Paper 7

FERTILISER MANAGEMENT FOR GRAIN MAIZE

K.W. Steele
Ruakura Soil & Plant Research Station,
Ministry of Agriculture and Fisheries,
Hamilton.

INTRODUCTION

Increasing production costs during recent years have adversely affected the profitability of producing maize grain. To maintain an adequate financial return it is necessary for producers to consider ways in which production costs can be stabilised or reduced. A survey of 65 Waikato maize producers conducted during the 1982-83 season showed that average fertiliser costs were $247/ha or approximately 22% of the total cost of producing a 12 t/ha grain crop. Fertiliser management policies therefore merit consideration as a possible area in which costs may be reduced.

On average, 116 kg N (nitrogen), 69 kg P (phosphorus) and 56 kg K (potassium)/ha were applied to maize crops in the Waikato during the 1982-83 season. N concentrations in the ear-leaf on 36 properties ranged up to 4.2% and 30 crops (83%) had N concentrations associated with over 95% of maximum yield. These crops had apparently received more N fertiliser than was required for maximum economic return (Steele, 1983). Similar results were obtained in a survey conducted in the Waikato and Bay of Plenty during the 1980-81 season, where 75% of the crops had N concentrations associated with over 95% of maximum yield (Steele, 1983).

The average amount of P applied (69 kg/ha) was 173% of that removed in a 12 tonne/ha grain crop. Of the 65 maize producers surveyed, 87% applied pre-plant fertiliser even though on 65% of farms the Olsen soil test was above the level at which application of pre-plant fertiliser can be recommended. Eleven % of producers applied P to soils having an Olsen test over 22, where yield depressions will be expected to occur. Such activities place unnecessary financial costs on producers and indicate some major deficiencies in formulating fertiliser policies.

The amount of K applied (56 kg/ha) was only slightly above maintenance requirements for a 12 tonne/ha grain crop. However, the small number of K responsive trials in New Zealand do not support application of K at this level.

Applying the correct amount of fertiliser is desirable for both economic and environmental reasons. If insufficient fertiliser is applied, crop yields will be restricted, whereas excessive application represents an unnecessary cost to the producers, will reduce yields and may result in environmental pollution. The high fertiliser inputs noted above support repeated warnings that large amounts of fertiliser applied to maize crops are essentially wasted (Cumberland & Douglas, 1970; Cumberland *et al.*, 1970; Douglas *et al.*, 1972; Steele & Cooper, 1981; Steele *et al.*, 1981).

This paper reviews New Zealand literature on estimating fertiliser requirements for maize grain production and provides guidelines to assist producers in formulating fertiliser policies.

DECIDING HOW MUCH FERTILISER TO APPLY

The information required to estimate the amount and type of fertiliser to apply includes:

- the total nutrient requirements of the crop;
- the time when the crop requires a particular nutrient;
- the amount of each nutrient removed in crop products;
- the amount of each nutrient provided by the soil;
- the proportion of any added fertiliser that will be taken up by the crop.

The first three factors are relatively easily measured. However, estimating the ability of soils to supply a given nutrient and the efficiency with which added fertiliser is used by the crop is more difficult and requires the calibration of soil and plant analysis against yield response to added fertiliser.

NUTRIENT REQUIREMENT OF GRAIN MAIZE

The nutrient requirement of maize is dependent on the level of attainable yield and, therefore, on climate, characteristics of the soil and crop management. Districts differ substantially in their level of yield because of variations in soil and climate. These differences are shown in the average annual yields by district (Table 1) and also in potential yields as given by the highest yields achieved in the annual Ammo-Phos National Maize Yield Competition (Table 2).

Table 1: Average maize grain yield (t/ha) by district* (Steele, 1983).

	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

Table 2: Highest maize grain yield (t/ha) recorded in six districts by entrants in the Ammo-Phos National Maize Yield Competition between 1978 and 1982 (Steele, 1983).

	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

Differences in soil fertility influence the amounts of N, P and K taken up by maize plants but do not markedly affect the seasonal patterns of uptake and distribution of these elements in the plant (Hanway, 1962). However, management practices, eg. the time of application of fertiliser N, will influence the pattern of nutrient accumulation, and fertiliser applications should be timed to take account of plant demand for various nutrients. Under conditions of adequate soil N, N uptake by maize continues from emergence to maturity (Berger, 1962; Hanway, 1962; Barker & Olsen, 1968; Thom & Watkin, 1978), with a maximum rate of uptake occurring during the period of intensive vegetative growth prior to tasselling when it may exceed 4 kg/ha/day (Thom & Watkin, 1978). P accumulation pattern follows vegetative growth except that it is more rapid early in the season (Hanway, 1962). The rate of K accumulation exceeds that of N and dry matter during early growth stages but unlike N and P, K accumulation reaches a maximum before ear formation when about 60% of total dry matter has accumulated (Sayre, 1968).

