Effects of Irrigation and Nitrogen Fertiliser on Yield and Quality of Malting Barley Grown in Canterbury, New Zealand

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Introduction

Adjustment of application rates of nitrogen (N) fertiliser and irrigation are the primary ways growers of malting barley (*Hordeum vulgare* L.) can consistently produce malting grade grain. Current specifications include grain N concentrations below 2% and screenings (<2.38 mm) not exceeding 5%. Decisions on acceptance or rejection of malting barley crops in New Zealand are primarily based on these crop variables.

It is difficult to achieve consistent high yield and high quality in the variable growth environments that occur in Canterbury and on soils with differing fertility and cropping history. Previous work (de Ruiter and Brooking 1994, 1996) has shown that high yield and good grain quality can be achieved when grain growth is not limited by water stress. However, relationships between yield, quality, environment and management remain ill-defined. The purpose of the study was to determine the scale of the response of barley yield and quality variables to seasonal influences and crop management effects. The objective for growers is to maintain high yield without compromising the quality of grain. Data from three experiments over three seasons were used to determine the scale of variation due to 1) climatic influence, 2) soil fertility, and 3) interacting effects of soil water and soil N on yield and quality.

Materials and Methods

Commercial crops (Experiment 1)

Thirty-three and thirty-two crops of barley were grown in 1996/97 (year 2) and 1997/98 (year 3), respectively, within a 50 km radius in Central Canterbury. Randomly positioned 50 m x 10 m blocks were selected within the paddocks and divided into five contiguous plots to define within-paddock replicates. Approximately half of the crops were irrigated. Growers used their normal management practices for fertiliser, sowing options, herbicide and fungicide use.

Nitrogen experiment (Experiment 2)

At three sites an additional 50 kg N/ha was applied as urea at tillering. The experiment at each site was conducted as a split plot design with N constituting the sub-plot treatment. The crops were irrigated by overhead sprinkler according to paddock rotation rather than by water budget. Crops were managed optimally for weed control and disease suppression.

Rain shelter study (Experiment 3)

This experiment was conducted in a mobile rain shelter in 1995/96 (year 1) on a Templeton sandy loam (Udic Ustochrept, USDA soil taxonomy) at Lincoln, New Zealand (lat 34°38'S, long 172° 30'E). The soil had an available water capacity of 190 mm, assuming a maximum rooting depth of 100 cm. Soil N reserves were low following four crops of ryegrass and one of wheat. Two pre-season irrigations of 50 mm were used to reduce the inorganic N by leaching. Potassic superphosphate was applied at 200 kg/ha and incorporated during pre-sowing cultivation. Barley (cv.Valetta) was sown at 15 cm row spacing on 20 October at 150 kg/ha to achieve a mean population of 280 plants/m^2. Individual plot size was 3.6 x 5.0 m with 0.5 m borders on all sides.

Five water and three N treatments were arranged in a factorial randomised incomplete block design with two replicates. Three drought treatments (full drought, early drought and late drought) were located inside the shelter and two treatments (rain-fed and fully irrigated) were exposed to the weather. Irrigation by trickle reticulation commenced on 15 November. During periods of irrigation, water was applied at weekly intervals in amounts equivalent to the net change in the previous week's soil water, measured by time domain reflectometry (0-20 cm) and by neutron probe (20-100 cm). Calculation of water use was by the Penman (1971) equation. In the early drought treatment, water was withheld until early stem elongation (GS 31; Zadoks *et al.* 1974). Late drought was imposed by withholding water from plots from early stem elongation until grain maturity. Further details of irrigation treatments are reported by de Ruiter (1999).

Nitrogen treatments were chosen to represent a range of low to high fertility levels. Applications were nil; one application of 50 kg N at sowing applied by hand; two applications of 50 kg N at sowing and second node respectively; and three applications of 50 kg N each at sowing, tillering and second node, respectively. The second and third applications were applied in irrigation water using a minimum (2 mm) of water.

