The use of late nitrogen on milling wheat in the Manawatu

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Abstract

The Manawatu Mills Ltd. operate a variable payment scheme for milling wheat based on a quality index. The index is determined by the cultivar and protein content.

This study was carried out to investigate the use of late Nitrogen (N) as a means of increasing grain protein content and grain yield in milling wheat. Trials were conducted at three sites in the Manawatu region. Nitrogen was applied at Feekes G.S.9.

Late N significantly increased grain protein content at all sites. However, at one site, grain protein contents were above the threshold level for obtaining premiums. There was a strong relationship between grain protein content and MDD bake score. Late N significantly increased grain yields at two sites. The yield response at one site was the result of an increase in grain weight whereas at the other responsive site, late N increased ear numbers/m^2 at harvest.

As a result of an increase in grain yield and grain protein, the use of late N would have been highly economic at two of the sites used in this study.

The feasibility of using late N to increase the profitability of milling wheat in the Manawatu is discussed.

Additional key words: *Grain yield, grain protein content, yield components, bake score, economic feasibility.*

Introduction

Milling wheat sourced by the Manawatu Mills Limited, Palmerston North is subjected to a number of quality tests which determine its acceptability for milling. These are outlined in schedule 1 of the wheat purchasing contract (Anon., 1991a) and include tests for moisture content, test weight, kernel weight, falling number, black point and physical appearance. The price a grower receives for milling wheat which has met the conditions specified in schedule 1 is dependant on the cultivar and grain protein content of that wheat. These two parameters together determine the number of quality index points achieved by a line of wheat (Schedule 2). The base price is set at 100 index points. Lines can achieve more or less than the base price depending on the final index points they achieve. The bulk of the potential variation in quality index is determined by grain protein content (22 points) rather than cultivar (2 points). Wheat with less than 10.0% grain protein content may be rejected.

The protein content of milling wheat is largely determined by the supply of nitrogen (N) to the developing grain (Langer and Liew, 1973; Spiertz and Ellen, 1978). This N can originate from uptake during the grain filling period (Quin and Drewitt, 1979) or from mobilisation of plant reserves (Spiertz and Ellen, 1978). Nitrogen fertiliser can be used to increase the N supply to wheat crops, increasing grain protein content (Martin *et al.*, 1989). However it has consistently been found that applications of N made after the main yield determining growth stages are more effective at raising grain protein content than earlier applications (Drewitt, 1975; Drewitt and Dyson, 1987). The efficacy of late N for increasing grain protein content declines rapidly if application is delayed until after anthesis (Strong, 1982). It is probable that late N is more effective than early N at increasing grain protein content because it is less effective at increasing grain yields, (Strong 1986; Drewitt and Dyson, 1987), consequently protein dilution does not occur to the same degree.

The last nationwide surveys of wheat protein contents occurred in 1982 and 1983 (Lindley and Humphrey-Taylor, 1987). In 1982 the cultivars Oroua and Rongotea had an average protein content of 10.9% and 10.2% respectively in the southern North Island. In 1983 there was a small increase to 11.2% for Oroua and 10.8% for Rongotea. More recently, Rongotea had an average protein content of 11.5% for lines received at the Manawatu Mills Ltd from the 1990 harvest (G. Georgiou, pers. comm.). The upper threshold for obtaining additional quality index points occurs at 12.9% protein (Anon., 1991a). This presents wheat growers with an opportunity to increase the protein content and therefore the price they receive for milling wheat. The primary objective of this study was to investigate the feasibility of using late applications of N fertiliser to improve profitability.

Protein content is used worldwide as a quick, convenient measure of baking quality in milling wheat (Wilson, 1990). While there is a positive relationship between protein content and baking quality in milling wheat (Moss, 1981), several New Zealand studies have found that this relationship is too imprecise to be used as a predictor of baking quality (Dengate, 1983; Wilson, 1983; Stevenson, 1987). The relationship varies with cultivar (Cawley, 1981) hence the inclusion of cultivar in the quality index. Much of the variation in baking quality at any given level of grain protein content appears to be due to the strong influence of location on baking quality (Douglas, 1987). In order to assess the ability of grain protein content to predict baking quality in the Manawatu, the relationship between grain protein content and mechanical dough development (MDD) bake score was investigated in this study.

