Relationships between wheat grain yield and plant-available soil N, and monthly rainfall and potential evapotranspiration

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Abstract

Data were obtained from 18 field experiments in Canterbury with autumn-sown and winter-sown wheat, not treated and treated with a single dressing of fertiliser nitrogen (96 kg N ha^{-1}) in late winter at early tillering (GS 22-23). Wheat grain yield in the absence of fertiliser nitrogen (N), and wheat grain yield response to applied fertiliser N, were correlated with 40 soil N variables, 21 monthly rainfall variables, and 21 monthly potential evapotranspiration (ET) variables. Grain yield harvested from wheat not treated with fertiliser N correlated poorly ($P<0.10$) with six soil N variables, two monthly rainfall variables and four monthly potential ET variables. Wheat grain yield response to applied fertiliser N correlated significantly ($P<0.10$, $P<0.05$ and $P<0.01$) with 20 soil N variables, two monthly rainfall variables and 12 monthly potential ET variables. The soil tests proposed by Ludecke (1974) and Quin *et al.* (1982) for use in wheat cultivation, were inferior to a new test based on the measurement of initial nitrate N (NO_3-N) and the incubation-induced increase in nitrate N in soil sampled to a depth of 45cm.

Additional key words: *soil test, grain yield response, nitrate N (NO_3-N), ammonium N (NH_4-N), mineral N (NO_3-N + NH_4-N), correlation coefficient*

Introduction

It is generally acknowledged that wheat grain yield response to applied fertiliser N is inversely proportional to the concentration of "plant-available" N in arable soil, and consequently that efficient use of nitrogen fertiliser requires reliable information concerning the quantity and quality of mineral N in the seedbed. However, there is less agreement regarding either the best method for determining "plant-available" N concentrations in arable soils or the interpretation of the soil test data (Robinson, 1975; Goh, 1983). This confusion is demonstrated locally in that two alternative soil testing procedures (Ludecke, 1974; Quin *et al.*, 1982) have been proposed for the determination of soil "plant-available" N in arable soils and as a basis for recommendations regarding nitrogen fertiliser for wheat. One test (Ludecke, 1974) is based on the initial soil nitrate N (NO_3-N) concentration to a depth of 60 cm, while the other (Quin *et al.*, 1982) is based on a combination of initial and incubated soil mineral N (NO_3-N + NH_4-N) concentrations to a depth of 15 cm. In view of the marked differences between these procedures, it was decided to compare their efficiencies by examining relationships between wheat grain yield and various measures of soil concentrations of mineral N, as well as other variables which influence grain yield in wheat, namely rainfall and evapotranspiration (ET).

Materials and Methods

Data were obtained from 19 field experiments with wheat sited in central districts of Canterbury. Six field experiments were carried out in each of the 1981/82 and 1983/84 cropping seasons, and seven field experiments were carried out in the 1982/83 cropping season.

At each experimental site, "Rongotea" wheat (McEwan and Vizer, 1979) was combine drilled with 250 kg ha^{-1} superphosphate (N:P:K:S, 0:9:0:11) into a cultivated seedbed either in the late autumn (mid May) or in mid winter (late June/early July). In late winter (August), after the wheat crops had become well established but before wheat growth accelerated with the onset of milder spring weather, soil samples were taken from the seedbed horizons 0-15cm, 15-30cm, 30-45cm and 45-60cm from plots not previously treated with nitrogen fertiliser. Subsequently at early tillering (G.S. 22-23; Zadoks *et al.*, 1974), selected plots were topdressed with a single application of N fertiliser, either urea (N:P:K:S, 46:0:0:0) or ammonium sulphate (N:P:K:S, 21:0:0:24), at an average rate of 96 kg N ha^{-1}. The experimental wheat crops were treated with applications of herbicide, insecticide and fungicide as considered necessary. In late summer (late January/early February), the experimental wheat crops were harvested for grain yield and other data using quadrats taken from the two middle rows of each plot. For 12 sites, 6 quadrats, each 0.333 x 0.30 m^{-2}, were taken, while for the other 7 sites, 2 quadrats, each 2.0 x 0.3 m^{-2}, were harvested. The resulting sheaves were barn dried and subsequently dissected into wheat plant components and grain.