Maize requires, and removes in grain, more N than any other nutrient derived from soil or fertiliser (Table 3). The proportion of each nutrient taken up by the plant which is removed in the grain varies between nutrient, the highest proportional removal for major nutrients occurring with P (Table 3). Only minute amounts of calcium (Ca) and sodium (Na) occur in grain and removal of these nutrients is small (about 0.03 kg/t). Concentrations of trace nutrients are in the order of manganese (Mn) 9 ppm, zinc (Zn) 35 ppm, copper (Cu) 4 ppm, iron (Fe) 58 ppm, boron (B) 5 ppm, cobalt (Co) 0.014 ppm, molybdenum (Mo) 0.16 ppm and selenium (Se) 0.019 ppm (Harris & Douglas, 1982).

ROLE OF SOIL AND PLANT ANALYSIS

Soil tests measure the pH and estimate the amounts of major nutrients (N, P, K, Mg, S and Ca) available to the plant. Regular soil testing provides a basis for fertiliser recommendations and a means of monitoring the effects of applying fertilisers. The normal sampling depth for maize is 0-600 mm for N and 0-150 mm for all other nutrients.

Plant analysis provides a check on the adequacy of the fertiliser applied during the season in which the sample was collected and information for modification of fertiliser policy for the subsequent season. When used with soil tests, plant analysis can improve fertiliser recommendations. Because plant composition changes with the age of the plant and varies between plant parts it is necessary to standardise sampling procedures. Conventionally, maize is sampled for chemical analysis at 50% silking and the leaf sampled is the ear leaf. Although sampling at silking is too late to correct nutrient deficiencies in the current year, it will provide a basis for fertiliser management for subsequent years.

Interpretation of maize leaf analyses is generally based on one of two systems:

- comparison with critical values or optimum ranges of nutrient concentrations derived from fertiliser response trials.
- Determination of nutrient ratios (diagnosis and

Table 3: Percent concentration and removal of N, P, K, Mg and S in maize grain (Steele *et al.*, 1981).

	N	P	K	Mg	S
Mean concentration of nutrient in grain (% of dry weight)	1.48	0.38	0.48	0.16	0.10
Range	0.08 to 2.00	0.13 to 0.69	0.25 to 0.75	0.08 to 0.26	0.05 to 0.16
Kg nutrient removed in 12 t grain (14% moisture)	153	40	50	17	10
Nutrient in grain as approximate % of total in plant	57	72	30		

recommendation integrated system, DRIS) and comparison with DRIS norms. DRIS is claimed to minimise variations in concentrations resulting from the part of the plant sampled and to provide a ranking of the relative importance of each nutrient in determining the yield achieved (Beaufils, 1973; Sumner, 1977).

The optimum nutrient concentrations for maize in New Zealand have been determined by measuring the nutrient concentrations associated with crops yielding greater than 13 t/ha grain (Table 4). DRIS norms have also been calculated for New Zealand conditions (Table 5). Diagnosis of a single nutrient deficiency by comparison of the concentration of that nutrient with optimum nutrient concentrations can be affected by nutrient balance in the plant. For example, extreme N deficiency may result in an apparently "deficient" P concentration in maize herbage. This is also a problem with identification of nutrient deficiencies using DRIS. Because DRIS is based on the balance of nutrient, it will fail to recognise a N deficiency if the concentration of other nutrients is also low (Steele *et al.,* 1981). It is generally considered that deficiencies of a single nutrient can be adequately identified using optimum nutrient concentrations (Cornforth & Steele, 1981).

Table 4: Optimum ear-leaf nutrient concentrations for maize at 50% silking (Cornforth & Steele, 1981; Steele *et al.*, 1982b).

Major nutrients (%)		Minor nutrients (ppm)	
N	2.66-3.30	Mn	18-140
P	0.18-0.32	Cu	8-20
K	1.70-3.00	Zn	22.85
Ca	0.40-0.80	B	4-25
Mg	0.13-0.25		
S	0.12-0.30		

Table 5: DRIS norms calculated from maize crops grown in New Zealand (Cornforth & Steele, 1981).

