A SURVEY OF THE VARIABILITY IN YIELD AND QUALITY OF MALTING BARLEY IN THE RANGITIKEI REGION

J.M. de Ruiter, I.R. Brooking, R.M. Haslemore and R.A. Carran*
Plant Physiology Division, DSIR, Private Bag, Palmerston North
*Grasslands Division, DSIR, Private Bag, Palmerston North

ABSTRACT

Twenty-one crops of spring malting barley (*Hordeum vulgare* cv Triumph and Acclaim) in the Rangitikei region were surveyed in the 1987/88 season to assess the range of variability of grain yield and grain quality amongst farms. Crops were sampled at maturity for total dry matter, dry matter partitioning, yield components, nitrogen content and nitrogen partitioning. Grain malting quality was assessed using micromalting procedures. Six of these crops were monitored in detail throughout the season to study patterns of growth, development and nitrogen uptake.

Grain yields ranged from 4.7 to 9.5 tonnes/ha (14% moisture), with a coefficient of variation of 16%, and were most highly correlated with grain number/m² (r = 0.80) and ear number/m² (r = 0.75). The optimum ear population for grain yield was greater than 900 ears/m², which required in excess of 300 plants/m². From the observed relationships between ear number and plant population, and between grains/ear and ear number, half of the crops were identified as being stressed during the tillering and stem elongation phases. Limited available soil nitrogen was the most likely stress at this stage. Average weight/grain (range 32.8 to 44.9 mg/grain) was significantly correlated with grain yield(r = 0.61), but showed no association with grain number/m². Available soil water during the grain filling period was the most likely cause of variation in weight/grain. Grain size distributions varied from normal to skewed distributions, influencing the levels of screenings (grains <2.38 mm width), which ranged from 3.6 to 24.4%.

There was no significant association between grain yield and fine malt extract, whereas grain nitrogen content (range 1.33 to 2.07%) was positively associated with grain yield (r = 0.45). However, as all crops had acceptable quality as judged by fine malt extract and nitrogen content, high yields were obtained in this season with no detriment to grain quality.

On average, 80% of the nitrogen in the above-ground crop was derived from soil reserves, and current cropping practices appear to be depleting the available soil nitrogen reserves by about 16 kg/ha per year of cropping. Management strategies for obtaining high yields of high qality malting barley in this region are discussed, and the importance of establishing and maintaining an adequate tiller population early in the season is stressed.

INTRODUCTION

Barley has been traditionally grown in the North Island as a feed grain, but the opening of a 40,000 tonne/year capacity malting plant at Marton in 1981 by the Canterbury (NZ) Malting Co. Ltd (CMC) created a market for malting barley. In the 1986/87 season, about 10,000 tonnes of malting barley was grown under contract to the CMC out of total southern North Island barley crop of 66,000 tonnes.

Crop management for malting barley is more demanding than that of feed barley, as strict quality criteria are laid down for acceptance of the grain. The cultivar grown is determined by the CMC, grain nitrogen levels must not exceed 2%, and levels of screenings above 5% reduce the returns to the grower. Management of nitrogen inputs is therefore quite crucial, as the grower will maximise economic returns by producing high yields of high quality barley. Studies from both the USA (Stark and Brown, 1987; Varvel and Severson, 1987) and in Southland (Haslemore and Risk, 1985) suggest that high yields of high quality malting barley can be attained through appropriate management of nitrogen inputs.

Management recommendations for malting barley in the North Island are based on limited quantitative information. The work of Wauchop and Field-Dodgson (1978) remains the only published information concerning grain quality in the North Island, and pre-dates the introduction of the current cultivar, Triumph. Much of the published work from the South Island concerns barley growth under irrigated conditions (Thompson *et al.*, 1974; Drewitt and Smart, 1981), and cannot be readily transferred to the predominantly non-irrigated North Island cropping farms.

The objectives of this present study were to document the range of variation of grain yield and grain quality amongst 21 crops grown in the Rangitikei regions during the 1987/88 season, and to relate this variation to management practices, cropping history, and the current environment. A more detailed study was made of six of these crops to relate crop growth, development and nitrogen uptake patterns to both the environment and the prevailing management practices. Only generalisations can be made from such an approach, as intensive, multidisciplinary studies are required to resolve and quantify the sources of variation (Gales, 1983; Thorne, 1986).

MATERIALS AND METHODS

Twenty-one crops from farms contracted to produce grain for the CMC were included in the survey, and all were located within a 10 km radius of Marton. Crops were sown at 15 cm row spacing with Baytan IM fungicide-treated seed, and were not irrigated. Further details of crop management practices are provided in Table 1. Sites 1 to 6 were visited on average once per week, whereas sites 7 to 21 were visited and sampled only at maturity. On sites 1 to 6, four contiguous plots of 20 x 20 m were located on areas with minimal slope and uniform plant establishment, approximately three weeks after sowing.

Management practices

Heavy rainfall between October 7 and October 14 led to most of the crops being sown between October 18 and October 31, with only three of the crops being sown earlier than this (Table 1). Paddock history ranged from first year out of pasture (sites 4, 10 and 12) to 12 seasons of continuous cropping (site 18). Nitrogen application rates averaged 20 ± 11 kg N/ha for crops one to five years out of pasture, whereas 68 and 52 kg N/ha were applied to the crops which followed 8 and 12 years of cereals, respectively. Herbicides were used by all growers, whereas only ten applied fungicide.

Crop environment

Instruments recording rainfall, air temperature and total incoming short-wave radiation were located at site 3. A soil water balance for this site was calculated using the model of Kerr *et al.*, (1986). Calculations were based on an available soil water capacity of 87 mm for this soil type, and assumed a maximum rooting depth of 70 cm. Available soil water capacity was defined as the volumetric water content held between field capacity and 1500 MPa.

Soil mineral nitrogen levels (NO_3^- and NH_4^+) were determined at sites 1 to 6 during early tillering (Zadoks stage 21). Soil samples were kept in an insulated container for up to four hours before sieving (2 mm) and subsampling for extraction with 2M KCl containing 5 mg/ml phenyl mercuric acetate (soil:solution, 1:10). Nitrate and ammonium concentrations were determined by automated colorimetry.