Following their removal from the experimental sites, the soil samples were held in a cool store at 2-4°C for a day or two prior to analysis by the methods described by Quin *et al.* (1982) for both nitrate N (NO_3-N) and ammonium N (NH_4-N), both before and after aerobic incubation at 37°C for seven days. In that way, pre-incubation or initial concentrations, and post-incubation or final concentrations of both nitrate N (NO_3-N) and ammonium N (NH_4-N) were obtained.

Monthly rainfall data for the period August to January of each cropping season were obtained from New Zealand Meteorological Service rainfall observation stations closest to the experimental sites. Monthly irrigation data, supplied by co-operating farmers, were added to the rainfall data for irrigated crops.

Calculated monthly potential ET (Coulter, 1973) for each cropping season for stations at the Christchurch International Airport, Harewood, and at Winchmore Research Station, Ashburton were supplied by staff of the National Institute of Water and Atmospheric Research.

Grain yield produced by wheat not treated with nitrogen fertiliser, and wheat grain yield response to applied fertiliser N (averaged over the rates of N used in each experiment), were both correlated with the explanatory variables described below. For soil N status, the (40) variables were five measures of both nitrate N (NO_3-N) and mineral N (NO_3-N + NH_4-N) to four depths, 15, 30, 45 and 60 cm. The five measures were those given in Table 4 of Quin *et al.* (1982), namely the initial concentration of N (IN), the incubation-induced increase in N concentration (ΔN), the final concentration (IN+ΔN), and the initial plus either two or three times the increase (IN+2ΔN and IN+3ΔN). For rainfall, the (21) variables tried were the total rainfall during each of the months of August to January inclusive and the total rainfall in each sensible combination of 2, 3, 4, 5 or 6 consecutive months. For potential ET, the same (21) corresponding variables were tried.

Results

In general, the experimental wheat crops established successfully and subsequently most made satisfactory growth. However, in the first cropping season at one experimental site, grain yield response to applied fertiliser N was exceptionally high in comparison with the responses in the other experiments. This anomaly may have been due to the infestation of Takeall (*Gaeumannomyces graminis* var. tritici) throughout the crop. It was therefore decided to omit the corresponding data from the analyses reported in this paper.

For each experimental site, monthly rainfall exceeded monthly potential ET from late autumn (May) to early spring (September), while the reverse occurred from late spring (October) to mid summer (January).

Grain yield from wheat not treated with nitrogen fertiliser, and wheat grain yield responses to applied fertiliser N, differed widely among experimental sites. Grain yield from wheat crops not treated with nitrogen fertiliser ranged from 3.0 to 9.3 t ha^{-1}, with an average of 5.8 t ha^{-1}. Applied fertiliser N (averaging 96 kg N ha^{-1}) induced improvements in wheat grain yield ranging from 0.2 to 3.4 t ha^{-1}, with an average of 1.6 t ha^{-1}. At all but one site, responses were highly significant ($P<0.01$).

Grain yield harvested from wheat not treated with nitrogen fertiliser correlated positively, but weakly ($P<0.10$) with only 6 of the 40 soil N variables. These were initial nitrate N (NO_3-N) concentration in soil to depths of 0-30, 0-45 cm and 0-60 cm, and initial mineral N (NO_3-N + NH_4-N) concentration plus one, two and three times the incubation-induced increase in mineral N in soil to the depth of 0-30 cm (Table 1).

Wheat grain yield response to applied fertiliser N correlated negatively and significantly with 20 out of 40 soil N variables. The significant negative correlations involved both nitrate N (NO_3-N) and mineral N (NO_3-N + NH_4-N) concentrations, with and without their incubation-induced increases in soil to the depths of 30cm, 45cm and 60 cm (Table 2). All soil N variables for soil sampled to 15 cm failed to correlate significantly with wheat grain yield response to applied fertiliser N.

Grain yield, produced by wheat not treated with nitrogen fertiliser, correlated weakly ($P<0.10$) though positively with only 2 of the 21 rainfall variables (Table 3).

