RESPONSE OF WHEAT TO FIVE NITROGEN FERTILISERS IN NORTHERN CANTERBURY

R.C. Stephen, D.J. Saville, B.F. Quin*
Agricultural Research Division, MAF, Lincoln
*Agricultural Research Division, MAF, Wellington

ABSTRACT

The effects of pelleted urea, an aqueous urea solution, ammonium sulphate, a lime/ammonium nitrate mix and potassium nitrate on grain yield in winter-sown 'Rongotea' wheat were assessed in 13 field experiments conducted in three cropping seasons. The nitrogen fertilisers were applied in early spring to the tillering wheat at rates which supplied 35, 70, 105 and 140 kg N/ha.

Grain yield responses to applied nitrogen were markedly affected by spring-summer rainfall and varied widely among cropping years and sites. Differences among nitrogen fertilisers were generally small and not significant, apart from an inferiority of the urea solution.

Additional Keywords: *urea, ammonium sulphate, ammonium nitrate, potassium nitrate, spring-summer rainfall, 'plant-available' nitrogen, shallow and deep soils.*

INTRODUCTION

Application of nitrogen fertiliser to wheat in New Zealand has been practised commercially for less than 15 years and in this time farmers have relied on overseas sources of supply. The announcement in 1978 that a New Zealand petrochemical organisation planned to use local natural gas to manufacture urea for use as a nitrogen fertiliser prompted questions concerning the cost and efficacy of urea compared with other nitrogen fertilisers.

Overseas, urea has been used as a nitrogen fertiliser for some 60 years. Reports giving details of agronomic research on cereals with urea and other commonly available nitrogen fertilisers indicate variously, either that they had similar effects on grain yields (Russell, 1939; Widdowson and Penny,1977) or that their relative efficiencies differed significantly (Gardner, 1955; Widdowson and Penny, 1960; Templeman, 1961; Webber, 1962; Alessi and Power, 1972).

It was decided in view of the conflicting reports regarding the relative efficacy of urea to assess the material as a source of nitrogen for winter-sown wheat in the northern Canterbury environment.

MATERIALS AND METHODS

In the three cropping seasons 1980-81, 1981-82 and 1982-83, experiments were established in wheat fields on commercial farms in northern Canterbury to test the effects of single applications of urea, ammonium sulphate, a lime/ammonium nitrate mix and potassium nitrate on grain yield in winter-sown wheat.

At least four experimental sites which had been intensively cropped in the immediate preceding years, were chosen deliberately each season in anticipation that soil concentrations of 'plant-available' nitrogen would be inadequate for normal wheat growth and that large positive responses in grain yield to applied nitrogen would result. In order to sample as wide a range of arable cropping conditions as possible the 13 experiments were located on 13 different farms. Also, an attempt was made to factorially locate experiments on shallow and deep soils in low and high rainfall districts in each season. Brief details of individual sites are given in Table 1.

The wheat cultivar 'Rongotea' (McEwan and Vizer, 1979) was sown at all sites since experience had shown it to be responsive to fertiliser nitrogen. In early winter (late May/early June), 120 kg/ha fungicide-treated seed, and 250 kg/ha reverted superphosphate, were combine-drilled into conventionally cultivated seed-beds in nine-row plots, each 1.6 m wide × 25 m long.

The nitrogen fertilisers tested were pelleted urea (46% N), an aqueous urea solution which was made up by dissolving an appropriate quantity of pelleted urea in clean water and applied at 180 l/ha, crystalline ammonium sulphate (21% N), a coarsely granulated lime/ammonium nitrate mix (26% N) and finely crystalline potassium nitrate (13% N). In mid-September, each nitrogen fertiliser was applied to the actively tillering wheat in single dressings at rates which supplied 35, 70, 105 and 150 kgN/ha. The solid materials were broadcast evenly onto plots. The urea solution was jetted onto the soil surface in eight 10 mm wide bands with one band midway between each pair of neighbouring drill rows.

