EFFICIENT UTILISATION OF SOIL AND FERTILISER N TO OPTIMISE MAIZE GRAIN YIELD

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ABSTRACT

Until recently, recommendations for N fertiliser for maize grain crops in New Zealand were based on time out of pasture and were imprecise in many cases. Research on soil and plant analysis during the late 1970's resulted, however, in a major improvement in the precision with which N fertiliser requirements could be estimated.

Three methods were proposed based on (i) the concentration of nitrate in the sap of young maize plants; (ii) mineral N in soil samples collected prior to sowing and dried under controlled conditions and (iii) total N in ear-leaves at silking or in grain at harvest. The advantages and disadvantages of these methods are discussed.

The economic amount of N to apply is quite distinct from the amount required to achieve maximum yield. At 1982-83 prices, maximum nett income occurred when N was applied to achieve 94 percent of maximum grain yield. During the 1982-83 season an estimated 2400 tonnes of N were applied to 22,000 hectares of maize. Plant analyses indicate that many crops receive too much N. Growers must therefore rationalise their fertiliser N use to optimise crop yield for maximum nett income.

***Additional Keywords:** Zea mays; estimating nitrogen fertiliser requirements; economics of fertiliser use; sap tests, soil tests, grain nitrogen, herbage nitrogen, critical levels.*

INTRODUCTION

The area under maize in New Zealand increased from 3000 ha in 1965-66 to a peak of 29,000 ha in 1976-77. The area has declined since 1976, 22,000 ha being planted in 1982. A shift in production from the traditional Poverty Bay area into the Auckland, Bay of Plenty, Hawkes Bay, Manawatu, Taranaki and Waikato districts necessitated information on nitrogen fertiliser requirements for a wider variety of soils under more diverse climatic regimes.

When it is necessary to supplement naturally available soil N for maize grain production, nitrogen fertiliser may be broadcast before sowing (pre-plant), applied as a band below the soil surface at the time of planting (starter), applied as an inter-row band below the soil surface after germination (side-dressing) or as some combination of these methods. Pre-plant N is not widely practised in New Zealand. Crop response to starter and side-dressed N is generally similar (Douglas *et al.*, 1972) and the decision when to apply N is therefore dependent on how the application best fits into the overall crop management programme.

Where N fertiliser is applied, an estimate of the amount of N to achieve either maximum grain yield or maximum financial return to the grower is desirable. Grain yields are restricted when insufficient N is applied but excessive applications depress grain yield causing an unnecessary cost to the grower. Leaching and denitrification may also be promoted with associated environmental problems. Any procedure used as a basis for N application should therefore go further than simply identifying responsive sites and estimate as accurately as possible the crop requirements.

There is no universally accepted method for estimating fertiliser N requirements for maize grain production. This is largely because the mineralisation of soil organic N is complex and dynamic.

This paper reviews New Zealand literature on estimating N fertiliser requirements for maize grain production, provides guidelines to assist growers in estimating how much fertiliser N to apply and examines the current use of fertiliser N in the maize grain industry.

PRINCIPLES OF ESTIMATING FERTILISER N REQUIREMENTS

The information required to estimate the amount of fertiliser N for a maize crop (N_F) includes:

(i) The total N requirement of the crop (N_C);
(ii) The amount of soil mineral N that will be taken up by the crop (N_S); and
(iii) The proportion of any added fertiliser N that will be taken up by the crop (E_F).

N_F can then be estimated from (Stanford 1973).

$$N_F = \frac{N_C - N_S}{E_F}$$

N_F may be optimised for either maximum crop yield or financial return depending on the objectives of the grower. Estimation of N_F may be based on individual estimates of N_C, N_S and E_F or on empirical relationships between crop yield and some measured parameter related to fertiliser N application.

