Irrigation management of perennial ryegrass (*Lolium perenne*) seed crops

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Abstract

An experiment on a first year perennial ryegrass (*Lolium perenne*) seed crop, cv. 'Grasslands Samson' was established at the FAR Arable Site, Chertsey, Canterbury in the 2009-10 season. Eight irrigation treatments were applied with an above ground trickle tape irrigation system. Treatments ranged from 0 to 310 mm for the untreated and fully irrigated treatments respectively. Maximum potential soil moisture deficit ranged from 45 to 281 mm. Untreated plots achieved 1997 kg/ha seed compared with 2500 kg/ha for the fully irrigated treatment, an increase of 1.6 kg of seed per mm of applied irrigation. Maximum seed yields were achieved from treatments where greater than 205 mm of irrigation were applied. Application rates lower than the measured evapotranspiration rate but greater than 205 mm allowed for efficient capture of rainfall, compared with the fully irrigated treatment where the majority of rainfall was lost to drainage. Any period of drought reduced seed yield regardless of timing. Reduction in seed yield was associated with a 22% change in thousand seed weight (2.02 versus 2.59 g). There was no difference among treatments in the number of reproductive tillers produced or the dry matter present at harvest.

Additional keywords: evapotranspiration, lodging, potential soil moisture deficit, seed yield

Introduction

About 70% of all the perennial ryegrass (*Lolium perenne* L.) seed crops in New Zealand have the potential to be irrigated. Crops are grown on a wide range of soil types with varying water holding capacity. Grass seed crop responses to irrigation and timing of irrigation (e.g. pre anthesis versus seed fill) have been difficult to measure because of the effect of untimely rainfall on irrigation treatments and changes in harvest index. Martin *et al*. (2003) found that in a second year ryegrass crop, where rainfall was excluded through the use of a mobile rain shelter, seed yields responded linearly to increasing potential soil moisture deficits (PSMD) on a deep soil at Lincoln, Canterbury. However, an experiment at the same location where rainfall was excluded on a first year crop found no difference in harvested seed yield when PSMD approached 500 mm (Geary, 2002). Growers report that ryegrass seed yield is heavily impacted when drought occurs but not all research supports these observations. All of the experiments in New Zealand have been done on heavy soil types with readily available water holding capacity of >130 mm/m of soil depth. This experiment was set up on a soil with a readily available water holding capacity of approximately 60 mm (total water holding capacity 120 mm, 0-0.6 m depth). The aim of this experiment was to compare results by Martin *et al*. (2003) with results generated on lighter soil types without rainfall exclusion and produce guidelines for growers on irrigation management in perennial ryegrass seed crops.

Materials and Methods

The experiment was sown at the FAR Arable Site, Chertsey, Canterbury (43° 47' S, 171° 58' E) with the diploid cultivar 'Grasslands Samson'. Plots were 10 m by 1.6 m with treatments in a randomised block design with four replicates. The experiment was sown 10 April 2009 at 12 kg/ha with 15 kg/ha of suSCon Green® (a.i. 100 g/kg chlorpyrifos) for grass grub control. The soil type was a Chertsey silt loam (Kear *et al*., 1967) comprised of approximately 0.6 m of silt loam over gravel with no impermeable layers which would restrict rooting depth. The total water holding capacity, 0-0.6 m depth, was approximately 120 mm of which approximately half is readily available.

Irrigation was applied via an above ground trickle tape system at approximately 12 mm/hour. Lateral tapes were spaced 0.33 m apart on which drippers were 0.33 m apart. The trickle tape had an application capacity of 150 l/100 m/hour. Application rates were based on replacing evapotranspiration, calculated using the Priestly-Taylor equation (Priestly and Taylor, 1972) using data from a weather station located 150 m from the experimental site. Irrigation treatments (Table 1) started on 5 November when the measured soil moisture deficit was approximately 20 mm. Soil moisture was measured in each plot by neutron probe in the 0-0.6 m layer of the soil, with an assumed full-point averaging 112 mm. Readings were made weekly from 1 November to 2 or 10 January depending on windrowing date.

Table 1: Irrigation treatments applied to perennial ryegrass, cultivar 'Grasslands Samson', FAR Arable Site, Chertsey, Canterbury during the 2009-10 growing season.

