The influence of nitrogen and sulphur fertiliser on amino acid composition of wheat and barley grain

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Abstract

Improved grain protein quality through fertiliser management has potential benefits for growers and feed processors. Stable high quality grain is demanded by feed processors to facilitate grain handling and to reduce the cost of additives in feed formulation. In this experiment we examine the potential gains from altering grain protein quality with fertiliser management. A factorial experiment was conducted at Lincoln to determine the response of grain yield and quality to nitrogen (N) and sulphur (S) fertiliser treatments. Wheat (*Triticum aestivum* L. cv. Impact) and barley (*Hordeum vulgare* L. cv. Dash and an experimental naked barley) were grown under N and S levels ranging from 0 to 150 kg/ha. Amino acid composition of grain was predicted using near infrared spectroscopy. Nitrogen fertiliser consistently increased the concentration of component amino acids in grain. However, S fertiliser had little effect on these components. Higher levels of amino acids in grain were associated with increased levels of N and S taken up by the plants. Regional trials showed that improved grain amino acid profiles could be achieved through fertiliser management and cultivar selection. Sowing date and plant population also had significant effects on amino acid concentration in grain.

Additional key words: *near infrared reflectance spectroscopy, crop management*

Introduction

Compound feed production in New Zealand in 1999 was 0.683 million tonnes with 87% used for monogastric feeding. Of this, barley, wheat and maize were the major ingredients with 0.208, 0.108 and 0.110 M tonnes, respectively (New Zealand Pork Outlook, 2000). Protein supplements comprised 0.158M tonnes. More precise definition of the variation in quality of raw ingredients would improve the streaming of grain products, quality control during storage and consistency in grain production. It would also allow the specifications for grain quality that determines feed conversion efficiency and nutritional requirements of pigs and poultry to be more accurately prescribed. Consistency of grain production, quality and supply before and after crops leave the farm are also important for improved production efficiency. Improved systems for the production of feed grain with 'prescription' quality will benefit both producers and grain processors.

Agronomic treatments such as nitrogen (N) fertiliser are known to influence the level of protein (Birch and Long, 1990; Dalal *et al.*, 1997) in grain and the quality of protein in cereals (Abrol *et al.*, 1971; de Ruiter *et al.*, 1998). In bread wheat, management of soil N and sulphur (S) and the interactions involved in N and S nutrition have been studied extensively for improving bread quality for baking, (Martin, 1997; Zhao *et al.*, 1999; Luo *et al.*, 2000; de Ruiter and Martin, 2001). Pot experiments with wheat have shown that S deficiency decreases the concentration of methionine and cysteine in grains relative to the total amino acid content (Wrigley *et al.*, 1980). The response to S fertilisers and level of S uptake on feed grain quality and composition of the protein (proportions of S amino acids constituting the protein) are less well known. Sulphur deficiency has been reported to decrease concentrations of essential grain amino acids such as isoleucine, leucine, valine and threonine in grain and, therefore, reduce nutritional value (Byers

and Bolton, 1979; Wrigley *et al.*, 1980; Randall and Wrigley, 1986). High N fertiliser management usually contributes to elevated N:S ratios in barley (Byers and Bolton, 1979; Randall *et al.*, 1981). However, with high levels of plant N uptake, the interactions between N and S supply and consequent effects on grain N, grain S and amino acid composition become more important (Moss *et al.*, 1981).

The objective of the study was to determine levels of uptake of N and S for three feed grains (wheat cv. Impact, barley cv. Dash and an experimental naked barley line cv. 1822.28). In addition, the influence of varying rates of N and S application on the amino acid profiles of mature grain were evaluated in the context of biomass production and partitioning of N and S in the plant. Crop management effects on grain amino acid composition were determined in eight field trials with combinations of cultivar, sowing date, plant population and N fertiliser treatments. In addition, using the variation in sample composition, we aimed to develop universal calibration for each species that could be used to predict amino acid concentrations in grain derived from a wide range of feed cultivars and crop management situations.

Materials and Methods

Lincoln Trial

A field trial (Experiments 1 and 2) was sown on 1 September, 1999, at Lincoln (Lat. 43° 39'S; Long. 173° 30'E) on a Templeton sandy loam (Udic Ustochrept, USDA soil taxonomy). Potassic superphosphate (15%) was applied at a rate of 150 kg/ha to the trial area on 21 September on the basis of a low K soil test taken on 12 August (Table 1).