Nutrient ratio		Nutrient ratio	
N/P	11.54	Ca/K	0.25
N/K	1.30	Mg/N	0.06
K/P	9.23	P/Mg	1.41
Ca/N	0.20	Mg/K	0.08
Ca/P	2.22	Mg/Ca	0.34

ESTIMATION OF NUTRIENT REQUIREMENTS

Nitrogen (N)

Traditionally, recommendations have been based on past cropping practice and grower experience. 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 & 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 & 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 (Steele, 1983).

- 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.

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 10 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 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 and 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.

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

The second method allows estimation of the additional N sidedressing needed. It requires the determination of:

the grain yield without added N;
the potential yield of grain; and
the increase in yield per unit of N applied at different levels of relative yield.

$$\text{Where: Relative yield} = \frac{\text{Yield without added N}}{\text{Potential yield}} \times 100 \quad (1)$$

The grain yield without N is derived from the relationship between soil mineral N level in October, in the top 600 mm, and crop yield (Fig. 1). The potential yield is derived from district and farm records. The increase in grain yield per unit of N at different levels of relative yield is based on a single predictive relationship derived from the yield response to N measured in crops covering a wide range of climates, crop managements and soil types (Steele *et al.*, 1982a) (Fig. 2). This relationship has the form

$$Y = -12 + 7\sqrt{101 - x} \quad (2)$$

Where Y is the yield increase (kg grain per kg N) and x the percent relative yield.

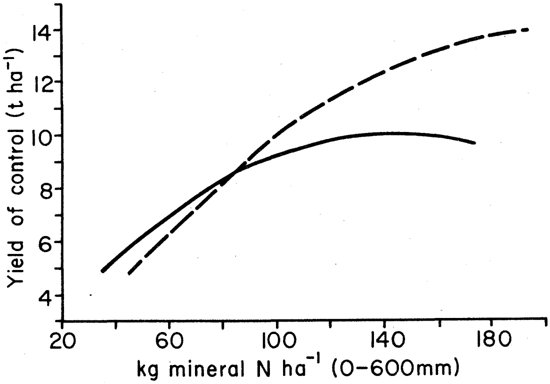

Figure 1. Relationship between maize grain yield and mineral N determined in dried soil (33 °C). The slashed line represents Bay of Plenty/Poverty Bay results and the solid line represents Waikato results (Steele *et al.*, 1982).

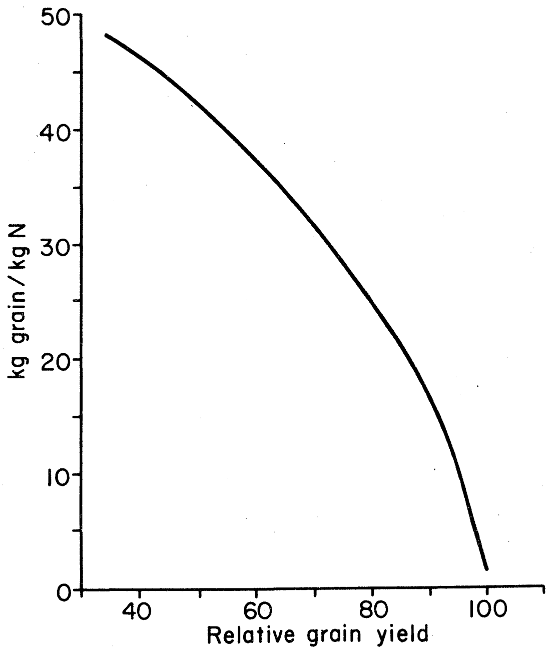

Figure 2. Increase in grain yield per unit of N applied plotted against relative yield. (Steele *et al.*, 1982a).

Using equation (2), the yield response curve to N applied can be constructed for any site provided the relative yield is recalculated for each additional increment of 50 kg N/ha.

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 net income. The disadvantage of the method is collecting 0-600 mm soil samples and minimising changes in soil mineral N between collection and drying.

