THE EFFECT OF NITROGEN MANAGEMENT AND PADDOCK HISTORY ON BARLEY GROWTH AND YIELD

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ABSTRACT

A field experiment was conducted at four adjacent sites on the marginal cropping soil Tokomaru silt loam to study the influence of nitrogen management and paddock history on growth and yield of barley (cv. *Magnum*). The N treatments were no-N (control), 60 kg N/ha applied at sowing, G.S.3, G.S.6 or split between G.S.3 and G.S.6 and a higher rate determined by soil test results (70-90 kg N/ha depending on site) applied at sowing. Site histories were immediately out of pasture and previously cropped with barley for 1, 2 and 3 years. Crop N status was monitored by nitrate test strip.

Control plot yield decreased almost linearly from 5.78 t/ha out of pasture to 3.55 t/ha on the site previously cropped for three years. This indicated that regular cropping without N fertiliser on this soil could substantially reduce the yield of barley.

Application of N significantly increased yield over control at all sites. Average yield on nitrogen plots were maintained for the first two years cropping (7.09 and 6.86 t/ha respectively) then declined rapidly for the third and fourth years of cropping (5.90 and 5.94 t/ha respectively). Plots receiving the high N rate based on soil test results were also unable to maintain yield as cropping history increased. The yield decline could have been caused by other factors not related to N or possibly the soil test underestimated the N rate required to maintain yield. Maintaining adequate N toward later stages of growth was found to be important as soil fertility reduced. Effect of N on tiller dynamic and ear production are discussed.

The sap nitrate test was a better indicator of crop response to the soil N status than soil tests and so it may have potential for assisting the nitrogen management of crops.

***Additional Key Words:** Nitrogen fertilizer timing, nitrogen fertilizer rate, tillering pattern, ear density, sap nitrate test, soil test.*

INTRODUCTION

The response of cereals to N fertiliser application is variable ranging from economical yield increases to reductions in yield. Nitrogen status of the soil is one of the factors that influences the pattern of response. Soil N is higher after pasture or leguminous crops and lower after cereals (Malcolm and Thompson, 1968).

Response of wheat and barley to applied N increases with decreasing levels of available N at planting (Nuttal *et al.*, 1971; Soper and Huang, 1973; Dougherty *et al.*, 1974). Ludecke (1974) proposed that if available N in the top 60 cm of soil is less than 60 kg/ha, a response to N application could be expected.

A review of earlier work on wheat by Stephen (1982) showed that yield responses are dependent on paddock history related to previous crops. Wheat responded to applied N fertilizers most frequently when the preceeding crop was cereal and least frequently when it was a pasture or forage. Yield responses of wheat to N are reported to occur only for second and subsequent crops but not in the first crop after pasture (McLeod, 1974; Stephen, 1982). For barley following pasture or other restorative crop, application of N is reported to give no yield advantages (Drewitt, 1983; Malcolm, 1983).

It is a common practice for spring-sown cereals to apply N at sowing. Early N application increases yield by increasing ear population (Feyter and Cossens, 1977; Dougherty *et al.*, 1979). However, high nitrogen application at early stages of growth may reduce yield by promoting excessive vegetative growth that can lead to rapid exhaustion of available moisture and higher tiller mortality (Dougherty and Langer, 1974; Dougherty *et al.*, 1975). Late N application increases tiller survival but may give no advantage to final grain yield (Millner, 1983).

In the Manawatu and Rangitikei areas, only 10-20 kg N/ha were previously recommended for second and subsequent crops of barley after pasture (Unwin and Cornforth, 1980). Recent work has shown some potential for increasing N rate over that normally used but there is a need to be able to predict which paddock will respond to this rate (Withers; unpublished report).

According to Drewitt (1983), a means for predicting the correct amount and timing of N is still the urgent requirement of cereal growers. The method described by Quin *et al.* (1982), where the amount of nitrate-N and ammonium-N, before and after 7-day incubation were used to estimate the amount of fertilizer needed has been suggested for this purpose. A simple nitrate sap test discussed by Scaife and his co-workers (Scaife, 1979; Scaife and Barnes, 1977) and locally evaluated by Withers (1982) and Withers and Palenski (1984) has shown some potential for monitoring crop nitrogen status during the growing season.