Wheat grain yield response to applied fertiliser N correlated positively, though weakly ($P<0.10$) with 2 out of the 21 monthly rainfall variables (Table 4).

Grain yield produced by wheat not treated with nitrogen fertiliser correlated negatively, and weakly ($P<0.10$ and $P<0.05$) with 4 out of the 21 potential ET variables (Table 5).

Wheat grain yield response to applied fertiliser N correlated significantly though weakly ($P<0.10$ and $P<0.05$) with 12 out of the 21 potential ET variables (Table 6). These correlations were negative in 11 out of 12 cases.

Table 1. Statistically significant correlations between grain yield produced by wheat not treated with fertiliser N, and soil N variables. In this and subsequent tables, only correlations of P<0.10 are reported, where † = P<0.10, * = P<0.05, ** = P<0.01.

Soil N variable	Soil depth (cm)	Correlation coefficient
Initial nitrate N	0-30	0.415 (†)
	0-45	0.434 (†)
	0-60	0.443 (†)
Initial mineral N + incubation increase	0-30	0.416 (†)
Initial mineral N + 2 x incubation increase	0-30	0.421 (†)
Initial mineral N + 3 x incubation increase	0-30	0.418 (†)

Discussion

Chemical analyses of soil, or soil tests, are carried out to identify and quantify soil deficiencies of nutrient elements essential for arable crop growth. The analytical data are used as bases for recommendations regarding fertiliser use, for predictions of crop response to applied fertiliser, and for estimation of the profitability of fertiliser use.

The soil N test proposed by Ludecke (1974) is based on the measurement of initial nitrate N (NO_3-N) concentration in soil sampled to 60 cm and does not involve either determination of ammonium N (NH_4-N) or incubation of soil. The soil N test sponsored by Quin *et al.* (1982) is based on initial mineral N (NO_3-N + NH_4-N) concentration plus twice the incubation-induced increase in mineral N in soil sampled only to 15 cm. The essential differences between the two soil tests are the depths to which soil is sampled (60 cm vs. 15 cm), the forms of soil N measured (NO_3-N vs. NO_3-N + NH_4-N), the use or otherwise of a soil incubation procedure, and either the exclusion or addition of post-incubation soil N data in soil test values.

Most of the assessed soil N variables failed to correlate significantly with grain yield produced by

Table 2. Statistically significant correlations between wheat grain yield response to applied fertiliser N, and soil N variables.

Soil N variable	Soil depth (cm)	Correlation coefficient
Initial nitrate N	0-30	-0.424 (†)
	0-45	-0.573 (*)
	0-60	-0.480 (*)
Initial nitrate N + incubation increase	0-30	-0.416 (†)
	0-45	-0.667 (**)
	0-60	-0.552 (*)
Initial nitrate N + 2 x incubation increase	0-45	-0.651 (**)
	0-60	-0.522 (*)
Initial nitrate N + 3 x incubation increase	0-45	-0.615 (**)
	0-60	-0.478 (*)
Initial mineral N	0-45	-0.533 (*)
	0-60	-0.434 (†)
Initial mineral N + incubation increase	0-30	-0.414 (†)
	0-45	-0.603 (*)
	0-60	-0.457 (†)
Initial mineral N + 2 x incubation increase	0-30	-0.403 (†)
	0-45	-0.611 (*)
	0-60	-0.444 (†)
Initial mineral N + 3 x incubation increase	0-45	-0.603 (*)
Incubation increase in mineral N	0-60	-0.491 (*)

Table 3. Statistically significant correlations between grain yield produced by wheat not treated with fertiliser N, and monthly rainfall variables.

Monthly rainfall variable	Correlation coefficient
Sept + Oct	0.453 (†)
Sept + Oct + Nov + Dec	0.406 (†)

Table 4. Statistically significant correlations between wheat grain yield response to applied fertiliser N, and monthly rainfall variables.

Monthly rainfall variable	Correlation coefficient
Aug + Sept	0.404 (†)
Aug + Sept + Oct	0.446 (†)

Table 5. Statistically significant correlations between grain yield produced by wheat not treated with fertiliser N, and monthly potential ET variables.