Sampling and analysis

Yield components in all experiments were determined on 0.3 m^2 quadrat samples and grain yield on duplicate 1.0 m^2 quadrats. Samples were dried to constant weight at 70°C for 48 hours, then threshed using a Kurt Pelz stationary thresher. Percent screenings were determined by hand separation over a 6A (2.38 mm) screen. Three independent 100 g subsamples from each plot were passed over screens with slot dimensions of <2.00, > 2.00, > 2.10, > 2.36, > 2.50, and > 2.76 mm, respectively, to determine proportions in standard size classes: < 5.0, > 5.0, > 5.5, > 6, > 6.5, and > 7. N content of grain and herbage fractions was determined by combustion of 200 mg of finely ground sample in a LECO 2000 analyser. Soil mineral N was measured in duplicate cores (0.3 m depth). Nitrate and ammonia levels were determined on an RFA 300 autoanalyser following extraction of 4 g (fresh weight) in 20 ml of 2 M KCl.

Statistical analysis

Analysis of variance with standard tests for significance was performed using Genstat 5. In the rain shelter experiment, variables were analysed according to a design separating inside- and outside-shelter effects. In all cases, the shelter effect was not significant. Thereafter, the experiment was treated as a factorial fully randomised complete block design.

Results and Discussion

Weather

Years 1, 2 and 3 were considered 'cool-dry', 'cool-wet' and 'warm-dry', respectively. Temperatures in November and January in years 1 and 2 were cooler than the long-term mean. In particular, January in year 2 had up to 70 fewer degree-days/month than average and coincided with 44 mm more rain than the January average of 50 mm. Evaporation was 38 mm less than average. Cumulative potential soil deficits in Year 3 were significantly greater than in the previous two years. December in year 1 was significantly warmer than average. All other months (except January in year 2) for years 1-3 were drier than the mean for Canterbury. Solar radiation was close to or greater than the mean in all monthly periods.

The latter part of Year 2 was considered a La Niña period. The following season (1997/98) was typical of an El Niño weather pattern on the East Coast of the South Island with below-average rainfall through to crop maturity. Rainfall over the growing period from late October to the end of January was 106 mm less than the 23-year average.

Soil nitrogen

Seasonal soil mineral N patterns (Experiment 1) within sites were similar, but there were differences between the seasons (Fig. 1). In both years, the starting levels of mineral N were less than 100 kg N/ha. These increased up to a mean over three sites of 165 kg N/ha and 199 kg N/ha for the respective years (0-30 cm soil depth) following fertiliser application. Soil mineral N was rapidly depleted at the time of grain filling. Given the unusually wet conditions during grain fill in 1996/97 there was not a surplus of mineral N for late uptake. Higher than average N losses could have occurred through leaching, gas emission and immobilisation. In 1997/98, when temperatures were higher and rainfall lower, there were higher levels of available N for uptake during grain fill.