The use of paddock history as the indicator of fertilizer need is very empirical and subjective. The problems associated with this have been cited by many workers (McLeod, 1962; Walker, 1969; Ludecke, 1974; Quin *et al.* 1982). Steele and Cooper (1980) indicated that some North Island soils can be cropped continuously for 11 years without responses to applied N while other soils give responses even in their first year out of pasture.

In Manawatu, Tokomaru silt loam is mainly used for fattening lambs and some dairying and is not normally used for cropping. Yield of wheat grown on this soil is only 3.4 to 4 t/ha (Cowie, 1978). However, the interest in growing crops on this and similar soils is now increasing. This paper reports some preliminary results of an experiment which aimed to study the effect of different N management on yield and yield components of barley grown at various sites differing in paddock history in order to provide growers and advisors with information on N use on Manawatu terrace soils.

MATERIALS AND METHODS

The response of barley *Hordeum vulgare* cv. Magnum to six N managements was investigated in 1983/1984 at four adjacent sites located on Tokomaru silt loam (Cowie, 1978) at Massey University. The history of the sites were immediately out of pasture and previously cropped with barley for one, two and three years following pasture. At all the sites, pasture was re-established in 1977 from old pasture and continuously produced good quality pasture until the cropping was imposed. The experiment was a randomised complete block design within each site with three replications and plots were 2.25 m x 15 m. Before planting, soil samples were taken from each site and immediately sent to Winchmore Irrigation Research Centre for determination of nitrate-nitrogen and ammonium-nitrogen by the incubation method described by Quin *et al.* (1982). The amount of fertiliser needed was calculated for each site based on the test results for an expected yield of 7 t/ha and 40 kg N/ton yield responses (Quin *et al.* 1982) (Table 1). Except for this treatment, 60 kg N/ha was applied but at different times. Nitrogen was applied as urea broadcast and raked in at sowing and surface broadcast for other applications (Table 1). Barley was sown in 15 cm rows at 100 kg seed/ha.

Between crop establishment and harvest, the experimental crops were treated with 4 l/ha Salvo (210 gm/l mecoprop, 233 gm/l dichlorprop, 107 gm/l MCPA, 17 gm/l dicamba) and 50 ml/ha Tilt (250 gm/l propiconazole) as weedicide and fungicide respectively. No insecticide was applied and none of the crops was irrigated.

Measurements

For the purpose of sampling, each plot was divided into two sections; one half for destructive sampling and the other for final harvest of grain.

During the early growth period, crop N status was monitored regularly by Merckoquant nitrate test strips, as described by Withers (1982). The time taken to reach maximum colour was taken and converted to nitrate concentration by a standard calibration curve.

Five harvests of whole plants were made by taking three random quadrats of 0.1 m². Sub-sampling was done for tiller counts, dry matter partitioning, leaf area measurement and analysis of herbage N. Grain yield harvest was done on an area of 1.3 m x 5 m by plot harvester and adjusted to 14% moisture content.

Data analysis

Variability of plant growth was noted at sites 1-3 especially at both ends of the trials where soil compaction appeared to be a problem. Initially plot position was tried as a covariate but later it was found that initial plant counts made at establishment were closely related to plant performance and this was used as a concomitant variable to adjust the results in the analysis of variance.

RESULTS

All experimental crops established well and no pest, disease or sign of water stress was observed. For simplicity of presentation and discussion, only the results at site 1 and

TABLE 1: Characterization of site and treatments.

