Yield and quality of milling wheat in response to water deficit and sowing date on a shallow soil

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Abstract

The yield and quality response of a spring-sown milling wheat ('Conquest') to four levels of irrigation and two sowing dates (27 August 2010 and 27 September 2010) was determined in a Canterbury shallow soil (<30 cm to gravel). Irrigation treatments were: full replacement of potential evapotranspiration (PET) weekly, half PET every week, half PET every 2 weeks and no irrigation. The full PET replacement irrigation significantly increased all measured yield components over the no irrigation treatment. The two PET replacement treatments had similar yields. The total amount of water applied had a greater effect on yield than did the frequency of its application. Grain yields were related to maximum potential soil moisture deficit and decreased by 1.4 t ha^{-1} for each 100 mm increase. Grain yield was directly correlated to total aboveground biomass production (with a harvest index of 0.44) and the grain population (grains m^{-2}) rather than to individual grain weight. Delaying the sowing date increased protein levels by an average of 0.93% over all irrigation treatments. Grain quality measured using rheological properties also improved with delayed sowing without any reduction in grain yield, but irrigation had no effect on grain quality. Overall, these results confirm that in order to maximise grain yields growers should irrigate their milling wheat crops to maximise crop biomass production by maintaining soil moisture above a critical deficit.

Additional keywords: drought, harvest index, protein, soil moisture

Introduction

The availability of water is a key driver of crop yield (Passioura and Angus, 2010). Most milling wheat in New Zealand is now irrigated to supplement rainfall and make up the water deficit during the late spring and summer months. Efficient use of this irrigation water resource is required to maximise yields, profits and environmental sustainability. Growers generally schedule irrigation so that a limiting soil moisture deficit is avoided. To do this growers use a water balance, an irrigation scheduling tool such as the Sirius wheat calculator (Armour *et al*., 2002; 2004) or a direct measurement soil moisture. The research underlying these approaches was collected from The New Zealand Institute for Plant & Food Research Limited's rainout shelter at Lincoln (Jamieson *et al*., 1995). This research showed that as maximum potential soil moisture deficit (MPSMD) increased above a critical deficit (D_c) the grain yield of wheat also decreased. The clear implications of this research are that growers should irrigate their wheat crops to maintain MPSMD above D_c. However, this research facility is located on a deep alluvial top soil (2 m) with high water-holding capacity (approximately 280 mm of plant available water in the top 1.5 m), raising the question as to the relevance of this research to milling wheat grown on shallow soils (<30 cm to gravel) that are typical of much of the Canterbury Plains. Furthermore, the effect of soil water deficit on grain quality has not been adequately addressed.

Shallow soils have a low water-holding capacity (<80 mm of plant available water in the top 1.5 m). As a result, they require more frequent and lower rates of irrigation. Forecasting the frequency and quantity of water applied accurately is paramount if farmers are to implement efficient and environmentally sustainable crop husbandry practices and maximise their profitability. Coupled to this is the need to balance high yields with the quality requirements of milling wheat.

This trial assessed the yield and quality of spring-sown milling wheat at two different sowing dates under increasing soil moisture deficits in a low water-holding capacity soil. The focus of this paper was the effect of MPSMD on final grain yield and quality.

Materials and Methods

The site was located on the AgResearch farm, Lincoln (43°37'16"S; 172°28'15"E). It consisted of an Eyre silt loam soil that had been in pasture for more than 5 years. On average the top soil was 30 cm to gravel across the site, with more than 2% of stones in the top soil.

Experimental design

A total of 32 plots (10 x 4 m) were sown for the 2010-11 season with 'Conquest' wheat into a conventionally prepared seed bed using a Taege 13 coulter (150 mm row) direct drill to reach a target population of 275 plants m^{-2}. 'Conquest' is a high quality milling wheat with good dough strength. The experiment consisted of four replicates and eight treatments. The treatments consisted of a factorial design of two spring sowing dates, 27 August 2010 and 27 September 2010; and four irrigation treatments:

(1) full replacement of potential evapotranspiration (PET) weekly,
(2) half PET every week,
(3) half PET every 2 weeks, and
(4) no irrigation.