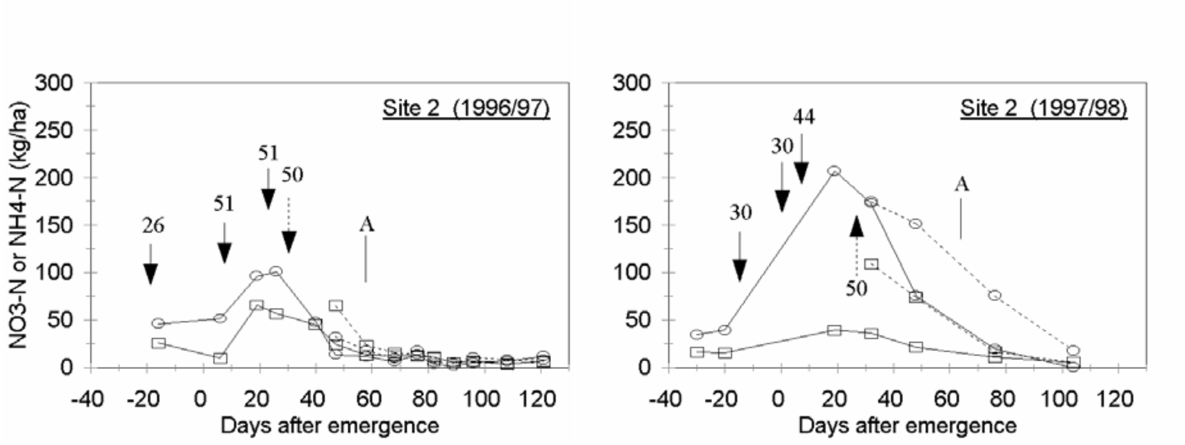

Figure 1. Typical pattern of nitrate (○) and ammonium-N (□), (0-30 cm depth) in 1996/97 ('cool-wet') and 1997/98 ('warm-dry') seasons. Values indicate fertiliser applications and dashed lines are for the additional N treatment, (A = anthesis).

Soil water

Maximum deficits (Experiment 1) at the respective sites were 65, 106 and 66 mm in year 2, and 86, 99 and 91 mm in year 3. These deficits were not sufficiently significant to reduce yields, except at site 3 in year 3. This site was on a shallow soil type (< 110 mm available capacity) while the others were on deep soils with up to 150 mm available soil capacity.

Maximum measured soil deficits within the rain shelter for the full drought, late drought and rain-fed treatments were 159, 150 and 146 mm, respectively. These all occurred early in grain filling. Throughout grain filling these crops were generally under moderate to severe stress (Jamieson *et al.* 1995). Soil deficits in the rain-fed treatment closely followed the full drought treatment as the season was particularly dry. Maximum soil deficit of 103 mm in the early drought treatment occurred 7 days before anthesis, and the maximum-recorded deficit in the fully irrigated treatment was 61 mm.

Yield variation

Over the three experiments, grain yield varied from 3 to 9 t/ha. Kernels/m^2 were highly correlated with final grain yield (r = 0.95) confirming results of Biscoe *et al.* (1975). Up to 20,000 kernels /m^2 were required to achieve an 8 t/ha crop without significant water or N stress. High yielding crops were also required to initiate and support sufficient populations of ear bearing tillers and high numbers of grain per ear and/or fill kernels close to their potential. In the rain shelter the number of ear bearing tillers also explained a high proportion (93%) of the yield variation. An apparent maximum yield response to tiller population occurred at 900 ears/m^2. Any gains in yield attributed to further increases in tiller populations were offset by reductions in grain size.

Commercial crops

Irrigation responses

Crops were compared for systematic trends in yield components and grain N concentrations that could be related to irrigation response (Table 1). In the 'cool-wet' year all but one crop had acceptable grain N concentration. Interpreting responses to irrigation should, however, be done in the context of level of fertiliser N applied. In year 2 ('cool-wet'), growers, on average applied 92 kg N /ha. In the following 'warm-dry' year, generally more N was applied despite a reduced requirement because of higher accumulation of mineral N. This exacerbated the problem of high grain N concentrations. Two-thirds of the grain crops did not meet the quality standard of 2% N or less. Excess grain N accumulation in year 3 occurred in both irrigated and dryland crops, although mean N concentrations were lower with irrigation (Table 1).

The N uptake and partitioning patterns of crops in the contrasting seasons were different. For example, mean N uptake at three sites monitored at anthesis were higher in year 2 (22.5 g/m^2) than in year 3 (19.4 g/m^2). In the period until grain maturity there was a net loss of 3.1 g/m^2 in year 2 and a net gain of 4.0 g/m^2 in year 3. Uptake during grain filling and consequent effects on grain N concentration were obviously related to both the demand and supply of soil N for uptake. Crops with higher N at anthesis were more likely to rely on remobilisation than uptake of N from soil (de Ruiter and Brooking 1996).