In Experiment 1 (*Triticum aestivum* L. cv. Impact) and Experiment 2 (*Hordeum vulgare* L. cv. Dash) nine-row plots (11 m x 1.35 m) were arranged in a randomised complete block design with three replications and fertiliser treatments listed in Table 2. Randomisation within blocks was restricted by applying treatments 1-6 and 6-12 in strips to minimise inter-plot fertiliser effects. Both wheat and barley were sown in 15 cm rows for a target plant population of 300 plants per m^2. Nitrogen fertiliser was applied as urea (46% N) in split applications as defined in Table 2. Sulphur (S) was applied as 18% potassium sulphate (0:0:42:18) and the potassium level balanced for each plot with potassium chloride. The total potassium application of 350

Table 1. Mean soil test results for experiments conducted at Lincoln (Experiments 1 and 2).

Experiment/depth	pH	Ca (QT)	P (µg/ml)	K (QT)	SO_4 (ppm)	Mg (QT)	Na (QT)	Mn (QT)
1. Low N treatment [a]								
0-30 cm depth								
Mean	6.2	8.0	16.5	10.3	3.3	12.0	6.0	46.8
SE	0.09	0.82	1.29	1.50	0.50	0.82	-	5.85
30-60 cm depth								
Mean	6.05	5.3	9.0	2.8	8.5	16.3	6.0	11.8
SE	0.13	0.50	2.16	0.50	1.29	3.00	-	2.21
2. High N /High S treatment [b]								
0-30 cm depth								
Mean	6.1	8.3	17.7	9.7	15.7	11.3	6.3	44.3
SE	-	0.57	1.53	1.15	9.60	0.58	0.58	7.57
30-60 cm depth								
Mean	6.0	4.0	7.3	2.3	7.7	11.7	5.0	10.7
SE	0.15	-	0.58	0.58	2.89	2.52	-	2.31

[a] Values are means over four sampling dates from 12 August to 21 December.
[b] Values are means over three sampling dates beginning 8 November and ending 21 December.

kg/ha was consistent over the trial area. While there were plot-to-plot differences in the amount of chloride applied it was assumed that differences in chloride had little or no impact on the plant response to N or S treatment.

In the naked barley trial (Experiment 3), also conducted at Lincoln and sown on 1 September in a randomised complete block design with three replicates, treatments were limited to N application (urea) with applications on 21 September, 24 October and 19 November, respectively (Table 3).

Table 2. Treatments comprising N and S fertiliser applications at emergence or tillering for wheat cv. Impact and barley cv. Dash. Urea was applied on 20 September and 24 October, and potassium sulphate on 5 October and 23 October for the respective emergence and tillering applications.

	Urea (kg N/ha)		K_2SO_4 (kg S/ha)	
Treatment	Emergence	Tillering	Emergence	Tillering
1	0	0	0	0
2	0	0	50	0
3	0	0	100	0
4	0	0	100	50
5	50	0	0	0
6	50	0	50	0
7	50	0	100	0
8	50	0	100	50
9	50	50	0	0
10	50	50	50	0
11	50	50	100	0
12	50	50	100	50

Table 3. Treatments comprising N fertiliser applications to naked barley cv. 1822.28 (Expt 3) at emergence, tillering and at stem elongation.

	Urea (kg N/ha)		
Treatment	Emergence	Tillering	2nd node
1	0	0	0
2	40	0	0
3	40	40	0
4	40	40	40
5	80	80	0
6	160	160	0

The trial area was irrigated three times with 25 ml on 29 October and 40 mm on 1 December and 16 December, respectively. Glean at 20 g/ha (a.i. chlorosulphuron) was applied as a pre-emergence herbicide. A preventative spray programme was adopted to minimise effects of disease and insect damage. Applications of Folicure (a.i. terbuconazole) applied at 440 ml per ha and Cerious (a.i. triadimenole) at 500 ml per ha were applied on 17 November. Pirimor (a.i. perimicarb) was applied at 250 g/ha on 12 October.

At anthesis, one 0.1 m^2 quadrat from each plot was sampled for biomass by cutting plants at ground level. The number of ear bearing tillers was determined in each sample. At maturity, two 0.1 m^2 quadrats were combined for biomass and tiller counts. Twenty stems were separated into ear and non-ear (dead leaf and stem) and grain fractions and dried at 60°C for 24 hours in preparation for N analysis (LECO CNS 2000 analyser). Samples were ground to pass a 1 mm screen using an Udy mill. Total S was determined by oxidising a 10 mg sample with bromine, drying and extraction on a Johnson and Nishita (1952) still. Variables were derived for N and S uptake of total plant and grain components, and the N:S ratio of grains was determined.

A 1.0 m^2 quadrat was also cut from all plots for the determination of grain yield, screenings and thousand grain weight. Screenings and thousand grain weight (TGW) were determined on air-dried grain. Subsamples of dressed grain (100 g) were saved for near infrared analysis of constituent amino acids in the grain protein. Laboratory procedures for amino acid determination are given in de Ruiter *et al.* (1998). Grain protein was calculated from 6.25 x total LECO N content.

