Irrigation management of autumn sown feed wheat

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Abstract

The yield response of autumn sown feed wheat 'Wakanui' to nine irrigation treatments was determined at the FAR Arable Site, Chertsey, Canterbury in the 2012-13 season. Above ground trickle tape was used to apply the irrigation ranging from 15-295 mm for the untreated and fully irrigated treatments respectively. Yields ranged from 9.4 t/ha for unirrigated crops through to 13.8 t/ha for fully irrigated treatments. The maximum potential soil moisture deficit ranged from 86 to 331 mm. Grain yields were related to maximum potential soil moisture deficit and decreased by 2.6 t/ha for each 100 mm increase. The rate of yield loss due to drought was the same regardless of crop growth stage. Maximum yield was achieved from treatments applying more than 171 mm through the season.

Additional keywords: grain yield, potential evapotranspiration, potential soil moisture deficit, *Triticum aestivum*.

Introduction

Irrigated wheat (*Triticum aestivum* L.) production is an important component of cropping in New Zealand. There are approximately 50,000 ha of wheat grown annually, the majority of which is concentrated in Canterbury. About 70% of North and Mid-Canterbury arable farms are irrigated (Fraser and Lawrence-Smith, 2011) and efficient irrigation management is central to increasing grain yield and profitability. For example, at the FAR Chertsey Arable Site, the grain yield advantage of autumn sown feed wheat from irrigation, compared with dryland, over the last 4 years has been 48% (Foundation for Arable Research, 2013).

Research to guide wheat irrigation management in New Zealand is limited. An experiment in a rainout shelter at Lincoln, Canterbury in 1991 (Jamieson *et al.*, 1995) showed that as maximum potential soil moisture deficit (MPSMD) increased above a critical deficit (D_c) (262 mm) the grain yield of wheat decreased linearly. This experiment was sited on a deep alluvial soil (top soil 2 m) with high water holding capacity (approximately 280 mm of plant available water in the top 1.5 m) typical of only a small proportion of irrigated wheat in the region. A recent survey of mid- and north Canterbury arable farmers showed that 22% described their farms as having heavy soil (Fraser and Lawrence-Smith, 2011). Therefore, research on lighter soil would be useful. More recent work at Lincoln on a shallow soil was not able to establish a D_c (Minchin *et al.*, 2011). Also, wheat production has changed since this work was done with feed wheat sowing brought forward into April from June and the availability of cultivars with higher yield potential.

The aim of the current experiment was to refine management guidelines to assist farmers to irrigate wheat efficiently on medium soils typical of arable farms in Canterbury, using current crop production practices.

Materials and Methods

The experiment was at the FAR Arable Site, Chertsey, Canterbury (43° 47’ S, 171° 58’ E). The previous cropping history was peas preceded by two years of pasture. The soil type is a Chertsey silt loam (Kear *et al.*, 1967) with approximately 0.7 to 0.8 m of silt loam over gravel.

The seeds were sown on 26 April 2012 at 86 kg/ha with 15 kg/ha of SuSCon® Green (a.i. 100 g/kg chlorpyrifos) for grass grub control. A total of 36 plots (10 x 3 m) were drilled with ‘Wakanui’ feed wheat into a conventionally prepared seed bed. The experiment consisted of four replicates and nine treatments in a randomised block design (Table 1). A single application of 15 mm of water was applied to all treatments in early October, to water in the September application of nitrogen. Irrigation was applied with an above ground trickle tape system, installed on all plots, at approximately 12 mm/hour. A flow meter was installed to measure the volume of water applied. Lateral tapes were spaced 0.32 m apart. Soil moisture was measured in each plot by neutron probe in the 0-0.8 m profile of soil. Autumn drilled wheat can extract water from deeper than 0.8 m but because of a cemented gravel layer it was not possible to install access tubes deeper than 0.8 m (nor was water extraction by roots in this layer likely to be substantial). Readings were taken weekly from 26 September to 1 February.