N REQUIREMENTS OF MAIZE CROPS

The N requirement of maize is dependent on attainable yield and therefore on climate, characteristics of the soil and crop management (Steele, 1982). Under conditions of adequate N, uptake continues from emergence to maturity but the rate peaks during the period of intensive vegetative growth prior to tasselling when it may exceed 4 kg N/ha/day (Thom and Watkin, 1978). Over 50 percent of the total plant N is in the grain at harvest (Table 1).

TABLE 1: Percentage distribution of nitrogen in plant parts of maize (cultivar PX610) at harvest (after Thom and Watkin, 1978).

Plant part	% of total plant N
Roots	6
Stem	14
Leaf	14
Husk	4
Cob	5
Grain	57

In a survey of the N concentration of ear-leaves at silking in 1133 crops, Cornforth and Steele (1981) found that yields of greater than 13 t grain/ha occurred with concentrations of N in dry matter ranging from 2.25 to 3.30 percent. Subsequently Steele *et al.* (1982b) predicted that maximum grain yield occurred with a N concentration of 3.21 percent in the ear-leaf at silking and 1.52 percent in the grain. Therefore about 15 kg of N are removed per tonne of grain under conditions of maximum yield.

TABLE 2: Average maize grain yield by district*. (t/ha)

	1975/76	1976/77	1977/78	1978/79	1979/80
North Auckland	5.2	5.4	6.1	5.5	5.6
Auckland Central	6.1	6.8	6.0	6.5	7.8
South Auckland/ Bay of Plenty	7.3	7.8	7.1	8.2	8.0
Poverty Bay	7.2	7.2	7.4	8.3	9.8
Hawkes Bay	7.0	6.7	7.2	8.4	7.8
Taranaki	4.8	5.7	6.5	7.6	6.6
Manawatu	5.8	6.9	6.5	7.3	6.1

*New Zealand Department of Statistics.

The dependence of attainable yield on soil and climate results in large variations in grain yields between districts (Table 2) and therefore N requirements for crops also vary. The present potential yields are indicated by the highest grain yield achieved in each district by entrants in the Ammo-Phos National Maize Yield Competition over the last five years (Table 3). Yields in the Bay of Plenty, Hawkes Bay and Poverty Bay are generally higher than those in Rangitikei-Manawatu and Waikato. Nitrogen fertiliser requirements may therefore be expected to be lower in the Waikato than in the Bay of Plenty, Poverty Bay or Hawkes Bay districts. This is supported by the lower proportion of trials in the Waikato (45 percent) compared with the Bay of Plenty and Poverty Bay (85 percent) which have been reported to show a significant response to N fertiliser in grain yield (Steele *et al.,* 1982a). The lower incidence of response in the Waikato was attributed to higher levels of mineral N present at planting in the Waikato soils and the lower attainable yields.

TABLE 3: Highest maize grain yield (t/ha) recorded in six districts by entrants in the Ammo-Phos National Maize Yield Competition between 1978 and 1982.

	1978	1979	1980	1981	1982	Mean
Bay of Plenty	15.1	15.4	17.8	14.3	14.7	15.5
Hawkes Bay	15.5	15.3	14.6	14.8	14.0	14.8
Poverty Bay	16.0	15.2	15.8	15.7	17.4	16.0
Rangitikei-Manawatu	14.4	13.1	13.3	13.3	14.4	13.6
Waikato	13.6	13.9	13.9	13.9	14.6	14.0
Wairarapa	10.6	11.0	*	*	*	10.8

*not reported

EFFECT OF CONTINUOUS CROPPING ON SOIL AVAILABLE N

A change from permanent pasture to continuous cropping normally results in an initial sharp fall in organic matter followed by a more gradual decline (Gradwell and Arlidge, 1971). Under continuous maize cropping in the Waikato, a 40 percent decrease in total C was measured at 0 to 5 cm depth of Horotiu silt loam relative to pasture after 9 years and a 53 percent decrease in Puniu silty clay loam after 6 years. At 6-16 cm the fall was only 15 percent in both soils (Cotching *et al.,* 1979). The decline was accredited to increased oxidation or organic matter as a result of cultivation and a reduction in the return of plant residues relative to a pasture.