Site	mineral nitrogen (ppm) before incubation	mineral nitrogen (ppm) after incubation	estimated* yield without-N (t/ha)	soil test rate (calculated) N Kg/ha
Site 1 — Immediately after pasture	8.6	47.4	5.31	70
Site 2 — 1 year cropped with barley	6.2	45.3	5.04	80
Site 3 — 2 years cropped with barley	5.5	45.0	4.98	80
Site 4 — 3 years cropped with barley	6.3	41.2	4.70	90

Treatments

Cont.	— control
60B	— 60 kg N/ha applied at sowing
60E	— 60 kg N/ha applied at early tillering (G.S.3)
60L	— 60 kg N/ha applied at late tillering (G.S.6)
SOILT	— Soil test rate at sowing
60SP	— 60 kg N/ha split between early and late tillering

*Yo = 1 + 0.0417 (IN + 2 N) (Quin *et al.*, 1982).

site 4 will be given whenever the results show a trend across the sites, however the results at other sites will be cited when necessary.

Grain Yield

Average grain yield over all treatments showed a decreasing trend from site 1 to site 4. Yield of control plots decreased at an almost constant rate of about 0.74 t/ha/year of cropping. Nitrogen application at all sites significantly increased grain yield over the control with a tendency for increased N response as years in cropping increased. Yield of N treatments was held constant for the first two years of cropping but dropped sharply for the third year, which were similar to the yield of plots cropped for the fourth year (Figure 1 and Table 2).

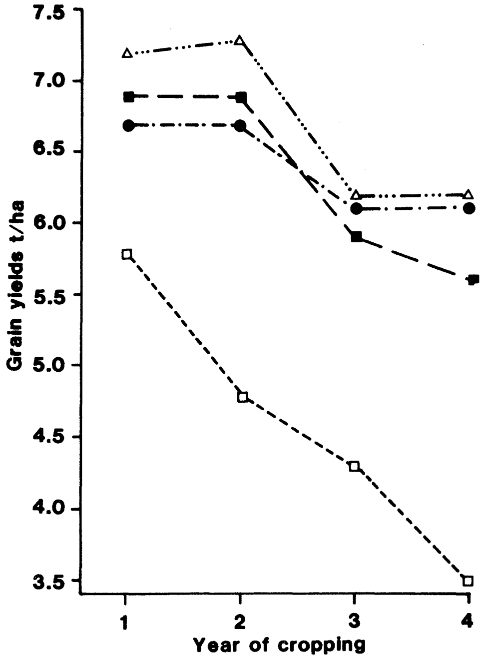

Figure 1: Grain yield response of barley to rate and timing of N application of various site differing in year of cropping; (□) control; (■) 60B; (△) average 60L + 60SP; (●) soilt.

Different N managements showed various responses at sites 2-4. Nitrogen application at early tillering (60E) tended to give the lowest yield of the N management treatments although this was significant at site 3 only. Treatments involving late application (60L and 60SP) and the higher application rate (SOILT) did not differ from each other. These treatments consistently gave higher yield particularly at site 4, where 60SP yielded significantly higher than the early application at the same rate.

Yield Components

Simple correlations between components of yield over all the sites indicated a strong correlation between grain yield and ear density at harvest (r = 0.864**), this component accounted for more than 70% of the yield variation. The number of grains/ear (r = 0.623**) and 1000 grain-weight (r = 0.629**) were less well correlated with yield.

TABLE 2: Effect of different nitrogen managements on yield and ear density of barley at the various sites.

	N-treatment	Yield (t/ha)	Ear Density (number/m²)
Site 1	CONT.	5.78 a	818 a
	60B	6.89 b	1022 b
	60E	7.32 b	1013 b
	60L	6.93 b	965 b
	SOILT	6.70 b	908 ab
	60SP	7.50 b	996 b
	Mean	6.85	954
	C.V. (%)	7.1	6.5
	LSD (5%)	0.90	114
Site 2	CONT.	4.84 a	751 a
	60B	6.95 bc	868 a
	60E	6.02 b	863 a
	60L	7.54 c	908 a
	SOILT	6.74 bc	914 a
	60SP	7.03 bc	894 a
	Mean	6.52	867
	C.V. (%)	9.1	9.4
	LSD (5%)	1.12	—
Site 3	CONT.	4.31 a	696 a
	60B	5.87 c	834 a
	60E	5.21 b	788 a
	60L	6.23 d	874 a
	SOILT	6.09 cd	902 a
	60SP	6.12 cd	881 a
	Mean	5.64	829
	C.V. (%)	3.3	9.4
	LSD (5%)	0.35	—
Site 4	CONT.	3.55 a	667 a
	60B	5.60 b	773 ab
	60E	5.52 b	757 ab
	60L	5.93 bc	898 c
	SOILT	6.09 bc	810 bc
	60SP	6.55 c	858 bc
	Mean	5.54	794
	C.V. (%)	7.9	7.5
	LSD (5%)	0.80	108