Table 1: Irrigation treatments and applied irrigation to wheat, cultivar ‘Wakanui’ at the FAR Arable Site, Chertsey, Canterbury during the 2012-13 growing season. Anthesis occurred 5 December 2012 (PET = potential evapotranspiration).

Treatment number	Treatment	Applied irrigation (mm)
1	No irrigation	15
2	Replace PET every week	295
3	Replace PET every 2 weeks	160
4	Replace 33% PET until anthesis then nil	38
5	Replace 66% PET until anthesis then nil	62
6	Replace 100% PET until anthesis then nil	85
7	Nil until anthesis then 33% PET	85
8	Nil until anthesis then 66% PET	155
9	Nil until anthesis then 100% PET	225

Water was applied based on replacing potential evapotranspiration using data from a weather station located 150 m from the experimental site. Any rainfall between irrigations was subtracted from the irrigation to be applied. Evapotranspiration exceeded rainfall each month from September to January, although by only 6 mm in October (Table 2).

Weed control consisted of the application of 0.3 l/ha Firebird® (a.i. 400 g/l flufenacet and 200 g/l diflufenican) on 7 May, 4 l/ha

Legend (a.i. 600 g/l mecoprop, 150 g/l MCPA and 18.7 g/l dicamba) on 22 June and 0.3 l/ha Twinax® (a.i. 100 g/l pinoxaden) and 0.75 l/ha Starane™ (a.i. 333 g/l fluroxpyr) on 18 September. Pest control was maintained with 40 ml/ha Karate® zeon (a.i. 250 g/l lambda-cyhalothrin) on 22 June. Fertiliser was applied so that nutrition was not a limiting factor. The soil mineral nitrogen content on 6 August from 0 to 0.6 m was 31 kg/ha. Urea (46% N) was applied at 70 kg/ha on the 28 August, 120 kg/ha on 19 September and 120 kg/ha on 5 November. The preventative fungicide programme consisted of 1 l/ha Opus® (a.i. 125 g/l epoxiconazole) on 26 October, 1 l/ha Opus® and 0.8 l/ha Comet (a.i. 250 g/l pyraclostrobin) on 13 November and 6 December. A plant growth regulator was applied at 2.0 l/ha Cycocel® (a.i. 750 g/l chlormequat) to reduce the risk of lodging on 18 September.

Before flowering, nets were installed over the plots to prevent bird damage.

The experimental crops were harvested with a Sampo plot combine at approximately 14% moisture content. Plot yields were weighed on board using a load celled bin and grain moisture was measured at the same time using a whole grain moisture probe. A sample of approximately 1 kg grain from each plot was retained for later quality testing. The harvest date was 13 February. Grading tests included: Screenings (%), Thousand Grain Weight (g), and Test Weight (kg/hl).

Actual soil moisture deficit

Neutron probe access tubes were installed in each plot in late September and soil moisture content was measured at 0.1 m depth increments from 0.15 to 0.75 m at approximately weekly intervals thereafter. Measurements from the 0.15 m depth were used to represent the moisture content of the 0-0.2 m layer and subsequent measurements represented the 0.1 m of soil surrounding the measurement depth. A measurement of soil moisture content was taken on 15 October, two days after a week of heavy rain (73 mm of rain in the preceding week and 45 mm two days prior) and these values were used to represent field capacity. The actual soil moisture deficit (ASMD) was calculated on each measurement date by subtracting the measured value from field capacity and the maximum actual soil moisture deficit was the highest value recorded for each treatment during the season. The plant available water content (PAWC) in the top 0.8 m of soil was calculated by subtracting the lowest measured water content from field capacity.