Temperature and radiation throughout the season were generally consistent with the 11-year means (Fig. 1). Notable exceptions were a warm period in late October/early November soon after the crops were sown, and low radiation levels during an extended period of wet weather in February. The rainfall in February occurred after all of the crops had completed grain filling, but caused considerable delays in harvesting many of the crops in the region.

Crop development

At sites 1 to 6, crop canopy development was determined on several occasions from the difference between above- and below-crop PAR levels using a Licor quantum sensor (above crop) and Licor line sensor (below crop). Physiological maturity was defined by attainment of maximal grain weight, and was determined from sequential samples of 10 ears per replicate at weekly intervals during grain filling. The mean durations for crop development

TABLE 1: Crop management of trial sites.

Site	Sowing Date	Sowing Rate (kg/ha)	Paddock History (previous years in cereal)	Chemicals: Herbicide	Chemicals: Fungicide	Nitrogen Fertiliser applied (kg/ha)	Soil N (NH_4^+ + NO_3^-)[a] (kg/ha)
1	31 Oct	143	2	Glean + Bromoxynil	—	20	139
2	20 Oct	136	2	Combine	TILT	24	85
3	21 Oct	148	1	Glean + Bromoxynil	TILT	25	153
4	24 Oct	136	0	2,4 – D Amine	—	24	115
5	21 Oct	136	2	Butyl/MCPA	TILT	24	153
6	24 Oct	148	2	Glean + Bromoxynil	—	17	139
7	19 Oct	128	2	Glean	—	23	—
8	6 Oct	128	2	Glean	—	22	—
9	18 Oct	130	1	Glean	TILT	7	—
10	29 Sept	128	0	Glean	TILT	0	—
11	20 Oct	130	1	Butyl/MCPA	TILT	10	—
12	20 Oct	130	0	Butyl/MCPA	TILT	10	—
13	20 Oct	130	4	Butyl/MCPA	TILT	10	—
14	20 Oct	136	2	Glean + Bromoxynil	—	14	—
15	20 Oct	136	2	Glean + Bromoxynil	—	14	—
16	20 Oct	136	1	Glean + Bromoxynil	TILT	38	—
17	20 Oct	136	3	Glean + Bromoxynil	TILT	38	—
18	20 Oct	130	12	Cougar	—	52	—
19	24 Oct	130	8	Cougar	—	68	—
20	4 Oct	130	3	Butyl/MCPA	—	68	—
21	26 Oct	130	4	Butyl/MCPA	—	33	—

[a] Determined on 9 November (Zadoks 21).

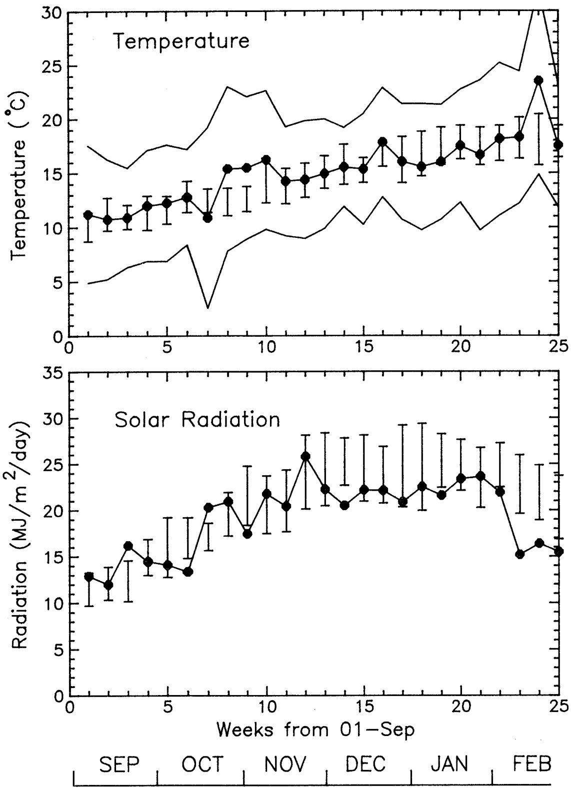

Figure 1: Weekly mean temperature and radiation for 1987/88 (●), compared with the 11 year standard errors. Upper and lower lines on the temperature graph are corresponding maximum and minimum temperatures.

stages were : sowing to canopy closure, 47 ± 2.3 days; sowing to anthesis, 59 ± 1.9 days; sowing to physiological maturity, 91 ± 2.0 days; grainfilling period, 32.3 ± 1.0 days. These durations are equivalent to thermal time of 792, 915, 1442, and 528 degree-days, respectively (0 °C base temperature). Disease incidence was generally low at these six sites. Few symptoms of barley yellow dwarf virus were noted, and although spot blotch and net blotch symptoms were noted on all of the six crops, considerable green leaf area was present at anthesis.

Crop measurements

At sites 1 to 6, plants were completely removed from single 0.25 m^2 quadrats per replicate at canopy closure, anthesis and physiological maturity. Plant and ear number were determined prior to removing and discarding root material. Ten-plant subsamples were separated into dead leaf, green leaf + stem, and, where appropriate, ear or grain and chaff components. The subsample and remainder were then dried at 85 °C. At the remaining 15 sites, three 0.22 m^2 quadrats were removed at random after physiological maturity, and processed as for sites 1 to 6. At all sites, an additional yield and grain quality sample was obtained from 1 m^2 quadrats (four per site from sites 1 to 6, three for the remaining sites), and grain separated with a stationary thresher.

Grain and malting quality

Distributions of grain weights were determined from individual weights of greater than 300 grains per site. Comprehensive mixing and subsampling of grain was achieved with multiple passes through a grain splitter. Distributions were determined for the whole sample, and for the fraction which passed through a 2.38 mm screen. Screening percentages on experimental samples were approximately double that expected from combine samples, because of complete grain recovery.

Grain was ground in a Cyclotec mill (0.5 mm screen) and all other plant fractions in a Wiley mill (1.0 mm screen). Nitrogen content of the grain (oven dry basis) and vegetative fractions was determined on the 10-plant subsamples by micro-Kjeldahl analysis, (Haselmore and Roughan, 1976). For sites 1-6, the stalk fraction comprised stem, dead and green leaf; and for the remaining sites, this fraction also included the chaff (ear minus grain).