Treatment	Treatment
1	No irrigation
2	Replace 33% ET
3	Replace 66% ET
4	Replace ET
5	Nil until anthesis then replace ET
6	Nil until anthesis then 50% ET
7	Replace ET until anthesis then Nil
8	Replace ET until anthesis then 50% ET

Weed control was achieved by the application of Jaguar® (a.i. 25 g/l diflufenican and 250 g/l bromoxynil) at 1.5 l/ha on 6 October 2009. The experiment was defoliated twice using a ride-on lawn mower to control excess crop dry matter with the final defoliation on 25 September 2009. Nitrogen was applied at 40 kg N/ha in mid-August (as urea) and 140 kg N/ha on 25 September 2009 (as SustaiN®).

Moddus® (a.i. 250 g/l trinexapac ethyl) plant growth regulator was applied to all treatments at 1.6 l/ha on 28 October 2009 in a mix with 0.3 l/ha Opus® (a.i. 125 g/l epoxiconazole) fungicide. Additional fungicides, 0.4 l/ha Proline® (a.i. 250 g/l prothioconazole) and 0.5 l/ha Amistar® (a.i. 250 g/l azoxystrobin), were applied at ear emergence/anthesis as part of a preventative fungicide programme on 30 November 2009.

Lodging was visually assessed weekly following anthesis and scored as a percentage where 0% was completely vertical, at 50% the whole plot was leaning on a 45° angle and at 100% the whole plot was horizontal.

At seed harvest plots were windrowed using a plot windrower at 40% seed moisture content (SMC) and threshed at approximately 12% SMC using a Wintersteiger plot combine. Treatments where <200 mm of irrigation were applied were windrowed on 3 January 2010, all remaining treatments were windrowed on 11 January 2010. Seed was cleaned to a 1st Generation purity standard (≥98.0%) and the machine dressed yield (kg/ha) calculated. Seed yield and thousand seed weights are reported at 12% SMC.

Long term rainfall records for the experimental area are based on those from AgResearch Winchmore, located 13 km west of the experimental site. All statistical analysis was completed using Statistix 9 (Analytical Software, Florida, USA). Seed yield data was tested by analysis of variance (ANOVA) and where significant effects were observed ($P<0.05$), differences were compared using the least significant difference (LSD) procedure ($P=0.05$). All relationships were tested by linear regression.

Rainfall

Rainfall in spring 2009 was similar to evapotranspiration with winter soil recharge and frequent rainfall events maintaining adequate soil moisture levels until November. Evapotranspiration exceeded rainfall from October to January inclusive (Table 2) resulting in a potential soil moisture deficit (PSMD) of 261 mm by 11 January 2010.

Table 2: Rainfall (mm) and evapotranspiration (mm) for 2009-10 at the FAR Arable Site, Chertsey, Canterbury and long term average rainfall from AgResearch Winchmore (13 km west).

Month	2009-10 rainfall (mm)	2009-10 evapotranspiration (mm)	Long term average rainfall (Winchmore) (mm)
October	76	101	61
November	18	118	65
December	38	134	69
1 to 11 January	19	55	64 (monthly)
Total	151	408	259

Results

Seed yield

Seed yield was increased by treatments where greater than 205 mm of irrigation was applied (Figure 1, Table 3). The seed yields were similar ($P<0.05$) to that of the untreated control where 33% of ET was replaced or in those treatments which experienced a period of drought e.g. prior to or following anthesis. For the applications between approximately 150 and 210 mm of applied irrigation, the seed yield response was 8.5 kg of seed/mm of irrigation.

No seed yield difference was shown between the timing of applied irrigation when drought was experienced either prior to, or following anthesis (Table 3). Water stress prior to anthesis reduced seed yield by approximately 500 kg/ha, a similar yield loss to when water stress occurred post anthesis, indicating that the response to timing of drought is similar regardless of when water stress occurs.

