrass cv. Grasslands Nui, were transplanted from the field in August 1994 into 230 x 4 litre pots with drainage holes. Plants were then five months old and each had four tillers; plants were chosen for uniformity of size. Pots contained a 4:1 soil:gravel mix by volume, to a constant bulk density of 1.2 kg m^{-3} and a constant weight of 5347 g. Forty g of Osmocote Plus Controlled Release Fertiliser was added to each pot. The soil was a Templeton silt loam (Udic Ustochrept) and the gravel was screened (2-5 mm) and washed greywacke. Mixing of the media components was done in a cement mixer. Field capacity of pots was determined by saturating the contents, allowing the pots to drain for 24 hours, weighing, drying to constant weight at 105 °C, and calculating the difference. Pots were maintained at around 90 % field capacity by twice-daily watering; pots were weighed weekly to ensure no over- or under-watering had occurred. During imposed moisture depletion events, pots were protected from rain.

Different soil moisture treatments (90 % (control), 70, 60, 50, 40, or 30 % of field capacity) were imposed on the ryegrass plants at each of four different developmental stages (stem elongation, head emergence, anthesis or seed-fill), by withholding watering. Pots were weighed twice daily during the stress period to assess soil moisture depletion. During stem elongation and head emergence, soil moisture treatments were maintained for 1 day after reaching the desired soil moisture. During anthesis and seed-fill soil moisture treatments were maintained for 5 days; it took twice as long to reach 30 % field capacity (4 days) as it did to reach 70 % field capacity. Plants were then rewatered to 90 % field capacity. Each treatment had five replicates. Reproductive development was assessed by dissecting tillers from ten non-experimental plants.

Plants were harvested when seed shattering was imminent. Reproductive analyses (spikelets per head, florets per spikelet and seeds per floret) were done on 20 heads per plant. Samples were threshed by hand and dressed using a Buro seed cleaner at 30 mm aperture for one minute. Floret site utilisation was calculated from the actual seeds per head divided by the potential seeds per head (florets).

Leaf photosynthetic rates were measured using a LI-COR LI6200 Portable Photosynthesis System with the LI6250 Infra Red Gas Analyser (IRGA) on one leaf per plant five times between 1200 and 1400 h for each stage of development and soil moisture treatment. Leaves of the same size, age and position on the plants were selected. Rates of photosynthesis for a given treatment were expressed as a proportion of the rates for the control plants measured the same day.

Analyses of variance were performed on the data using GENSTAT 5 (Rothamsted). Regression analyses were performed using Sigma plot.

Depleting soil moisture at stem elongation was associated with a significant ($P<0.05$) decrease in seed yield at moisture stresses of 50% field capacity or below (Table 1). Much of the decrease in yield (Seed yield = 0.12 x heads per plant - 6.35, $R^2 = 0.72$) was due to a decrease in head numbers with increasing stress, thus confirming the results of Hebblethwaite (1977).

Although soil moisture deficits do not traditionally occur prior to head emergence, they are not unknown in Canterbury; climate predictions indicate that these early deficits are likely to increase (N. Cherry, Lincoln University, pers. comm., 1997). These results indicate the importance of avoiding early stress to plants by irrigating if necessary; heads are a major determinant of yield potential (Hebblethwaite, 1977) and their numbers should not be compromised. Removal of the stress by irrigation later in the season is likely to stimulate secondary tillers, but these tend to have reduced numbers of florets per spikelet and spikelets per head (Anslow, 1963). Furthermore, they are unlikely to be ready for harvest at the same time as the main crop, and will increase harvesting difficulties.

Soil moisture depletion during anthesis also caused a significant ($P<0.05$) reduction in seed yield at 70, 40 and 30% field capacity (Table 1). This yield loss may reflect the sensitivity of the pollen tube and the developing ovule to moisture stress (Anslow, 1963; Hill, 1980), resulting in failure of pollination or early abortion, and supports observations by Hebblethwaite (1977). A further consideration is that current photoassimilate supply is important for the development of ovules (Warringa, 1997);

Table 1. Effect of soil moisture depletion to the indicated % field capacity at four stages of perennial ryegrass development on seed yield

	Stress	**Seed yield (g plant^{-1})**						
Growth stage	**(days)**	**Control**	**70 %FC**	**60 %FC**	**50 %FC**	**40 %FC**	**30 %FC**	
Stem elongation	1	7.23	5.89	6.58	4.66	4.78	4.66	LSD$_{P<0.05}$=2.3
Head emergence	1	7.23	8.27	7.18	5.80	8.83	7.23	ns
Anthesis	5	7.23	3.22	6.42	5.71	4.03	4.52	LSD$_{P<0.05}$=3.1
Seed fill	5	7.23	4.26	5.44	8.84	6.05	9.61	LSD$_{P<0.05}$=2.8

moisture stress causes stomata to close and photosynthesis to be reduced (Hsaio, Acedevo, Fereres and Henderson, 1976).