The nitrogen fertiliser treatments, ie. the five nitrogen fertilisers, each at four rates, plus five nil nitrogen 'controls' were completely randomised in twice replicated blocks of 25 plots.

Prior to the application of nitrogen fertilisers, soil samples were taken from each site for laboratory determination of soil concentrations of nitrate-nitrogen and ammonium-nitrogen, both before and after a 7-day

TABLE 1: Details of Experimental Sites.

Cropping year	Site	Locality	Soil	Preceding crop	Number of preceding arable crops
1980/81	1	Methven	Mayfield	Peas	6
	2	Barrhill	Barrhill	Peas	3
	3	Darfield	Eyre	Grass seed	4
	4	Sheffield	Lyndhurst	Wheat	2
1981/82	5	Hororata	Ashley	Linseed	1
	6	Darfield	Chertsey	Fallow	2
	7	Leeston	Waterton	Peas	3
	8	Annat	Lyndhurst	Potatoes	5
1982/83	9	Ashburton	Kaiapoi	Barley	6
	10	Leeston	Waterton	Wheat	1
	11	Waddington	Lyndhurst	Potatoes	4
	12	Rokeby	Hatfield	Kale seed	5
	13	Methven	Mayfield	Barley	1

TABLE 2: Grain yields (t/ha) at individual experimental sites.

Cropping Year	1980/81				1981/82				1982/83				
Site	1	2	3	4	5	6	7	8	9	10	11	12	13
'Control' mean	5.16	5.95	5.46	3.76	5.14	2.61	6.26	5.71	2.81	4.66	4.07	5.36	5.97
'Nitrogen' mean	7.48	6.21	5.21	5.09	5.16	3.73	6.29	5.04	4.40	5.10	5.81	6.12	8.16
L.S.D. (5%)	0.36	0.20	0.24	0.30	0.19	0.20	0.32	0.28	0.25	0.09	0.12	0.11	0.38
Forms of Nitrogen													
Ammonium sulphate	7.52	6.29	5.24	5.40	5.22	3.60	6.45	5.01	4.51	5.10	5.84	6.17	8.57
Lime/ammonium nitrate	7.73	6.17	5.16	5.15	5.03	3.73	6.21	4.75	4.41	5.06	5.79	6.14	8.10
Urea pelleted	7.29	6.19	5.29	4.79	5.19	3.65	6.26	5.23	4.42	5.14	5.70	6.05	8.10
Aqueous urea solution	7.09	6.20	5.15	4.88	5.28	3.78	6.33	5.26	4.28	5.03	5.75	6.12	8.17
Potassium nitrate	7.74	6.21	5.23	5.24	5.09	3.87	6.18	4.93	4.36	5.19	5.98	6.11	7.86
L.S.D. (5%)	0.50	0.29	0.38	0.42	0.27	0.29	0.46	0.40	0.35	0.12	0.17	0.16	0.54
Rates of Nitrogen													
35	6.50	6.16	5.22	4.58	5.36	3.22	6.19	5.38	3.55	4.94	5.00	5.81	7.11
70	7.19	6.15	5.16	5.11	5.20	3.58	6.44	5.23	4.02	5.06	5.86	6.20	7.90
105	7.90	6.31	5.21	5.17	5.06	4.04	6.44	4.85	4.80	5.18	6.17	6.21	8.53
140	8.32	6.24	5.27	5.52	5.02	4.06	6.09	4.68	5.23	5.24	6.23	6.25	9.10
L.S.D. (5%)	0.46	0.25	0.33	0.38	0.23	0.25	0.42	0.36	0.31	0.11	0.15	0.14	0.48
Significance of components of nitrogen rate response curve													
Linear	***	n.s.	n.s.	**	**	**	n.s.	***	***	**	***	**	***
Quadratic	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.	**	**	n.s.
Significance of interaction of nitrogen forms and components of nitrogen rate response curve.													
Form x Linear	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Form x Quadratic	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Coefficient of Variation (%)	6.5	4.4	6.9	8.0	4.9	7.4	6.9	7.5	7.6	2.3	2.7	2.5	6.3

incubation of field moist soil at 37 °C. Subsequently concentrations of 'plant-available' nitrogen were calculated as detailed by Quin *et al.* (1982).