Grain for NIRS was prepared using a Retch grinder and scanning the samples with an NIRS Systems 6500 monochromator (Tegel Analytical Laboratory). Reflectance data were processed using WinISI software (Shenk and Westerhaus, 1991). Separate calibrations were developed for wheat and barley and for either whole grain or ground grain samples.

Analysis of variance using the randomised block model for each experiment was performed using Genstat 5 Release 4.1, making the usual checks for validity of assumptions.

Regional Trials over Two Seasons

For the 1999 harvest, barley grain was collected from trial sites at Marton (n=48), Rakaia (n=48) and Oreti (n=36) and wheat from a trial at Wakanui (n=60). The barley trials comprised two N treatments (control and 40 + 40 kg N/ha) and four cultivars in a factorial layout. Nitrogen applications were applied at sowing and tillering. The barley cultivars Dash, Fleet, Optic and Sherwood were included at all sites except at Oreti where cv. Sherwood was omitted.The Wakanui wheat trial comprised five cultivars (Hussar, Hunter, Torfrida, Consort and CGP 96/10) and three sowing dates (28 April, 22 May and 9 July). All trials contained four replicates in randomised complete block designs. Fertiliser application rates were consistent with traditional farmer practice on soils with average to high fertility. A total of 52 samples were selected for amino acid determination and subsequent derivation of NIRS calibrations. Sample selections covered the range of protein concentrations for the season and included representatives of all cultivars in the trials. Amino acid composition in the remaining plots was predicted using validated NIRS equations (D. Karl, pers. comm.).

In the 1999/2000 season, barley grain samples were collected from regional trials at Rakaia (n=72) and Temuka (n=16). Similarly, wheat was sampled from trials at St Andrews (n=24) and Wakanui (n=16). Cultivar and N constituted the agronomic treatments at each of these sites. These trials provided a source for an additional 8 barley and 11 wheat samples that were added to the NIRS calibration developed in the previous year. Following successful calibration, remaining samples were scanned in duplicate and predictions made of the amino acid content. Sample unknowns predicted using the NIRS calibrations were checked for validity by checking for H values not exceeding 6 (WinISI software). Samples outside these specifications were omitted from the prediction sets.

Results and Discussion

Lincoln Trial

Crop establishment

Good consistent establishment was achieved in all cultivars. Mean populations for cv. Impact, Dash and 1822.28 on 24 September were 288, 329 and 255 plants per m^2, respectively.

Soil nutrients

In experiments 1 and 2, total mineral N did not exceed 16 and 12 ppm in the respective 0-30 and 30-60 cm soil depths in the control (Treatment 1). However, measured mineral N was significantly higher in 'high N' (Treatment 12) plots. Maximum levels of mineral N were 36 ppm on 9 November, following the second split fertiliser application. Measured sulphate levels were also higher in the high N/high S (Treatment 12) plots following S application compared with the control (Table 1). Significant levels of sulphate were present in the 30-60 cm soil depth in both high and low S treatments.

In experiment 3, the differences in measured mineral N in the high and low N treatments were not large. For example, total mineral N was 26 ppm in the high N treatment on 8 November compared with 17 ppm in the control treatment. It was apparent that the N available for uptake was rapidly depleted, especially when the demand for growth was high between the onset of stem elongation and grain filling.

Yield components

Fertiliser N significantly ($P<0.001$) influenced above ground biomass and grain yield but had lesser influence on ear number, mean grain size, grains per ear, harvest index or ear weight (Table 4). Application of 100 kg N/ha raised grain yield on average by 3.1 t/ha over the control treatment. None of the yield components was influenced by S fertiliser treatment (data not shown). In our study, there were no significant interactions between N and S fertiliser levels for yield components. However, significant interactions have been reported for grain yield (Moss *et al.*, 1981); as yield was reduced in a high N and low S treatment.

For naked barley, the maximum yield response (total biomass and grain) was achieved with three applications of 40 kg N/ha, and there was little benefit from higher N applications. Maximum ear number was also achieved with this level of N fertiliser and there was little influence on other yield components.

N uptake

Fertiliser N had a strong influence on grain N concentration and uptake of N into herbage and grain fractions (Table 5). Up to half of the N in the plants in the high N treatment was potentially derived from fertiliser application. In contrast, S fertiliser had little influence on the N balance in the crops.

Table 4. Mean yield components under different N fertiliser (kg N/ha) treatments given split applications to wheat and barley in the Lincoln trials.