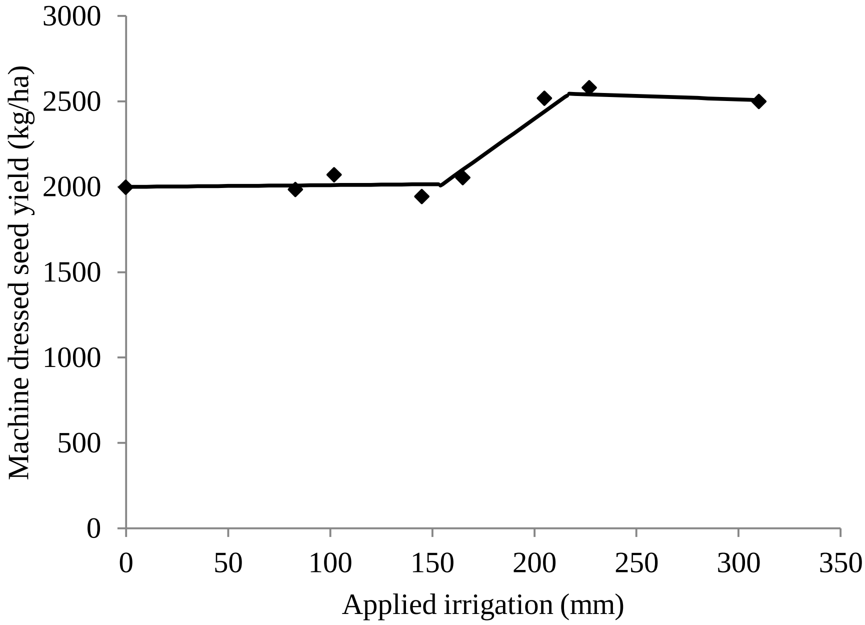

Figure 1: Perennial ryegrass, cultivar 'Grasslands Samson', seed yield response to applied irrigation (mm) at the FAR Arable Site, Chertsey, Canterbury during the 2009-10 growing season.

Table 3: Applied irrigation and seed yield responses to eight different irrigation treatments for 'Grasslands Samson' perennial ryegrass, FAR Arable Site, Chertsey Canterbury. Mid-anthesis occurred 5 December 2009 (ET = evapotranspiration).

Treatment	Applied irrigation (mm)	Seed yield (kg/ha)
No irrigation	0	1997
Replace 33% ET	102	2070
Replace 66% ET	205	2518
Replace ET	310	2500
Nil until anthesis then replace ET	165	2054
Nil until anthesis then 50% ET	83	1984
Replace ET until anthesis then Nil	145	1943
Replace ET until anthesis then 50% ET	227	2581
$LSD_{(0.05)}$		290

Lodging

Lodging developed more rapidly from the onset of anthesis in treatments where irrigation was applied early in the season.

When irrigation was applied to replace ET prior to anthesis, crops reached 50% lodging approximately 17 days after anthesis. The 'no irrigation' and 'no irrigation until anthesis followed by replace 50% ET' did not lodge prior to harvest (Table 4). At harvest all treatments were fully lodged with the exception of those where irrigation was excluded prior to anthesis.

Soil moisture deficits

The maximum potential soil moisture deficit (MPSMD) (calculated as the sum of ET minus rainfall and irrigation) ranged between 45-281 mm in the fully irrigated and no irrigation treatments respectively (Table 5). Only where MPSMD did not exceed 53 mm was the seed yield significantly increased (≥2500 kg/ha).

Table 4: Days to 50% lodging following anthesis (0 = anthesis, 33 = harvest) and lodging percentage at harvest for eight irrigation treatments 'Grasslands Samson' perennial ryegrass at the FAR Arable Site, Chertsey, Canterbury during the 2009-10 growing season. 50% lodging described as the plot area leaning on a 45° angle.

Treatment	Days to 50% lodging	Lodging at harvest (%)
No irrigation	33[1]	14
Replace 33% ET	21	93
Replace 66% ET	17	95
Replace ET	18	93
Nil until anthesis then replace ET	26	44
Nil until anthesis then 50% ET	33[2]	58
Replace ET until anthesis then Nil	16	99
Replace ET until anthesis then 50% ET	19	96
$LSD_{(0.05)}$	9.2	15

[1]50% lodging not reached.
[2]50% lodging observed on day of cutting only.

Table 5: Maximum potential soil moisture (MPSMD) and timing when MPSMD deficit occurred for eight irrigation treatments 'Grasslands Samson' perennial ryegrass at the FAR Arable Site, Chertsey, Canterbury in the 2009-10 growing season.