Monthly potential ET variable	Correlation coefficient
September	-0.481 (*)
January	-0.457 (†)
September + October	-0.560 (*)
December + January	-0.448 (†)

Table 6. Statistically significant correlations between wheat grain yield response to applied fertiliser N, and monthly potential ET variables.

Monthly potential ET variable	Correlation coefficient
August	-0.431 (†)
September	0.472 (*)
November	-0.480 (*)
Oct + Nov	-0.484 (*)
Nov + Dec	-0.449 (†)
Aug + Sept + Oct	-0.443 (†)
Sept + Oct + Nov	-0.451 (†)
Oct + Nov + Dec	-0.449 (†)
Nov + Dec + Jan	-0.401 (†)
Aug + Sept + Oct + Nov	-0.456 (†)
Sept + Oct + Nov + Dec	-0.404 (†)
Aug + Sept + Oct + Nov + Dec	-0.419 (†)

wheat not treated with fertiliser N (Table 1). It may be concluded from this result that soil N variables are poor identifiers of N-deficient sites and are therefore of little value as soil tests. However, because wheat grain yield is the product of the effects of the many factors which make up the wheat crop environment, it is unlikely that grain yield in wheat not treated with fertiliser N will ever correlate significantly with any soil N variable so long as other environmental factors are not standardised but allowed to vary independently. The failure by soil N to predict grain yield in wheat not treated with fertiliser N may also be in part a consequence of locating the experimental crops on sites believed to be nitrogen deficient.

Apart from soil N variables derived from soil sampled to 15 cm, many (20) soil N variables, especially those derived from soil sampled to 45 cm, correlated negatively and moderately strongly ($P<0.05$) with wheat grain yield response to applied fertiliser N (Table 2). These significant correlations indicate that soil samples need to include much of the rooting horizon of the crop (0-45 cm), that the inclusion of ammonium N (NH_4-N) concentrations as proposed by Quin *et al.* (1982) may not be advantageous, and that the addition of incubation-induced increases in nitrate N (NO_3-N) may be helpful. These results suggest that neither the soil test proposed by Ludecke (1974) nor that sponsored by Quin *et al.* (1982) is wholly satisfactory. It is suggested that a more promising test is the Ludecke (1974) test modified by the incorporation of post-incubation measurement of soil nitrate N (NO_3-N) in soil sampled to 45 cm (Fig. 1).

The suggestion that another soil test be introduced as an aid to fertiliser N use in wheat cultivation, may be seen as an addition to existing confusion. However, the suggestion that another soil test be used is based on more extensive comparisons of combinations of more factors, viz. forms of soil N, soil incubation and soil sampling depths, than were done by the earlier writers.

It should be noted that the field experiments from which the data were obtained, were not designed specifically for the evaluation of soil tests. Before detailing possible problems, however, we point out that this handicap also applies to the studies reported by Ludecke (1974) and Quin *et al.* (1982).

As noted above, most field experiments were sited in nitrogen deficient fields. Therefore, the range of plant-available soil N concentrations was not as wide as would have been desirable, thus reducing the chance of obtaining a significant correlation between wheat grain yield and soil N variables. A second aspect is that experiments were carried out on 18 different farms in three seasons by two different experimenters (the first and third authors). This is both a strength and a weakness. The strength is that results are applicable to a wider range of situations than if the experimental sites had been more closely standardised. The disadvantage