Grain for micro-malting was screened (No. 6A, 2.38 mm) and held in sealed plastic bags at 40 °C for 10 days to break dormancy. Samples were micro-malted at constant 15 °C using the equipment and conditions described by Haslemore *et al.*, (1985). Malting performance was monitored by measuring water uptake (%) during steeping and malting loss (%). Malt extract values were determined using a test-tube scale, modified Institute of Brewing mashing technique, (Slack *et al.*, 1986). Fine/coarse difference was calculated as the arithmetic difference between malt fine and coarse extract values.

Statistical Analysis

Error mean squares for testing site effects were based on pooled rep within site variability. All effects were analysed by standard analysis of variance methods (SAS, 1985). Means separation was by the Fisher's protected LSD.

Tests of normality for seed size distributions was by either the Shapiro-Wilk W statistic ($n<51$), or by the Kolomogorov D statistic ($n>50$), (SAS 1985).

RESULTS AND DISCUSSION

Yield and yield components

A principal finding of this study was that both grain yield and grain quality varied appreciably from site to site within a relatively small survey area (Table 2). Grain yields ranged from 4.7 to 9.5 tonnes/ha, with a coefficient of variation of 16%. This level of variation is in agreement with that found by Church and Austin (1983) for cereal crops grown in the United Kingdom. The higher yielding crops were taller and bulkier, with correlation coefficients of 0.88 and 0.96 between grain yield and plant height, and grain yield and crop dry matter, respectively, (Table 3).

The relationships between yield components will now be used to make inferences about the possible causes of this yield variation.

TABLE 2: Crop characteristics for survey sites at Canopy Closure (CC), Anthesis (AN) and Physiological Maturity (PM).

	Dry Matter Yield			Tiller Number			Height	Physiological Maturity					
								Grain Yield	HI	Plant No.	Grains per Ear	Grain No.	TGW[b]
	CC	AN	PM	CC	AN	PM							
	t/ha			/m²			cm	t/ha		/m²		/m²	g
						Sites 1—6							
Low	3.0	6.2	11.4	909	661	701	57.5	6.2	0.46	226	18.4	13800	33.7
Mean	4.2	7.5	12.9	1166	784	787	67.5	7.2	0.48	257	21.0	16606	37.2
High	4.9	8.3	15.4	1347	922	894	74.0	8.5	0.50	322	23.1	19339	41.2
LSD (P<0.05)	0.7	1.0	2.1	151	105	109	3.3	1.3	0.01	56	2.2	2764	3.7
Site Effect	***	***	**	***	***	*	***	**	***	*	***	***	*
						Sites 7—21							
Low	—	—	8.3	—	—	596	60.0	4.7	0.48	177	18.6	11636	32.8
Mean	—	—	11.8	—	—	734	70.6	6.9	0.50	234	21.2	15606	38.2
High	—	—	15.0	—	—	825	87.7	9.5	0.54	273	23.9	18170	44.9
LSD (P<0.05)	—	—	1.5	—	—	111	5.1	1.0	0.02	59	2.0	2866	4.5
Site Effect	—	—	***	—	—	**	***	***	***	*	***	**	***

[a] Grain yield at 14% moisture
[b] Thousand grain weight (g)
[c] * ** ***; significant at P<0.05, 0.01 and 0.001, respectively

TABLE 3: Correlation matrix for quality and yield components of 21 barley crops.

	Dry Matter Yield	Grain Yield	Harvest Index	Grain Number	Ear Number	Plant Number	Ears per Plant	Height
Dry Matter Yield	—	0.96***	ns	0.86***	0.79***	ns	0.70***	0.73***
Grain Yield		—	ns	0.80***	0.75***	ns	0.65**	0.75***
Grain Number				—	0.84***	ns	0.61**	0.56**
Ear Number					—	ns	ns	ns
Plant Number						—	− 0.81***	− 0.65**
Weight per grain	0.46*	0.61**	0.63**	ns	ns	ns	ns	0.52*
Grains per ear	0.50*	0.44*	ns	0.69***	ns	− 0.54*	0.61**	0.47*
Plant Nitrogen	0.73***	0.65***	ns	0.77***	0.58**	ns	0.65**	0.66**
Grain Nitrogen	0.67***	0.58**	ns	0.75***	0.53*	− 0.48*	0.73***	0.74***
Fine Extract	ns	ns	0.61**	ns	ns	ns	ns	—

ns, *, **, ***; non significant, significant of P<0.05, 0.01, 0.001, respectively

Grain number

Most of the variation in grain yield (64%) could be accounted for by variation in grain number/m² (Table 3), with the remainder being accounted for by variation in weight/grain. Such a strong association between grain yield and grain number has been demonstrated in many previous studies (Gallagher *et al.*, 1975; Gales, 1983). Grain number/m² is largely determined by events prior to anthesis (Kirby, 1973), and would therefore be expected to be influenced by management factors such as sowing rate and the timing and rate of fertiliser application.

Grain number/m² can be further separated into the following two components:

a) Ear number
In the present study, 63% of the variation in grain number was associated with variation in ear number/m² (range 596 to 894), with the remainder being associated with variation in grain number/ear (range 18.5 — 23.9; Table 2). Over the range of plant populations observed at the 21 sites (177 to 322 plants/m²), ear number/m² would have been expected to increase linearly with plant population density