A decline in organic matter is consistent with observations that, in general, N fertiliser requirements of maize increase with the number of years of continuous cropping (Cumberland and Douglas, 1970; Douglas *et al.,* 1972). However, response to fertiliser N is extremely variable, even within soil types. It has been reported that, whereas some first year maize crops after pasture respond to N fertiliser, on some soils crops can be grown for at least 12 years without showing any response to fertiliser N (Steele and Cooper, 1980). This leads to the conclusion that "The N status of a field is characteristic of that particular field and fertiliser recommendations cannot be extrapolated to other fields even within the same soil type and farm" (Steele *et al.,* 1982a).

When maize is sown in October or early November following a previous crop, much of the available N in the soil is some distance below the soil surface and not immediately available to seedlings (Steele and Cooper, 1980). Because of this, maize is normally sown with a starter fertiliser containing a minimum of 20 kg N/ha which is about the amount of N required by the crop until it is able to utilise the mineral N present at depth or until side-dressed N is applied.

METHODS FOR ESTIMATING FERTILISER N REQUIREMENTS

Until recently, recommendations for N fertiliser for maize in New Zealand were generally based on the number of years a paddock had been cropped and the previous experience of growers. General recommendations were that maize could be grown on paddocks cultivated from high producing pastures without applying fertiliser N. Second crops would normally benefit from 55 kg N/ha as starter and additional side-dressed N was not required until the third or fourth crop (Cumberland and Douglas, 1970; Douglas *et al.,* 1972). Subsequent research showed this method to be unsatisfactory because of the variability of crop response to fertiliser N on similar soils (Steele and Cooper, 1980).

Since 1980, three alternative methods have been suggested for estimating fertiliser N requirements and each represents a considerable improvement in optimising N fertiliser applications.

(i) **Sap nitrate test** (Cornforth, 1980)

Maize absorbs much of its nitrogen as nitrate, which, once in the plant is reduced to ammonium. If the supply of nitrate from the roots is in excess of current requirements nitrate accumulates. Measurement of the nitrate concentration in parts of a plant can provide a sensitive measure of its current N status.

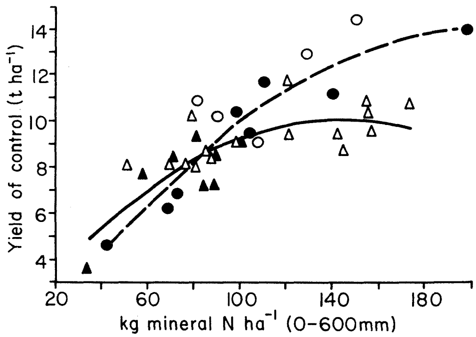

Figure 1: Relationship between maize grain yield and mineral N determined in dried soil (33 °C). Solid points identify N-responsive trials and were accorded a weight of 1 when fitting the curves. Open points identify non-N-responsive trials and were accorded a weight of 0.5. The slashed line (open and closed circles) represents Bay of Plenty/Poverty Bay results and the solid line (open and closed triangles) represent Waikato results. (Steele *et al.,* 1982).

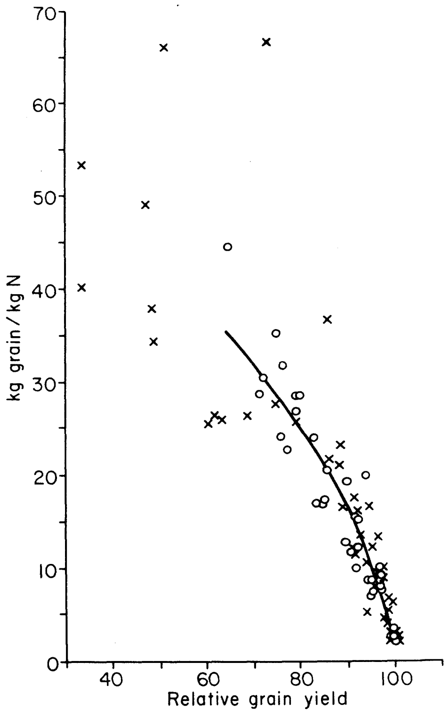

Figure 2: Increase in grain yield per unit of N applied plotted against relative yield. Open circles represent 1978/79 trial results and crosses represent 1979/80 trial results (Steele *et al.,* 1982a).