Cultivar/N treatment [1]	Biomass (t/ha)	Grain yield (t/ha)	Ears/ m^2	TGW (g)	Grains/ ear	Ear weight (g)	HI
Barley cv. Impact							
Control	9.8	4.8	308	43.9	47.7	2.53	0.50
50 0	15.0	7.3	323	43.1	62.1	3.24	0.49
50 50	15.6	7.7	343	41.4	68.1	3.43	0.49
LSD $_{(P<0.05)}$; df = 6	3.05	1.70	91.8	4.23	4.60	0.447	0.029
Barley cv. Dash							
Control	10.5	5.8	692	46.0	22.5	1.14	0.55
50 0	13.7	7.3	752	45.3	22.6	1.13	0.53
50 50	17.6	9.2	920	46.1	25.2	1.28	0.52
LSD $_{(P<0.05)}$; df = 6	1.00	0.53	109.5	1.27	0.94	0.028	0.016
Barley cv. 1822.28							
Control	9.4	4.8	667	42.9	17.8	0.98	0.50
40 0 0	13.1	6.8	797	44.1	20.0	1.10	0.52
40 40 0	14.4	7.5	838	45.4	20.2	1.15	0.51
40 40 40	16.0	8.3	936	44.8	20.1	1.10	0.52
80 80 0	15.7	8.3	915	45.3	20.8	1.16	0.53
160 160 0	15.8	8.0	942	43.2	22.6	1.19	0.50
LSD $_{(P<0.05)}$; df = 10	2.72	1.64	168	3.15	2.74	0.18	0.027

[1] Main effects averaged over S treatments. Treatments 1, 5, 9 and 12 (Table 2) included in analysis for cv. Impact and cv. Dash.

Table 5. Nitrogen concentration and N uptake in grain and herbage in response to N fertiliser (kg N/ha) treatments given in split applications in the Lincoln trials.

Cultivar/treatment [1]	N concentration (%)			N uptake (g/m^2)	
	Grain N	Stem + Dead leaf N	Chaff N	Grain	Total
Wheat cv. Impact					
Control	1.83	0.41	0.63	9.3	11.5
50 0	1.72	0.43	0.59	13.1	16.6
50 50	2.24	0.60	0.76	18.3	23.1
LSD $_{(P<0.05)}$; df = 6	0.137	0.15	0.119	3.42	4.16
Barley cv. Dash					
Control	1.31	0.34	0.47	8.3	9.8
50 0	1.47	0.46	0.43	11.4	14.1
50 50	2.25	0.51	0.68	22.1	26.2
LSD $_{(P<0.05)}$; df = 6	0.209	0.146	0.067	1.82	1.97
Barley cv. 1822.28					
Control	1.71	0.42	0.51	8.7	10.7
40 0 0	1.59	0.58	0.42	11.2	14.5
40 40 0	1.70	0.58	0.53	13.4	17.1
40 40 40	1.88	0.64	0.52	16.8	21.1
80 80 0	1.87	0.70	0.54	16.2	20.8
160 160 0	2.32	1.06	0.78	19.9	26.9
LSD $_{(P<0.05)}$; df = 10	0.183	0.197	0.085	3.52	4.23

[1] Selected treatments as for Table 4.

S uptake

Grain S concentration, amount of S in grain and grain N:S ratio were all significantly increased by N fertiliser ($P<0.05$) (Table 6) for the cv. Impact and Dash. There was, however, little effect of S fertiliser on S accumulation in the plants. The amount of S uptake was influenced more by N treatment than S in the soil. Rates of S applied were well in excess of the rates recommended to ameliorate S deficiencies and yet the plants did not respond with increases in the S composition of herbage or grains. None of the yield components were influenced by S fertiliser treatment (data not shown). Therefore, there was little prospect for altering grain quality and particularly the levels of S-containing amino acid using S fertiliser treatment.

Table 6. Sulphur concentration, whole plant S uptake and grain N:S ratio in response to N fertiliser (kg N/ha) treatments in the Lincoln trials.

Cultivar/treatment [1]	Grain S (%)	Grain S uptake (g/m^2)	Grain N:S Ratio
Wheat cv. Impact			
Nitrogen			
Control	0.12	0.60	15.7
50 0	0.11	0.82	15.8
50 50	0.13	1.03	17.1
LSD $_{(P<0.05)}$; df = 6	0.032	0.409	3.76
Sulphur			
Control	0.13	0.86	16.1
100 50	0.12	0.89	17.4
LSD $_{(P<0.05)}$; df = 6	0.037	0.472	4.3
Barley cv. Dash			
Nitrogen			
Control	0.10	0.58	13.3
50 0	0.09	0.66	16.3
50 50	0.13	1.19	17.8
LSD $_{(P<0.05)}$; df = 6	0.008	0.080	3.76
Sulphur			
Control	0.11	0.95	15.8
100 50	0.11	0.77	17.9
LSD $_{(P<0.05)}$; df = 6	0.009	0.099	4.37
Barley cv. 1822.28			
Control	0.139	0.66	12.6
40 0 0	0.122	0.84	13.2
40 40 0	0.134	1.01	12.8
40 40 40	0.127	1.06	15.0
80 80 0	0.126	1.04	14.9
160 160 0	0.149	1.19	15.6
LSD $_{(P<0.05)}$; df=10	0.032	0.322	3.05

[1] Selected treatments as for Table 4.