Materials and Methods

Three field trials were conducted during the 1989/90 season at different sites in the Manawatu. These trials were carried out in commercial, spring sown, milling wheat crops. The cultivar used was Rongotea, described by McEwan and Vizer (1979). It is currently on the Recommended List for spring wheat in the southern North Island (Anon., 1991b). At each site, the crop was established and managed by the farmer as they would 'normally' manage a potentially high yielding crop of milling wheat. All three farmers consistently produce above average yields of wheat.

Site 1. Property is located on Wilson Road, near Waituna West. Soil type is Kiwitea silt loam with an Olsen P level of 11 and pH of 5.6. Previous cropping history: wheat in 1988/89 and peas in 1987/88 with permanent pasture prior to that. Fertiliser applied by the farmer: 46 kg N/ha, 22 kg P/ha and 8 kg K/ha. Sown 8th August. Weeds were controlled with Glean/bromoxynil applied at Feekes G.S.4. At early ear emergence a systemic fungicide (Tilt) was applied to control stripe rust (*Puccinia striiformis*).

Site 2. Situated at Almadale, just north of Feilding. Soil type is a Manawatu sandy loam with an Olsen P level of 27 and a pH of 5.3. Paddock was previously in permanent pasture. A herbicide (Glyphosate) was used to control couch (*Agropyron repens*), utilising a short fallow. Fertiliser applied: 18 kg N/ha, 20 kg P/ha and 2 kg S/ha. Sown 20th August. A Glean/bromoxynil mix used at Feekes G.S.4 to control weeds. At the early 'boot' stage a systemic fungicide (Tilt) was used to control stripe rust. During the grain-fill period a take-all (*Gaeumanomyces graminis*) infection became apparent (early senescence, blackening of stem base).

Site 3. Situated on Lockwood Road, near Kairanga. Soil type is Kairanga fine sandy loam with an Olsen P level of 22 and a pH of 5.7. Paddock had been in perennial ryegrass following a seed harvest in 1988/89 but had been continuously cropped with barley, red clover, peas and wheat during the previous four years. Fertiliser applied: 30 kg N/ha, 20 kg P/ha, 20 kg K/ha and 14 kg S/ha. Sown 12th September. Weeds were controlled with Glean/bromoxynil at Feekes G.S 4. At the same time a systemic fungicide (Cereous) was applied to control an early stripe rust infection. A second application was made at Feekes G.S. 7 and a third, using a new product (Folicure) was applied at early anthesis.

The treatments at each site were 0, 20, 40 and 80 kg N/ha applied at Feekes G.S 9 (Large, 1954). Treatments were arranged in a randomised complete block design with six replicates. Nitrogen was applied as ammonium sulphate by hand broadcasting. Treatments were applied on the 9th, 16th and 23rd of November 1989, at Site 1, 2 and 3 respectively.

After anthesis, ear samples were collected (ten ears/plot) to enable measurement of grain growth. Ears were dried, hand rubbed, and after separation, 100 grains counted and weighed. During grainfill, flag leaf samples were collected (10 leaves/plot) so that any treatment effect on the rate of senescence could be identified. Immediately prior to harvesting four 0.1 m^2 quadrats were taken from each plot for determination of total crop dry matter and yield components. Subsamples (20 ears/plot) were used to determine the spikelets/ear and grains/spikelet components. Further subsamples were taken for N analysis of straw.

Final grain yields were obtained by harvesting a 1.3m wide strip from each plot with a Wintersteiger plot harvester. Plots were 8.0 m long. Site 1 and 2 were harvested on 6th February, 1990 and site 3 on 5th February. After weighing in the field, a 1.2 kg subsample was taken. From this further samples were drawn for determination of grain moisture content, grain N content and grain weight. A 1 kg sample from two replicates from each site were sent to the Wheat Research Institute for test baking (125 g MDD).

All samples used for calculation of dry matter were dried at 85°C for 24 hours. Micro Kjeldahl digestion was used to determine straw and grain N content (on a

0% moisture basis). However grain N content was converted to a protein content, using a conversion factor of 5.7 (Jones, 1926). Grain yield and grain protein content are presented on a 14.0% moisture basis.

At each site, rainfall was recorded with a standard 250 mm capacity gauge and temperature with an Omnidata DP219 datapod. The datapod was housed in a standard Stevenson screen, 1 m above the ground.

Statistical analysis was carried out with the SAS software package. Results have been presented with F test significances and LSD's. Those results with F test significances greater than 5% have been reported as non-significant (NS). For those attributes for which treatment effects were non-significant, a t-test has been used to test for differences in other effects.