For each site, the number within column followed by same letter is not significantly different by LSD test at 5%.

Application of N produced variable effects on ear density at harvest (Table 2). The general trend across the sites show the advantage of high N (SOILT) on ear density up to 3 years cropping but, in the fourth year, late or split application of 60 kg N/ha tended to be more beneficial for this component of yield.

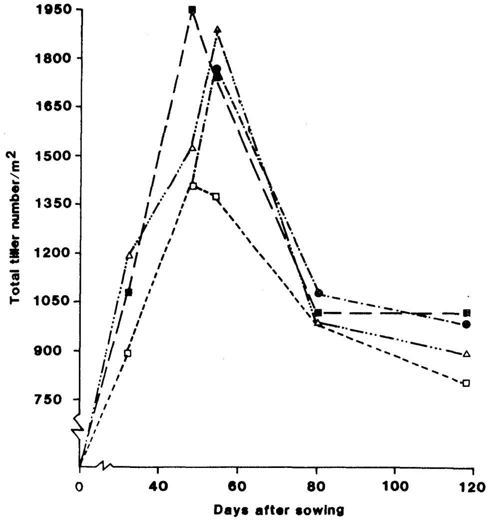

Figure 2: Effect of different nitrogen managements on total tillers at various stages of growth at site 1 (first year cropping); (□) control; (■) 60B; (●) average 60L + 60SP; (△) soilt.

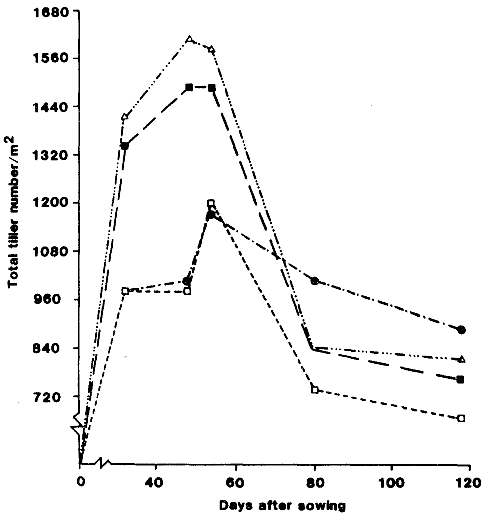

Figure 3: Effect of different nitrogen managements on total tillers at various stages of growth at site 4 (fourth year cropping); (□) control; (■) 60B; (●) average 60L + 60SP; (△) soilt.

Ear density at harvest is the result of tiller production during vegetative growth and subsequent tiller death that might occur. At all sites, N application at sowing (60B and SOILT) boosted earlier tiller formation and produced highest maximum tiller numbers compared to control and other treatments (Figures 2 and 3). The effectiveness of late N application to increase tiller number reduced from site 1 to site 4.

After the peak tillering period, total tillers reduced at a rate that differed between treatments. Amount of tiller death was highly correlated with the maximum number of tillers produced (r = 0.947**). At site 1, early and late N applications had similar patterns of tillering and tiller death that resulted in similar ear densities (Figure 2). The pattern became obviously different as years of previous cropping increased. At site 4, late applications gave relatively low maximum tiller numbers but there was high tiller survival which was reflected in high ear density at harvest compared to other treatments (Figure 3).