Between crop establishment and harvest, individual experimental crops were treated as required with appropriate herbicides and fungicides. Applications of insecticide were not required and none of the test crops was irrigated.

Monthly rainfall data for the winter-sown wheat growing season, June to February inclusive, for each site were obtained from nearby New Zealand Meteorological Service rainfall observation stations.

When the experimental crops matured, plots were trimmed to a common length and all nine drill-rows of each plot were harvested with a small self-cleaning header. Grain harvested from each plot was weighed and a sample tested for moisture. Where the moisture content of threshed grain exceeded the standard 15 percent, grain yield data were reduced proportionately. No adjustments were made where grain moistures were less than 15 percent because deviations from the standard were small.

Grain yield data for individual sites were subjected to analysis of variance. It was anticipated that differences among the nitrogen fertiliser treatments would show most clearly in data for the more responsive sites. Accordingly it was decided that, for an overall analysis of treatment effects, data for individual sites be assigned to grain yield response classes on the basis of overall mean grain yield response to applied nitrogen. It was decided also that, within each response class, an analysis of variance would be performed using the 20 nitrogen fertiliser treatment means for each site in a 5 × 4 factorial design, with sites treated as blocks. Regressions of overall mean grain yield responses to fertiliser nitrogen on the site parameters detailed in Table 3 were also calculated.

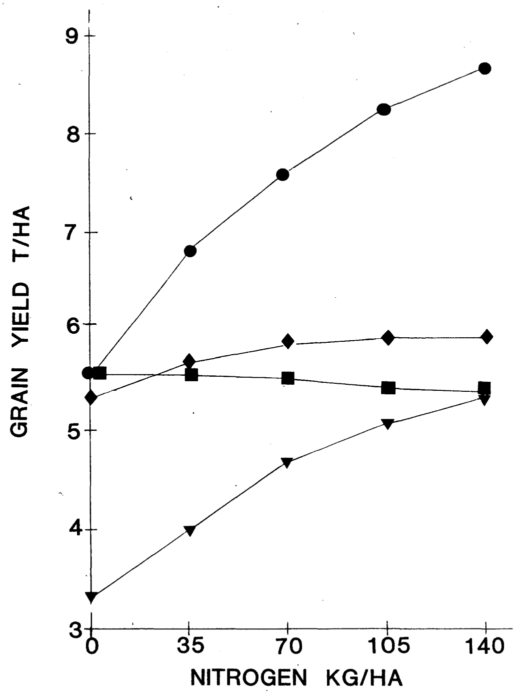

Figure 1: Mean response curves for grain yield response classes.
Class 1. ●—● Class 2. ▼—▼
Class 3. ◆—◆ Class 4. ■—■

TABLE 3: Grain yield response classes and site parameters.

Response Class	Site	'Control' grain yield t/ha	Overall mean response t/ha	September/January rainfall mm	'Plant available' nitrogen ppm	Soil depth cm
1	1	5.16	2.32***	489	123.5	90
	13	5.97	2.19***	501	89.9	70
2	11	4.07	1.74**	363	62.4	45
	9	2.81	1.59***	249	62.4	125
	4	3.76	1.33***	317	86.3	45
	6	2.61	1.12**	219	64.8	45
3	12	5.36	0.76**	313	72.7	50
	10	4.66	0.44**	285	110.4	45
	2	5.95	0.26*	238	59.9	120
4	7	6.26	0.03ns	233	117.8	90
	5	5.14	0.03ns	257	157.3	100
	3	5.46	-0.25*	276	157.6	40
	8	5.71	-0.67**	227	70.1	45

RESULTS

All experimental crops established well and made satisfactory growth. The experimental crops were not visibly affected by diseases and/or pests apart from slight infections of "Take-all", caused by *Geaumannomyces graminis* var *tritici* Walker at sites 1, 2, 4 and 9. Severe drought conditions were experienced from early summer in the 1981/82 cropping year.