The effect of N fertiliser on S uptake into grain was significant for cv. Dash barley ($P<0.001$), but not for cv. Impact wheat ($P=0.11$). It was apparent that treatments enhancing the uptake of N also had an impact on the levels of S in the herbage and grain (Table 6). For the naked barley, grain S uptake was affected by N fertiliser treatment ($P<0.05$). However the effects of N fertiliser was not significant on grain S concentration or grain N:S ratio. Experiments with bread wheat have shown significant changes in N:S ratio with S fertiliser treatment (de Ruiter and Martin, 2001) but we were unable to show a significant response in these experiments. In grains, N:S ratios were less than the threshold values of 17-18 suggested by Byers and Bolton (1979) indicating that S availability was not limiting in soil.

Amino acid concentrations in grain

Fertiliser N and S effects on amino acid composition (Lincoln trials)

Levels of all individual amino acids in the respective cultivars were strongly increased by N fertiliser. The percentage increase due to N fertiliser varied among the amino acids. On average, cv. Dash was more responsive than cv. 1822.28 or cv. Impact with mean increases over all amino acids of 59, 37.2 and 25.8% for the respective cultivars. The mean concentrations for low and high N treatments are shown in Table 7.

There were no S fertiliser effects on individual amino acids, in contrast to reported elevated levels of aspartate/asparagine and decreases in other essential amino acids (Byers and Bolton, 1979; Wrigley *et al.*, 1980). Sulphur deficiency has been shown to reduce levels of sulphur-rich B-hordeins in barley (Rahman *et al.*, 1983) and, more particularly, to lower the concentration of methionine and cysteine in grains (Renner *et al.*, 1953), but this was not the case in this trial.

Amino acid composition

Separate NIRS calibrations were developed for whole and ground grain that included samples selected from the present experiments. The base sample set was

Table 7. Mean (n=3) amino acid levels (%) in respective control and high N fertiliser treatments in experiments 1 and 2 at Lincoln.

Amino acid	Wheat cv. Impact		Barley cv. Dash		cv. 1822.28	
	Control	High N	Control	High N	Control	High N
Aspartic Acid	0.58	0.65	0.52	0.72	0.61	0.72
Threonine	0.29	0.33	0.26	0.40	0.32	0.43
Serine	0.41	0.48	0.29	0.47	0.36	0.51
Glutamic Acid	2.82	4.02	1.64	3.04	2.04	3.32
Proline	0.88	1.29	0.77	1.59	0.88	1.51
Glycine	0.41	0.52	0.32	0.47	0.36	0.46
Alanine	0.36	0.45	0.32	0.46	0.39	0.48
Valine	0.44	0.56	0.38	0.60	0.47	0.65
Isoleucine	0.35	0.46	0.26	0.46	0.34	0.49
Leucine	0.68	0.89	0.52	0.85	0.63	0.90
Tyrosine	0.30	0.40	0.24	0.40	0.29	0.42
Phenylalanine	0.46	0.61	0.37	0.68	0.43	0.66
Histidine	0.24	0.31	0.18	0.29	0.21	0.29
Lysine	0.30	0.34	0.30	0.41	0.34	0.43
Arginine	0.53	0.62	0.39	0.59	0.48	0.64
Cysteine	0.26	0.30	0.19	0.24	0.24	0.30
Methionine	0.20	0.25	0.16	0.23	0.21	0.27

supplemented with grain samples from regional cultivar trials. Samples were chosen to capture variation induced by cultivar, location and N management. The mean H values (index of dispersion) were consistently higher for ground barley (5.20), than either whole barley (3.86) or whole wheat (1.81). This suggested that wheat amino acid content was significantly more stable than that for either whole or ground barley during sample storage.