There was no significant effect of increasing moisture stress at head emergence (probably because the duration of stress was too short) and limited effect during seed fill (possibly because the soil moisture depletion event was too close to harvest) on seed yield. A further consideration is that with increasing maturity the plants were more acclimatised to conditions of transient moisture stress (caused, for instance, by hot Föhn winds) and were thus less susceptible to the imposed moisture stress.

Growth stage at which moisture stress occurred had a significant effect (P<0.05) on FSU (Table 2). Average FSU for moisture stress at stem elongation (17%) was significantly lower than average FSU for moisture stress during seed fill (23%); FSU for moisture stress during head emergence and anthesis was intermediate. There was a significant interaction (P<0.05) between stage at which moisture stress occurred and degree of moisture stress on FSU. Plants undergoing stem elongation were more sensitive to a 24 h water stress of 40 or 30% field capacity than plants at head emergence; plants at anthesis were more sensitive to a five-day moisture stress of 40 or 30% field capacity than those at seed fill. Low FSUs associated with soil moisture depletion at stem elongation may be associated with sterile florets or degenerated ovules (as defined by Elgersma and Sniezko, 1988); this requires further investigation. There is no apparent biological explanation for the fact that the FSUs associated with 30-50 % field capacity during seed fill and 50 % field capacity at anthesis were significantly greater than other treatments. Indeed, more abortion, and hence a reduced FSU %, might have been expected with drought during seed fill (Hebblethwaite, Wright and Noble, 1980). Change in FSU accounted for almost half of the reduction in seed yield at anthesis ($R^2 = 0.49$); small but insignificant decreases in head numbers and spikelets per head also contributed.

Moisture stress had no significant effects on thousand seed weight (average=2.4g), florets per spikelet (average=9.1) or spikelets per head (average=17.8). Thousand seed weights for all treatments were above 2.1 g, but seed cleaning imposes a threshold weight and can remove treatment differences. However, moisture stress did not affect the proportion of seconds (light weight seed) in the treatments (average=6.1%). This result contrasts with reports that moisture stress during seed fill will reduce thousand seed weight (Hebblethwaite *et al.*, 1980). It is possible that the moisture stress occurred too near to harvest to affect starch accumulation (Stoddart, 1968).

No decrease in photosynthesis was apparent during the 24 h stresses imposed at stem elongation or head emergence (data not presented). For this reason subsequent stress periods were increased to 5 days. Increasing moisture stress during anthesis or seed fill resulted in a significant (P< 0.01) decrease in rate of photosynthesis (Fig. 1). At anthesis the reduction became apparent below 70 % field capacity; during seed fill the reduction was apparent below 90 % field capacity. The apparent increase in sensitivity during seed fill was not related to a decrease in seed yield. This may reflect the fact that current photosynthate was not required for starch accumulation in the seed; in ryegrass translocation of pre-flowering stored reserves from the stem can account for 50% of seed starch (Roy and Rolston, 1994). However, only one 'representative' leaf was measured per plant. It is likely that improved sensitivity would have been obtained by using a chamber encompassing the whole plant (A. Grau, Invermay, pers. comm., 1996).

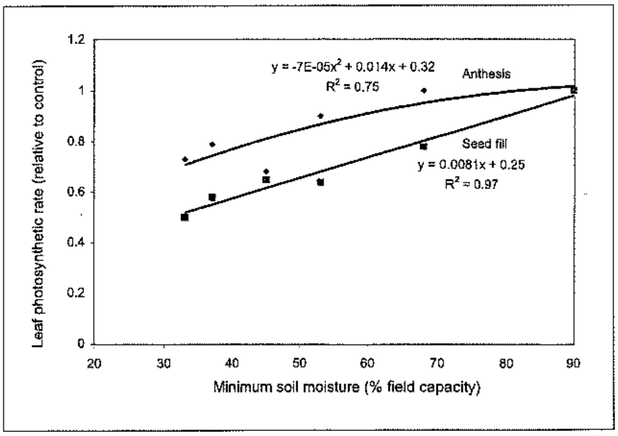

Fig 1. Relationship between relative photosynthesis and soil moisture (% field capacity) at anthesis and during seed filling. Photosynthesis on the third day of the indicated soil moisture stress is presented relative to photosynthesis of the control pots at 90% field capacity.