Results

Climate

Mean daily average temperature and rainfall for the months of December 1989 and January 1990 are presented in Table 1. Comparisons with the long term mean were only available for site 3, which is in close proximity to the Grasslands Division, DSIR, at Kairanga.

Long term average temperatures at Kairanga are 15.8°C for December and 17.5°C for January. Temperatures in December 1989 were 0.7°C below average but in January 1990 were close to the long term mean. Temperatures have declined with increasing altitude of site, at a rate of 0.52°C/100 m of altitude.

Long term average rainfall at Kairanga is 80.0 mm for December and 74.0 mm for January. Rainfall has increased with increasing altitude, the pattern normally found in the Manawatu (Burgess, 1988). It is evident therefore that December rainfall for all sites is well below the long term mean. January rainfall was higher than normal, although the January 1990 figures were inflated by a large rainfall event recorded on 31 January, 1990. At site 3 for example, 63.5 mm of rain was recorded.

Rain fell within 1-2 days after the application of N at all sites. This will have ensured rapid dissolution of fertiliser into the soil solution.

Canopy senescence

The dry weights of flag leaves collected at 34 and 41 days after the beginning of anthesis were used as an indirect measure of the loss of nutrients, particularly of N, from these leaves. There is a reliable relationship between the dry weight of various canopy components during the grain-fill period and the N content of those components (Spiertz and De Vos, 1983). There was a strong visual response from Late N at site 1 and 3. This became noticeable at the end of the grain-fill period. Plots receiving high rates of N retained a greater proportion of green leaf compared to plots receiving little or no late N.

Late N has reduced the rate of dry matter loss from the flag leaves at sites 1 and 3 (Table 2). There was no effect at site 2. This may have been due to the influence

Table 1. Climatic data for December 1989 and January 1990.

	Site 1		Site 2		Site 3	
	Dec	Jan	Dec	Jan	Dec	Jan
Average temperature (°C)	13.4	16.4	14.0	16.9	15.1	17.4
Rainfall (mm)	62.0	164.5	56.5	140.0	45.3	120.5

Table 2. Dry weight (g) of flag leaves at 34 and 41 days after anthesis.

	Site 1		Site 2		Site 3	
Nitrogen (kg/ha)	34 days	41 days	34 days	41 days	34 days	41 days
0	1.38	1.07	1.32	1.25	0.667	0.597
20	1.31	1.12	1.32	1.15	0.612	0.581
40	1.56	1.24	1.30	1.25	0.673	0.576
80	1.54	1.26	1.36	1.31	0.758	0.659
Significance	0.011	0.012	NS	NS	0.002	0.0025
$LSD_{(0.05)}$	0.13	0.10	—	—	0.053	0.034

of take-all at this site. The application of late N has therefore delayed senescence at site 1 and 3.

Grain yield and yield components

The yield and yield components for each site are detailed in Table 3. The grains/m^2 component has been calculated on an individual plot basis.

Late N has significantly increased grain yields at each successive rate at site 1. At site 3 grain yield responded to the 40 kg N and 80 kg N treatments only. Grain yield was unresponsive to late N at site 2. The response mechanism differed between sites. At site 1, late N significantly increased ear numbers whereas at site 3 it increased grain weight. A small increase in the grains/spikelet component at site 1 and site 3 was not significant. The grains/m^2 component at site 1 responded to late N primarily as a result of increased ear numbers. Grain weight for the 20 kg N treatment at site 2 was significantly lower than the other treatments. This was probably the result of a higher incidence of take-all amongst those plots receiving 20 kg N. This treatment ranked lowest for yield but differences were not significant (Table 3). The incidence of take-all at site 2 was assessed by counting the proportion of ears which were dark/discoloured as the result of early senescence. The incidence of discoloured ears for each treatment is given in Table 4. The 20 kg N treatment has a greater proportion of discoloured ears, although differences were not significant. A further investigation of differences in some yield components between 'healthy' and discoloured ears from the same plot, revealed no differences for the spikelets/ear component. However, the discoloured ears had significantly fewer grains/spikelet and lower grain weight than 'healthy' ears (Table 5). This indicates a relatively late infestation of take-all.

At site 3, late N did not begin to influence grain weight until some time between 34 days and 41 days after anthesis (Fig. 1). Late N appears to have increased the duration of the linear phase of grain growth rather than increased the maximum rate of grain growth. There does not appear to have been any effect on the length of the grain-fill period.