Treatment	Maximum potential soil moisture deficit (MPSMD)	Date of MPSMD
No irrigation	281	3 January 2010
Replace 33% ET	136	3 January 2010
Replace 66% ET	53	11 November 2009
Replace ET	45	11 November 2009
Nil until anthesis then replace ET	136	29 November 2009
Nil until anthesis then 50% ET	156	3 January 2010
Replace ET until anthesis then Nil	93	3 January 2010
Replace ET until anthesis then 50% ET	45	11 November 2010

Yield loss and Maximum Potential Seed Moisture Deficit

The relationship between MPSMD and seed yield was linear with a loss of 3.2 kg/ha seed for each mm of potential deficit above approximately 50 mm. However, while statistically significant ($P<0.05$) the model does not visually fit the data perfectly, partly due to the untreated plots yielding higher than expected (data not presented). One possible explanation for this result is the differential lodging which occurred with the variations in applied irrigation. Seed yield was adjusted based on a 22 kg/ha/day loss for every day spent at >50% lodging in an attempt to remove the differences associated with lodging (Rolston *et al*., 2010). After transformation, MPSMD explained approximately 72% of the variability among treatments, with a seed yield loss of 4.3 kg/ha/mm of deficit above 50 mm (Figure 2).

Harvest Components

Irrigation treatments produced no difference in total dry matter/ha, harvest index or seed heads/m^2 (Table 6), spikelet's/head ($P=0.45$) or fertile florets ($P=0.94$) (data not presented). There was a 22% reduction in thousand seed weight for the no irrigation treatment (2.02 g) compared with the fully irrigated treatment (2.56 g).

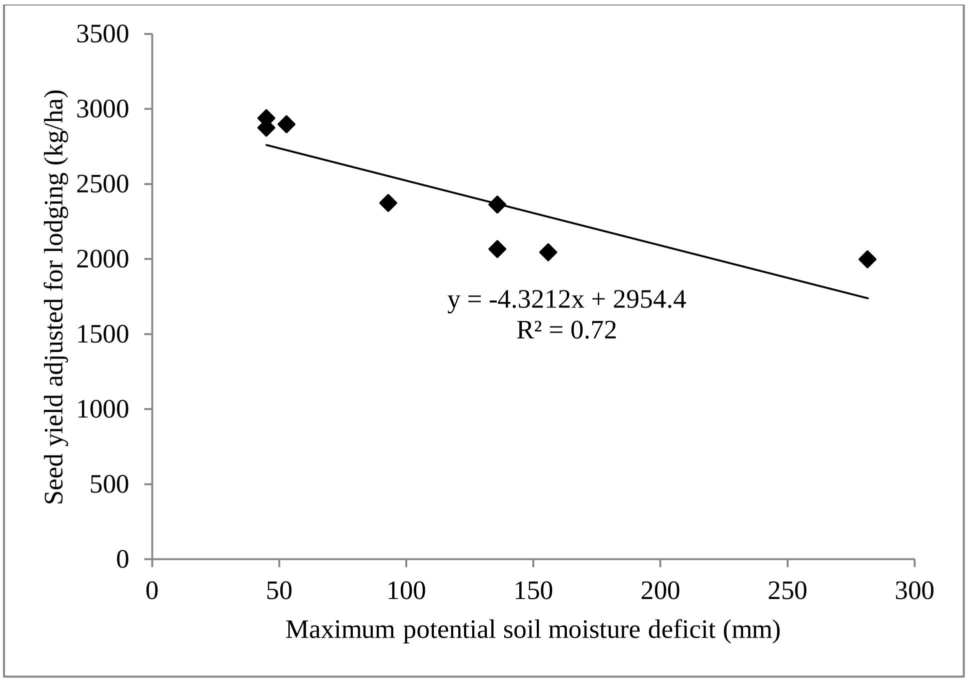

Figure 2: Relationship between seed yield adjusted for lodging and maximum potential soil moisture deficit for 'Grasslands Samson' perennial ryegrass grown at the FAR Arable Site, Chertsey, Canterbury in the 2009-10 season, (lodging adjusted at 22 kg/ha/day for each day ≥ 50% lodging, defined as the crop leaning on a 45° angle).

Table 6: Dry matter, seed heads/m^2, harvest index and thousand seed weight (TSW) for eight irrigation treatments on 'Grasslands Samson' perennial ryegrass at the FAR Arable Site, Chertsey, Canterbury in the 2009-10 growing season.