Potential soil moisture deficit

Potential soil moisture deficit (PSMD) was calculated with rainfall, temperature and solar radiation data collected from an electronic weather station on-site following the method of Jamieson *et al.* (1995). Potential evapotranspiration (PET) was calculated using the Priestly Taylor method (Jamieson, 1982). The PSMD was calculated each day by adding the current days PET to the previous days total and subtracting rainfall and irrigation. PSMD was not allowed to decrease below zero and the maximum value achieved during the season, measured from the 15 October, when the soil was at field capacity, was taken as the maximum potential soil moisture deficit (MPSMD).

Statistical analyses

Grain yield data were 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) using Statistix 9 (Analytical Software, Florida, USA). All relationships were tested by split line regression using Genstat 15.1.

Table 2: Rainfall (mm) and evapotranspiration (mm) for 2012-13 at the FAR Arable Site, Chertsey, Canterbury and long term average rainfall from AgResearch Winchmore (13 km west).

Month	2012-13 rainfall (mm)	2012-13 evapotranspiration (mm)	Long term average rainfall (Winchmore) (mm)
September	11	73	52
October	100	106	58
November	56	123	58
December	30	153	63
January	54	172	56
Total	251	627	287

Results

Grain yield

Grain yield increased (P<0.001) with irrigation from 9.4 t/ha for unirrigated crops through to 13.8 t/ha for fully irrigated crops (Table 3). There was a higher yield loss due to drought following anthesis (3.6 t/ha) compared with before anthesis (1.2 t/ha) (Table 3).

For irrigation applications up to 171 mm, the grain yield response was 27 kg/mm of water/ha and the response appeared consistent regardless of the time of irrigation (Figure 1). There was no further yield response to higher levels of irrigation.

When grain yield was compared with MPSMD, it remained constant at 13.5 t/ha for a MPSMD less than 179 mm. There was a constant rate of yield loss (26 kg/mm of water/ha) regardless of the time of drought as MPSMD increased beyond this (Figure 2). The point of inflection (179 mm) is the soil's critical deficit (Jamieson *et al.*, 1995).

When grain yield was compared with maximum actual soil moisture deficit (MASMD) the point of inflection and therefore critical deficit was at 100 mm (Figure 3). Grain yield declined with further soil moisture deficit.

Table 3: Grain yield, heads/m^2, thousand grain weight (TGW), test weight and grain population for nine different irrigation treatments applied to wheat, cultivar ‘Wakanui’, FAR Arable Site, Chertsey, Canterbury during the 2012-13 growing season.

Treatment	Grain yield (t/ha)	Heads/m^2	TGW (g)	Test weight (kg/hl)	Grain population (grains/m^2)
No irrigation	9.4	504	43.1	71.5	21,756
Replace PET every week	13.8	505	55.6	78.5	24,871
Replace PET every 2 weeks	13.2	477	55.1	77.7	23,977
Replace 33% PET until anthesis then nil	9.4	448	44.8	71.9	21,968
Replace 66% PET until anthesis then nil	10.1	463	44.9	72.3	22,502
Replace 100% PET until anthesis then nil	10.2	484	44.3	72.7	23,015
Nil until anthesis then 33% PET	11.1	463	50.7	76.9	21,980
Nil until anthesis then 66% PET	12.8	489	54.3	78.1	23,478
Nil until anthesis then 100% PET	12.6	453	56.4	78.3	22,292
$\text{LSD}_{(0.05)}$	0.79	66	2.6	1.5	1,748
p-value		0.57	<0.001	<0.001	<0.05