Table 3. Grain yield and yield components.

Nitrogen (kg/ha)	Yield (t/ha)	Ears /m^2	Spikelets	Grains per Spikelet	Grains /m^2	Grain wt. (mg)
Site 1						
0	6.39	521	13.83	2.15	15453	41.8
20	6.67	542	13.57	2.17	15956	41.2
40	6.96	585	13.75	2.16	17387	42.3
80	7.23	598	13.57	2.23	17812	41.8
Significance	0.0001	0.008	NS	NS	0.008	NS
LSD$_{(0.05)}$	0.22	37	—	—	1163	—
Site 2						
0	5.91	557	15.4	1.94	16589	37.6
20	5.57	527	15.6	1.84	15119	36.6
40	5.91	560	15.5	1.96	17121	37.1
80	6.00	552	15.5	1.97	16894	37.7
Significance	NS	NS	NS	NS	NS	0.048
LSD$_{(0.05)}$	—	—	—	—	—	0.71
Site 3						
0	6.12	432	15.3	2.05	13563	43.6
20	6.19	421	15.2	2.15	13732	44.6
40	6.50	436	15.7	2.16	14766	46.1
80	6.94	436	15.6	2.28	15507	47.9
Significance	0.0001	NS	NS	NS	NS	0.0001
LSD$_{(0.05)}$	0.25	—	—	—	—	0.75

Table 4. The proportion of discoloured ears at site 2.

Nitrogen (kg/ha)	% Discoloured
0	27.0
20	32.5
40	27.9
80	25.6
Significance	NS

Table 5. Comparison of healthy and discoloured ears for differences in yield components at site 2.

	Spikelets /ear	Grains /spikelet	Seed wt. (mg)
Healthy	16.2	2.23	40.7
Discoloured	17.3	1.77	23.5
Difference	-1.1	0.46	17.2
Significance	NS	0.05	0.01

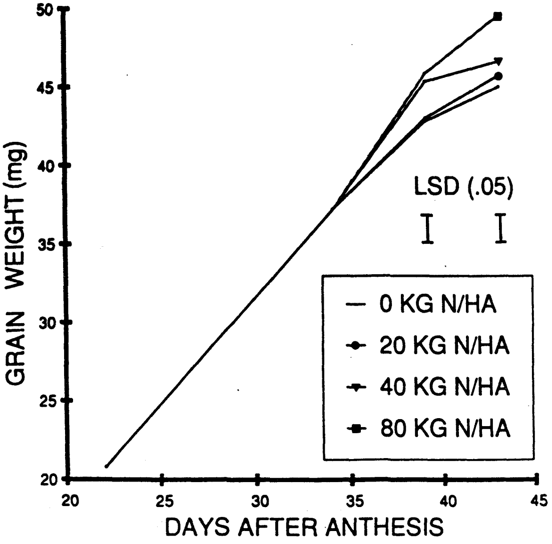

Figure 1. The effect of late N on grain weight at site 3.

Simple linear correlations for the yield data in Table 3 show that the component most closely associated with yield at site 1 and site 3 is grain weight (Table 6). For site 3, this is expected because the yield response to late N at this site was the result of increased grain weight whereas at site 1, the yield response was due to an increase in ears/m^2. Although the correlation between yield and ears/m^2 at site 1 is significant it is much weaker than the correlation between yield and grain weight. At site 1 there was a strong block effect on the association between yield and yield components. Very dense growth in one block resulted in lodging, and as a consequence, low grain weights and low grain yield. Ear numbers were highest in this block. Removing this block from the analysis resulted in the yield : ears/m^2 correlation increasing to 0.668** and the yield:grain weight correlation becoming non-significant. At site 2, it was the proportion of take-all infected ears which had the greatest association with yield.

Grain Protein Content

Late N significantly increased grain protein content at all sites (P = 0.0001 at site 1, 0.009 at site 2 and 0.0001 at site 3). Responses have been greatest at site 3, intermediate at site 1 and least at site 2 (Figure 2). The response appears to be linear at all sites, although at site 2 there was a plateau between the 20 kg N and 40 kg N treatments.

It was only at the highest rate of Late N that grain protein content achieved the Manawatu Mills Ltd optional minimum of 10.0% protein for the 1991/92 season (Anon. 1991a). However at site 2, all treatments produced grain protein contents which were above the upper limit (12.9%) for obtaining additional quality index points.