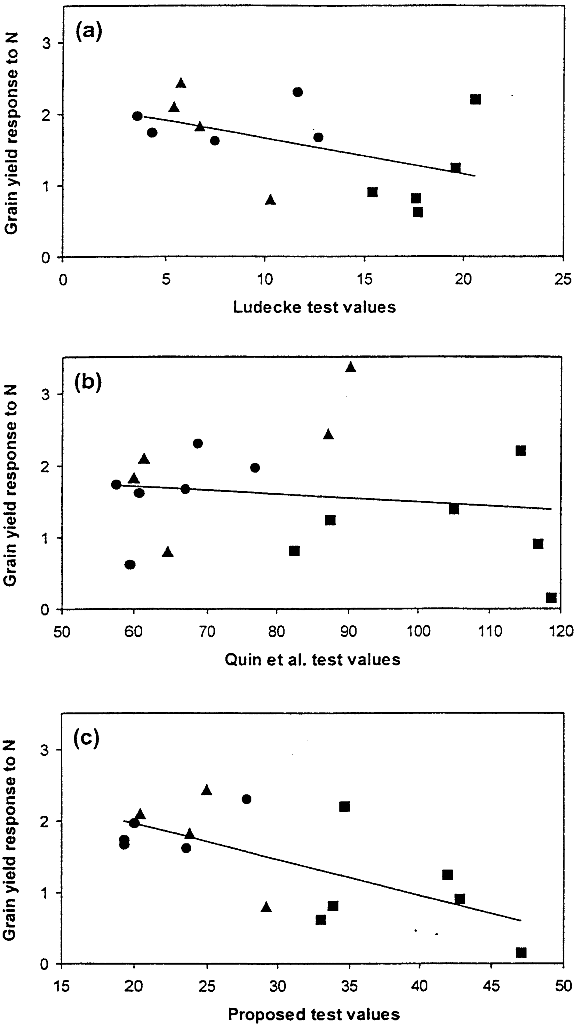

Figure 1. Wheat grain yield response to applied N fertiliser against (a) initial nitrate N concentration for soil to a depth of 60 cm (as in Ludecke, 1974), (b) initial mineral N concentration plus twice its incubation-induced increase for soil to a depth of 15 cm (as in Quin *et al.*, 1982), and (c) initial nitrate N plus its incubation-induced increase for soil to a depth of 45 cm. Years are ● = 1981/82; ■ = 1982/83; ▲ = 1983/84. Fitted regression lines are also shown.

is that the variation between experimental sites, seasons and experimenters may have added extra variation to the data, thereby weakening correlations.

In their study of the relationship between soil mineral N and maize grain yield response to applied N, Steele *et al.* (1982) dried soil samples at 33°C for 18 hours in a forced air oven prior to soil analyses. Such a procedure, which is more convenient than aerobic incubation of soil, should be evaluated locally.

In spite of the common belief that wheat grain yield is affected by rainfall, few monthly rainfall variables correlated positively and significantly with either grain yield produced by wheat not treated with fertiliser N or wheat grain yield response to applied fertiliser N (Tables 3 and 4). The paucity of significant and strong coefficients of correlation between monthly rainfall variables and wheat grain yield may be the result of the occurrence of potential evapotranspiration which substantially exceeded rainfall in the late spring and summer months. This is borne out by the greater numbers of, albeit weak, significant correlations between wheat grain yield and monthly potential ET variables (Table 5 and 6).

Because potential ET is the result of a calculation involving several variables such as nett radiation, ground heat flux and wind run, it could be useful to correlate wheat grain yield data with the individual contributing variables. This has not been attempted in this study.

There were more significant correlations involving wheat grain yield response to nitrogen fertiliser than grain yield of untreated wheat (20 out of 40 vs. 6 out of 40). This can be explained by the fact that each response to nitrogen fertiliser was calculated as a difference between treatment means within each trial. This had the effect of removing site differences.

The high incidence of significant correlations between grain yield response to fertiliser N and potential ET variables suggests that recommendations regarding nitrogen fertiliser use need to take into account the effects of anticipated potential ET and associated climatic phenomena.

In their study of the relationship between wheat grain yield response to applied fertiliser N and rainfall in South Otago and Southland, Feyter, Cossens and Risk (1977) concluded the leaching of plant-available N by winter rains to be important. Locally, for Canterbury, the negative correlations between wheat grain yield responses and some monthly potential ET variables are presumed to be due to the net effects of rainfall and high ET on the adequacy of soil moisture reserves in the period of maximum grain growth.

Conclusions

The experimental results presented in this paper suggest that a soil test based on nitrate N (NO_3-N) concentrations in non-incubated and incubated soil sampled to 45 cm would assist more effectively the making of decisions regarding the use of nitrogen fertiliser in wheat cultivation than the soil tests proposed by Ludecke (1974) and Quin *et al.* (1982).

The poor correlations of wheat grain yield with monthly rainfall variables and monthly potential ET variables suggest that their relationships with wheat grain yield require more intensive study.

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