- 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, ie. 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:

$$\text{Potential yield} = \frac{100\,(\text{achieved yield})}{\text{relative yield}} \qquad (3)$$

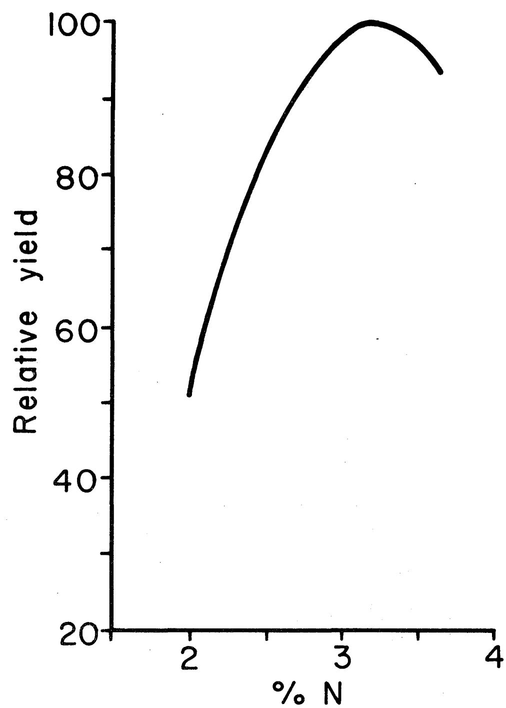

Figure 3. Relationship between the yield of maize grain, expressed as a percentage of maximum, and %N in ear leaves collected at 50% silking (Steele *et al.*, 1982b).

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 equation (2) above (Steele *et al.*, 1982a). Using equation (2) 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. A step-by-step example of using the method was given by Steele (1981).

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 and 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. The disadvantage is that it is supplying retrospective information.

Phosphorus (P)

Recommendations for fertiliser P are generally based on soil test information and may be summarised as follows:

Olsen P test	>14	Do not apply pre-plant P. Apply 20 kg P/ha in starter.
Olsen P test	11-14	Do not apply pre-plant P. Apply the amount of P in starter that will replace the P removed in grain.
Olsen P test	<11	Apply 50 kg P/ha pre-plant and 20-35 kg P/ha in starter depending on expected yield.

The crop yield response to pre-plant P falls as the soils test value increases so that the replacement of P removed in a 12 t/ha grain crop (40 kg P/ha) becomes uneconomic when the Olsen P test rises above 15. Yield is depressed when pre-plant P is applied to soils with an Olsen P test above 22 (Steele *et al.*, 1981).

Maize yields are generally increased more per unit of P when P is banded rather than broadcast (Nelson, 1956; Welch *et al.*, 1966), except where there is a very low P status (Yost *et al.*, 1979). P maintenance programmes may therefore be best directed towards policies based on the use of starter fertiliser. On Gisborne soils, which have a naturally high P status, it has been suggested that starter P is unnecessary (Sinclair & Douglas, 1974). Steele *et al.* (1981) reported a yield in excess of 14 t grain/ha on a Makaraka heavy silt loam without addition of pre-plant or starter P.

Potassium (K)

Recommendations for fertiliser K are also generally based on soil test information. Response to fertiliser K in New Zealand trials has been rare (Douglas *et al.*, 1982; Steele *et al.*, 1981) and regular application of K is not recommended unless the K soil test is less than 5. However, where previous crops have lodged badly or suffered from stem rot, K fertiliser application may be considered since K has been implicated in preventing lodging and stem rot in maize and may counteract the effects of excess or unbalanced N supply (Kockler, 1960; Murdock *et al.*, 1962). N fertiliser policies should, however, be reviewed before application of K.

Placement of K fertiliser appears to be less critical than placement of P (Barber 1959; Johnson *et al.*, 1960; Burson *et al.*, 1961; Vasey & Barker, 1963) and K may be applied either in pre-plant or starter fertiliser.

Steele *et al.* (1981) suggested that the low incidence of yield response to K fertiliser, even at relatively low soil test values, indicated an efficient cycling of K within the maize crop system. This is consistent with the small amount of K removed in maize grain relative to total K uptake and the release of large amounts of K during stover decomposition near to planting time.

Magnesium (Mg)

At present there is no evidence to support application of Mg to maize crops in New Zealand. Unnecessary application of Mg may depress yield (Steele *et al.*, 1981).

Sulphur (S)

No increases in grain yield have been measured in New Zealand following S application to maize crops. However, although the amount of S removed in grain is small (0.9 kg/t), the S status of maize crops should be monitored if soils have a low S status and particularly if fertilisers containing little S are used (Steele *et al.*, 1981).

Trace elements

No trace element deficiencies have been identified in maize crops on mineral soils in New Zealand. However, yield increases have occurred following application of copper (Cu) to some Waikato peat soils (Elliott & van der Elst, 1956). Where copper application is required, the recommended rate is 20 kg copper sulphate per hectare.