Table 6. Simple correlation coefficients for grain yield and yield components.

	Yield location		
Yield Component	Site 1	Site 2	Site 3
Ears/m^2	0.413	0.431*	0.382
Spikelets/ear	0.400	0.482*	0.197
Grains/spikelet	0.016	0.296	0.506*
Grains/m^2	0.097	0.415*	0.532**
Grain wt	0.756**	0.386	0.647**
%discoloured ears		0.660**	

* Significant at the 5% level

** Significant at the 1% level

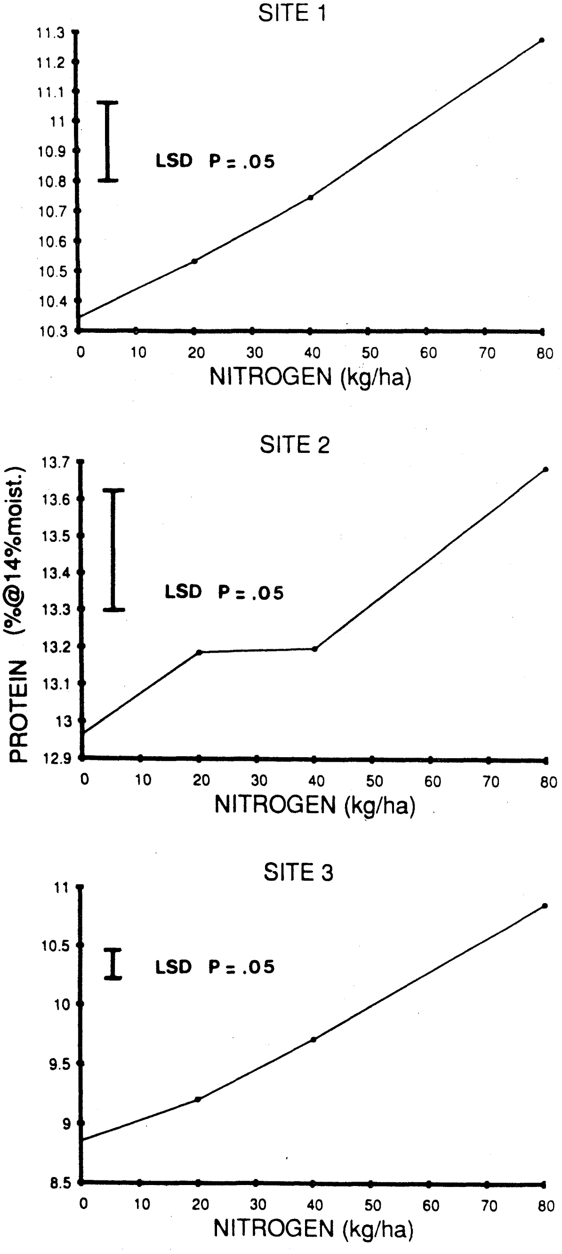

Figure 2. The response of grain protein content to late N.

Baking Quality

Grain samples from the highest and lowest yielding replicates from each site were assessed for bread baking quality. This was done to maximise the range of grain protein contents represented. These samples were subsequently used to determine the relationship between grain protein content and MDD bake score. There was a strong relationship between bake score and grain protein content (Fig. 3). The equation describing the relationship is:

Bake score = 1.4 + 1.81 (protein %)*
$r^2 = 0.83$
* P = 0.01%

Bake score has ranged from a low of 16.5 at about 9% protein to 28.5 at over 13% protein.

Discussion

Grain yield and yield components

The yield response to late N at site 1 and site 3 is similar to responses reported by others (Spiertz and Ellen, 1978; Withers 1986). At site 2 an infection of take-all limited yield, primarily by reducing grain weight. Take-all causes a crown and root rot, severely restricting uptake of nutrients into the plant (Harvey, 1979). There was a 42% decrease in grain weight in discoloured compared to 'healthy' ears at site 2. This is consistent with the effect of a late infection of take-all (Green and Ivins, 1984). The yield response to late N at site 1 and site 2 was 10.5 kg grain/kg N and 10.25 kg grain/kg N