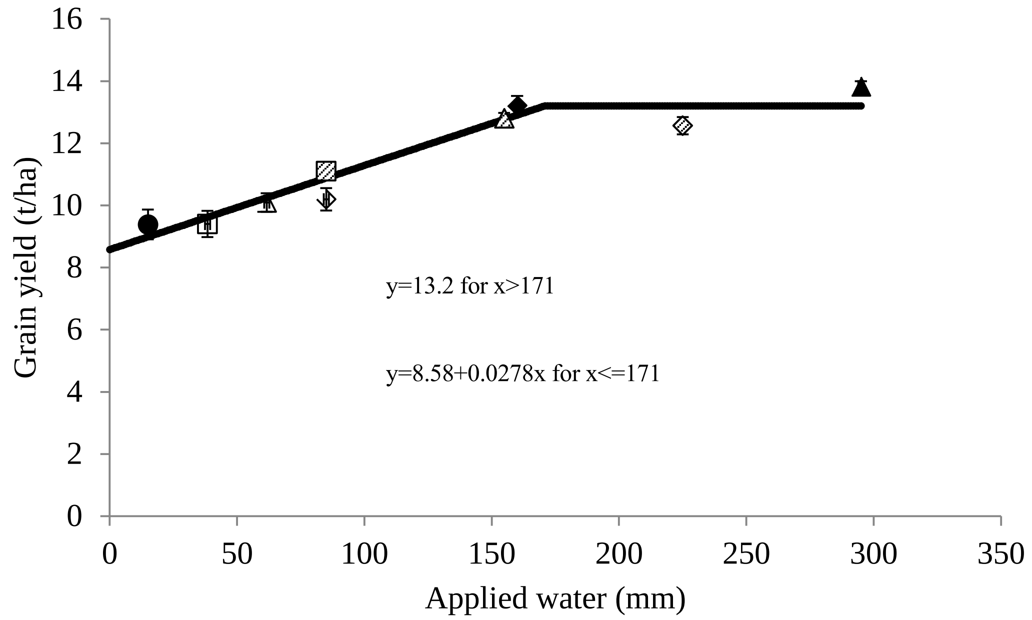

Figure 1: Wheat, cultivar ‘Wakanui’ grain yield response to (●) no irrigation, (▲) replace PET weekly, (◆) replace PET every 2 weeks, (☐) replace 33% PET until anthesis then nil, (△)replace 66% PET until anthesis then nil, (◇) replace 100% PET until anthesis then nil, (▨) nil until anthesis then 33% PET, (◬) nil until anthesis then 66% PET, (◈) nil until anthesis then 100% PET irrigation (mm) at the FAR Arable Site, Chertsey, Canterbury. Bars represent standard errors of means.

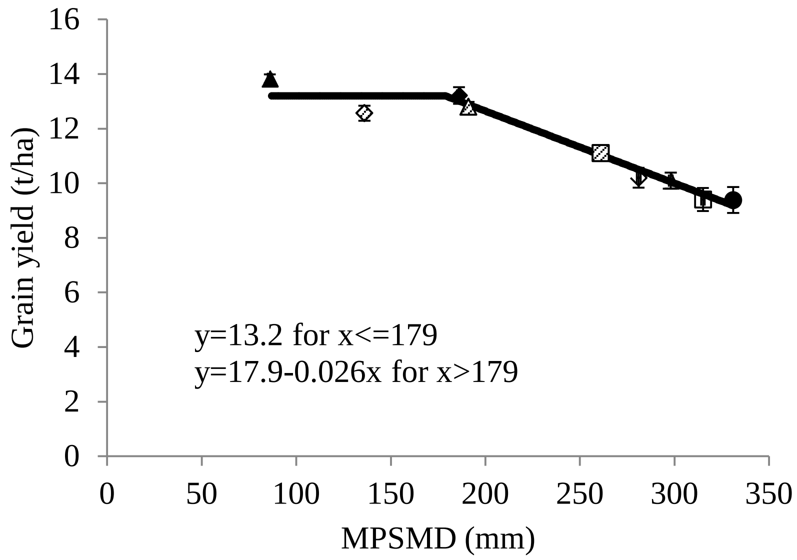

Figure 2: Relationship between grain yield and maximum potential soil moisture deficit for (●) no irrigation, (▲) replace PET weekly, (◆) replace PET every 2 weeks, (☐) replace 33% PET until anthesis then nil, (△)replace 66% PET until anthesis then nil, (◇) replace 100% PET until anthesis then nil, (▨) nil until anthesis then 33% PET, (◬) nil until anthesis then 66% PET, (◈) nil until anthesis then 100% PET treatments for wheat, cultivar 'Wakanui' at the FAR Arable Site, Chertsey, Canterbury. Bars represent standard errors of means.