N fertiliser responses

Applications of N at tillering (Experiment 2) had a significant effect on grain yield, grain N concentration, crop N uptake and grain number, but did not influence screenings or mean grain size (Table 2). Only the grain N and N uptake response to N application were different within each season. The mean grain N concentration was within the acceptable quality standard in year 2 ('cool-wet') under both N treatments. However, additional N caused a quality decline in year 3 ('warm-dry').

Combined data for both years (Experiments 1 and 2) showed few consistent crop responses to N fertiliser level. Significant trends only occurred in the 'cool-wet' season. Grain yield was weakly related to N uptake by the crops (r^2 = 0.39). Similarly, N fertiliser level and crop N uptake explained 21 and 29 % of the variation in grain N concentration, respectively. There was a correlation between crop N uptake level and the level of N fertiliser applied (r = 0.62), but this relationship broke down in the following dry year. Under limiting soil water environments, processes that govern crop performance in relation to crop N nutrition become more intricate.

Table 1. Effects of irrigation on yield and quality variables of grain harvested from commercial crops over two seasons (1996/97 and 1997/98).

	Year 2		Year 3	
Variable	Control n=18	+ Irrigation n=14	Control n=18	+ Irrigation n=15
Mean N fertiliser (kg/ha)	76 (38) a	111 (39)	87 (51)	129 (70)
Mean rainfall (mm)	329 (141)	304 (58)	211 (121)	147 (32)
Mean irrigation (mm)	-	204 (155)	-	282 (134)
Grain yield (t/ha)	6.7 (1.3)	7.8 (2.1)	5.6 (1.4)	7.0 (1.1)
N uptake (g N/m2)	14.4 (3.6)	17.5 (5.2)	18.3 (4.6)	22.2 (4.2)
Tiller population (per m2)	686 (121)	845 (226)	780 (153)	860 (138)
Thousand kernel weight (g)	42.0 (4.1)	42.4 (3.8)	37.0 (5.3)	41.6 (4.6)
Grain N (%)	1.60 (0.26)	1.64 (0.48)	2.28 (0.33)	2.11 (0.33)

[a] Values in parentheses are standard deviations.

N x water interactions (Experiment 3)

In the rain shelter the early drought treatment was chosen to influence processes involved in determining grain number (Fischer, 1985), while the effect of late drought was anticipated to influence grain expansion alone (Aspinall, 1965). Full drought was likely to affect both grain number and grain size development, while the fully irrigated treatment outside the shelter provided optimum conditions for both processes.

In the field, differences in crop performance could be associated with seasonal variation. However, separation of weather-related influences from soil fertility variables was imprecise. In the controlled soil water conditions of the rain shelter experiment, crop yield and quality responses were related to the levels of crop water use and fertiliser N applied. Variations in components of yield were strongly influenced by seasonal crop water use, but there were varying responses to N fertiliser (Table 3). Full drought reduced grain yield by 60% in the low N treatment, whereas in the high N fertiliser treatments there was significant recovery. Early drought significantly ($P<0.05$) reduced the number of kernels/m^2. Fertiliser rate also had a strong effect on grain number ($P<0.05$). In contrast, grain size was not influenced by N treatment. However, there was a significant response to seasonal water use. Therefore, effects of drought at an earlier stage were carried over to processes of grain development. An exception to the water use response for grain size occurred in the rain-fed treatment. Despite the dry year, grain size was comparable to the fully irrigated treatment. Little but significant rainfall (53 mm) during grain filling (and earlier during development) was effective for grain fill although there were significantly fewer grains than in the fully irrigated treatment. For all variables, interactions between water and N treatments were not significant ($P>0.05$).