Figures 1-3 comprise both calibration and prediction data for selected treatments 1, 5, 9 and 12 (Table 2, cv. Impact and Dash) and treatments 1 and 6 (Table 3, cv. 1822.28). Total amino acids were highly correlated (r=0.73) to the amount of N taken up by the crops (Fig. 1A) and to the concentration of N (r=0.79) in the grain (Fig. 1B). A significant proportion of the variation in individual amino acid levels was accounted for by the level of crop N uptake and grain N content. For example, 44 and 37% of the variation in lysine was explained by these respective variables (Fig. 2A and 2B). This was not unexpected as correlation coefficients between total amino acid and the individual levels were in excess of 0.88, except for threonine (r=0.73), serine (r=0.44), lysine (r=0.84), cysteine (r=0.61) and methionine (r=0.35). The reduced correlations of total amino acids with the latter group is significant in that all these, except serine, are essential amino acids in monogastric diets. A similar result was achieved in a previous experiment with barley cv. Dash when cysteine, lysine and methionine concentrations explained less than 64% of the variation in total amino acid concentration (de Ruiter and Karl, 2001). Therefore, field management practices that result in a general increase in protein and consequently the total amino acid content are less likely to impinge on the important nutritional ones.

The strength of the relationships between levels of sulphur uptake and methionine and cysteine concentration was of particular interest. Furthermore, relationships between grain S content with the respective S-containing amino acid levels may point to possible field management solutions for improving cysteine and methionine levels. Increased levels of S uptake did improve cysteine and methionine concentration in grains (Fig. 3A and 3C) and there were significant correlations between the respective cysteine and methionine concentrations and the grain S concentration (Fig. 3B and 3D). As previously mentioned, this result was

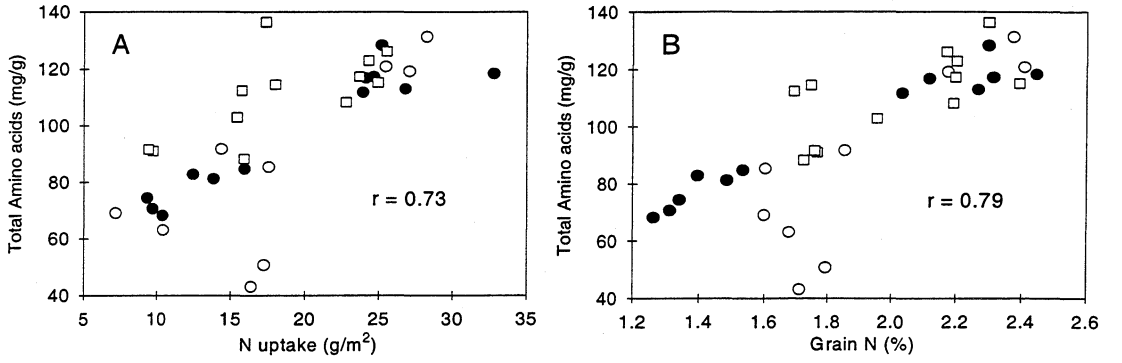

Figure 1. Combination of calibration data (ground grain) and whole grain prediction of amino acid content in wheat cv. Impact (□) and barley (• cv. Dash; ○ cv. 1822.28) and their relationship with total crop N uptake (A) and grain N concentration (B).

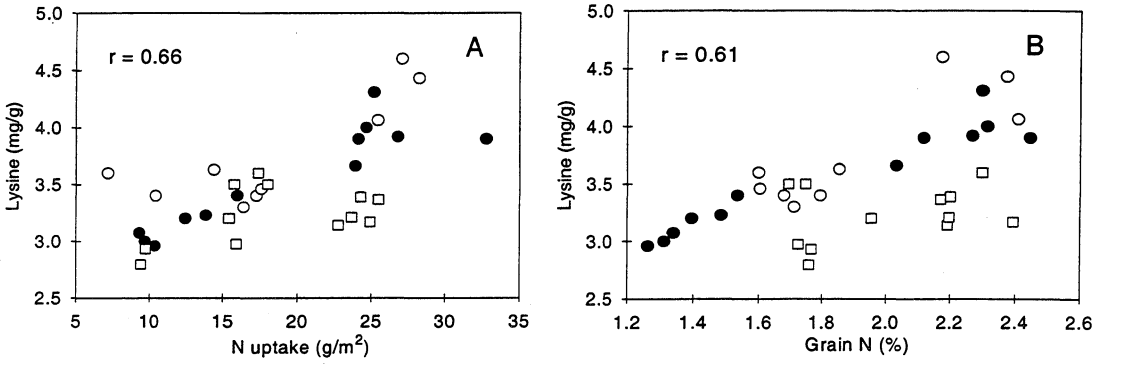

Figure 2. Combination of calibration data (ground grain) and whole grain prediction of lysine content in wheat cv. Impact (□) and barley (• cv. Dash, ○ cv. 1822.28) in response to total crop N uptake (A) and grain N concentration (B).

more likely to be related to the dynamics of N uptake than S uptake.

