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GRAIN YIELD AND QUALITY RESPONSES TO EARLY AND LATE APPLICATIONS OF NITROGEN IN THREE SPRING WHEAT CULTIVARS UNDER THREE IRRIGATION LEVELS

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ABSTRACT

Fertiliser nitrogen was applied to spring-sown wheat cultivars at tillering (early) or booting (late). Experiments were carried out in five seasons on light stony soil out of pasture. Two cultivars, Oroua and Rongotea were used throughout; Karamu was included in the first two experiments and Otane in the last three. Irrigation was applied by the border strip method at 10%, 15% or 20% soil moisture.

Grain yields were comparatively high in Experiments 1, 3 and 5 and low in Experiments 2 and 4. Cultivars varied in their responses to nitrogen timing but there was no consistent pattern. Responses to nitrogen were higher with heavier irrigation. Irrigation at 15% soil mositure increased the yield above 10% in four experiments, there was a further response to 20% in only one of these.

Mean grain weight was generally unaffected or reduced by early nitrogen and increased by late nitrogen. There was considerable seasonal variation in the way mean grain weight responded to frequency of irrigation.

Grain protein was low in Experiments 1, 2 and 5, and high in Experiments 3 and 4; responses to nitrogen were also higher in Experiments 3 and 4. Late applications of nitrogen improved protein levels more than early nitrogen and improved baking Score. Grain protein decreased with increasing irrigation frequency.

Overall, medium irrigation with late N gave a quality product (6t/ha at 13% grain protein) whilst a lower yield of higher quality was obtained by reducing irrigation inputs.

INTRODUCTION

Deregulation of the wheat industry has focused attention on the quality of New Zealand-grown wheat. High yield is no longer the only objective of growers who traditionally were not rewarded for producing a quality product other than by way of a cultivar premium.

The main quality attributes which feature in a range of wheat purchasing contracts are grain size and either grain protein or baking score as determined by test baking procedures. These characterisitcs are strongly influenced by irrigation and nitrogen fertiliser, especially on the light Lismore soil in Canterbury. Here, irrigation is required to produce satisfactory yields in practically every year (Drewitt, 1974) and unless crops are grown on areas previously in long-term pasture fertiliser nitrogen is also needed. Improved yields resulting from irrigation are generally associated with increased grain size and a reduction in grain protein and bread baking quality (Drewitt, 1979a, 1979b; Drewitt and Rickard, 1971, 1973).Cultivars differ in their response to irrigation (Drewitt, 1974; Drewitt and Rickard, 1973) and to time of nitrogen application (Drewitt, 1982). the interaction between irrigation frequency and time of nitrogen application for different cultivars had not been investigated on Lismore soil prior to the commencement of the series of experiments reported here.

The present study was designed to measure yield and quality responses to irrigation frequency and time of fertiliser nitrogen application in new cultivars and to compare them with established cultivars. Five experiments were carried out between 1980-81 and 1986-87; all were spring sown out of pasture. The series began with three cultivars in common use, Oroua, Rongotea and Karamu. Oroua has retained its popularity up to the present time and Rongotea has only recently lost favour because of comparatively low baking quality. Karamu, a poor baking but good biscuit wheat, was replaced by Otane after the first two experiments. Otane has gained widespread acceptance as a high quality bread wheat. Two times of nitrogen application were chosen; at tillering, which is generally considered the optimum time for yield response (eg McCloy, 1980, Stephen *et al.*, 1984) or at booting, which in preliminary investigations gave similar yield responses and the added benefit of improved grain quality (Drewitt, 1982). The rate of nitrogen was increased from 50kg/ha to 100kg/ha after two experiments to ensure that the potential of the cultivars was not restricted by nitrogen rate. Experiment 3 was subjected to an economic analysis in 1985 (Drewitt, 1985).

An understanding of the varied irrigation and nitrogen requirements of individual cultivars will allow the grower to make better use of limited water resources and more efficient use of nitrogen fertiliser. Growers will be more favourably placed to meet the demands of the milling and baking industry in open competition if they can consistently produce high quality wheat.

MATERIALS AND METHODS

Experiment sites

The five experiments were carried out on Lismore stony silt loam at Winchmore Irrigation Research Station. All experiments were first year crops on an area which had had since 1964 a strictly managed rotation of four years pasture and two years crop. Results of soil quick tests in the experimental years prior to drilling showed pH to be around 6.1, Ca 10, K 7, P 8 and Mg 11.