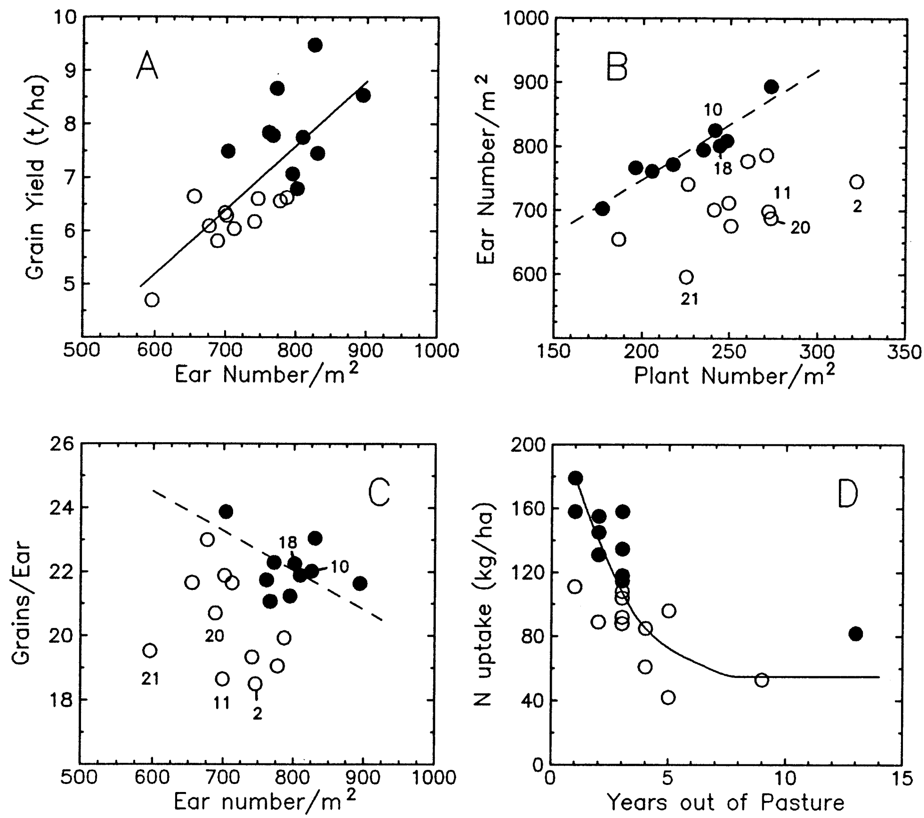

Figure 2: A-C; Yield component relationships of 21 sites. Solid lines were fitted by least squares. Broken lines were fitted by eye and based on expected responses, (Kirby, 1967).
D; Relationships between non-fertiliser nitrogen uptake and years of cropping. Closed and open circles represent crops yielding above and below 6.7 t/ha respectively.

(Kirby, 1967). Although there was no significant correlation between ear number and plant number amongst the 21 sites (Table 3), a plot of the data suggested that crops at about half of the sites could be considered as fitting the expected relationship (Fig 2B). These crops were also the higher yielding ones, all exceeding 6.7 tonnes/ha, (Fig 2A). Crops at the remaining sites had poorer tiller production and/or survival. Soil water supply was adequate during tillering (Fig. 3), suggesting that soil nitrogen supply at this time was more likely to have been the factor limiting tiller numbers (Power and Alessi, 1978; Ismail and Withers, 1984). Soil nitrate levels were only measured at six of the sites, but were lowest at site 2 (Table 1), which had a lower than expected ear number (Fig 2B).

The average response of grain yield to ear number was 1.2 tonnes/ha per additional 100 ears (Fig. 2A), with no evidence of a plateau. The optimum ear population for grain yield at these sites in this season was therefore greater than 900 ears/m², which, from Fig. 2B, would require a plant population in excess of 300 plants/m². This figure is higher than the 200 to 250 plants/m² recommended by Millner (1983), but is in agreement with Risk *et al.'s* (1984) report of 10 tonne grain yields of Triumph barley in Southland from plant populations of 300 to 350 plants/m².

b) Grains per ear

Grain number/ear has been observed to decline in response to increases in ear population at a site (Kirby, 1967; Kirby, 1969). Amongst the 21 sites, however, there was no significant correlation between these yield components (Table 3). A plot of the data suggested that, again, half of the crops fitted the expected relationship (Fig. 2), these crops being the same ones that fitted the expected response of ear number to plant population density (Fig. 2B) i.e. the factor(s) that influenced tiller production and/or survival also influenced grain number/ear in these crops. In all cases, crops which fitted the expected relationships for both ear number and grains/ear were taller than the average.

Weight per grain

Amongst the 21 sites, average grain dry weights ranged from 32.8 to 44.9 mg/grain (Table 2). The almost complete independence of weight/grain and grain number/m² (Table 3) suggests that factor(s) which influenced final grain size were not necessarily those which had influenced grain numbers. For example, crops at sites 10 and 18 had similar grain numbers and fitted the expected developmental patterns (Fig. 2B and 2C), but had final average grain weights of 44.9 and 32.8 mg/grain, respectively.

Weight per grain can be influenced by accelerated senescence during grainfilling as a result of either limited soil water (Aspinall, 1965; Lawlor *et al.,* 1981), limited available soil nitrogen (Gregory *et al.,* 1981; Spiertz and de Vos, 1983) or foliar disease. A water balance calculated for the crop at site 3 showed that soil water reserves at this site were reduced to less than 30% of field capacity during the latter stages of grain filling (Fig. 3). Although the weight/grain at this site was equal to the average of the 21 sites (37.9 mg, Table 2), it may well have been reduced from a higher potential weight as a result of this water deficit. The extent and timing of the deficit would be expected to have varied amongst sites, depending on the crop sowing date and the soil available water capacity, and may explain at least part of the observed variation in grain weight.

Irrigation during grain filling is not a management option in the Rangitikei, as barley is normally grown here as a dryland crop. However, earlier sowing may be one way of avoiding water deficits during grain filling on this soil type. Indications from the water balance (Fig. 3) suggest that sowing could have been advanced by about 30 days in this season.

The incidence of foliar disease was not assessed in this survey, but control measures with fungicide were practised on about half of the crops (Table 1). The possible effects of nitrogen supply on weight/grain will be discussed below in relation to grain quality.