Lime

Little research has been undertaken in New Zealand on the effect of soil pH on maize grain yield. It is generally considered that soil pH levels which are optimum for pasture growth (pH 5.8-6.0) are adequate for maize.

FACTORS AFFECTING CROP UTILISATION OF FERTILISER

Time of N application

When maize is sown in October or early November following a previous maize crop, much of the available N in the soil is some distance below the soil surface and not immediately available to seedlings (Steele & Cooper 1980). Because of this, it is advantageous to sow maize 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 side-dressed N is applied. Any additional N required may be applied in the starter or as a pre-plant or side-dressed fertiliser. Application of N as a pre-plant fertiliser is not commonly practised in New Zealand and does not appear warranted unless there is a problem with large amounts of undecomposed stover being present in the soil close to planting. Some experimental evidence suggests that the response to N is similar whether it is applied as a single dressing at planting or split into applications at planting and post-emergence (Douglas *et al.*, 1972). Applying all the fertiliser N at planting has the advantage of reducing application costs and preventing possible crop damage by side-dressing equipment. However, in situations where heavy rainfall occurs soon after planting, side-dressing N may be advantageous. The timing of side-dressing does not seem to be critical up to about 6 weeks from planting.

Type of fertiliser

There appears to be no difference in crop response to fertiliser N whether it is applied as urea, ammonium sulphate or in a compound NPK fertiliser (Douglas & Sinclair unpublished). Selection of the form of N to apply is therefore dependent on the cost per unit of N.

As previously noted, maize yields are generally increased more per unit of P when P is banded rather than broadcast. It is important to use water-soluble P sources when fertilisers are applied as a band, since both yield and P uptake increase with P water solubility (Web & Pesek, 1958; 1959). It is advantageous to band N with P, as when N is in the ammonium form P uptake is increased (Robertson *et al.*, 1954; Miller & Ohlrogge, 1958; Miller, 1974). However, inclusion of K in starter fertiliser does not affect N or P uptake (Robertson *et al.*, 1954), so K can be broadcast pre-plant.

There is a large variation in the cost per kg of various fertiliser nutrients and a detailed analysis of the content and price per unit of nutrient is necessary to determine which fertiliser is the best value.

Fertiliser placement

Placement becomes important when fertilisers are banded in the soil. Fertilisers placed too close to the seed may result in injury delaying or preventing germination. The extent of injury is dependent of soil moisture, soil type and the kind and amount of fertiliser applied. Seed injury results from either a high osmotic pressure due to high soluble salt content, or a direct toxic effect of fertiliser or fertiliser reaction products such as ammonia. To prevent injury, fertiliser is normally placed 5 cm to the side and 5 cm below the seed.

Foliar fertiliser application

In recent years there has been a growing interest in foliar application of fertilisers to maize crops, either prior to silking or during grain filling. The purpose of applying foliar fertiliser during the grain filling period is not to serve as an amendment for insufficient soil applied fertiliser, but to delay the senesence of foliage by resupplying nutrients that are being rapidly translocated to the developing grain (Garcia & Hanway, 1976). Only a limited amount of research has been conducted on foliar application of fertilisers to maize and results have been inconsistent, ranging from yield depressions, to no effect, to significant yield responses (eg. Harder *et al.*, 1982). Insufficient information is available to make firm recommendations in New Zealand.

Weed control

Weeds compete with maize for available nutrients, particularly N. Poor weed control can be expected to reduce the grain yield per unit of fertiliser applied. Weed control in maize is outlined in Rahman (1985).

Soil factors

Many soil properties affect the efficiency of fertiliser use by crops. In general, any improvement in the physical characteristics of soil which improves plant growth, will improve the efficiency of fertiliser uptake by maize.

Low soil temperature after planting restricts root development and growth of young maize plants. Wet soils increase in temperature slower in the spring than well drained soils, reducing root penetration and promoting loss of plant available N through denitrification. At the other extreme, nutrient uptake is limited in soils where plant growth is restricted by insufficient moisture.

Excessive compaction of surface soil, by machinery or the presence of compacted layers in the soil, also reduces root penetration and nutrient uptake.