Nitrogen Tests and Yield

There were similar patterns in total available N (NH4 + NO3) as indicated by the incubation soil test before planting and grain yield of control plots across the sites (Figure 4) although the absolute changes in soil test values were small. Control yields decreased with increasing years of cropping. Amount of the total available N decreased from site 1 to site 4 with no apparent differences between site 2 and site 3. Trends of other soil test values were similar (Table 1) except for N levels before incubation at site 4.

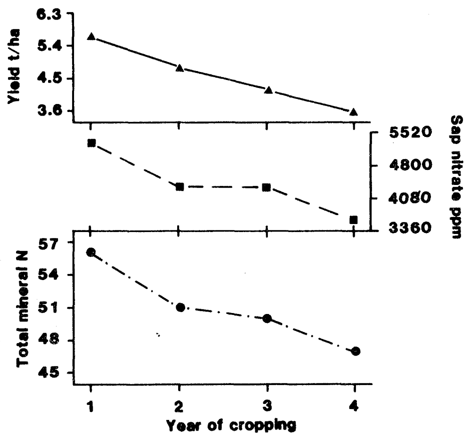

Figure 4: Grain yield (▲); maximum sap nitrate concentration (■) and total mineral nitrogen (●) of control plots at sites differing in year of cropping.

Nitrate sap test directly measures the nitrate status of the plant at any particular time. At all sites and treatments, sap nitrate concentration rapidly increased to a maximum at 22 DAS (days after sowing) then steadily dropped to a level that could not be detected by the test. The maximum concentration varied among treatments and sites (Figures 5 and 6).

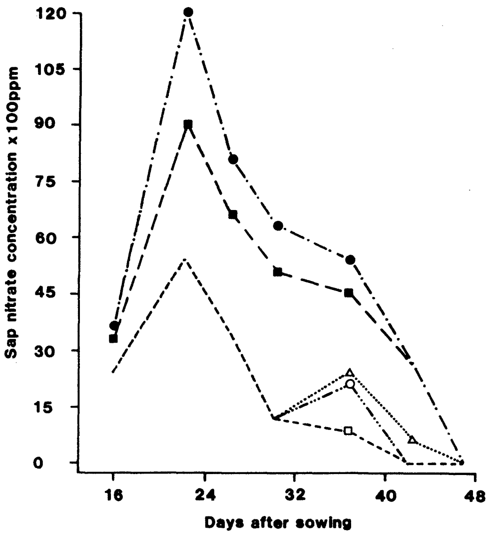

Figure 5: Sap nitrate concentration as measured by merckoquant test strip at various growth stages for different nitrogen managements at site 1; (□) control; (■) 60B; (△) 60E; (○) 60SP; (●) soilt.

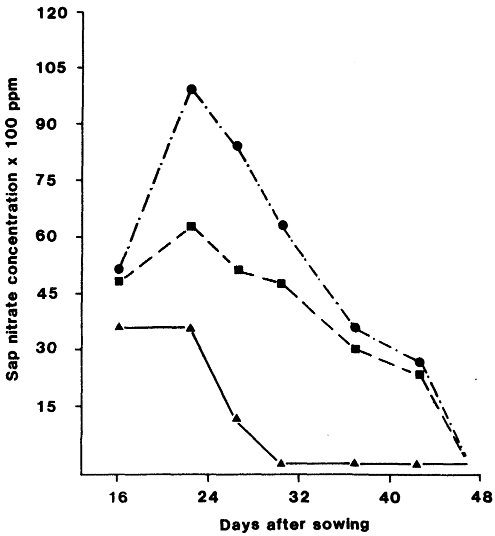

Figure 6: Sap nitrate concentration as measured by merckoquant test strip at various growth stages for different nitrogen managments at site 4: (▲) control; (■) 60B; (●) soilt.