Treatments

The trial design was a split-split plot arranged as in Table 1, with the main plot (irrigation level) occupying one complete border strip.

Irrigation was applied by the border-strip method when soil moisture, in the top 15cm of soil fell to the prescribed level (as measured by the gravimetric method). Soil moisture levels of 10, 15 and 20% are approximately equivalent to nil, 25% and 50%

available soil moisture respectively. Irrigation was discontinued once the wheat grains were beyond the soft dough stage.

Crop Management

Cultivars were drilled using a 10 coulter Connor Shea drill with 15cm row spacing. Sowing rates ranged from 130 to 200 kg/ha with adjustments made for seed size. Superphosphate was applied with the seed at rates ranging from 275 to 400 kg/ha. Sowing date, together with nitrogen application dates are given in Table 2.

Nitrogen as ammonium sulphate was applied by hand topdressing.

Weeds, diseases and pests were not allowed to develop. Neither cultivars nor treatments were selectively sprayed.

Treatments were harvested as they matured, this usually occurring in early to mid February.

Measurements

Climatic data were recorded on station, approximately 1km from the experimental sites. Mean daily temperatures were calculated from minimum and maximum screen temperature.

Grain harvesting was carried out with a small plot Hege header, and the outer rows from the 10 row plots were discarded. Grain samples were screened on an A5 (2.00mm) screen and yields corrected to 12% moisture. For mean grain weights 1000 seeds per sample were counted. Grain protein was determined by analysing grain nitrogen by the Kjeldahl method and converting to protein on a 14% moisuture base. Baking tests on a bulked treatment basis were carried out at the Wheat Research Institute in Christchurch. Baking score is the sum of loaf volume and texture scores after baking by the MDD (mechanical dough development) process.

RESULTS

Climate and Crop Development

Weather conditions varied considerably across the five seasons in which the experiments were carried out. Contrasting rainfall and temperature patterns influenced irrigation, cultivar and N responses and probably also contributed to a wide variation in grain yield and quality throughout the series.

Table 1. Details of irrigation treatments, cultivars and nitrogen treatments.

Main plots: Irrigation	1. Irrigated at 10% soil moisture (Low)
	2. Irrigated at 15% soil moisture (Medium)
	3. Irrigated at 20% soil moisture (High)
Sub plots: Cultivars	1. Karamu/Otane
	2. Oroua
	3. Rongotea
Sub-sub plots: Nitrogen	1. No nitrogen
	2. 50/100 kg/ha N at tillering
	3. 50/100 kg/ha N at booting

Table 2. Sowing dates and dates of nitrogen applications at tillering and at booting.

Experiment	Sowing date	N at tillering	N at booting
1	12 Sept '80	20 Oct	24 Nov
2	3 Sept '82	19 Oct	25 Nov
3	4 Sept '84	20 Oct	26 Nov
4	25 Sept '85	2 Nov	6 Dec
5	5 Sept '86	30 Oct	22 Nov

The season in which Experiment 3 was carried out was relatively dry, especially in spring. Experiments 4 and 5 were grown in seasons with high rainfall and it was particularly wet in the latter part of the season in Experiment 4. In Experiment 5 the wet winter was succeeded by a very wet spring and a comparatively dry summer, Table 3.

Table 3. Rainfall (mm) for winter, spring and summer periods.

Period	Experiment 1	2	3	4	5
Winter, May - July	**139**	**101**	**128**	**180**	**228**
Spring, August - October	**102**	**187**	**79**	**155**	**334**
Summer, November-January	**201**	**169**	**133**	**240**	**120**

The number of irrigations required varied from 1 to 3 at 10% sm, 2 to 5 at 15% sm and 4 to 8 at 20% sm.

There were small differences in the rate at which the cultivars developed; Oroua was the median cultivar with Karamu and Otane developing slightly earlier and Rongotea slightly later. The most extreme developmental lag between early and late cultivars was approximately 10 days. The application of N, especially at tillering, delayed development slightly, while delays caused by irrigation were from seven to 10 days. These cultivar and treatment differences led to small differing demands for moisture. Irrigation was applied when soil moisture on one of the more rapidly depleted treatments reached the required level.

Growth development periods in Table 4, based on Oroua with medium irrigation, have been calculated from observation at approximately weekly intervals so there could be some small inaccuracies in the number of days attributed to each period, and consequently, total radiation.