Any precipitation that fell between irrigations was subtracted from the irrigation to be applied. The trial was laid out in a split-plot design with sowing date as the main-plots and irrigation treatment as the sub-plots. Small amounts of irrigation were applied to all plots during crop establishment and also following fertiliser N applications to avoid volatilization losses. For 27 August sowing date, irrigation treatment 1 received 240 mm, treatment 2 received 125 mm, treatment 3 received 105 mm and treatment 4 received 28 mm of irrigation. For 27 September sowing date, irrigation treatment 1 received 268 mm, treatment 2 received 137 mm, treatment 3 received 134 mm and treatment 4 received 28 mm of irrigation.

Experimental management

Water was applied as per the treatment schedule using drip irrigation. Potential evapotranspiration was measured from the Broadfields weather station (situated <1 km from the trial).

Fertiliser was applied so as not to be a limiting factor across all treatments. In total, 160 kg N ha^{-1} was applied in three applications: 30 kg N ha^{-1} as Cropmaster 15 before sowing and the rest as urea at the end of tillering (23 November 2010) and at early (7 December 2010) grain fill (80 and 50 kg N ha^{-1}, respectively).

Before ear emergence, nets were installed in every plot to protect the final harvest area from bird damage.

At harvest, a 0.5 m^{-2} quadrat was cut to ground level within the netted area from each plot. The whole sample was air-dried to constant weight. Once dry, the sample was weighed and 20 undamaged stems were removed for further partitioning into leaf, stem, grain and chaff components. The rest of the sample was threshed in a Kurtpelz thresher, after which the seed sample was further cleaned in a Kornservice sample cleaner. The total seed weight was recorded and then assessed for 1000 seed weight using a Numigral seed counter, with the percent moisture and hectolitre weight (kg hl^{-1}) of the grain determined using a Dickey John GAC500 XT moisture meter. Screenings were separated out of a 250 g whole sample of seed using a 2 mm screen. The resulting fractions were weighed separately.

Grain quality assessment

Grain quality assessments included protein content (percent white flour protein on a NIR machine adjusted at 14% moisture) and a modified version of the mixograph method (Pon *et al*., 1989) testing dough rheology. Briefly, a 30 g sample of flour was prepared for each plot by milling a 50 g sample of grain tempered to 15.5% on a Brabender quadrumat Junior mill. Afterwards, a 10 g mixograph analysis was performed on each flour sample with a pre-set maximum mixing time of 5 min at 64% hydration. Data for mid-line peak development time (MDT) and mid-line peak height were recorded using MIXSMART version 3.36 (National Manufacturing Division, TMCO, Lincoln, Nebraska).

Statistical analyses

Data were modelled with a mixed model fitted with Restricted Maximum Likelihood (REML) using GenStat v12. An estimate of the variation associated with estimates was given by an approximate Least Significant Difference (LSD) at the 5% level. This approach was necessary to handle the unbalanced data and missing observations of four of the later sowing date plots that were abandoned due to bird damage. Grain yield was compared with maximum potential soil moisture deficit (MPSMD) using least squares regression. The MPSMD was calculated using the method of Jamieson *et al*. (1995). Relationships between measured yield components and grain properties were modeled with least squares regression.

Results

Grain yield

Irrigation had a significant effect ($P<0.001$) on grain yield, which decreased when less irrigation was added (data not shown). There was no evidence of a difference in grain yield between the two sowing dates ($P=0.118$). Thus, when the grain yields were compared with MPSMD it was assumed that a single response was adequate for both sowing dates. Averaged over both sowing date treatments, mean grain yields were 6.7, 5.6, 5.1 and 3.0 t ha^{-1} for irrigation treatments, full replacement of PET weekly, half PET every week, half PET every 2 weeks and no irrigation, respectively.

When these grain yields were compared with MPSMD there was a clear decline in grain yield with increasing MPSMD (Figure

1). For every 100 mm increase in MPSMD grain yield decreased by 1.4 t ha^{-1}. There was no clear evidence of a point of inflection in this relationship; therefore a D_c could not be defined.

