RESPONSES OF GRAIN YIELD COMPONENTS OF WINTER-SOWN WHEAT TO NITROGEN FERTILIZER APPLIED AT FOUR GROWTH STAGES

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ABSTRACT

Early winter-sown Rongotea wheat on five sites was treated with urea, ammonium sulphate, lime/ammonium nitrate and potassium nitrate at rates which supplied 75 kg N/ha at crop emergence, early tillering, late tillering or late stem elongation.

Applications of fertilizer nitrogen improved grain yields significantly at four sites. Improved grain yields were associated with higher numbers of heads/m^2, higher numbers of grains/head and lower mean grain weight.

Applications of fertilizer nitrogen made at late stem elongation were less effective than earlier applications. This was associated with both fewer heads/m^2 and grains/head.

The effects of the different forms of fertilizer nitrogen on grain yields and individual components of grain yield did not differ significantly.

***Additional Key Words:** urea, ammonium sulphate, lime/ammonium nitrate, potassium nitrate.*

INTRODUCTION

Grain yield (y), in wheat, is the nett expression of the aggregated contributions of individual components of grain yield, *viz.* the average number of plants per unit area (p), the average number of heads per plant (h), the average number of grains per head (n), and the average weight of individual grains (g) (Engledow, 1925):

$$y = phng$$

Individual components of grain yield respond to the wheat crop's environment including the adequacy of plant nutrients. Analyses of components of grain yield describe the structure of grain yield and have been used to compare wheat cultivars (Frankel, 1935; McEwan, 1964; Langer, 1965) and to study the effects agronomic treatments and their interactions with wheat cultivars (e.g. Drewitt and Rickard, 1973; Scott *et al.*, 1973; Dougherty and Langer, 1974; Dougherty *et al.*, 1975; Feyter and Cossens, 1977; Drewitt, 1982).

However, despite the wide use of grain yield component analyses to describe the effects of agronomic treatments, there has been no local field investigation concerning responses of wheat grain yield components to either various forms of fertilizer nitrogen or the timing of their application. In view of the now greater role of fertilizer nitrogen in the maintenance of satisfactory grain yield in the New Zealand wheat crop (Stephen, 1982) it was considered useful to obtain data concerning responses by individual components of grain yield in wheat to various nitrogen fertilizers and the timing of their application.

MATERIALS AND METHODS

Wheat samples required for the determination of grain yield components were obtained from five of thirteen field experiments included in a programme designed to test the effects of four nitrogen fertilizers and the timing of their application on grain yield of winter-sown Rongotea wheat (Stephen *et al.*, 1984). The field experiments which were numbered 1, 2, 3, 4 and 6 previously, were established on commercial farms in northern Canterbury in the late autumn/early winter period (May/June) of 1980 and 1981 by combine drilling 125 kg/ha fungicide-treated seed of the wheat cultivar Rongotea (McEwan and Vizer, 1979) and 250 kg/ha reverted superphosphate into conventionally cultivated seed-beds in nine-row plots each 1.6 m wide x 24 m long.

The nitrogen fertilizer treatments were applied as the wheat attained previously selected growth stages as described by Feekes' scale (Large, 1954) *viz.* crop emergence (G.S. 1), early tillering (G.S. 2), late tillering (G.S. 5), and late stem elongation (G.S. 9). At these growth stages 75 kg N/ha as pelleted urea (46% N), crystalline ammonium sulphate (21% N), lime/ammonium nitrate (26% N) and potassium nitrate (13% N) were topdressed onto the soil surface.

A split plot design with three replicates was used with the nitrogen fertilizers (4) applied to the main plots and times of fertilizer nitrogen application (4) allocated to sub plots. A single nil nitrogen 'control' treatment plot was included in each replicate.