Two seasons, those of Experiments 2 and 4, were distinctive insofar as they may be characterised by temperature and radiation. Experiment 2 endured a cold, long season relieved only

Table 4. Duration of growth periods for Oroua at medium irrigation, mean daily air temperature and total radiation.

Growth Stage	Experiment 1	2	3	4	5
	Number of Days				
1. Establishment	17	18	21	18	28
2. Tillering	14	20	15	17	16
3. Stem extension	27	23	17	18	13
4. Booting and anthesis	31	29	37	27	32
5. Grain filling	29	34	26	28	23
6. Ripening	21	22	16	23	17
Total	139	146	132	131	129
	Mean daily air temperature (°C)				
1	12.6	8.5	8.7	9.4	10.4
2	11.0	9.3	12.5	11.1	12.9
3	12.3	14.7	13.2	13.0	13.0
4	13.8	13.8	14.8	15.0	14.5
5	15.7	14.3	17.4	18.4	17.1
6	17.2	13.9	18.3	16.1	18.2
	Total radiation (MJ/m^2				
1	314	306	336	324	374
2	253	366	360		

by a comparatively warm period at stem extension, whilst Experiment 4, in addition to having a wet summer, received low radiation from stem extension, whilst Experiment 4, in addition to having a wet summer, received low radiation from stem extension to grain fill inclusive. Although Experiment 4 was later sown the toal above-ground period was not reduced.

Grain yield

In the presence of applied N, Experiments 1, 3 and 5 were higher yielding than Experiments 2 and 4, (Figure 1). The mean N response was just over 600 kg/ha in the first three experiments, 320 kg/ha in Experiment 4 and 1760 kg/ha in Experiment 5.

Irrigation at 15% soil moisture increased the yield over irrigation at 10% soil moisture in four experiments; the smaller differences between medium and high irrigation were weakly influenced by cultivars and by the time of N application. Yield differences with N timing were small in the first four experiments, whilst in Experiment 5 the early application outyielded the late by approximately 1 t/ha under medium and high irrigation. We assert that the leaching of N prior to Experiment 5 was so severe as to introduce some artificiality into the assessments of N responsiveness. The grower of high quality, high yielding grain must have reacted to the situation and applied N at the tillering stage at the latest. The effects of N timing and irrigation level on grain yields, meaned over Experiments 1-4, are presented in Figure 2.

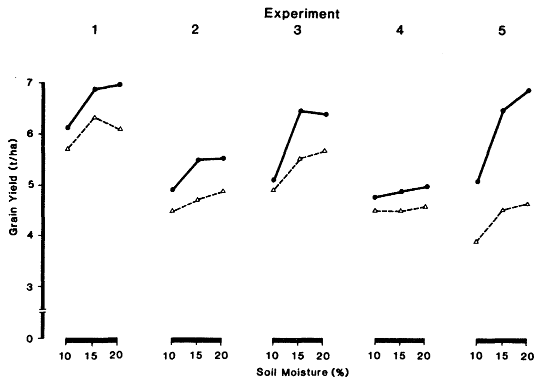

Figure 1. **Mean grain yield of three cultivars; No N (△---△), and the mean of N at tillering and N at booting (●——●) at three irrigation levels (soil moisture %).**

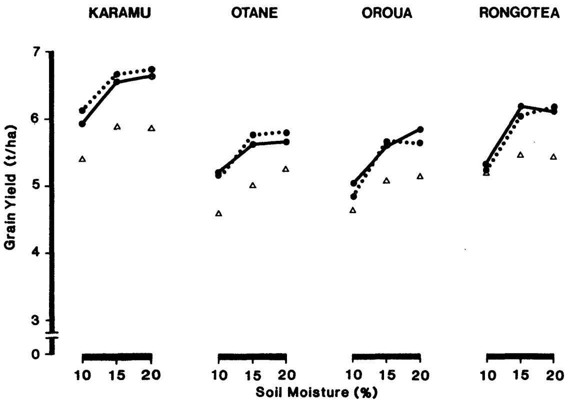

Figure 2. **Effect of nitrogen timing and irrigation level (soil moisture %) on the mean grain yield of Karamu and Otane (2 experiments) and Oroua and Rongotea (4 experiments). No N (△) N at tillering (●---●). N at booting (●——●).**