Grain yield was closely related to aboveground biomass (P<0.001) in response to applied irrigation (7.3-16.1 t ha^{-1}) (Figure 2), as sowing date did not have a significant effect (P=0.591). Although the harvest index was significantly influenced by both irrigation (P<0.001) and sowing date treatments (P=0.04), the overall range of harvest index was small (0.38-0.45) and therefore had only a minor influence on grain yield. The dominant influence on grain yield was crop biomass (Figure 2). The linear relationship in Figure 2 is forced through the origin; therefore the slope of the relationship represents the average harvest index of 0.44 across all treatments.

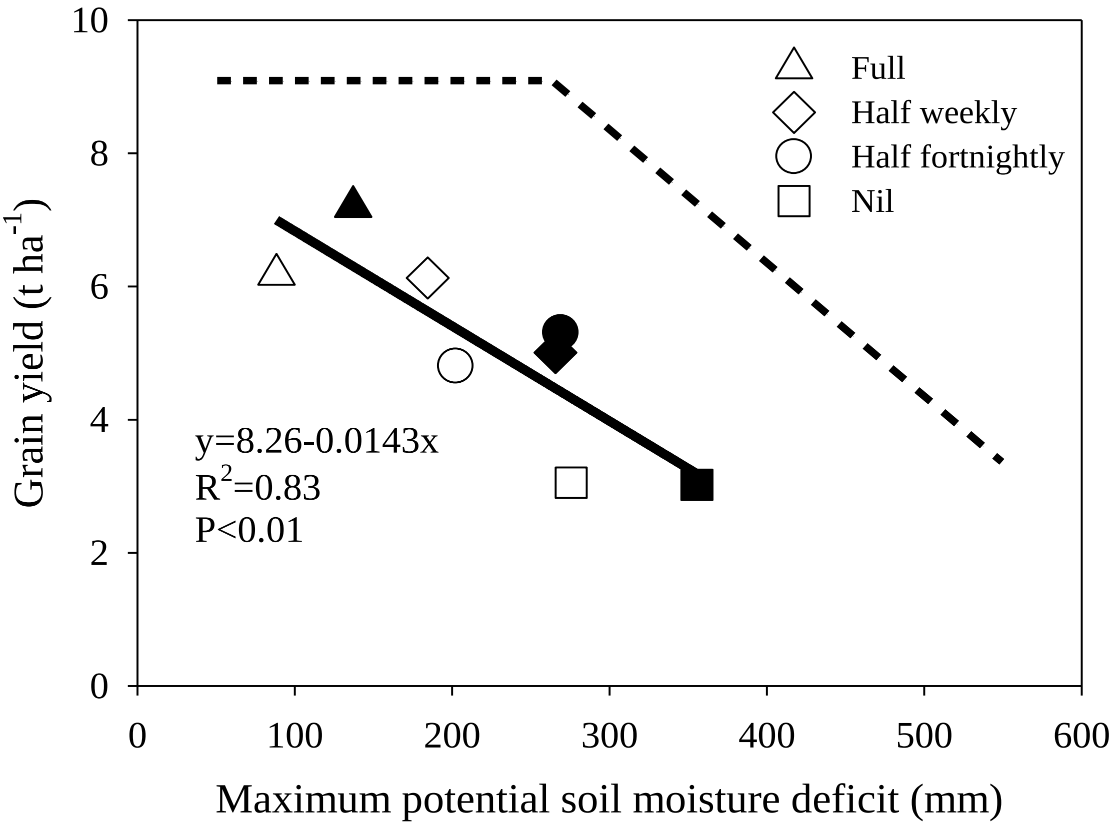

Figure 1: Irrigation treatments (full replacement of PET weekly, half PET every week, half PET every 2 weeks and no irrigation) versus grain yield (t ha^{-1}) for sowing dates one (27 August 2010) and two (27 September 2010), open and closed symbols, respectively. For comparison the relationship of Jamieson et al. (1995) between grain yield and MPSMD for winter wheat is also plotted (dashed line).