When it seemed likely that no more wheat seedlings would emerge, six permanent quadrats each 52.5 cm $\times$ 38.1 cm were randomly located, across the three centre drill rows of each plot. At that time, immediately prior to the first application of the nitrogen fertilizers, the number of wheat seedlings within each quadrat were counted. At crop maturity but prior to machine harvest of whole plots, plants within each quadrat were dug up and stored. After drying

TABLE 1: **Grain yields (t/ha) estimated from quadrat yields, at individual experimental sites.**

Site	1	2	3	4	6
'Control' mean	5.36	6.25	6.03	4.60	3.38
'Nitrogen' mean	7.63	7.45	6.52	5.87	4.70
LSD (P = 0.05)	1.26	0.76	0.75	0.71	0.67
Significance	***	**	n.s.	**	***
Nitrogen application times					
Emergence	7.85	7.36	6.50	6.14	5.14
Early tillering	7.64	7.66	6.49	6.53	4.70
Late tillering	8.43	7.52	6.59	5.95	4.85
Late stem elongation	6.61	7.24	6.50	4.87	4.09
LSD (P = 0.05)	0.79	0.47	0.51	0.52	0.46
Contrast:					
"LSE v Earlier"	**	n.s.	n.s.	**	**
Subplot CV (%)	12.2	7.4	9.2	10.5	11.6

and the removal of the roots, each quadrat sample was weighed, the number of heads counted, threshed, and grain yield and yield components measured.

After wheat plants in each quadrat had been removed, plot grain yield data were obtained by harvesting the remainder of the crop on each plot with a small self-cleaning header using techniques described previously (Stephen *et al.*, 1984).

All data obtained from each experimental site were subjected to analysis of variance. In these analyses, data for the first three nitrogen fertilizer applications were meaned and the means contrasted with data for the application at late stem elongation. This contrast is referred to in the tables as the "LSE v Earlier" contrast. Additionally, mean data for each experimental site were combined in overall analyses of variance as described by Saville (1980).

RESULTS

The experimental wheat crops established well and made satisfactory growth though low summer rainfall at site 6 limited grain yield. 'Take-all' infections caused by *Gaeumannomyces graminis* var *tritici* Walker damaged small scattered areas of the experimental crops at sites 1, 2, and 4. Other diseases and/or pests were not detected.

At all five sites differences among the effects of the four forms of fertilizer nitrogen on grain yields and each component of grain yield were small and not statistically significant.

Grain yields based on quadrat data indicated significant responses to fertilizer nitrogen at sites 1, 2, 4 and 6. At three sites (1, 4 and 6) fertilizer nitrogen applied at late stem elongation was significantly less effective than that applied earlier (Table 1).

Plant populations, which were determined only at sites 1, 2, 3 and 4, were not significantly affected by applications of fertilizer nitrogen or by the timing of fertilizer nitrogen applications.

The numbers of heads/m² which were counted at all sites, were increased significantly by application of fertilizer nitrogen at sites 1, 2, 4, and 6. Apart from site 1, applications made at late stem elongation had significantly less effect on numbers of heads (Table 2).

TABLE 2: **Numbers of heads/m² at individual experimental sites.**

Site	1	2	3	4	6
'Control' mean	404	491	465	445	384
'Nitrogen' mean	629	547	475	560	517
LSD (P = 0.05)	87	52	44	72	65
Significance	***	*	n.s.	**	***
Nitrogen application times					
Emergence	627	540	479	589	622
Early tillering	584	565	481	598	546
Late tillering	623	555	471	584	529
Late stem elongation	684	528		469	373
LSD (P = 0.05)	59	34	33	47	45
Contrast:					
"LSE v Earlier"	*	†	n.s.	**	**
Subplot CV (%)	11.2	7.5	8.3	9.9	10.3

Calculations of the mean numbers of grains/head for individual sites indicated application of fertilizer nitrogen had significant positive effects only at sites 4 and 6. However, calculations of mean effects concealed the fact that there were fewer grains/head when fertilizer nitrogen was applied at late stem elongation than at earlier stages of growth (Table 3). This was highly significant at the four responsive sites *viz*. 1, 2, 4 and 6.

At sites 1, 4 and 6, where substantial responses in grain yield were induced by fertilizer nitrogen, the mean weight of individual grains obtained from wheat treated with nitrogen fertilizer was significantly lower than that obtained from untreated wheat (Table 4). However, mean grain weight was higher when fertilizer nitrogen was applied at late stem elongation than at earlier stages of growth and exceeded that of untreated wheat at all sites except site 1.