Grain Quality

Screenings

Screenings ranged from 3.6 to 24.4% (Table 4), with a coefficient of variation of 42%. The level of screenings was in part related to the average grain size, as there was a significant negative correlation between the percentage of screenings and weight/grain (r = −0.71). This effect is demonstrated for crops at sites 2, 4 and 18 (Fig. 4). Screenings are separated out on the basis of grain width, and tended to have a more conservative, normally distributed pattern of grain weight compared with the unscreened grain (Table 4). Overall, the screenings averaged 27 mg/grain, and seldom exceeded 40 mg/grain

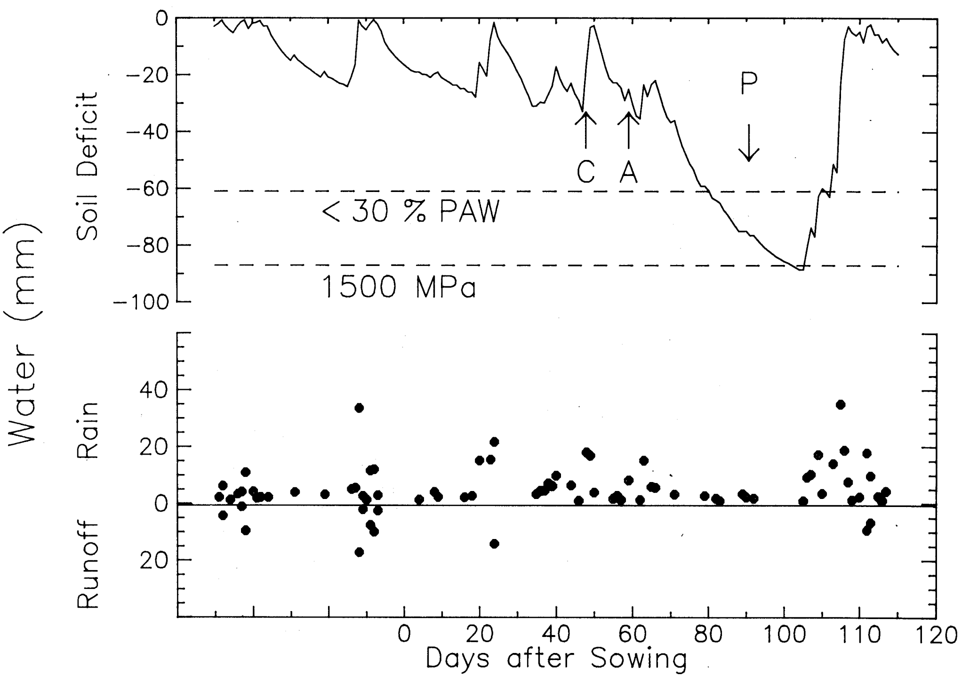

Figure 3: Water balance for Marton Site 3; C = canopy closure, A = anthesis, P = physiological maturity; PAW = plant available water.

TABLE 4: Statistics for grain size distributions of 21 sites.

Site	Unscreened Sample Grain Weight (mg) Mean	sd	Coeff. of Skewness	Grain <2.38mm Dia. Grain weight (mg) Mean	sd	Coeff of Skewness
1	44.1	9.9	−0.16	30.6	6.2	−1.19
2	45.2	9.6	−0.21	27.2N	5.4	−0.76
3	45.5	9.9	−0.46	29.4N	6.5	−0.30
4	42.1	9.8	−0.22	31.1N	6.6	−0.27
5	38.9N	10.7	−0.11	27.1	5.8	−0.22
6	39.9	10.5	−0.33	29.2N	7.3	−0.11
7	41.3	11.7	−0.15	27.0N	6.1	−0.11
8	43.2	15.4	−0.14	26.5	7.7	−0.52
9	51.8	13.5	−0.68	26.5N	6.8	0.13
10	49.7	11.5	−0.47	26.7N	6.4	−1.10
11	42.3	12.3	−0.53	23.9N	6.8	−0.17
12	44.6	13.1	−0.46	26.3N	6.9	−0.29
13	41.6	10.5	−0.22	26.2N	5.2	−0.33
14	50.8	11.4	−0.79	27.5	6.5	−0.75
15	45.3N	12.0	−0.13	27.3N	6.5	−0.36
16	48.0	11.9	−0.57	27.2N	6.9	−0.02
17	44.4	13.4	−0.11	25.8	6.4	−0.02
18	37.4N	9.6	0.15	29.3	6.2	−0.07
19	39.1	10.8	−0.23	26.6	6.9	−0.27
20	42.0	13.3	−0.28	25.3N	7.0	−0.03
21	42.7	11.4	−0.40	25.0	6.6	−0.73

N = Grain weights normally distributed at probability level $P \geqslant 0.05$.
Alternatively, the grain weights were not normally distributed, ($P < 0.05$).

(Fig. 4). Thus as the average weight/grain decreased amongst these sites, a greater proportion of grain was included in the screening category.

Amongst the other sites, a wide variety of grain size distributions was observed, ranging from positive skewness, through normal distributions, to negative skewness (Table 4). Site 8 was an early sown crop which established poorly, and showed a very broad distribution of grain size together with high level of screenings (Fig. 4). This distribution may reflect the broader age-distribution of tillers present in this crop, which averaged 4.0 shoots/plant compared with an average over all sites of 3.2 shoots per plant. Site 9 had a relatively low level of screenings, but was unusual in that it had a strong negative skew (Fig. 4). This was a high yielding crop, and the skew may have resulted from a small proportion of higher order tillers in the crop.

Nitrogen content

The nitrogen content of grain with screenings removed prior to micromalting was within the upper limit of 2% nitrogen set by the CMC for all except the crop at site 16, which was cultivar Acclaim (Table 5). Several of the crops (sites 2, 11, 20 and 21) had grain nitrogen contents below 1.5%. These crops were identified as having limited supplies of available soil nitrogen during tillering. Over all sites, grain nitrogen content showed a significant positive correlation with grain yield (r = 0.58, 0.45 screened grain), indicating that higher grain yields were associated with higher grain nitrogen content. Grain nitrogen contents were generally quite low with only one crop exceeding the acceptable level. The negative relationship between nitrogen content and malt extract levels is well established (Drewitt and Smart, 1981; Wauchop and Field-Dodgson, 1978), a result supported by this study.

Micromalting

Micromalting of the grain showed that grain quality for malting in this season was generally good. Two-thirds of the crops had fine extracts exceeding 80% (Table 5), with the lowest value being 78%. The standard Triumph sample in this micromaltring assay averaged fine extract values of 81.1% with a fine-coarse difference of 2.8%. At five of the sites, grain was also sampled for malting quality after weathering in the field. Weathering of the grain had no effect on fine malt extract or grain nitrogen content, but with the micromalting procedures used, water uptake was increased. This effect was significant, but once detected, could be allowed for in the commercial malting process. The effects of seasonal weather patterns such as a moist early-season and dry grainfilling period, as experienced in this season, may be quite significant. Drewitt and Smart (1981), and Smart (1983) reported that moisture stress conditions late in development can cause decreased yield and malting quality, this being associated with pinched grain, higher than normal grain nitrogen concentrations, decreased malt extract and a higher endosperm β-glucan content.