Table 2. Effect of soil moisture depletion to the indicated % field capacity at four stages of perennial ryegrass development on floret site utilisation (FSU)

	Stress				FSU (%)[1]		
Growth stage	**(days)**	**Control**	**70 %FC**	**60 %FC**	**50 %FC**	**40 %FC**	**30 %FC**
Stem elongation	1	18	19	21	15	15	13
Head emergence	1	18	21	19	19	23	21
Anthesis	5	18	13	26	28	16	19
Seed fill	5	18	18	19	28	25	27

[1] *LSD (P<0.05)= 7.7 for comparisons between control and individual treatments*

Further research should include longer stress events mimicking different rates of evapotranspiration, plus relief (irrigation) at different stages. Whole plant physiology should be related to soil moisture depletion to determine the degree of soil moisture necessary to prevent moisture stress in ryegrass.

ACKNOWLEDGEMENTS

This work was facilitated by the award of an AgResearch Summer Scholarship to the third author and the assistance of Mrs Lesley Hunt, statistician, AgResearch Grasslands. The authors also thank Mrs Tro Rowarth for assisting with harvesting and Professor Ian Cornforth for commenting on the manuscript.

REFERENCES

1. Anslow, R.C. 1963. Seed formation in perennial ryegrass. I. Anther exsertion and seed set. *Journal of the British Grassland Society* 18: 90-96.
2. Cookson, W.R., Rowarth, J.S. and Cameron, K.C. 1997. Effects of nitrogen fertilizer on the irrigation requirements of a perennial ryegrass (*Lolium perenne* L.) seed crop. *Journal of Applied Seed Production* 15: 95-98.
3. Elgersma, A. and Sniezko, R. 1988. Cytology of seed development related to floret position in perennial ryegrass (*Lolium perenne* L.). *Euphytica* S: 59-68.
4. Griffith, S.M. 1992. Changes in post-anthesis assimilates in stem and spike components of Italian ryegrass (*Lolium multiflorum* Lam.) I. Water soluble carbohydrates. *Annals of Botany* 69: 243-248.
5. Guy, B.R., Archie, W.J. and Rowarth, J.S. 1990. Browntop seed production: past, present and future. *Proceedings of the New Zealand Grassland Association* 52: 87-89.
6. Hebblethwaite, P.D. 1977. Irrigation and nitrogen studies in S.23 ryegrass grown for seed 1. Growth, development, seed yield components and seed yield. *Journal of Agricultural Science, Cambridge* 88: 605-614.
7. Hebblethwaite, P.D. (ed.) 1980. Seed Production. Butterworths, London-Boston, 694 pp.
8. Hebblethwaite, P.D., Wright, D. and Noble, A. 1980. Some physiological aspects of seed yield in *Lolium perenne* L. (perennial ryegrass). In: Seed Production (ed. P.D. Hebblethwaite), Butterworths, London-Boston, pp 71-90.
9. Hill, M.J. 1980. Temperate pasture grass seed crops: formative factors. In: Seed Production (ed. P.D. Hebblethwaite), Butterworths, London-Boston, pp 137-149.
10. Hsaio, T.C., Acedevo, E., Fereres, E. and Henderson, D.W. 1976. Water stress, growth and osmotic adjustments. *Philosophical Transactions of the Royal Society, London* 273: 479-500.
11. Lambert, 1967. The effects of nitrogen and irrigation on timothy (*Phleum pratense*) grown for production of seed. *Journal of Agricultural Science, Cambridge* 69: 231-239.
12. Rolston, M.P., Rowarth, J.S., DeFilippi, J.M. and Archie, W.J. 1994. Effects of water and nitrogen on lodging, head numbers and seed yield of high and nil endophyte perennial ryegrass. *Proceedings of the Agronomy Society of New Zealand* 24: 91-94.
13. Rowarth, J.S. 1997. Nutrients and moisture inputs for grass seed yield. *Journal of Applied Seed Production* 15: 103-110.
14. Roy, S.K. and Rolston, M.P. 1994. Contribution of pre-flowering stored stem reserves to developing seeds of different field crops: a review. *Proceedings of the Agronomy Society of New Zealand* 24: 51-55.
15. Seed Statistics. 1995. Ministry of Agriculture and Fisheries, Christchurch, Canterbury.
16. Stoddart, J.L. 1968. Biochemical aspects of seed ripening in grasses. *Journal of the National Institute of Agricultural Botany* 11: 370-377.
17. Warringa, J.W. 1997. Physiological constraints to seed growth in perennial ryegrass (*Lolium perenne* L.). Unpublished Doctoral thesis, Wageningen Agricultural University, Wageningen, Netherlands. 139 pp.
18. Warringa, J.W. and Kreuzer, A.D.H. 1996. The effect of new tiller growth on carbohydrates, nitrogen and seed yield per ear in *Lolium perenne* L. *Annals of Botany* 78: 749-757.