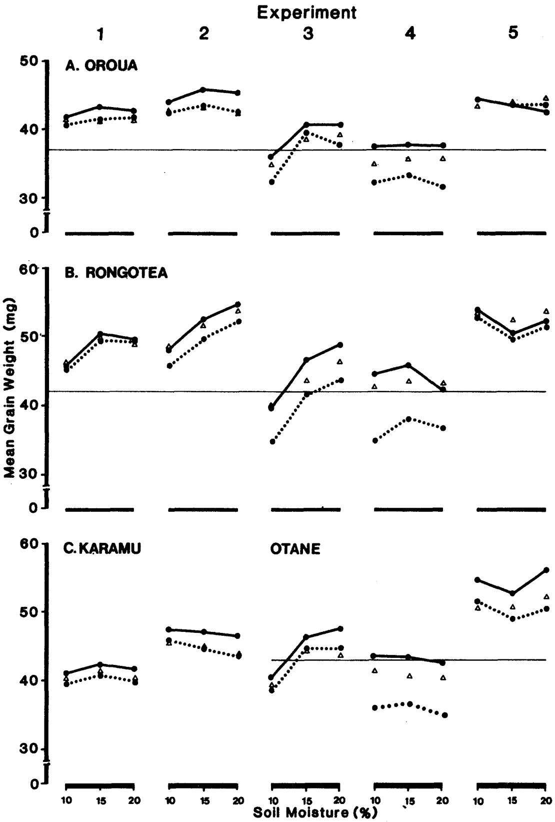

Figure 3. **Mean grain weight of Oroua, Rongotea, Karamu and Otane. No N (△), N at tillering (●---●), N at booting (●——●). Price reductions for under-weight grain commence at approximately the level indicated by the fine line.**

In four experiments Rongotea outyielded Oroua by 0.5 to 1.0 t/ha but in Experiment 3 their yields were similar. Otane yielded similarly to Rongotea. In the first two seasons Karamu gave a slightly higher yield than Rongotea. As a biscuit wheat the yield and grain protein percentage of Karamu are of interest.

Mean Grain Weight

Mean grain weight was comparatively high in Experiments 1, 2 and 5, Figures 3a, b and c. Early N decreased grain weight of Oroua in one experiment and Rongotea in four, whilst late N increased grain weight of Oroua in four experiments and Rongotea

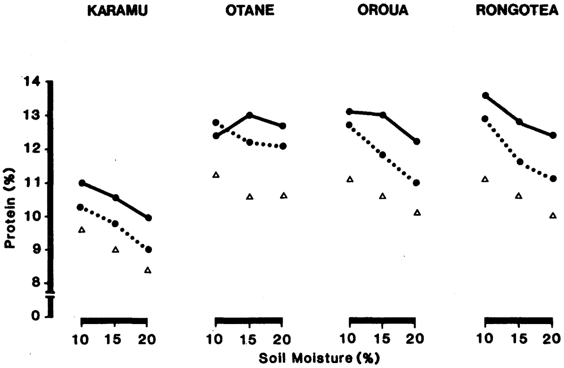

Figure 4. **Effect of nitrogen timing and irrigation level (soil moisture %) on the mean grain protein % of Karamu and Otane (2 experiments) and Oroua and Rongotea (4 experiments). No N (□), N at tillering (● - - - ●), N at booting (●——●).**

in two. Irrigation responses were remarkably similar under both early and late N application. Cultivar penalty levels are indicated, and are the means of between two and four current contracts.

For Oroua, medium irrigation increased grain weight substantially in Experiment 3, otherwise there was little effect with irrigation frequency, Figure 3a. The mean advantage of late N over early N was 2mg. Overall, the mean grain weight of Rongotea was approximately 7mg heavier than Oroua. However, Rongotea was more sensitive to irrigation and N timing, Figure 3b. Late N showed an overall advantage of 3.5mg over early N. The anomalous result in Experiment 5 in which medium irrigation appears to have depressed grain weight is more likely to be due to artificially high grain weight associated with low grain yield on the low irrigation treatment. The probable explanation for this is that soil moisture on this treatment hovered just above 10% (wilting point) for a few days at the booting stage.

Mean grain weight and irrigation responses in Otane were similar to Rongotea. However, in Experiment 3 early N did not decrease grain weight and in Experiment 5 late N averaged about 4 mg higher than early N, (Figure 3c).

Grain Protein

Grain protein percentage was comparatively high in Experiments 3 and 4. Means over the first 4 experiments are shown in Figure 4. Protein percentage increased with applied N, with late N exceeding early N in all cultivars and in all experiments, and generally decreased with increasing irrigation frequency.