Grain quality

Size distribution

Drought treatment had a strong effect on grain size distribution with significant differences between treatments for most size classes (Fig. 2). Full drought and late drought caused large reductions in grain size. In these treatments, 50% of the kernels were in the 6.0-6.5 category and 30% of kernels in the uppermost (>7) size class. In contrast, early drought and irrigated treatments had at least 70% of the kernels in the largest size category (>7) and only a small proportion in the < 6 class.

Table 2. Effects of site and additional N fertiliser on yield, yield components and quality at three irrigated sites in respective 'cool-wet' and 'warm-dry' seasons.

Effect	Treatment	Grain yield (t/ha)	Grain number (per m2)	N uptake (g/m2)	Grain N (%)	Scr[a] (%)	TKW b (g)
Site	1	8.0	17 968	21.8	1.94	1.7	44.7
	2	7.7	17 089	20.4	2.02	2.9	45.0
	3	7.5	19 432	21.9	2.02	7.4	38.8
SED; df=2		0.65	780	1.57	0.11	0.21**	2.71
Interaction (Year x Nitrogen)							
Yr 2	N (control)	7.8	17 678	18.1	1.77	-	44.5
	N (+ 50 kg/ha)	8.4	19 554	19.5	1.98	-	42.9
Yr 3	N (control)	7.2	17 206	20.6	1.86	3.4	42.3
	N (+ 50 kg/ha)	7.5	18 215	27.3	2.38	4.6	41.6
SED; df=24		0.30ns	901.5ns	1.03***	0.065**	1.59 ns	1.15ns

[a] Effects for year and site were all non significant, except for screenings ([a]year 3 only; site was significant at P<0.001; df for N effect =12). Site and year effects were tested against year x site interaction.

ns, *, **, ***; weakly or non significant, significant at P<0.05, 0.01 and 0.001, respectively.

[b] Thousand kernel weight.

SED, standard error of difference between means.

The pattern for the rain-fed treatment was similar to the less drought-affected treatments in the lower size classes, but this treatment had a lower proportion (50% of the sample) of large size (>7) kernels.

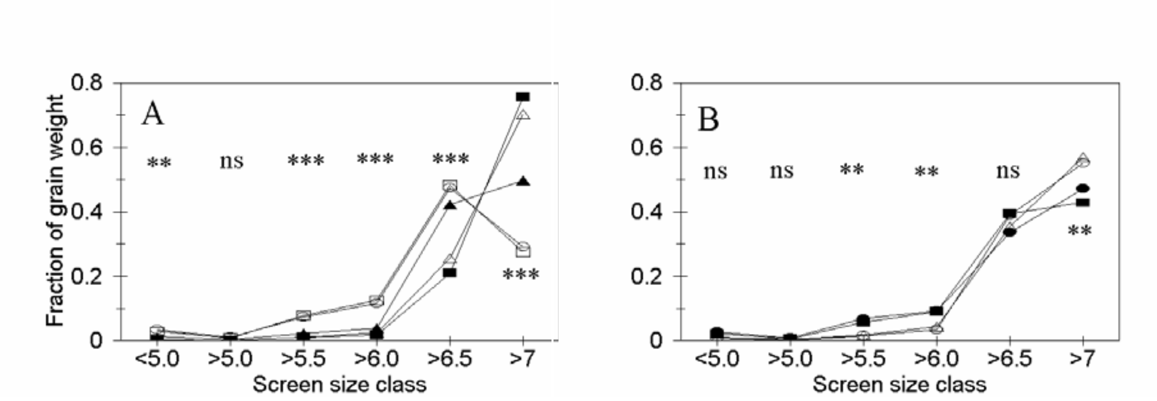

Figure 2. Kernel weight distributions (proportion of sample) at maturity for drought (A; ○ = full drought, Δ = early drought, □ = late drought, ▲ = rain fed, ■ = irrigated) and N (B; ○ = 0 N (control), Δ = 50 kg N/ha, ● = 2 x 50 kg N/ha and ■ = 3 x 50 kg N/ha) treatments means. Analysis of variance was performed for each size class with significance levels as for Table 2.