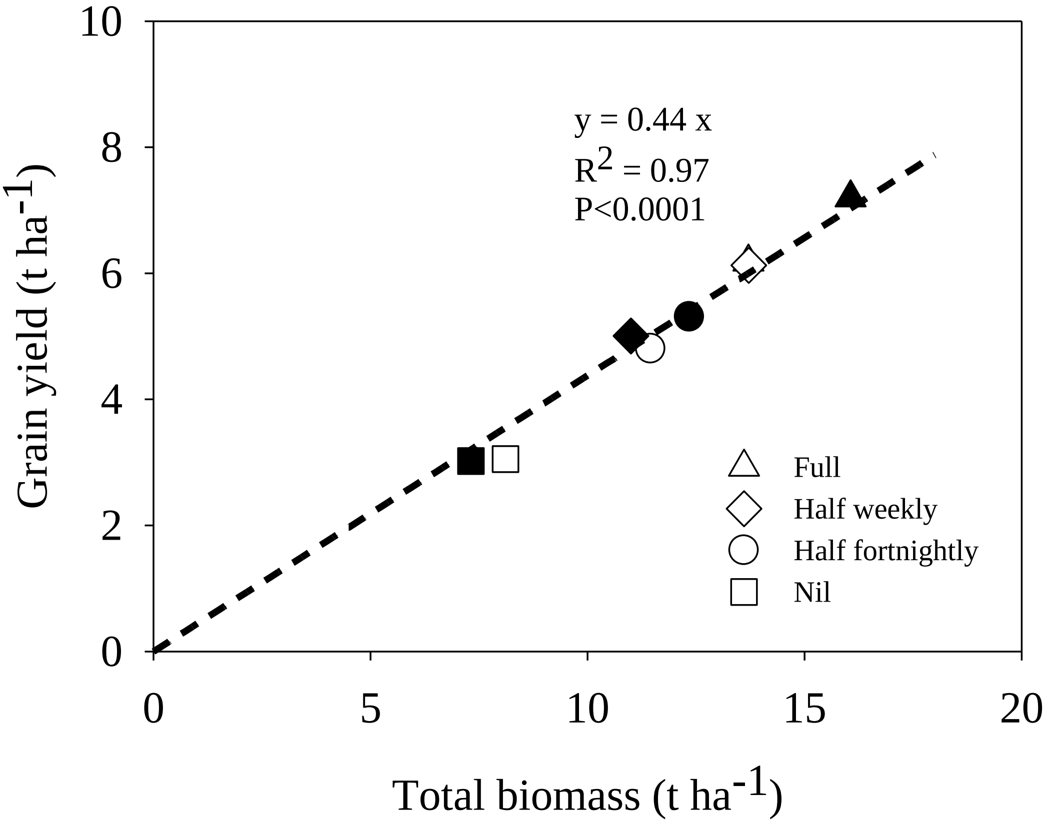

Figure 2: Total biomass (t ha^{-1}) versus grain yield (t ha^{-1}) for irrigation treatments (full replacement of PET weekly, half PET every week, half PET every 2 weeks and no irrigation) and sowing dates one (27 August 2010) and two (27 September 2010), open and closed symbols, respectively.

Grain population (measured as grains m^{-2}) was closely related grain yield (Figure 3a). In contrast, individual seed weight had only a small change in response to irrigation (Figure 3b). Increasing irrigation significantly (P<0.001) increased the grain population and seed weight while sowing date had no influence on either (P=0.411 and 0.161, respectively). For every 1000 grains m^{-2} increase, yield increased by 0.41 t ha^{-1} (R^2=0.89).

Although both irrigation (P<0.001) and sowing date (P=0.005) had significant effects on screenings, the overall screenings value was small (<4%) and had little effect on overall grain quality. The hectolitre sample weight declined (P=0.011) as decreasing amounts of water were applied (75.7, 70.2, 69.9 and 66.5 kg hl^{-1} for irrigation treatments, full replacement of PET weekly, half PET every week, half PET every 2 weeks and no irrigation, respectively). Sowing date, however, did not influence hectolitre weight (P=0.704).