In control plants, the maximum nitrate levels and number of days nitrate was detected differed between sites, highest level (5380 ppm) and longest duration (37 DAS) at site 1. Peak nitrate levels increased to almost the same amount at sites 2 and 3 (4360 ppm and 4440 ppm respectively) and nitrate was detected for the same period (30 DAS). At site 4, the maximum was only 3720 ppm and the nitrate was present for the shortest period (26 DAS). This trend of maximum values and the period nitrate was present was similar to soil available N and final grain yield of control plots (Figure 4).

Application of N at sowing (60B and SOILT) significantly increased sap nitrate at 22 DAS to 44 DAS over the control. Higher rates of N application (SOILT) generally give higher sap nitrate levels than the standard rate (60B). Nitrogen application after sowing failed to increase sap nitrate levels over the control except at site 1 where N application at early tillering (60E and 60SP) increased sap nitrate at 37 DAS and this was maintained to 42 DAS for the 60E treatment.

DISCUSSION

Grain yield of control plots and average grain yield over all treatments decreased from site 1 (first year cropping) to site 4 (fourth year cropping) and it is higher than that obtained by Withers (1982) after five years cropping on the same soil type. The control plot yields which represent the actual effect of previous cropping declined at about 0.74 t/ha/year of cropping, a rate more than double that indicated by Greenwood and McLeod (1980) for wheat six years in succession in the South Island. Stephen *et al.* (1973) however, got no yield reduction in their four years experiment. The difference is probably due to differences in soil type, as Tokomaru silt loam is considered a marginal soil for cropping due to its drainage limitations (Cowie, 1978). Therefore cropping of these soils for extended periods needs to be carefully considered.

All N treatments effectively increased grain yield over control at all sites. The response in the first year of cropping (site 1) was not expected as it is widely reported that no yield responses and even yield depressions on such paddocks. Van Der Paauw (1962) and Feyter *et al.* (1977) have established relationships between the response of spring-sown cereals to N and amount of winter rainfall that contributed to nitrate leaching. In this experiment however, the response is not likely to be related to those factors as the amount of rainfall before and during the cropping season (June 1983 to January 1984: 511 mm) was below the long-term average (689 mm for the same period). Possibly the inherent fertility of the soil itself was the significant factor as shown by the N requirement of this site based on the soil test. Therefore this indicates that normal paddock history criteria are not a good basis for determining crop N requirement of this type of soil and that the nitrogen requirements of Manawatu terrace soils have been under estimated.

Despite the increased response to N with increased cropping, the N did not fully compensate for the yield reduction in the 3rd and 4th year in crop (Figure 1). It is possible that insufficient nitrogen was used at these two sites. However, the additional nitrogen applied according to soil test results (90 kg N/ha at site 4) did not significantly increase yield over the basic 60 kg N/ha which would indicate that nitrogen was not the only limiting factor.

It is also possible that soil physical factors were reducing yields at sites 3 and 4. Jacks (1944) indicated that increasing fertility under herbage crops was attributable more to the improvement of physical rather than chemical conditions of the soil. Karageorgis *et al.* (1979) recorded a great variation in barley yield within Templeton soil mapping unit that was not only closely related to soil N but also to textural classes of the soil. A review by Greenland (1971) indicated that on most wheat growing soils in Australia with high silt and fine-sand contents, pasture is essential for the maintainance of favourable soil physical conditions that related to soil permeability and pattern of crop response to N. Continuous cropping on this type of soil has a tendency to develop a structure unsuitable for plant growth. Cowie (1978) indicated that Manawatu soils are readily broken down by continuous or intensive cropping, where the top soil become structureless and very compact. This is especially likely to happen on Tokomaru silt loam.

The reason for the inability of nitrogen to compensate for reducing yields therefore needs further investigation.

Treatments involving late application of N (60L and 60SP) tended to perform better at all sites and had a yield comparable to higher N application rates applied at sowing (SOILT) particularly at site 4, where 60SP gave a higher yield than earlier applications at the same rate. It appears that as years of cropping increased, it became increasingly important to maintain N level toward the later stages of growth. The results indicated that splitting or late application of 60 kg N/ha was comparable to high N rate (70-90 kg N/ha) applied at sowing and thus on soils of low fertility, split or late applications may be more efficient than high rates applied at sowing. Similar results have been found by Withers and Palenski (1984).