In this series of 13 field experiments, grain yield responses to applied nitrogen varied among cropping years and sites. Fertiliser nitrogen induced significantly higher grain yields at nine sites, had non-significant effects at two sites and significantly depressed grain yields at another two sites. Data for individual sites are summarised in Table 2.

There were distinct patterns in grain yield responses to fertiliser nitrogen among sites. To facilitate the overall analysis of nitrogen fertiliser treatment effects, grain yield data for individual sites were assigned to four response classes. Class 1 included data from sites where overall mean responses exceeded 2.0 t/ha, Class 2 where responses were between 1.0 and 2.0 t/ha, Class 3 where responses were between 0.1 and 1.0 t/ha and Class 4 where responses were less than 0.1 t/ha. Sites assigned to each response class are detailed in Table 3 and overall mean grain yield response curves for each class are shown in Fig. 1.

The analysis of variance of data combined in Class 1 (with 'control' yields omitted) showed grain yield response was linear ($P = 0.001$), with no significant quadratic curvature. For Class 2, both linear and quadratic

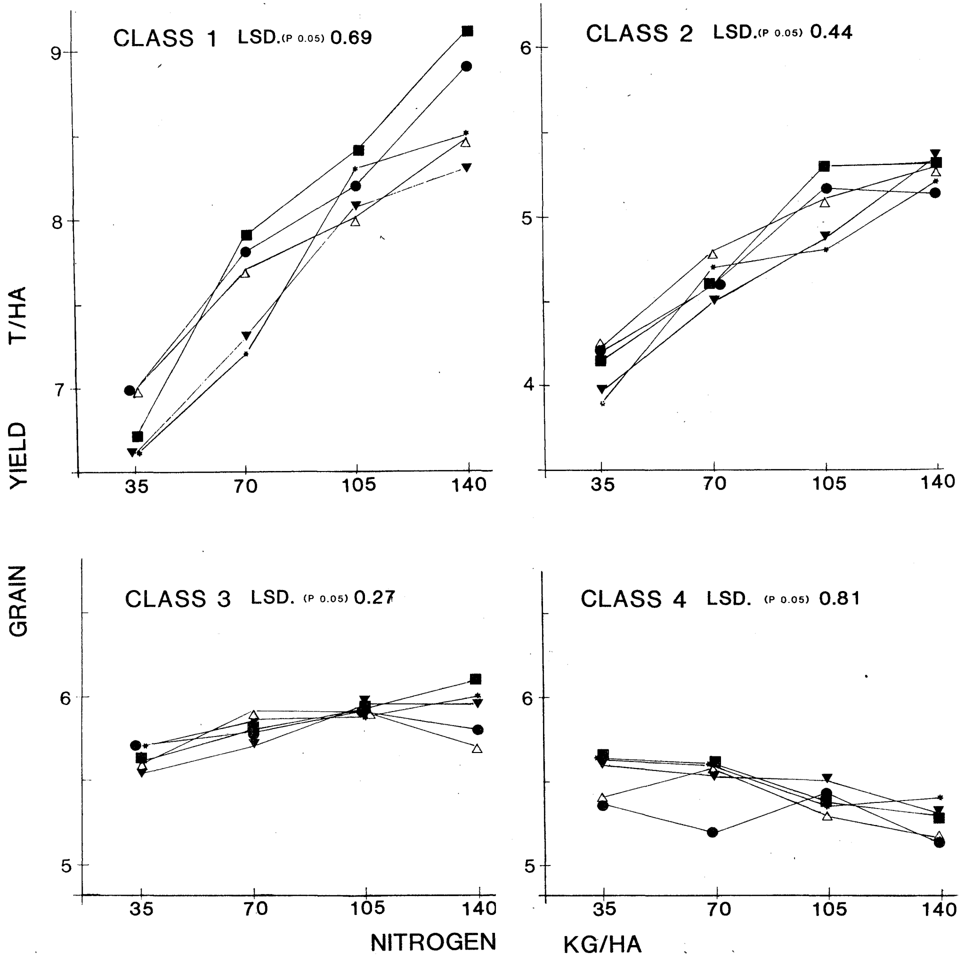

Figure 2: Response curves for individual nitrogen fertiliser pelleted urea ✱—✱, urea solution ▼—▼, ammonium sulphate ■—■, lime/ammonium nitrate ●—● and potassium nitrate △—△ in grain yield response Classes 1, 2, 3 and 4.

components of the response curve were significant, P = 0.001 and P = 0.05 respectively; indicating that grain yield response per additional increment of applied nitrogen declined. The linear component of the Class 3 response curve was not significant but the significant (P = 0.05) quadratic component indicated maximum response to fertiliser nitrogen was achieved at a low rate of application. For Class 4, the linear component was negative and marginally significant (P = 0.1).

Grain yield response curves for individual nitrogen fertilisers in each response class are shown in Fig. 2. In Class 1, mean grain yields for pelleted urea and the urea solution were significantly lower than for ammonium sulphate (P = 0.05). In Classes 2,3 and 4, differences among nitrogen fertilisers were not significant.