Analyses of mean data for the timing of fertilizer nitrogen applications obtained from individual sites (Table 5) indicate overall that application of fertilizer nitrogen made at late stem elongation was significantly less effective in improving grain yield than were earlier applications. This effect is reflected in the statistical significances for the "late stem elongation v earlier applications" effects. Although the effect of applying nitrogen at late stem elongation on the number of heads/m² varied among sites, the effects on the number of grains/head and the mean grain weight were sufficiently regular to cause a consistent and significant overall response in grain yield.

Grain yields based on whole plot data (Table 6) were on average 15 percent lower than grain yields based on quadrat data (Table 1) and indicate highly significant responses to fertilizer nitrogen at sites 1, 3, 4 and 6. At sites 1, 4 and 6 fertilizer nitrogen applied at late stem elongation was significantly less effective than that applied at earlier growth stages.

DISCUSSION

In the field experiments described in this paper wheat plant populations were not affected significantly by the nitrogen fertilizer treatments and moreover contributed little to total variation in grain yields. Likewise in other local field experiments, wheat plant populations over a wide middle range have had little effect on grain yield

TABLE 3: Numbers of grains/head at individual experimental sites.

Site	1	2	3	4	6
'Control' mean	25.9	32.0	32.3	22.7	21.7
'Nitrogen' mean	24.9	32.6	33.6	26.2	24.2
LSD (P = 0.05)	1.4	2.4	2.4	2.5	2.0
Significance	n.s.	n.s.	n.s.	**	*
Nitrogen application times					
Emergence	25.9	32.3	33.6	27.4	23.5
Early tillering	26.7	32.7	33.1	28.4	25.0
Late tillering	27.5	34.2	34.6	27.1	25.7
Late stem elongation	19.5	31.0	32.9	22.1	22.6
LSD (P = 0.05)	0.7	1.5	1.8	1.7	1.3
Contrast:					
"LSE v Earlier"	**	**	n.s.	**	**
Subplot CV (%)	3.3	5.6	6.2	7.8	6.4

TABLE 4: Mean grain weights (mg/grain) at individual experimental sites.

Site	1	2	3	4	6
'Control' mean	51.2	39.8	40.0	45.5	41.3
'Nitrogen' mean	49.0	42.0	41.0	40.5	38.7
LSD (P = 0.05)	1.4	2.8	2.4	3.4	2.3
Significance	**	n.s.	n.s.	**	*
Nitrogen application times					
Emergence	48.4	42.3	40.3	38.2	35.3
Early tillering	49.1	41.6	40.9	38.5	34.6
Late tillering	49.2	39.8	40.7	37.8	36.0
Late stem elongation	49.5	44.2	42.0	47.6	48.8
LSD (P = 0.05)	1.0	1.9	1.4	2.3	1.2
Contrast:					
"LSE v Earlier"	n.s.	**	*	**	**
Subplot CV (%)	2.3	5.2	4.3	6.7	3.7

TABLE 5: Overall means of grain yields (based on quadrat data), heads/m², grains/head and mean grain weights for wheat treated with nitrogen at each stage of growth.

	Grain yield (t/ha)	Heads/m²)	Grains/head	Mean grain weight (mg)
Nitrogen Application Times				
Emergence	5.59	572	28.4	40.9
Early tillering	5.62	554	29.2	40.9
Late tillering	5.65	552	29.8	40.7
Late stem elongation	5.16	504	25.6	46.4
Contrast:				
"LSE v Earlier"	.46	54	3.5	−5.6
s.e. ("LSE v Earlier")	.16	46	1.2	2.6
Significance	*	n.s.	*	†

TABLE 6: Grain yields (t/ha) estimated from plot yields, at individual experimental sites.