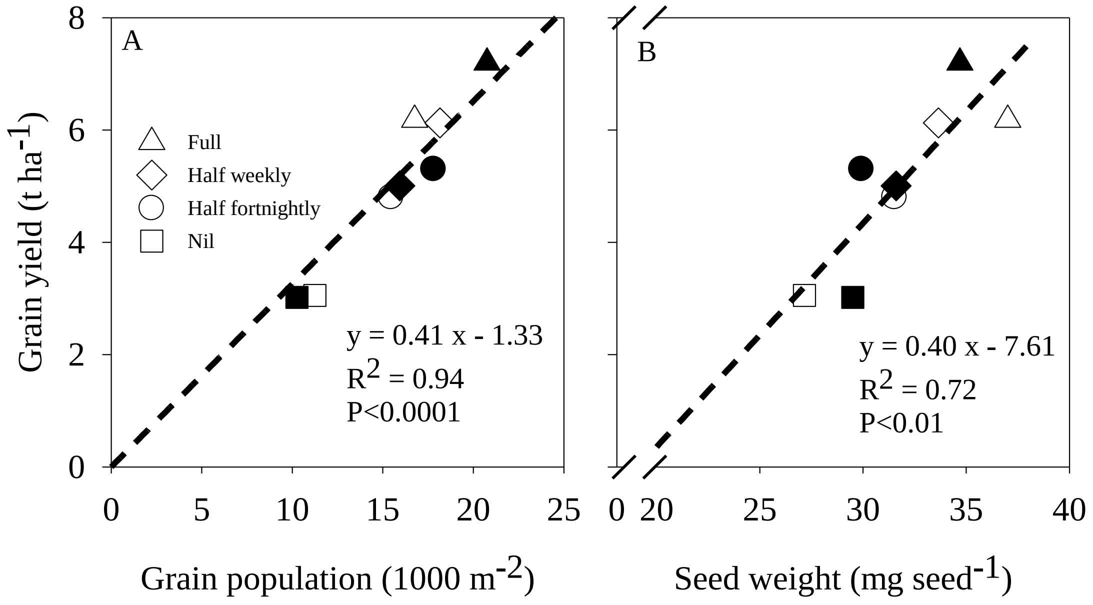

Figure 3: Grain population (A) and seed weight (B) versus grain yield for irrigation treatments (full replacement of PET weekly, half PET every week, half PET every 2 weeks and no irrigation) and sowing dates one (27 August 2010) and two (27 September 2010), open and closed symbols, respectively.

Grain quality

As grain yield decreased, protein levels increased across all irrigation treatments ($P<0.001$). The second sowing date on average yielded 0.93% more protein over all irrigation treatments ($P=0.002$) (Figure 4). For both sowing dates the decline in protein content with increasing grain yield was similar (-0.40% and -0.48% for each 1 t ha^{-1} increase in yield).

An example of a mixograph analysis is shown in Figure 5. Figure 5a shows a high quality sample with a short MDT and high peak height while Figure 5b shows a low quality sample.

MDT was significantly influenced by both irrigation and sowing date ($P<0.001$). A significant interaction ($P=0.003$) was also observed between irrigation and sowing date. Sowing date two was not influenced by irrigation treatment (all were <3 min) compared with sowing date one which increased in MDT from 3.2 to 4.2 min as the total water decreased (Table 1).

Peak height was also significantly influenced by irrigation ($P<0.001$) and sowing date ($P<0.001$) treatments. The peak height of wheat sown at the second sowing date consistently increased as total water decreased from full replacement of PET through to no irrigation (Table 1). Overall, peak height correlated with grain protein content ($R^2 =0.78$).