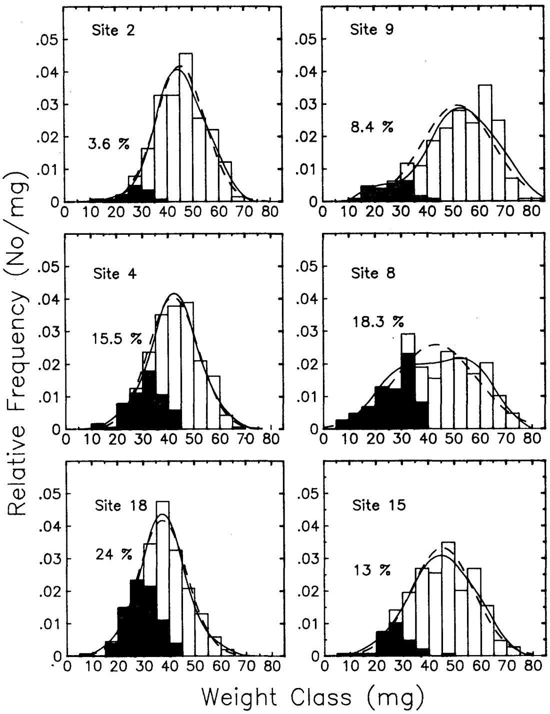

Figure 4: Seed size distributions for selected crops (site 2 = low nitrogen fertility; site 4 = medium nitrogen fertility; site 9 = high yielding crop; site 8 = early sown crop with low plant density; site 18 = low fertility site cropped for 13 successive seasons; site 15 = crop with high ear density). Percentages given are screening levels. Curves are fitted (———) and normal (---) distributions.

Yield and quality

Of the three quality parameters measured, grain nitrogen content showed the highest correlation with grain yield (r = 0.58, Table 3). Fine malt extract was not correlated with grain yield at all, and screenings showed a weak negative correlation (r = −0.36). However, as nearly all of the crops had grain nitrogen contents below 2%, and the two highest yielding crops had 1.76 and 1.80% grain nitrogen, high grain yields and high grain quality were not mutually exclusive in this season.

Nitrogen Uptake and Distribution

Sources of nitrogen

Above-ground crop nitrogen content at maturity ranged from 75 to 182 kg/ha (Table 6). When compared with the amount of nitrogen applied at sowing (Table 1), on average more than 80% of the crop's nitrogen must have been derived from soil reserves. Nitrogen content of the mature crop was highly correlated with total dry matter production (r = 0.95), suggesting that crop growth was closely dependent on the rate and extent of mineralisation of these soil nitrogen reserves.

TABLE 5: Grain quality characteristics of 21 survey sites.

Site	Nitrogen[a]	Fine Extract[a]	Screenings
		%	
1	1.68	78.0	17.3
2	1.33	80.6	3.6
3	1.53	80.3	9.5
4	1.71	78.3	15.5
5	1.70	79.2	16.6
6	1.96	78.6	18.8
LSD ($P<0.05$)	0.15	0.6	—
7	1.57	80.4	13.8
8	1.72	80.2	18.3
9	1.76	80.5	8.4
10	1.80	80.6	4.4
11	1.46	80.7	6.5
12	1.71	79.9	12.2
13	1.57	80.0	14.4
14	1.63	81.1	9.7
15	1.57	81.4	13.2
16	2.07	80.0	8.7
17	1.73	80.3	6.6
18	1.83	78.9	24.4
19	1.65	79.9	17.7
20	1.50	80.4	14.6
21	1.46	80.4	16.2
LSD ($P<0.05$)	0.14	0.9	—
CV	10.3	1.1	42
Triumph Std	1.8	81.1	—

[a] Samples were screened prior to analysis

This dependence on soil nitrogen reserves, however, should not lessen the tactical importance of applied nitrogen fertiliser. Whereas crop nitrogen requirements can be estimated prior to planting by a soil incubation test (Quin *et al.*, 1982), the actual pattern of release of soil nitrogen reserves to the crop will be influenced by the subsequent pattern of changes in soil temperature and water content (Campbell *et al.*, 1988). As discussed above, it is the actual level of soil nitrogen available during tillering which is crucial to the establishment of an adequate ear population, and this level can be estimated by means of a sap nitrate test (Withers and Palenski, 1984; Elliot *et al.*, 1987). Soil nitrogen levels could then be supplemented by fertiliser nitrogen application at this time to ensure the establishment of a target ear population. From the evidence provided by analysis of yield components, (Figs 2B, 2C) half of the crops could have benefitted from an additional dressing of nitrogen fertiliser during tillering by establishing a larger population of ears/m². Of sites 1-6, only site 2 showed signs of nitrogen deficiency, and this site had the lowest levels of available soil nitrogen when measured during tillering, (Table 1).

TABLE 6: Range of Nitrogen yield (g/m²) of various plant fractions at Canopy Closure (CC), Anthesis (AN) and Physiological Maturity (PM).

	Plant N Uptake			Ear		Stalk (+ Leaf)				
	CC	AN	PM	AN	PM	AN	PM	Chaff	Grain[a]	NHI[b]
					Sites 1-6					
Low	7.0	7.9	10.7	1.6	8.6	6.3	2.1	0.30	7.8	0.73
Mean	11.0	12.6	15.0	2.3	11.7	10.3	3.3	0.51	10.7	0.75
High	12.9	17.1	18.2	2.5	14.3	14.7	4.1	0.67	13.1	0.77
LSD (P<0.05)	2.2	2.9	2.5	0.4	2.0	2.8	0.8	0.16	1.9	0.03
Site Effect	***	***	***	**	***	***	***	**	***	*
					Sites 7—21					
Low	—	—	7.5	—	—	—		1.6	5.9	0.73
Mean	—	—	12.8	—	—	—		2.7	10.1	0.79
High	—	—	17.9	—	—	—		3.9	14.5	0.81
LSD (P<0.05)	—	—	2.3	—	—	—		0.7	1.8	0.03
Site Effect	—	—	***	—	—	—		**	***	**

[a] Grain and total yield from 0.25 m² quadrats and other components from 10 plant subsamples
[b] Nitrogen harvest index
* ** ***; significant at P<0.05, 0.01, 0.001, respectively.