Commercially available paper test strips can be used to measure the concentration of nitrate in the sap of young maize plants. This is done by cutting a 10 mm section of the stem 100 mm above the ground from maize plants of about 30 cm height. Sap from the cut section is squeezed onto a paper test strip and the concentration of nitrate estimated by measuring the time taken for the colour of the test strip to reach a standard colour. The concentration of nitrate is then used to estimate whether the likely response to side-dressed N will be none, small or large.

The advantages of the sap test are its simplicity, low cost and that growers can perform their own tests. Current inadequacies are insufficient calibration to estimate actual fertiliser N requirements and that the test provides information for side-dressing only.

(ii) **Soil N test** (Steele *et al.,* 1982a)

The second proposed method estimates the increase of grain yield with fertiliser N by using the expected grain yield without N fertiliser and the potential yield of each crop. The former parameter is derived from a relationship established between mineral N determined in soil (0-600 mm) collected in early October (dried at 33 °C) and maize grain yield (Fig. 1), and the latter from district and farm records or from total N analysis of previous crops (Steele *et al.*, 1982b). The procedure is based on a single predictive relationship which was derived for the N response of maize grain crops across a wide range of climates, crop managements and soil types (Fig. 2). The response in grain yield per unit of N is dependent chiefly on the relative yield of the crop (the yield expressed as a percentage of the maximum) at which N is applied and the potential yield of that site.

The advantage of this method is that a N response curve can be constructed for any site and the farmer can then select the rate of N application which will provide maximum grain yield or maximum nett income. The disadvantage of the method is collecting 0-60 cm soil samples and minimising changes in soil mineral N between collection and drying.

(iii) **Total N analysis of plant material** (Steele *et al.*, 1982b)

The third method is based on relationships between the relative grain yield of maize and the concentration of N in ear leaves or in grain (Fig. 3). Determination of total N in ear leaves or grain can be used to determine the N status of a crop, to check the adequacy of the N fertiliser application in that season and to estimate N fertiliser requirements for subsequent crops.

The potential yield for any season, i.e. the maximum yield which would have been achieved with adequate N, can be estimated by using the N concentration in ear leaves at silking, or grain at harvest, to determine the relative yield (Fig. 3), and the actual yield achieved in that year from:

$$\text{Potential yield} = \frac{100\ (\text{achieved yield})}{\text{relative yield}} \qquad (1)$$

The additional N fertiliser which was required to obtain the maximum yield or any proportion of it in that season may be determined from a response curve constructed using the following equation (Steele *et al.*, 1982a):

$$y = 12 + 7\sqrt{101\text{-}x} \qquad (2)$$

where y is the yield increase (kg grain per kg of N) and x is the relative yield (%) of the crop estimated from the N concentration in ear leaves or grain. This equation is for increments of up to 50 kg/ha of N. Using the equation sequentially a response curve can be constructed for any site. This will provide a basis for changing the amount of N fertiliser applied in the subsequent season.

The advantage of this method is that in continuous cropping systems, records of N concentration in ear leaves or grain, the amount of N fertiliser applied each year per paddock and the relative yield achieved will provide information on the change of potential yield with climate. This will permit growers to select the most profitable N fertiliser application over time, realising that in some years they will under-fertilise and in some years they will over-fertilise their crop. This method also permits all the fertiliser N requirement of the crop to be applied as starter N. The disadvantage is that it is supplying retrospective information.