There were no significant nitrogen fertiliser × nitrogen rate interactions in the combined analyses apart from a significant difference (P = 0.05) between cubic components of the response curves for ammonium sulphate and pelleted urea in Class 2.

Attempts were made to identify causes of variation among yield responses to fertiliser nitrogen by regressing overall mean grain yield responses on numbers of preceding arable crops, soil concentrations of 'plant available' nitrogen and rainfall for individual months and longer periods throughout the growing season (June to February).

Of the simple linear regressions calculated, overall mean grain yield response did not correlate significantly with either numbers of preceding arable crops or soil concentrations of 'plant-available' nitrogen or rainfall for any single month. Overall mean grain yield response correlated well with either spring rainfall or summer rainfall but correlated best with total rainfall for the spring-summer period, September to January.

It was concluded that the data was best summarised separately for shallow and deep soils by bivariate regressions of overall mean grain yield response to fertiliser nitrogen on total September to January rainfall and soil concentrations of 'plant-available' nitrogen.

For shallow soils:

Grain yield response t/ha = -1.22 + 0.0100 rainfall
(s.e. = 0.0050)
-0.0112 'plant available' nitrogen
(s.e. = 0.0081)

Residual standard deviation = 0.69

For deep soils:

Grain yield response t/ha = -0.74 + 0.0077 rainfall
(s.e. = 0.0015)
-0.0077 'plant available' nitrogen
(s.e. = 0.0051)

Residual standard deviation = 0.43

The predictive equations accounted for 37% of total variation in grain yield response to fertiliser nitrogen in the case of shallow soils and 84% of the variation for deep soils.

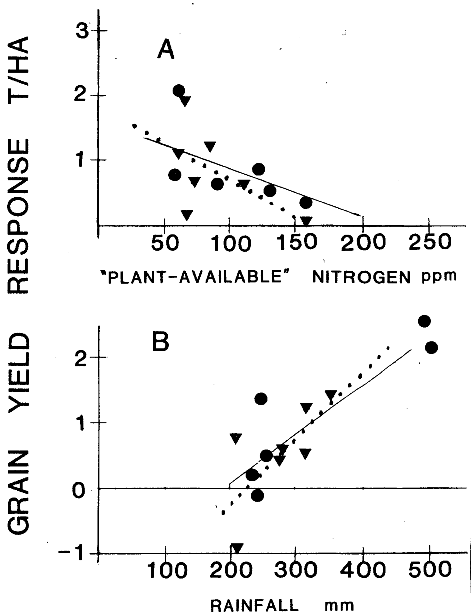

Figure 3: A. Relationship between grain yield response to nitrogen fertiliser adjusted to a mean spring-summer rainfall of 305 mm, and soil concentrations of 'plant-available' nitrogen for shallow soils (●) ...... and deep soils (▼) ______
B. Relationship between grain yield response to nitrogen fertiliser adjusted to a mean soil concentration of 'plant-available' nitrogen of 95 ppm, and spring-summer rainfall for shallow soils (●) ...... and deep soils (▼) ______