For all of the crops surveyed in this study, nitrogen fertiliser was applied at sowing, with the levels being similar to those recommended by Unwin and Cornforth (1980). In no case had a soil test been made to estimate nitrogen requirements, and for crops from 1 to 5 years out of pasture, there was no significant association between the amount of nitrogen applied and years of cropping (r = 0.39 ns). Based on estimates of the non-fertiliser nitrogen taken up by the crops, the pool size of available soil nitrogen in these soils apparently declined on average by about 16 kg/ha per year out of pasture (Fig. 2D). This suggests that higher levels of fertiliser nitrogen than those currently used would be required to maintain yield levels under continuous cropping.

Nitrogen partitioning and grain nitrogen

The majority of the nitrogen at maturity was in the grain, and the nitrogen harvest index (nitrogen content of the grain as a fraction of the total crop nitrogen) ranged from 0.73 to 0.81 (Table 6). These values are in general agreement with those reported for winter wheat (Austin *et al.*, 1977; Spiertz and de Vos, 1983). Grain nitrogen concentration ranged from 1.36 to 1.99%, and was highly correlated with nitrogen concentration in the mature crop (r = 0.96).

Nitrogen uptake patterns differed amongst the six crops examined in detail (Table 6), but on average, 73% of the final crop nitrogen had been taken up by canopy closure, at which stage the crop had only reached 33% of its final dry weight. By anthesis, these crops contained on average 84% of final crop nitrogen content and 58% of their final dry weight. These figures agree closely with those of Austin *et al.*, (1977) and Van Sanford and MacKown (1987) for winter wheat. The particular patterns of nitrogen uptake at the six sites presumably reflected differing patterns of mineralisation of soil nitrogen reserves. Release of soil nitrogen was apparently greatest at site 3, with 6.8 g/m² of nitrogen being taken up by the crop between canopy closure and physiological maturity, and least at sites 1 and 5.

Based on the changes in nitrogen content between anthesis and maturity, only between 3 and 38% of the grain nitrogen was estimated to have been derived from soil uptake during grain filling. Similarly wide ranges of values have been observed for wheat (Neales *et al.*, 1968; Gregory *et al.*, 1981; Van Sanford and MacKown, 1987). In agreement with findings of Cox *et al.*, (1985) for wheat, grain nitrogen concentration showed no association with the amount of nitrogen taken up during grain filling i.e. differences in nitrogen uptake during grain filling in this season were not responsible for the observed variation in grain nitrogen concentration.

However, for sites 1 to 5 there was a strong relationship between the amount of nitrogen taken up by the crop during grain filling and the increase in crop dry weight during this period, (Fig. 5). Crops which took up significant amounts of nitrogen during grain filling were also less dependent on stored assimilate reserves for grain filling. Austin *et al.*, (1977) observed a similar relationship in wheat, and suggested that this strong association results from the dependence of both carbon assimilation and nitrate reduction on energy made available from chloroplasts i.e. active green leaf area during grain filling decreases the plant's dependence on both stored carbon and nitrogen sources. The crop at site 6 was an exception to this trend, and differed in that it had the highest levels and concentration of crop nitrogen at anthesis. This crop appears to have had sufficient nitrogen reserves at anthesis to allow crop growth to continue to a level equivalent to that achieved with an uptake of about 0.3 g/m² of nitrogen.

CONCLUSIONS

1. Grain yield and grain malting quality for a single barley cultivar varied appreciably amongst sites within a season characterised by a moist period prior to anthesis and a dry period thereafter.
2. There were no detrimental correlations between grain yield and grain quality parameters, so that high yields of high quality grain were attainable in this season.
3. Grain yield was associated most highly with grain number/m² and ear number/m². Management practices should therefore aim to provide an adequate supply of soil nitrogen during tillering to ensure the survival of 800 to 900 ears/m².
4. On average, at least 80% of the nitrogen in the above-ground crop was derived from soil reserves. Results suggest that present farmer practices depleted soil reserves of nitrogen by about 16 kg/ha for each year of cropping on this soil type.
5. Management practices which minimise leaf senescence during grainfilling are required to ensure high grain quality. These include earlier planting to avoid drought during grain filling, and fungicidal sprays to control leaf diseases.

ACKNOWLEDGEMENTS

We appreciate the help of Ian Ross of the Canterbury (NZ) Malting Company for making the intial contacts with farmers. We also thank the farmers for allowing their crops to be surveyed, and for providing the requested information.

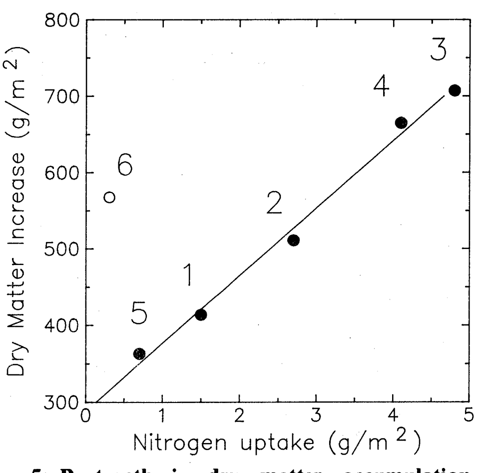

Figure 5: Post-anthesis dry matter accumulation in relation to nitrogen uptake in six crops at Marton. Numbers refer to sites as given in Table 1.

REFERENCES

Aspinall, D. 1965. The effects of soil moisture stress on the growth of barley 2. Grain growth. *Australian Journal of Agricultural Research 16:* 265-275.

Austin, R.B., Ford, M.A., Edrich, J.A., Blackwell, R.D. 1977. The nitrogen economy of winter wheat. *Journal of Agricultural Science 88:* 159-167.

Campbell, C.A., Jame, Y.W., De Jong, R. 1988. Predicting net nitrogen mineralization over a growing season: model verification. *Canadian Journal of Soil Science 68:* 537-552.