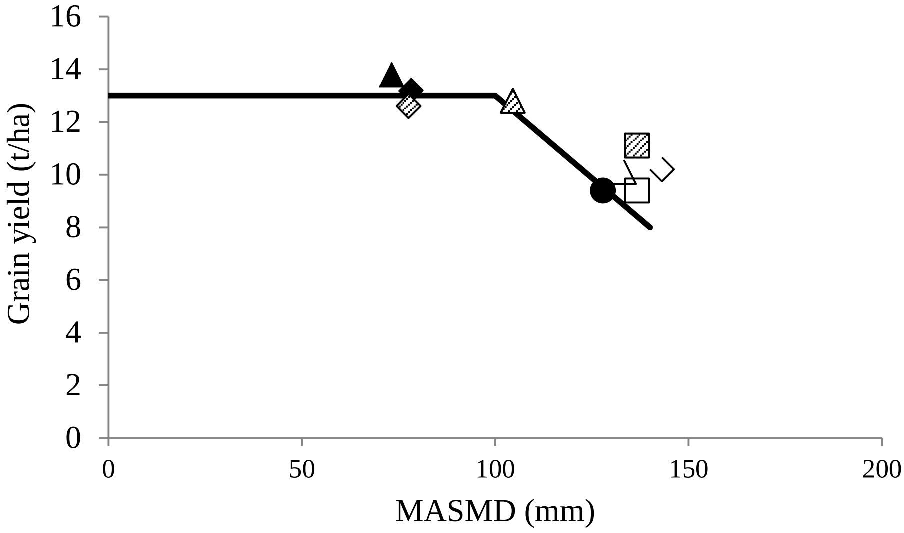

Figure 3: Relationship between grain yield and maximum actual soil moisture deficit for (●) no irrigation, (▲) replace PET weekly, (◆) replace PET every 2 weeks, (☐) replace 33% PET until anthesis then nil, (△)replace 66% PET until anthesis then nil, (◇) replace 100% PET until anthesis then nil, (▨) nil until anthesis then 33% PET, (◬) nil until anthesis then 66% PET, (◈) nil until anthesis then 100% PET treatments for wheat, cultivar 'Wakanui' at the FAR Arable Site, Chertsey, Canterbury.

Harvest components

Irrigation produced no difference in heads/m^2. There was a 22% reduction ($P<0.001$) in thousand grain weight for the dryland crops (43.1 g) compared with the fully irrigated crops (55.6 g) and an 8.9% reduction in test weight for the dryland crops (71.5 kg/hl) compared with the fully irrigated crops (78.5 kg/hl) (Table 3). Grain population was 13% lower (21,756/m^2) for the dryland crops compared with the fully irrigated crops (24,871/m^2).

Discussion

There was no response to irrigation in excess of 171 mm, suggesting this was the appropriate amount to maximise irrigation efficiency for this crop in this season (Figure 1). However, the appropriate amount will be different each season depending on seasonal rainfall, temperature and radiation. To apply efficient irrigation each season, an irrigation schedule should be used where soil water content is measured or predicted and irrigation applied when soil water content approaches levels that will cause yield reductions. To do this effectively growers need to know the soil water content to use as a trigger deficit (D_c), below which grain yield will be constrained.

Grain yield response to drought followed the same pattern as that shown by Jamieson *et al*., (1995). There was no yield loss until a D_c was reached, followed by a linear decrease in yield as MPSMD increased. In this experiment grain yield declined by 2.6 t/ha for every 100 mm increase in MPSMD (Figure 2). This was greater than the 2.1 t/ha for each 100 mm increase in MPSMD reported by Jamieson *et al*., (1995). This was probably due to the difference in yield potential caused by differences in sowing dates between the two crops. Higher yields can be obtained from earlier autumn sow dates. Many growers are of the belief that wheat crops are more drought sensitive at anthesis and grain fill compared to pre-anthesis. The constant decrease in yield with increasing MPSMD regardless of whether the drought was early or late indicates the time of drought was not important. It was the severity of drought that affected yield. Therefore the higher yield loss post-anthesis was due to higher PET, not that the crop was more sensitive to drought at this later growth stage.