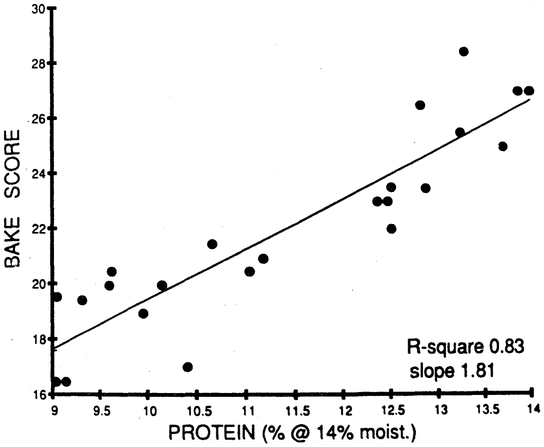

Figure 3. The regression of MDD bake score on grain protein content.

respectively, for the 80 kg N treatment. These responses are well below those achievable from early applications (Withers, 1986; Drewitt and Dyson, 1987).

Yield responses to late N have primarily been achieved through an increase in grain weight (Langer and Liew, 1973; Drewitt and Dyson, 1987). However late N can increase ear numbers in wheat (Stephen *et al.*, 1985; Withers, 1986). In both of these studies, favourable growing conditions (adequate soil moisture) allowed secondary tillers to respond to late N. The response in ear numbers at site 1 was probably also due to favourable growing conditions. Site 1 was the earliest sown and coolest site in this study, resulting in a relatively slow rate of crop development. Rainfall was also highest at this site. The combination of these factors favoured the development of late tillers in response to late N.

Grain yield in wheat is strongly associated with the ears/m^2 component (McCloy, 1980). Work in Canterbury (Scott, 1978a) and the Manawatu (Hampton, 1981) has shown that ear populations of 600-800 ears/m^2 are required for maximum yield. Ear populations in this study were generally below this range. High wheat yields have been obtained at ear populations below the levels indicated as being necessary for maximum yields (Scott, 1978b). In the above study, high yields were attributed to the grains/spikelet component being high. In this study, the high yields achieved at site 3 were primarily due to high seed weights (55.7 mg at 80 kg N/ha @ 14% moist). The flexibility of the yield components in wheat has been demonstrated previously (Nourafza and Langer, 1979; Hampton, 1981).

Grain weight in milling wheat is an important characteristic because it is a major determinant of final yield and an important quality characteristic. Small grains (<35 mg @ 14% moist) tend to have reduced flour extraction rates (Simons and Meredith, 1979). The grain weights listed in Table 3 are well above this level.

At site 3, late N increased grain weight by extending the linear phase of grain growth. This is consistent with the findings of other workers (Spiertz and van de Haar, 1978; Spiertz and Ellen, 1978). Spiertz and van de Haar, (1978) found that late N increased the duration of the green leaf area (Source capacity) of wheat which allowed photosynthesis to occur at higher rates during the latter stages of the grain-fill period. This increased the supply of assimilates to the grain, increasing grain weight. Late N increased the green leaf area duration at site 1 and site 3 (Table 2). At site 3, where late N did not influence sink size (grains/m^2), this resulted in an increase in grain weight. However, at site 1, late N increased sink size so that the balance between sink and source was unchanged. Consequently, grain weight did not respond to late N. Apart from N, moisture availability (Baier and Robertson, 1967) and disease prevalence (Daly and Dyson, 1987) can also influence the balance between sink and source and cause variation in grain weight.

Grain Protein Content

The response of grain protein content to late N has been greatest at site 3, intermediate at site 1 and least at site 2. At site 3, 40 kg N/ha was required to increase grain protein content by 1.0 percentage point. At site 1 it was 86 kg N/ha and at site 2, 111 kg N/ha. The magnitude of response appears to be related to the total N yield at harvest. Total N yield (mean of all treatments) was 128.8 kg N/ha, 178.2 kg N/ha and 227.5 Kg N/ha for site 3, site 1 and site 2 respectively. Each site is significantly different from the others (P = 0.1%). The rate of response of grain protein content to late N is inversley proportional to the total N yield at each site. Total N yield is a measure of the amount of N which was available to the crop. The rate of response of grain protein content to late N decreases as available supply of soil N increases (Strong 1982). Similar responses of grain content to late N have been reported (Miezan, Heyne and Finney, 1977; Cooper and Blakeney, 1990).