Church, B.M., Austin, R.B. 1983. Variability in wheat yields in England and Wales. *Journal of Agricultural Science Camb. 100:* 200-204.

Cox, B.M., Qualset, C.O., Rains, D.W. 1988. Genetic variation for nitrogen assimilation and translocation in wheat. I. Dry matter and nitrogen accumulation. *Crop Science 25:* 430-440.

Drewitt, E.G., Smart, J.G. 1981. The effect of irrigation and nitrogen fertiliser on the yield and malting quality of barley. *Proceedings Agronomy Society of New Zealand 11:* 23-28.

Elliott, D.E., Reuter, D.J., Growden, B., Schultz, J.E., Muhlhan, P.H., Gouzos, J., Heanes, D.L. 1987. Improved strategies for diagnosing and correcting nitrogen deficiency in spring wheat. *Journal of Plant Nutrition 10:* 1761-1770.

Gales, K. 1983. Yield variation of wheat and barley in Britain in relation to crop growth and soil conditions — a review. *Journal of the Science of Food and Agriculture 34:* 1085-1104.

Gallagher, J.N., Biscoe, P.V., Scott, R.K. 1975. Barley and its environment. V. Stability of grain weight. *Journal of Applied Ecology 12:* 319-336.

Gregory, P.J., Marshall, B., Biscoe, P.V. 1981. Nutrient relations of winter wheat 3. Nitrogen uptake, photosynthesis of flag leaves and translocation of nitrogen to grain. *Journal of Agricultural Science 96:* 539-547.

Haslemore, R.M., Risk, W.H. 1985. Variability in the malting quality of Triumph barley in Southland and Otago. *Proceedings of the Agronomy Society of New Zealand 15:* 51-54.

Haslemore, R.M., Roughan P.G. 1976. Rapid chemical analysis of some plant constituents. *Journal of the Science of Food and Agriculture 27:* 1171-1178.

Haslemore, R.M., Tunnicliffe, C.G., Slack, C.R., Shaw, S. 1985. An automated micromalting unit for quality assessment in a barley breeding programme. *Journal of the Institute of Brewing 91:* 101-105.

Ismail, S.B., Withers, N.J. 1984. The effect of nitrogen management and paddock history on barley growth and yield. *Proceedings of Agronomy Society of New Zealand 14:* 23-30.

Kerr, J.P., de Ruiter, J.M., Hall, A.J. 1986. The magnitude and variability of seasonal water deficits for pasture and crop growth. *New Zealand Agricultural Science 20:* 13-18.

Kirby, E.J.M. 1967. The effect of plant density upon the growth and yield of barley. *Journal of Agricultural Science 68:* 317-324.

Kirby, E.J.M. 1969. The effect of sowing date and plant density on barley. *Annals of Applied Biology 63:* 513-521.

Kirby, E.J.M. 1973. The control of leaf and ear size in barley. *Journal of Experimental Botany 24:* 567-578.

Lawlor, D.W., Day, W., Johnston, A.E., Legg, B.J., Parkinson, K.J. 1981. Growth of spring barley under drought: crop development, photosynthesis, dry-matter accumulation and nutrient content. *Journal of Agricultural Science 96:* 167-186.

Millner, J.P. 1983. Agronomy of barley production. *Agronomy Society of New Zealand, Special Publication No. 2.* 53-59.

Neales, T.F., Anderson, M.J., Wardlaw, I.F. 1963. The role of leaves in the accumulation of nitrogen by wheat during ear development. *Australian Journal of Agricultural Research 14:* 725-736.

Power, J.F., Alessi, J. 1978. Tiller development and yield of standard and semidwarf spring wheat varieties as affected by nitrogen fertilizer. *Journal of Agricultural Science 90:* 97-108.

Quin, B.F., Drewitt, E.G., Stephen, R.C. 1982. A soil incubation test for estimating wheat yields and nitrogen requirements. *Proceedings Agronomy Society of New Zealand 12:* 35-40.

Risk, W.H., Cossens, G.G., Crosbie, S.F., Greenwood, P.B. 1984. Barley responses to nitrogen fertiliser in Otago and Southland. *Proceedings Agronomy Society of New Zealand 14:* 35-38.

SAS. 1985. SAS Users Guide: Basics. SAS Institute Inc., Cary, N.C.

Slack, C.R., Hancock, D.A., Haselmore, R.M., Tunnicliffe, C.G. 1986. A simplified method for estimating hot water extract using small malt samples. *Journal of the Institute of Brewing 92:* 262-263.

Smart, J.G. 1983. Malting quality — what is it? *Agronomy Society of New Zealand, Special Publication No. 2:* 109-116.

Spiertz, F.H.J., de Vos, N.M. 1983. Agronomical and physiological aspects of the role of nitrogen in yield formation of cereals. *Plant and Soil 75:* 379-391.

Stark, J.C., Brown, B.D. 1987. Estimating nitrogen requirements of irrigated malting barley. *Communications Soil Science Plant Analysis, 18:* 433-444.

Thomson, W.J., Smart, J.G., Drewitt, E.G. 1974. Malting barley yield and quality responses to irrigation. *Proceedings Agronomy Society of New Zealand 4:* 41-44.

Thorne, G.N. 1986. Confessions of a narrow-minded applied biologist, or why do inter-disciplinary research. *Annals of Applied Biology 108:* 205-217.

Unwin, R.J., Cornforth, I. 1980. Fertilising for better barley harvests. *New Zealand Journal of Agriculture 140:* 29-31.

Van Sanford, D.A., MacKown, C.T. 1987. Cultivar differences in nitrogen remobilization during grain fill in soft red winter wheat. *Crop Science 27:* 295-300.

Varvel, G.E., Severson, R.K. 1987. Evaluation of cultivar and nitrogen management options for malting barley. *Agronomy Journal 79:* 459-463.

Wauchop, P., Field-Dodgson, J. 1978. Response of malting barley cultivars to different levels of P with and without N supplement, in the Southern North Island. *Proceedings Agronomy Society of New Zealand 8:* 11-13.

Withers, N.J., Palenski, F. 1984. An evaluation of the nitrate sap test for use on spring-sown wheat. *Proceedings Agronomy Society of New Zealand 14:* 17-21.