Yield is constrained when the crop is unable to extract sufficient water from the soil to satisfy atmospheric demand and a useful generalisation is to say that this occurs at a particular deficit, defined as the critical deficit. However, the value of D_c will vary depending on the available water capacity of the soil with lighter soils having smaller values of D_c. As expected, the D_c on the Chertsey shallow silt loam of 179 mm was lower than the 262 mm reported on a deeper Templeton silt loam soil by Jamieson *et al*. (1995). For most soils D_c is estimated at 50% of the PAWC (McLaren and Cameron, 1996). The PAWC on this soil was 140 mm in the top 0.8 m. Cemented gravels at about 0.8 m would have prevented water extraction below this depth. Therefore, a D_c of 179 mm appears too high. Also, a D_c of 262 mm on the Templeton silt loam in the Lincoln experiment with a total plant available water of 240 mm seems too high. These discrepancies suggest that winter wheat crops are using water at a rate less than PET for part or all of the season. This seems reasonable as total water use will be less than PET when the crop has incomplete cover. Also, a current review (Zykowski and Brown, 2013) of PET calculations has shown that the radiation function in the

Priestly-Taylor method used by Jamiesion, 1982 overestimates net radiation in the winter which will cause over-estimates in PET.

An alternative approach is to derive the D_c by comparing yield with the maximum actual soil moisture deficit (Figure 3). The D_c of 100 mm appears more reasonable at 71% of total plant available water but is higher than the 50% rule. The relationship between yield and MASMD was weak. The line in Figure 3 was fitted by eye to go through the nil irrigation point representing maximum stress. The relationship is weaker than that between yield and MPSMD, because MPSMD will continue to increase when less water is applied. ASMD will only increase until the crop has extracted all of the plant available water from the soil, then it will stop. ANOVA shows that the treatments close to the point of inflection, nil irrigation to anthesis and 66% PET after anthesis had a significantly lower yield (12.8 t/ha) than the fully irrigated weekly treatment (13.8 t/ha), indicating that the critical deficit was exceeded at a lower soil moisture deficit. The MASMD of the replace PET weekly treatment was 73 mm and replace PET every 2 weeks 78 mm close to the 50% of total plant available water rule of thumb. Grain yield was the same ($p<0.001$) whether irrigated weekly or every 2 weeks. Therefore the soil held sufficient water to maximise yield with longer intervals between irrigation.

Head numbers were set before the plants became water stressed. Therefore, no differences in head population (Table 3) between treatments were obtained in this experiment. The yield increase from irrigation was obtained by an increased grain size and grain population. There was a 29% increase ($P<0.05$) in grain size (Table 3) and 14% increase in grain population with the replace PET weekly treatment compared with no irrigation. A drought before anthesis could be expected to affect the grain population more and a drought after anthesis could reduce the grain fill period therefore decreasing grain size more.

Conclusions

The severity of drought, not the timing of drought, is more critical for determining wheat grain yield. Potential soil moisture deficit is strongly related with grain yield with a yield loss of 26 kg/mm/ha expected above the critical deficit in this experiment. For grower irrigation guidelines the relationship between yield and maximum actual soil moisture deficit gave a critical deficit similar to the 50% of PAWC rule. The relationship between yield and MPSMD gave a critical deficit that would need calibrating to individual soil types and to crops with different cover patterns.

Acknowledgement

NZ Arable are thanked for drilling, applying inputs and harvesting the trial and Hydroservices for neutron probe measurements.

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