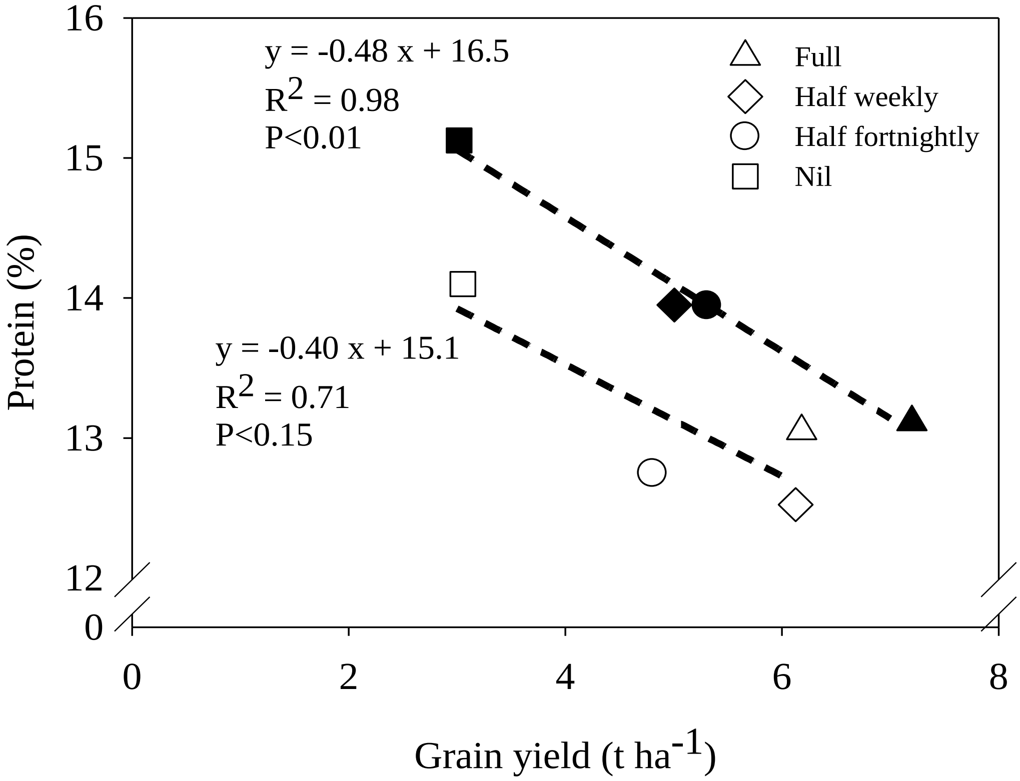

Figure 4: Grain yield (t ha^{-1}) versus protein (%) content for irrigation treatments (full replacement of PET weekly, half PET every week, half PET every 2 weeks and no irrigation) and sowing dates one (27 August 2010) and two (27 September 2010), open and closed symbols, respectively.

Table 1: Predicted means and statistical output of the mixograph development time (MDT) and peak height for irrigation treatments (full replacement of PET weekly, half PET every week, half PET every 2 weeks and no irrigation) and sowing date treatments one (27 August 2010) and two (27 September 2010), respectively.

Irrigation treatment	MDT Sowing date		Peak height Sowing date	
	1	2	1	2
(1) Full	3.18	2.90	68.08	68.91
(2) Half weekly	3.72	3.02	62.63	70.07
(3) Half fortnightly	4.13	3.00	63.18	71.57
(4) Nil	4.23	3.02	67.28	76.03
$LSD_{(0.05)}$	0.36		3.78	
Approximate df	16.99		16.96	