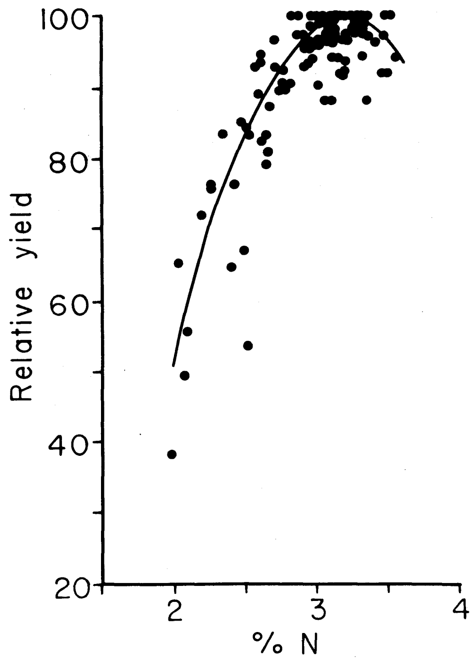

Figure 3: Relationship between the yield of maize grain, expressed as a percentage of maximum, and %N in ear leaves collected at 50% silking (Steele *et al.*, 1982b).

ECONOMICS OF N FERTILISER USE

Maximum monetary return to the grower will occur when N is applied until the marginal return (MR) from increased grain yield equates with the marginal cost (MC) of applying the N, i.e. until MR - MC = 0. This will seldom, if ever, equate with maximum yield.

Using costs at May 1983 in the Waikato (94.1 cents per kg of N side-dressed; grower price of $185 per tonne of grain; fixed production costs of $952 per hectare; variable production costs including cartage, drying and storage of grain of 2.8 cents per kg) the MR from increased grain yield equalled the marginal cost of applying N at a relative crop yield of about 94 percent of maximum (Fig. 4A). This relationship will hold for all crops at the stated costs, irrespective of absolute crop yield, because of the constancy of the response of maize crops to N applied at any given relative yield across a wide range of climates, crop managements and soil types. The response in grain yield per unit of N is dependent chiefly on the relative yield of the crop at which N is applied (Steele *et al.*, 1982a). Therefore maximum nett return per hectare in the 1982/83 season would have been achieved with a crop fertilised to attain 94 percent of maximum as shown in the example in Fig. 4B.

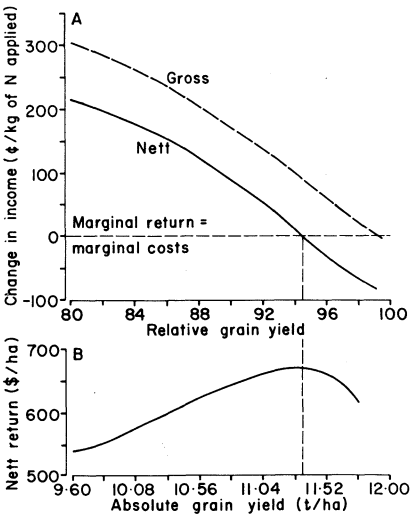

Figure 4: (a) Relationship between the change in gross and nett income per kg of N applied and relative grain yield.
(b) An example of nett return ($/ha) for a crop yielding 9.6 tonnes grain/ha without application of fertiliser N and having a maximum yield of 12 tonnes grain/ha.

CURRENT N FERTILISER USE

It is estimated that a total of 2400 tonnes of N were applied to 22,000 ha of maize during the 1982/83 season (Table 4). Starter N was applied as a compound NPK fertiliser whereas side-dressed N was applied mainly as urea, either as granules or in solution. Amounts of N applied varied between districts but this does not appear to be related to crop requirements for N.