Treatment	Dry matter (kg/ha)	Seed heads/m^2	Harvest index (%)	TSW (g)
No irrigation	12060	1860	14	2.02
Replace 33% ET	12450	1810	14	2.19
Replace 66% ET	12780	1800	17	2.59
Replace ET	12550	2090	17	2.56
Nil until anthesis then replace ET	12710	1730	14	2.22
Nil until anthesis then 50% ET	12694	1960	14	2.32
Replace ET until anthesis then Nil	13820	1840	13	2.11
Replace ET until anthesis then 50% ET	13460	2050	16	2.55
$LSD_{(0.05)}$	3160	600	4	0.14
P-value	0.96	0.89	0.25	<0.001

Discussion

The aim of this experiment was to generate data on the response of perennial ryegrass to periods of drought on lighter soil types and produce guidelines for growers on irrigation management in perennial ryegrass seed crops. Seed yield of perennial ryegrass declined as drought intensity increased above a MPSMD of 53 mm regardless of timing however, above 93 mm of deficit the seed yields were similar (Figure 2). Spring rainfall ensured limited drought stress prior to seed head emergence, although at anthesis a PSMD of 140 mm had accumulated, similar to the deficit to that accumulated post anthesis (Table 5). The yield loss of 3.2 kg/ha/mm of deficit above critical deficit is similar to the reported by Martin *et al*. (2003) (3.7 kg/ha/mm) for perennial ryegrass. However, both these experiments demonstrated different degrees of lodging associated with variation in applied irrigation. Lodging reduces seed yield at approximately 22 kg seed/ha/day when 50% lodging is exceeded (Rolston *et al*., 2010). In the current experiment the fully irrigated treatments all lodged at a similar time, reaching 50% lodging approximately 17 days after anthesis (Table 4). It is estimated that this will have significantly reduced the potential seed yield of these plots. The seed yield loss per mm of deficit above 53 mm was 4.3 kg/mm when seed yield was adjusted for the number of days spent at ≥50% lodging (Figure 2). In this experiment 1.6 l/ha Moddus was not adequate to remove lodging as a variable and as such in future irrigation experiments lodging should be controlled through the use of higher rates of plant growth regulators. There was no advantage in applying greater than 205 mm of irrigation (although the potential deficit was 280 mm) and therefore growers need to consider the economic implications of applying excess water (Figure 1, Table 3). If soils are maintained near field capacity, when rainfall occurs during the growing season it is lost through drainage. In this experiment where 205 mm of irrigation was applied, i.e. the replace 66% ET treatment, rainfall could be additionally captured for plant use compared with the replace ET treatments which could not capture and store rainfall. This has practical and economic implications for growers, even when drier than average conditions prevail such as in the 2009-10 season.

In this experiment the number of seed heads/m^2 (Table 6) and the spikelets/head were set before water stress was experienced, therefore no differences in these parameters were observed or in the calculated number of spikelets/m^2. Hebblethwaithe (1977) showed that early drought reduced reproductive tillers which reduced seed yield, but found that when drought occurred late in the season seed yield was reduced by declining seed size only (reduced TSW). Martin *et al*. (2003) showed seed yield was strongly correlated to seed head numbers, and generally those treatments which were drought stressed earlier in the season had lower head numbers. Therefore there are implications of drought timing on yield components. The number of seed heads in all treatments reported above was near the lower end of those required for high seed yields (Hampton and Hebblethwaite, 1983). Therefore the number of seeds/head and/or individual seed weight were major determinants in machine dressed harvested seed yield. There were sizable differences in the measured thousand seed weight between different treatments with 22% variation between the highest and lowest TSW (Table 6), compared to 25% variation in harvested seed yield. Lower seed weight is often associated with a shorter grain fill period and reduced green leaf area duration e.g. reduced grain size in barley (Day *et al*., 1987).

Conclusions

Drought at any period in the spring/summer will reduce seed yield in perennial ryegrass. Potential soil moisture deficit can be used to manage drought responses with a yield loss of 3.2 kg/mm deficit above critical deficit expected. Critical deficit will vary with soil type at approximately half the readily available water within the rooting zone. These data will help growers to complete an economic analysis of missed irrigation application and/or drought.

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