Site	1	2	3	4	6
'Control' mean	5.50	5.49	5.06	4.03	2.95
'Nitrogen' mean	7.32	5.52	5.62	5.15	3.93
LSD (P = 0.05)	0.62	0.22	0.15	0.30	0.17
Significance	**	n.s.	**	**	**
Nitrogen application times					
Emergence	7.41	5.42	5.72	5.23	4.19
Early tillering	7.36	5.54	5.63	5.44	4.14
Late tillering	7.87	5.54	5.59	5.37	3.89
Late stem elongation	6.64	5.58	5.55	4.56	3.48
LSD (P = 0.05)	0.43	0.14	0.10	0.21	0.21
Contrast:					
"LSE v Earlier"	**	n.s.	*	**	**
Subplot CV %	6.9	3.2	2.2	4.8	3.5

(Drewitt, 1982). In view of the apparent lack of close association of grain yield with wheat plant populations at densities commonly established in commercial crops, it may not be unreasonable to ignore the plant population factor in Engledow's model and to define grain yield in terms of mean numbers of head/m² (e), mean numbers of grains/head (n), and the mean weight of individual grains (g):

$$y = eng$$

Indeed, this has been done previously (Dougherty and Langer, 1974; Scott *et al.*, 1975; Sheath and Galletly, 1980).

In previous local field experiments in which the effects of fertilizer nitrogen on grain yield of wheat have been assessed in terms of responses in grain yield components, improved grain yields induced by application of fertilizer nitrogen were associated generally with increases in the numbers of heads/m², and reductions in both the numbers of grains/head and grain weights (Dougherty *et al.*, 1975; Feyter and Cossens, 1977; Scott *et al.*, 1977; Sheath and Galletly, 1980). In the case of field experiments detailed in this paper, when fertilizer nitrogen was applied at or prior to late tillering improved grain yields were associated with increases in head populations, irregular responses in numbers of grains/head and generally lighter mean grain weights. On the other hand when fertilizer nitrogen was applied at late stem elongation improved grain yields were smaller and generally associated with little change both in the numbers of heads/m² and in grains/head, but an increase in the individual grain weight. An exception to this trend occurred at site 1 where head numbers were substantially increased by fertilizer nitrogen applied at late stem elongation. This effect was probably due to the higher rainfall at that site, allowing later developing tillers to respond to this late application of nitrogen. However, the later formed heads had fewer grains than those produced from earlier nitrogen applications.

The improvement in mean grain weight associated with application of fertilizer nitrogen at late stem elongation might be seen as an advantage. However, this improvement was not sufficient to compensate for losses in grain yields deriving from the lower numbers of heads/m² and grains/head.

In comparison with the earlier nitrogen fertilizer treatments, applications of fertilizer nitrogen at late stem elongation were associated with both fewer heads/m² and fewer grains/head, and therefore fewer grains/m². It is probable that heavier grains developed because the fewer grains/m², sharing a similar pool of environmental inputs, were individually better nourished than was the case where there were more grains/m² as a consequence of earlier applications of fertilizer nitrogen.

The nitrogen response at site 3 calculated from the whole plot data was perhaps an anomaly since a similar response was not obtained in the adjacent experiment reported by Stephen *et al.* (1983), nor in the quadrat data.

The data derived from the field experiments described indicate that the structure of grain yield in Rongotea wheat responds to timing of nitrogen application relative to stage of growth, as generally the number of heads/m² increases and mean grain weight declines when fertilizer nitrogen is applied prior to the cessation of tillering while larger grains are produced by fewer heads when a later application is made. While components of grain yield indicate the physical structure of yield and are a historical record of grain yield development, they fail to explain the physiological processes which contribute to grain yield. Therefore a wholly satisfactory explanation for variation in grain yield is unlikely to be achieved without concurrent consideration of both the physiological processes and the structural components which contribute to grain yield.

ACKNOWLEDGEMENTS

The authors acknowledge the co-operation and assistance of P. McCaw, Methven; J.K. Lochhead, Barrhill; B.R. Gillanders, Darfield; A.R. MacDonald, Annat and Sir Walter Mulholland and Sons, Darfield; who made available experimental sites, D. Baird and Mrs Shirley Nesbit who provided biometrical aid; and B.W. Todd who measured components of grain yield.

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