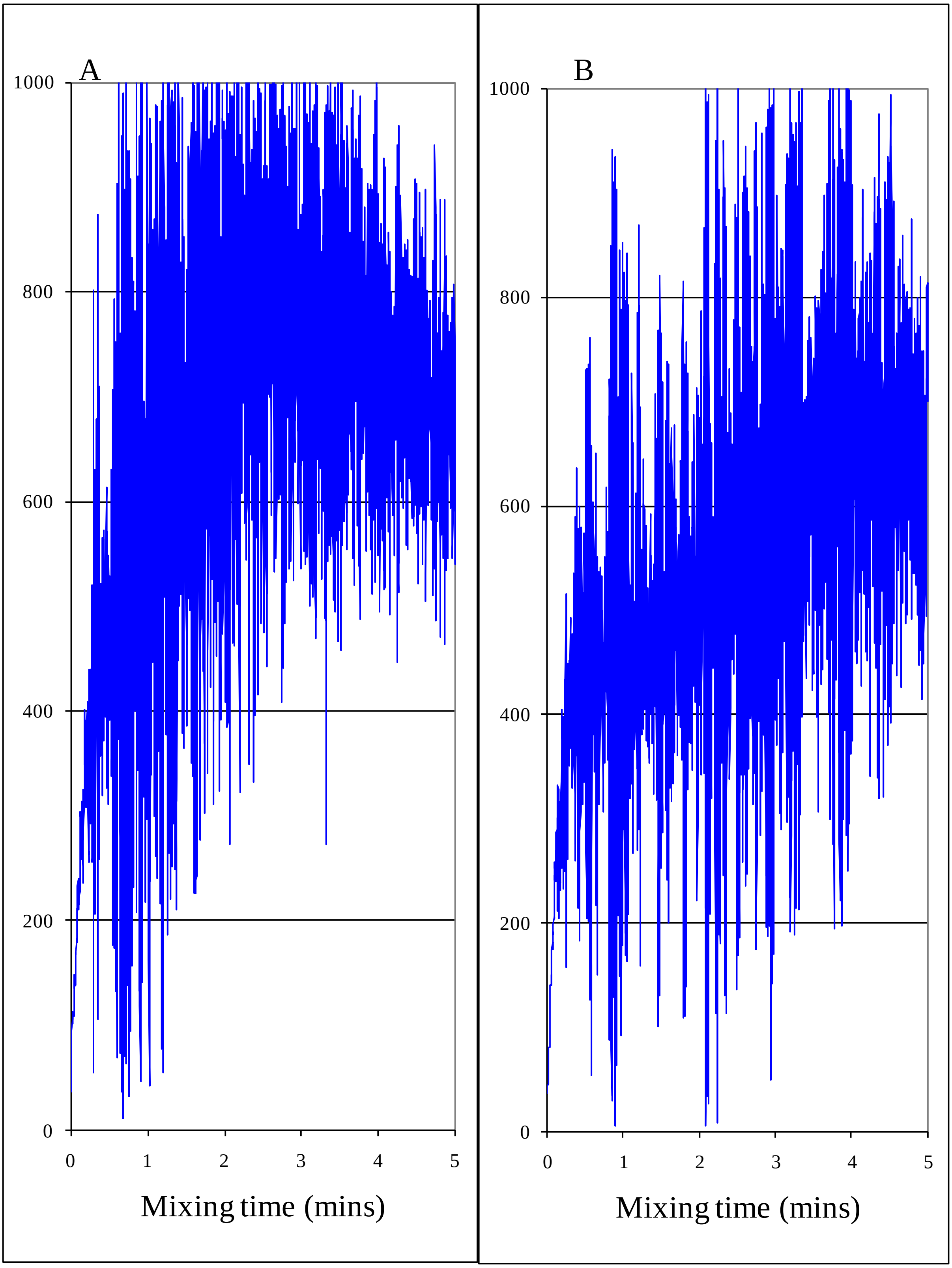

Figure 5: Mixograph output illustrating the relative differences between a wheat sample with good rheological properties A; (short MDT (x axis) and high peak height (y axis)) and B; a lower quality sample.

Discussion

Grain yield responses to water deficit recorded in this trial are consistent with those reported in other studies (Jamieson *et al*., 1995) in that increasing the MPSMD reduces grain yield. Total grain yields when half of PET was applied once per week and once every 2 weeks were not significantly different, suggesting that in this experiment the total amount of water applied was an important determinant of grain yield rather than the frequency of water application. However, wheat plants in both treatments two and three were under moisture stress from late tillering onwards. Therefore, because the critical soil water deficit was exceeded no significant differences in grain yield are expected between the two treatments. Nevertheless, Jamieson *et al*. (1995) also concluded that the total amount of water applied was more important than the timing of its application in determining overall grain yield of wheat. Our results also agree with those of Fischer (1993) who found that grain yield was directly correlated with aboveground biomass accumulation and kernel number m^{-2} as opposed to grain weight. Further work by Jamieson *et al.* (1995) also showed that the grain population and mean kernel mass were not influenced by drought timing. These results infer that maximising total biomass production is important for maximum grain yield. Therefore, irrigation management should focus on the total amount of water applied rather than solely irrigation timing to obtain maximum grain yields. Growers need to apply irrigation to ensure that the D_c is not exceeded (Jamieson *et al*., 1995). Unfortunately, in this experiment it was not possible to define the D_c for this soil.