Size distribution effects were not as strong for the N treatments (Fig. 2). There was no N effect in the largest size class (6.5-7) containing up to 40% of the grain sample, but proportions were different in the middle and upper size classes. There was a smaller proportion of large grains (>7.0) in the higher N application. The opposite trend occurred for the 5.5-6 and 6-6.5 categories where additional N tended to increase the proportion of small grain. Grashoff & D'Antuono

(1997) reported similar results with N response affecting yield potential by influencing grain number in preference to grain size.

Grain N

All grain was within specification (<2% N) for malting, even in the high fertiliser N treatments. The level of N application was strongly related to grain N ($r^2 = 0.66$). The response was linear (from 1.39 to 1.85%) over the range of total N applied. Water treatment had no effect on the upper level of grain N, although treatments with significant water stress late in development (full drought, late drought and rain-fed treatments) produced a greater range of N concentrations (Fig. 2). There was no interaction between water and N treatment for grain N concentration.

Table 3. Effects of drought and nitrogen fertiliser on the yield and quality of barley grown in a rain shelter (Experiment 3).

Treatment	Seasonal water use (mm)	Max. deficit (mm)	Grain yield (t/ha)	Grain number (per m^2)	TKW [a] (g)	Grain N conc. (%)
Drought						
Full drought (A)	124	163	4.1	10 954	37.2	1.62
Early drought (B)	151	103	4.9	11 258	43.4	1.64
Late drought (C)	186	163	4.8	12 651	37.7	1.54
Rain-fed (D)	241	151	3.9	9 487	40.7	1.66
Irrigated (E)	345	61	5.8	13 160	43.8	1.64
LSD (P<0.05), df=19	-	-	0.60 ***	1 386***	2.02***	0.108 ns
Nitrogen						
Control			3.7	9 294	40.1	1.39
1 x 50 kg N/ha			4.5	10 853	41.2	1.58
2 x 50 kg N/ha			5.1	12 631	40.1	1.65
3 x 50 kg N/ha			5.4	13 231	40.9	1.87
LSD (P<0.05), df=19			0.53***	1 240***	1.81ns	0.096***

[a] Thousand kernel weight.

^{ns}, *, **, ***; weakly or non significant, significant at P<0.05, 0.01 and 0.001; respectively.

Water x nitrogen interactions were non significant for all variables.

LSD, least significant difference.

Conclusions

There were quite marked differences among commercial crops grown in the contrasting seasons. In the ‘cool-wet’ year both yield and quality were acceptable. However, in the ‘warm-dry’ season grain quality was much reduced. Irrigation alone in a ‘warm-dry’ season was not effective in limiting excessive N accumulation in the grain. Higher plant N uptake occurred in this season because of increased N fertiliser use and higher base levels of mineral N, particularly during grain filling. N application increased the grain yield of crops in most situations, but water treatment or season modified the scale of the effect. The risks of high N grain were reduced in a wet year and increased in a dry year.

The study in the rain shelter confirmed patterns of yield and quality variation in commercial crops. Soil water deficits up to 100 mm during tillering and early stem elongation were effective in reducing grain yield by influencing grain number. Grain size was strongly influenced by late drought treatments (up to 160 mm soil water deficit). Fertiliser level was the main factor causing grain N variation under rain shelter conditions, but drought had the greatest impact yield and grain size.

Field experiments showed there was a large element of risk in dryland cropping, although this was reduced under irrigation. Nevertheless, crop quality problems were also evident with good water management. Grain quality (grain size and grain N concentration) was invariably reduced by ‘late’ N fertiliser. Early season monitoring of soil N may guide decisions that impinge on the yield potential and grain quality in particular seasons. Increased fertiliser inputs to enhance yield were not recommended given the decline in grain quality.

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