Amino acid composition data from eight trials (five barley and three wheat trials) over two seasons were analysed to determine whether field management or cultivar selection had significant impacts on individual amino acid concentrations in grain. Levels of amino acids were derived from calibration data and from predictions using the best calibration equations available at the time. For example, the predictions made on year 1 samples were made using year 1 calibrations and were not readjusted following completion of calibration development in year 2. Details of the trials sampled and the main effect treatments are given in Table 8. Grain from the regional trials was also saved from the 2000/01 season. Wheat (n=20) and barley (n=20)

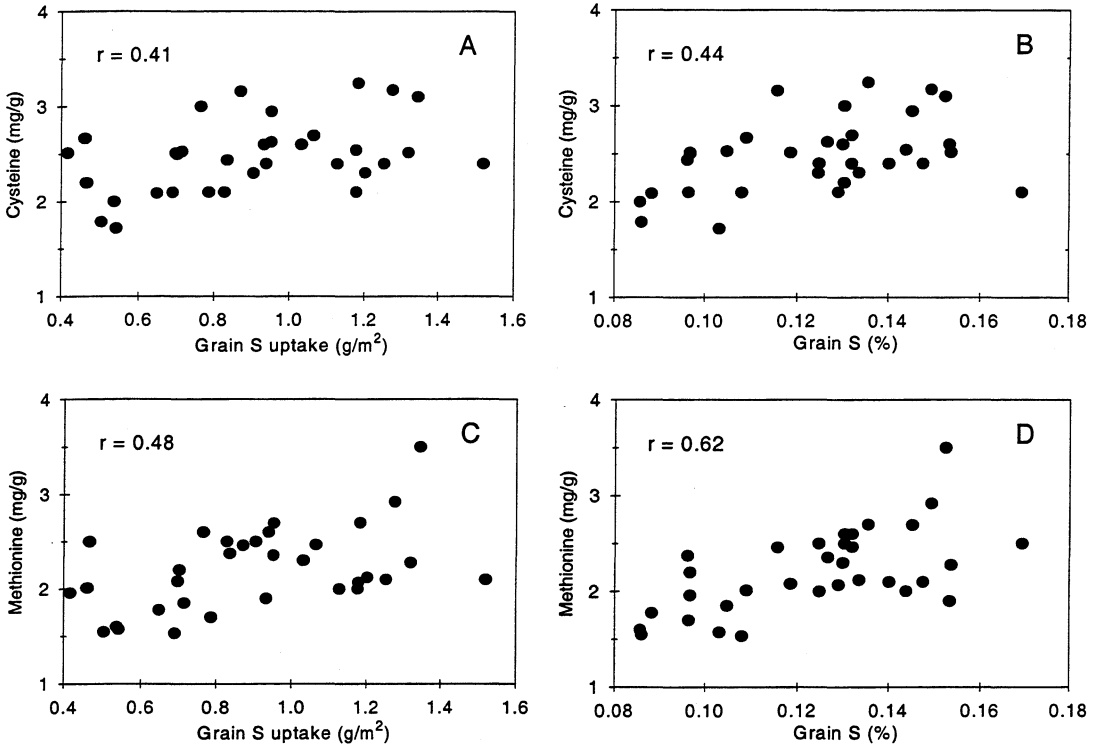

Figure 3. Combination of calibration data (ground grain) and whole grain prediction for cysteine and methionine content in wheat cv. Impact and barley cv. Dash in response to grain S uptake (A and C) and grain S concentration (B and D).

were added to the calibrations to widen the prediction range and to validate predictions on new season material.

Cultivar, N fertiliser and sowing date effects were evaluated for both wheat and barley for the 1998/99 and 1999/00 harvests (Tables 8 and 9). Only those amino acids that are essential or nutritionally limiting in monogastric diets are shown. In both seasons, there were strong responses ($P<0.05$) to cultivar and N but these were not always consistent among all amino acids. In most cases, the N effect was similar for all cultivars in the trial, because the interaction between cultivar and N was not significant ($P>0.05$). Cultivar was least influential in the barley trial at Oreti (1998/99), but cultivar effects were significant for all listed amino acids in the Marton barley (1998/99) and St Andrews wheat (1999/00). In most instances the level of any particular amino acid in grains can be influenced significantly by cultivar choice.

Fertiliser N effects were also quite variable among trials. On average, about half of the amino acids could be managed by strategic N fertiliser applications. There was only one trial (Wakanui wheat, 1999/00) in which a consistent statistically significant N fertiliser effect ($P<0.05$) was observed for all amino acids tested, although there were some very strong effects in most other trials except Rakaia barley (1998/99 and 1999/00), Temuka barley (1999/00) and St Andrews

Table 8. Cultivar (C), nitrogen fertiliser (N) and sowing date (SD) effects for selected amino acids in grain sampled from regional field trials in season 1 (1998/1999).