There was a general decline in grain yield with each increase in MPSMD with no apparent inflection point. This infers that the actual D_c was less than the lowest MPSMD obtained here (90 mm) and that even the full irrigation treatments (treatment 1) were under some moisture stress. The "rule of thumb" used by growers is that D_c is approximately half the plant available water for a given soil. Thus the hypothesis of a lower D_c would be in complete accord with the low plant available water on this shallow soil. For comparison the relationship between MPSMD and grain yield defined by Jamieson *et al*. (1995) has been plotted in Figure 1(dashed line). The much greater D_c defined by them is likely due to the deeper soil in their experiment and the higher potential grain yields (approximately 9 t ha^{-1}) for a winter wheat crop compared with the spring wheat crop. In this experiment grain yield declined by 1.4 t ha^{-1} for every 100 mm increase in MPSMD. This is less than the yield decline of 2.1 t ha^{-1} for each 100 mm increase in MPSDM reported by Jamieson *et al*. (1995) (dashed line in Figure 1).

There were no differences in grain yield between sowing dates for each irrigation treatment. However, grain quality, as measured by white flour protein levels and the mixograph method, revealed that sowing date had a greater influence on quality than irrigation treatment. Delaying the spring sowing date by 1 month increased grain quality without any significant yield loss, irrespective of irrigation treatment. Sowing date, therefore, might be a good way to maximise quality without sacrificing yield in spring-sown wheat. In effect, delaying the sowing date would enable growers to circumvent the well documented (Triboi *et al*., 2006) negative link between protein content and grain yield. However, the differences in grain protein content might be related to the timing of cultivation. Both sowing dates were cultivated together, therefore the second sowing date had an extra month for organic N to mineralise to plant available N before the crop was sown. This might explain the apparent higher protein content (Figure 4) and flour quality (Table 1) for the second sowing date. Within each sowing date the negative relationship between grain yield and protein content (Figure 4) agrees with the literature (Triboi *et al*., 2006). Under current price premiums for grain protein content in New Zealand it is unlikely that withholding irrigation would be an economically viable approach to raising grain protein.

The next step with these data will be to compare them with simulated yields generated by the Sirius Wheat calculator (Armour *et al*., 2002; 2004). This comparison will include within-season measurements of crop growth and water use. It will demonstrate whether the calculator can successfully schedule irrigation of milling wheat on shallow soils.

Acknowledgement

This research was funded by FRST through the **L**and **U**se **C**hange and **I**ntensification (C02X0812) programme.

References

Armour, T., Jamieson, P.D. and Zyskowski, R. 2002. Testing the Sirius wheat calculator. *Agronomy New Zealand* 32: 1-6.

Armour, T., Jamieson, P.D. and Zyskowski, R. 2004. Using the Sirius wheat calculator to manage wheat quality - the Canterbury experience. *Agronomy New Zealand* 34: 171-176.

Fischer, R.A. 1993. Irrigated spring wheat and timing and amount of nitrogen fertilizer. II. Physiology of grain yield response. *Field Crops Research* 33: 57-80.

Jamieson, P., Martin, R. and Francis, G. 1995. Drought influences on grain yield of barley, wheat and maize. *New Zealand Journal of Crop and Horticultural Science* 23: 55-66.

Passioura, J. and Angus, J. 2010. Improving productivity of crops in water-limited environments. pp. 37-75. *In*: Advances in agronomy v106. Ed. Sparks, D.L. Academic Press, San Diego.

Pon, C.R., Lukow, O.M. and Buckley, D.J. 1989. A multichannel, computer-based system for analyzing dough rheology. *Journal of Texture Studies* 19: 343-360.

Triboi, E., Martre, P., Girousse, C., Ravel, C. and Triboi-Blondel, A.M. 2006. Unravelling environmental and genetic relationships between grain yield and nitrogen concentration for wheat. *European Journal of Agronomy* 25: 108-118.