Grain protein percentage in Oroua and Rongotea was very similar. The mean protein percentage of Karamu was approximately 1.3% below Oroua and Rongotea and Otane averaged about 0.5% below Oroua, in corresponding experiments. Penalties were indicated at high irrigation levels both without N and, to a lesser extent, when N was applied at tillering.

Baking Score

Baking scores, were analysed on samples bulked across replicates using all 5 years data as a multifactorial array, using 3 and 4 factor interactions as error variance estimates. Current contract penalty scores are indicated in Figure 5.

Baking scores of both Oroua and Rongotea varied strongly across seasons, (Figures 5a and b) yet those of Rongotea were lower than Oroua in each experiment. Responses to N and irrigation were more variable than those of grain protein percentage but the effects of N were not shown to change across seasons. Overall, N increased baking scores, in particular when N was applied at booting, although the advantage of the later N over early N was not as pronounced as it was in grain protein percentage.

Medium irrigation decreased baking scores, with further slight reductions to heavy irrigation.

Mean baking scores of Otane were comparable with Oroua in Experiments 3 and 4 but higher by an average of 5 bake score points in Experiment 5 (Figure 5c).

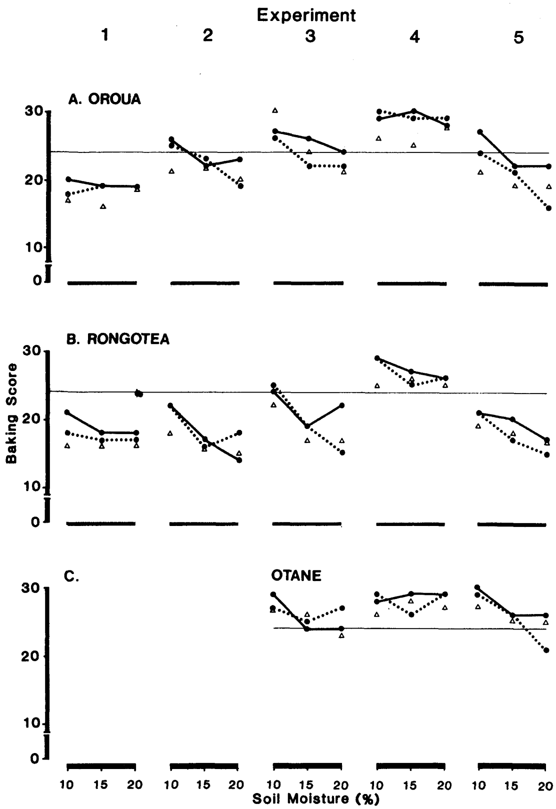

Figure 5. **Baking scores of Oroua, Rongotea, Karamu and Otane. No N (□), N at tillering (● - - -●), N at booting (●——●). Quality premiums and discounts apply above and below the fine line respectively.**

DISCUSSION

Grain Yield

Irrigation at the medium level required an average of two more irrigations than low irrigation and it produced a significantly higher and worthwhile yield in all cultivars. Further irrigation was not worthwhile. The infrequent interaction between irrigation level and cultivar indicates that irrigation does not have to be adjusted for the different cultivars used in these experiments, irrigation at the medium level being adequate for all cultivars.

All cultivars responded to N, variously, in all seasons but generally yield differences due to N timing were small.

Grain Quality

Minimum acceptable grain weight set by prospective buyers varies according to cultivar and to company requirements. For this reason it is not possible to be specific about critical values for any cultivar. Currently, the minimum acceptable mean grain weight of Oroua (32-37gm) is lower than that of Rongotea and Otane (about 40mg). The mean grain weight difference between Oroua and Rongotea in our experiments was about 7mg.

Irrigation was more effective in increasing mean grain weight of Rongotea that it was of Oroua, Karamu and Otane. However, it was only in Experiment 3 that irrigation raised grain weight from probably unacceptable to acceptable levels and it did so to all cultivars.

Time of N application had a decisive effect on mean grain weight. All cultivars gave higher grain weight with the later N but here also cultivar x N timing interactions did not show a consistent pattern across the seasons nor could they be linked to environmental events. Mean grain weight was improved more by the later N application probably because N retention in the free-draining Lismore soil is very low and most of the residual N would have been depleted by the time the plants reached the booting stage. It is likely that the early application N at tillering would have stimulated more grains per unit area, causing wider distribution of available N (Scott, 1981, Stephen *et al.*, 1985).