	Barley									Wheat		
	Marton (n=48)			Rakaia (n=48)			Oreti (n=36)			Tegel (n=60)		
Amino acid	C	N	C x N	C	N	C x N	C	N	C x N	C	SD	C x SD
Threonine	P<0.01	P<0.001	NS	P<0.05	NS	NS	NS	P<0.001	NS	P<0.05	P<0.05	NS
Proline	P<0.01	P<0.05	NS	P<0.001	P<0.01	NS	P<0.05	P<0.01	NS	NS	P<0.001	NS
Histidine	P<0.05	NS	NS	P<0.05	P<0.01	NS	NS	P<0.001	NS	P<0.001	P<0.01	NS
Lysine	P<0.01	P<0.001	NS	NS	NS	NS	NS	P<0.001	NS	NS	P<0.01	NS
Cysteine	P<0.05	NS	NS	P<0.05	P<0.05	NS	P<0.05	P<0.001	NS	NS	NS	NS
Methionine	P<0.01	P<0.01	NS	NS	P<0.05	NS	P<0.05	P<0.001	NS	NS	NS	NS
Total	P<0.01	P<0.01	NS	P<0.001	P<0.01	NS	NS	P<0.001	NS	P<0.05	P<0.01	NS

NS = non significant

Table 9. Cultivar (C) and nitrogen effects (N) for selected amino acids in grain sampled from regional field trials in season 2 (1999/2000).

	Barley						Wheat					
	Rakaia (n=88)			Temuka (n=40)			St Andrews (n=49)			Wakanui (n=40)		
Amino acid	C		C x N	C	N	C x N	C	N	C x N	C	N	C x N
Threonine	NS	NS	NS	P<0.05	P<0.05	P<0.05	P<0.05	NS	NS	NS	P<0.001	NS
Proline	P<0.05	NS	P<0.05	P<0.001	P<0.05	NS	P<0.001	P<0.01	NS	NS	P<0.001	NS
Histidine	P<0.05	P<0.01	NS	P<0.05	NS	NS	P<0.001	NS	NS	NS	P<0.001	NS
Lysine	NS	NS	NS	P<0.001	P<0.05	NS	P<0.05	NS	NS	NS	P<0.01	NS
Cysteine	P<0.001	P<0.01	NS	P<0.05	P<0.05	NS	P<0.01	NS	NS	NS	P<0.05	NS
Methionine	NS	P<0.01	NS	P<0.05	P<0.05	P<0.001	P<0.001	NS	NS	P<0.05	P<0.001	NS
Total	P<0.05	P<0.05	NS	P<0.001	P<0.05	NS	P<0.001	P<0.05	NS	NS	P<0.001	NS

NS = non significant

wheat (1999/00). One wheat trial showed significant responses for sowing date, but these effects were not strong for most amino acids.

Interactions between cultivar and N were generally not significant ($P>0.05$). Therefore, manipulation of grain amino acid composition with cultivar selection or strategic N fertiliser application is a practical solution for enhancing quality if the changes can be predicted in given crop situations. It was not easy to determine whether site by cultivar or site by N interactions were significant in these trials because of the variation in trial design among locations. Different levels of responsiveness to cultivar and N at the various sites does suggest that interactions at this level are important; however, factors such as the base N fertility at the various trial sites may have a significant bearing on the cultivar and N main effects tested.

Conclusions

- The impact of fertiliser on yield components was strongest at the lower N application rates. However, differences in quality occurred over the entire range of N treatments.
- The amount of S uptake was influenced more by N treatment than by soil S level. Rates of S applied were well in excess of the rates recommended to ameliorate S deficiencies and yet plants did not re-

spond with associated increases in the S composition of herbage or grains. Therefore, on soils where these experiments were conducted, which were not S deficient, there was little prospect for altering grain quality, and particularly the S-containing amino acid levels, with S fertiliser treatment.

- The most effective method for improving both total S uptake and the concentration of S in the grain was through N fertiliser addition. Even under high S and high N treatments, there was no evidence of increased uptake of S, or increased concentrations of S in grain that could be attributed to the S fertiliser treatment.
- In regional trials, significant variation in amino acid compositions could be accounted for by N fertiliser treatments. However, the effects of cultivar, sowing date and N were not ubiquitous. The extent of increase in amino acid level was dependent on the environmental and soil conditions under which the crop was grown. Significant gains in amino acid levels were, however, achieved through crop management intervention.

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