The linear response to late N is consistent with the results achieved by most workers (Spiertz and Ellen, 1978; Strong, 1986) when applying late N. Early applications of N result is less consistent increases in grain protein and may even reduce it in some situations (Benzian and Lane, 1981). Late N may increase grain yields without adversely influencing the response of grain protein to late N (Drewitt and Dyson, 1987). However, the greater the yield of the crop, the greater the amount of N required to lift grain protein content by a set amount (Guy, 1985).

Baking Quality

Many New Zealand studies have found that, while there is a relationship between grain protein content and bake score, it is not strong enough to be used as reliable predictor of bake score (Mitchell and Casutt, 1983; Wilson, 1983; Mitchell, 1985). This relationship is cultivar specific and tends to plateau (Douglas, 1987; Stevenson, 1987). The strong relationship found between grain protein content and bake score in this study agrees with the assertion of Moss (1981) that bread wheat quality increases with protein content at least up to 14.0% protein. A possible explanation for the weak relationships in the above studies is that they included grain samples taken across a large number of environments. Environment is known to influence the relationship between grain protein content and bake score (Stevenson, 1987). However, some overseas studies have found strong relationships between grain protein content and baking quality from samples representing a wide range of environments (Cooper and Blackeney, 1990).

Although the number of environments represented in this study is small, most of the milling wheat produced in the Manawatu is grown inside the region represented by these three sites. Temperature and rainfall have both varied across these 3 sites. Temperature (Stevenson, 1987) and moisture (Bunker *et al.*, 1989) have been shown to influence baking quality, apart from any effect they may have on grain protein content. The variation in temperatures experienced in this study were well below those of Stevenson (1987) and may not have been large enough to seriously effect the relationship between grain protein content and bake score.

The results of this study support the use of grain protein content to assess the baking quality of milling wheat in the Manawatu. There would appear to be minimal risk of wrongly accepting large numbers of poor quality lines.

Economic Feasibility

The financial benefits that would have resulted from the application of late N in this study are presented in Table 7. Assumptions used include N applied as ammonium sulphate, costing $250/tonne. Application is $15.00/ha. On a cents/kg N basis, urea has traditionally cost less than ammonium sulphate in New Zealand (Rogers and Little, 1982) and may be just as effective (Withers, 1986).

For the 80 kg N treatment, the combined effects of increased yield and grain protein content have resulted in net returns of $228/ha at site 1 and $254/ha at site 3. Returns have increased as the application rate of late N has increased. At site 2, the nil yield response and failure to obtain a price premium would have resulted in financial losses as a consequence of applying late N. Higher rates of late N than those used in this study may have been profitable at site 1 and site 3. At both sites grain protein contents were still well below the upper threshold of 12.9%. However, at site 1, the response in grain yield to late N was beginning to diminish at the highest rate of application.

Table 7. The economic benefits from using late N ($/ha).

Nitrogen (kg/ha)	Site 1	Site 2	Site 3
20	80	-39	-13
40	177	-63	38
80	228	-110	254

The potential increase in net returns indicated in Table 7 are high when compared to the gross margin for an average yielding crop of milling wheat in the Manawatu. For the 1991/92 season, this was $536/ha (Anon., 1991c).

Late N has been recommended for Southland milling wheat crops (Christie, 1989). In the Manawatu, Withers (1986) found that late N could be profitable if applied in addition to early applications. Late N applied in place of early applications is likely to be uneconomic because of the greatly reduced effectiveness of late N for increasing grain yield (Stephen *et al.*, 1985). Low soil moisture may reduce the effectiveness of late N (Needham, 1982). In this study, rainfall during the month of December (early grain-fill) was well below the long term mean, indicating that for the soil types represented by the sites used in this study, soil moisture levels are likely to be adequate, even in years of below average rainfall.

The economic benefits of late N are likely to be greatest in crops which are high yielding but with restricted N supply, particularly during the latter stages of development (Martin, *et al.*, 1989). Any factor limiting crop growth, such as disease (Spiertz and De Vos, 1983) or moisture stress (Drewitt and Dyson, 1987) will limit economic benefits.

The nitrate sap test (Withers and Palenksi, 1984) may be of use as a means of identifying paddocks which may produce an economic response to late N. Withers (1986) found a good relationship between sap nitrate levels during stem elongation in wheat and barley and subsequent grain protein content. However the relationship was site specific. Crops with a low sap nitrate content at stem elongation may still produce grain with a high protein content at low yielding sites. The most responsive sites are likely to be those with low sap nitrate levels but with a high potential yield.

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