Although baking scores of Oroua and Otane were much higher than those of Rongotea, responses to irrigation and N followed similar trends in all cultivars. The advantage of late N over early N was one baking score point as compared with 1% for grain protein, commercially equivalent to about 3 baking score points.

Cultivar Performance

The performance of Otane has shown it to be a suitable cultivar for spring sowing on light soil under irrigation. Overall, it yielded slightly better than Oroua and although its grain protein percentage was slightly lower and less responsive to late N it had a similar baking performance. In addition, Otane has stronger resistance to some diseases than both Oroua and Rongotea. Despite its high-yielding ability less Rongotea is expected to be sown because of the present demand for high quality wheat. Karamu yielded very well and, with medium or high irrigation and early N, grain protein percentage was in the premium grade for biscuit making.

Overview

In the absence of any consistency in the treatment x cultivar interactions throughout the five experiments it is not possible to conclude that the cultivars should be managed differently. When the relative merits of the treatments are considered it is necessary to combine yield and the quality attributes. Under the fertility constraints pertaining to these experiments low irrigation and N applied at booting gave the highest quality wheat but on balance, medium irrigation and N at booting was probably the most profitable combination depending on the quality standards and more especially the minimum acceptance levels set by the buyers.

Seasonal effects

The large variation in yield from season to season despite the uniformity of the paddock history indicates that the confidence often expressed in previous cropping history as an index in models predicting yields and N responses may be misplace. Indeed, not all workers agree that previous history is a suitable fertility index for predicting N requirements and Goh (1983) has pointed out the need for supporting available soil N measurements. Exploratory and incomplete soil N tests in the first three years indicated that Experiment 2 had more N available to it during the growing season than Experiments 1 and 3 using the N predictive method of Quin *et al.* (1982). However, the mean yield in Experiment 2 was much lower than its neighbours and all three experiments had a similar mean yield response to applied N.

Attempts have been made to relate N responses to rainfall at certain time periods. Feyter *et al.* (1977) found that grain yield responses to applied N in second crops were positively correlated with winter rainfall, while Stephen *et al.* (1983) showed that N responses were dependent on rainfall during crop growth and both programmes were carried out in unirrigated situations. Since all treatments in our experiments were irrigated to some degree, rainfall during the growing season can be discounted as contributing consistently to the variability of yields and N responses across the season. A change in the rate of N after two seasons could possibly explain some of the variation in mean yield and N response but sharp contrasts still existed within N rate groupings.

Mean yields with N added in Experiments 1, 3 and 5 were well above the district average and are regarded as satisfactory although they fall well short of the potential of about 8 t/ha of spring-sown Oroua under high managerial inputs for light soil under irrigation (Daly, pers comm).

Grain weight and grain quality also varied considerably across the seasons. Mean grain weight was comparatively low in Experiments 3 and 4 and these two seasons gave the best grain protein percentages. A negative correlation, across a group of experiments, between grain weight and grain N percentage in Karamu has been reported by Drewitt (1979b) and is repeated here when comparing Figures 3 and 5 within cultivars. Grain weight was below probable milling standard with early N in Experiment 3. Mean grain protein was high in Experiments 3 and 4 mainly because of the response to N, especially late N; thus late nitrogen's enhancement of grain weight does not correspond with a drop in grain protein percentage.

Baking scores followed similar seasonal trends to grain protein but were too irregular for there to be a substantive correlation between baking score and grain protein. Wilson (1983) showed that although there may be a significant correlation between baking score and flour protein it is not feasible to predict baking score from flour protein. Grain protein is about 1.0% higher than flour protein from the same sample (Scott, 1981) but can vary from 0.5 to 1.5% (Dengate, 1983).

DISCUSSION

Although the cultivars responded to irrigation in slightly different ways from season to season there were no consistent cultivar preferences and it is concluded that growers growing the cultivars used in these experiments do not have to adjust their irrigation regimes.

Following a wet winter, early N was essential, otherwise there was very little difference in yield between applying N early (at tillering) or late (at booting).

Late N improved grain protein percentage and baking score more than early N and the improvement was proportionally much larger in protein than in baking score.

Grain protein percentage of Rongotea was comparable to that of Oroua and Otane but its baking quality was inferior.

Mean grain weight was higher with later N; with Oroua grain weight was generally raised by late N while Rongotea grain weight was reduced by early N.

The most profitable treatment combination will depend largely on the pricing structure of the different cultivars. Overall, irrigation at the medium level with late N gave a moderate yield with acceptable quality, while low irrigation with late N gave lower yield but higher quality.

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