The above equations were used to adjust overall mean grain yield response to nitrogen fertiliser for each site to a mean rainfall of 305 mm, and the adjusted values were plotted against 'plant-available' nitrogen concentrations (Fig. 3a). Likewise, the equations were used to adjust overall mean grain yield responses to a mean 'plant-available' nitrogen concentration of 95, and the adjusted values were plotted against rainfall (Fig. 3b).

DISCUSSION

In this assessment of fertilisers used as sources of nitrogen for winter-sown wheat, either ammonium sulphate or potassium nitrate gave the highest mean grain yields at the most responsive sites. Other nitrogen fertilisers gave lower mean grain yields but, apart from the urea solution, these generally did not differ substantially from the best.

Studies of movements and transformations of nitrogen fertilisers in soils, losses of nitrogen from soils and the physiological performance of nitrate and ammonium ions within the plant point to potential for substantial differences among the efficacies of nitrogen fertilisers. The generally similar grain yield responses induced in winter-sown wheat by the nitrogen fertilisers included in this study suggest either that nitrogen losses were small and/or equal or that other compensatory inefficiencies occurred.

Crop response to some nitrogen fertilisers has been shown to be affected by resultant crop injury and/or losses of ammonia from the soil and that these can be affected by the application technique employed (Widdowson and Penny, 1963; Feyter and Cossens, 1977). In this series of field experiments, crop injury was minimised by applying the nitrogen fertilisers to the soil surface after crop establishment. However in the case of the urea solution, this procedure may have favoured hydrolysis of urea in the soil surface and thereby greater losses of ammonia to the atmosphere. This may have contributed to the lower overall efficiency of the urea solution.

Overseas, a mix of nitrate and ammonia nitrogen has been shown to be more effective than either alone (Cox and Rusenauer, 1973) but in this study the lime/ammonium nitrate mix tended to be less effective than either ammonium sulphate or potassium nitrate. A possible explanation for the superiority of ammonium sulphate is that application of this material may have corrected deficiencies of sulphur. This, however, appears unlikely because the basal applications of a reverted superphosphate made to all plots also supplied sulphate. The application of additional sulphate as ammonium sulphate is unlikely to have been beneficial unless the requirement for sulphate by wheat is much greater than has been acknowledged previously.

Grain yield response in non-irrigated winter-sown wheat to nitrogen fertiliser was markedly influenced by the adequacy of spring-summer rainfall. This accounted for much of the differences between response Classes 1 and 2 and response Classes 3 and 4. Where September-January rainfall was less than 300 mm, either limited or negative responses to fertiliser nitrogen generally occurred even though soil concentrations of plant-available nitrogen were apparently inadequate for high grain yield. It was anticipated that grain yield response to fertiliser nitrogen might be influenced by rainfalls over comparatively short periods corresponding to specific phases of reproductive development in the wheat but this did not eventuate. This points to the need for adequate moisture throughout much of the growing season if positive grain yield responses to fertiliser and soil nitrogen are to be obtained.

It is concluded that, apart form the urea solution, any of the nitrogen fertilisers tested would be an effective source of nitrogen for winter-sown wheat in northern Canterbury provided soil moisture can be maintained at adequate levels throughout the spring and summer. Therefore any decision regarding the use of individual nitrogen fertilisers could be based largely on their relative total cost per kg N applied to the wheat crop.

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