Generally, final ear density at harvest was not affected by various nitrogen managements however the dynamics of tiller production and tiller death during vegetative growth showed an interesting relationship with the treatments. Even though the highest maximum tiller number was produced by early N application (60B and SOILT), it was not an assurance of highest ear density as tiller death increased as the maximum tiller number increased. Kirby (1967) reported that in two-row types of barley, the maximum number of tillers was inversely related to final ear number. Competition between and within plants for nutrients and light was suggested as the reason for tiller death after the maximum tillering period or at high density (Bunting and Drennam, 1966). The high tiller number from early N application possibly increased the competition for depleted N and other growth requirement toward the later stages of growth. Therefore adequate N supply after the maximum tillering period seems important for tiller survival. On fertile soil at site 1, even though all treatments gave the highest maximum tiller number compared to other sites, it was still able to produce highest ear density of all sites. All N treatments at this site were equally effective for tiller production and tiller survival. On the less fertile soil at site 4, early N application that produced high maximum tiller number was insufficient to enable the tillers to survive in contrast to late and split application (60L and 60SP). The latter treatments which started with low tiller number were more effective in maintaining a high tiller survival and ear production. At this site, application of 60 kg N/ha either at late tillering or splitting between early and late tillering were equally effective as applying 90 kg N/ha at sowing for increasing ear density. A similar trend was apparent for site 2 and 3 (Figure 3 and Table 2).

Sap nitrate concentration may vary within a short period of time, but it well represents the current N status of crops (Prasad and Spiers, 1982; Withers and Palenski, 1984). Sap nitrate patterns of all treatments at all sites over the measured period were similar to laboratory nitrate analysis obtained by Papastylianou and Puckridge (1981) on barley planted after various cultural treatments. Prasad and Spiers (1982) reported a linear relationship between sap nitrate tested by Merckquant test strip and the autoanalyser method. Maximum sap nitrate concentration which occurred at early tillering was related to N availability and yield for the control plots in this experiment. Sap nitrate concentration increased with N application at sowing. Treatments 60E and 60SP on fertile soil at site 1 were able to increase the nitrate concentration over control levels which were low but not at other sites (Figure 5 and 6).

These results support the work of others (Papastylianou and Puckridge, 1981; Withers, 1982; Withers and Palenski, 1984) who have shown that the nitrate sap test could be used to monitor the nitrogen status of cereal crops. Sap tests were more sensitive to the apparent differences in nitrogen status than the soil test. The reduction of 8.5 ppm in total available N from site 1 to site 4 estimated by the soil test is relatively small compared with the reduction of about 1000 ppm in maximum sap nitrate concentration and when compared with the 2.23 t/ha control plot yield reduction. Detection of the small differences in the soil test value can be masked by error particularly during sampling and handling of the samples.

CONCLUSIONS

1. Yield of barley crops grown on Tokomaru silt loam reduced almost linearly (0.74 t/ha/year) with each year of continuous cropping if nitrogen fertilizer is not used.
2. Nitrogen fertiliser at 60-90 kg/ha alleviates the decline in yield after the second year in crop but not completely. Factors other than nitrogen fertiliser may be limiting yield after the second year but further work is required on this aspect.
3. Nitrogen fertiliser may be required on these soils even when the crop is ploughed out of pasture.
4. Although incubation soil test levels reflected changes in the yield of control plots, the magnitude of the soil test differences was small relative to the yield differences and this limits the wide use of the test.
5. Sap nitrate levels were sensitive to the nitrogen status of the sites and the various nitrogen treatments which indicates that the test has potential for monitoring the nitrogen status of cereal crops.

6. Timing of nitrogen application may become critical as soil fertility reduces such as by continuous cropping. Under low fertility, nitrogen applications which include a late application (about growth stage 5-6) may be more efficient than applications at sowing.

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