In the 1980/81 season, chemical analysis of ear leaves collected from 234 maize crops at silking in the Waikato and Bay of Plenty showed that 75 percent of the crops had N concentrations associated with over 95 percent of maximum yield (Table 5). These crops had apparently received more N fertiliser than was required for maximum economic return. The average amount of N applied to the crops sampled was 100 kg N/ha in the Waikato and 92 kg/ha in the Bay of Plenty. Limmer (1982) compared N leaf tissue analyses of growers using soil tests to estimate N fertiliser requirements for maize with an equal number of growers using their own means of determining N requirements. There was a shift towards higher N concentrations amongst growers not using the soil test, their average leaf tissue N concentration being 3.62 percent compared with an average of 3.22 percent for the former group. Both groups were above the N concentration associated with 94 percent of maximum yield (2.8%) but whereas 3.2 percent is associated with maximum yield, a yield depression of about 8 percent would occur at a N concentration of 3.6 percent (Steele *et al.,* 1982b). These results underline the need for growers to rationalise their fertiliser N applications if they are to maximise their nett income.

TABLE 4: Estimates of the area of maize for 1982/83 and the amount of fertiliser N applied.

	Area* (ha)	Average N application** Starter (kg N/ha)	Side-dressed (kg N/ha)	Total (kg N/ha)	Total N applied (t)
North Auckland	360	30	90	120	43
Auckland/ South Auckland	345	45	150	195	67
Waikato	9250	33	72	105	966
Bay of Plenty	6500	30	90	120	780
Poverty Bay	2543	22	90	112	284
Hawkes Bay	1000	22	90	112	112
Wairarapa	50	30	45	75	4
Taranaki	520	30	0	30	16
Wanganui	160	30	60	90	14
Manawatu	1200	30	60	90	108
Nelson-Marlb	240	45	142	187	45
	22168				2439

*Ministry of Agriculture and Fisheries preliminary estimates, October 1982 (Arable Farming, Dec/Jan 1983, p3)
**Estimates from fertiliser retailers and Ministry of Agriculture and Fisheries.

CONCLUSIONS

Nitrogen fertiliser recommendations for maize crops have traditionally been inadequate because of the lack of a suitable soil or plant test to assess N fertility status. Research conducted in the late 1970's has, however, given direction to the way in which N fertiliser requirements can be estimated. Three procedures have been proposed, each of which is useful in different circumstances. Where background information on a particular crop is lacking, the N soil test proposed by Steele *et al.* (1982a) will provide an

TABLE 5: Concentrations of N in ear leaves collected from 234 crops at silking and estimated relative yields.

% N in DM Estimated relative yield	2.44	2.45-2.53 (80-84)	2.54-2.65 (85-89)	2.66-2.81 (90-94)	2.82-3.21 (95-100)	3.21
Number of crops	16	6	15	23	122	52
% of crops tested	6	3	6	10	53	22

estimate of optimal N fertiliser application. The commercial applicability of the soil test on a large scale appears limited because of the difficulty associated with collection of 0-60 cm soil samples and rapid transport to the laboratory. Despite these limitations, the soil test has been successfully used by one commercial laboratory over the past two years.

The most applicable method for estimating N fertiliser requirements in continuous cropping situations appears to be that proposed by Steele *et al.,* (1982b) which is based on records of concentrations of N in ear leaves or grain, crop yields and the amount of N applied. This method provides an evaluation of the adequacy of the N fertiliser applied in a given season and provides a basis for estimating requirements for the subsequent season.

Further calibration of the nitrate sap test to develop a quantitative estimation procedure based on nitrate concentrations in young plants appears warranted, since sap tests are inexpensive, can be conducted by individual growers and produce results within minutes.

A clear distinction must be made between applying N for maximum grain yield or for maximum profit. At current prices, maximum nett income occurs when N is applied to achieve 94% of maximum grain yield. Plant analyses conducted over recent years indicate that many maize crops receive too much N. Growers, therefore, need to rationalise their fertiliser N use to optimise crop yield for maximum nett income.

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