N-Serve

During the late 1970's, the use of N-Serve as a nitrification inhibitor of urea or ammonium fertiliser applied to maize created widespread interest in New Zealand. It was suggested that by decreasing nitrification rates, crop yield may be increased by reducing soil nitrate losses through leaching and denitrification. Although some significant yield increases were recorded in trials conducted by Ivan Watkins Dow Ltd, the responses were inconsistent. Effective application of N-serve requires specialised equipment beacuse of the volatile nature of the product. The problems associated with application of N-serve and the finding that its use does not always result in increased grain yield resulted in the product being withdrawn from the New Zealand market. N-Serve is not commercially available in New Zealand.

ECONOMICS OF FERTILISER USE

Maximum monetary return to the producer will occur when fertiliser is applied until the marginal return (MR) from increased grain yield equates with the marginal cost (MC) of applying fertiliser, ie. until $MR - MC = O$. This will seldom, if ever, equate with maximum yield.

An example of the economics of N fertiliser use was recently presented by Steele (1983). Using costs as 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 net return per hectare in the 1982/83 season would have been achieved with a crop fertilised to attain 94% of maximum as shown in the example in Fig. 4B.

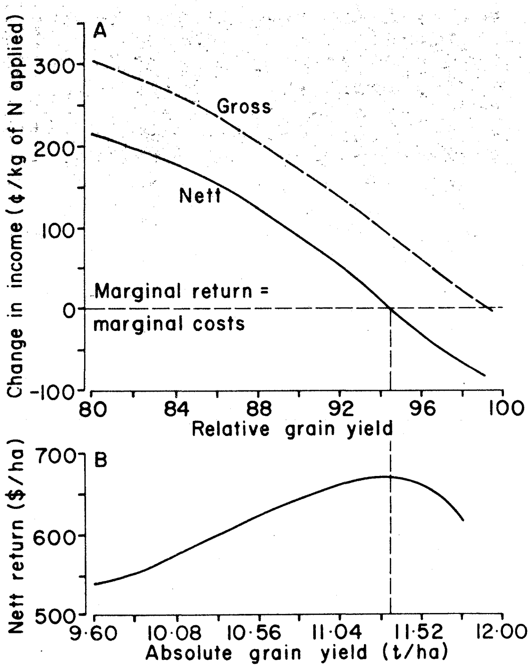

Figure 4. (A) Relationship between the change in gross and net income per kg of N applied and relative grain yield.
(B) An example of net return ($/ha) for a crop yielding 9.6 tonnes grain/ha without application of fertiliser N and having a maximum yield of 12 tonnes grain/ha.

CONCLUSIONS

Repeated warnings by many researchers that large amounts of fertiliser applied to maize crops are essentially wasted appear not to have been heeded by maize producers. Considerable reductions in production costs, in some cases accompanied by an increase in grain yield, may be achieved by using a carefully planned fertiliser programme.

On many soils, maize can be successfully grown without pre-plant fertiliser and using only relatively small amounts of N and P starter. Nitrogen is removed in grain in larger amounts than any other nutrient supplied by soil or fertiliser, and the grain yield and chemical composition of the maize plant is primarily determined by the N status of the soil within the confines imposed by climate and management.

Fertiliser management policies need to be based on regular soil and plant analyses, records of grain yields achieved and amounts of fertiliser applied in the past. A clear distinction must also be made between applying fertiliser for maximum grain yield or for maximum profit.

REFERENCES

Barber, S.A. 1959. Relation of fertiliser placement to nutrient uptake and crop yield. Effects of row potassium, potassium soil level, and precipitation. *Agronomy Journal 51:* 97-99.

Barber, S.A., Olsen, R.A. 1968. Fertiliser used on corn. In *Changing patterns in fertiliser use.* Madison, Soil Science Society of America: 163-188.

Beaufils, E.R. 1973. Diagnosis and recommendation integrated system (DRIS) *Soil Science Bulletin No. 1.* Department of Soil Science and Agrometeorology, University of Natal, Pietermaritzberg.

Berger, J. 1962. *Maize Production and Measuring of Maize.* Geneva Centre d'Elude de l'Azole.

Cornforth, I.S. 1980. A simple test for N status of plants. *N.Z. Journal of Agriculture Nov 1980:* 39-41.

Cornforth, I.S., Steele, K.W. 1981. Interpretation of maize leaf analysis in New Zealand. *N.Z. Journal of Experimental Agriculture 9:* 91-96.

Cumberland, G.L.B., Douglas, J.A. 1970. Fertiliser requirements of maize. *N.Z. Soil News 18:* 155-160.

Cumberland, G.L.B., McCormick, S.J., Douglas, J.A. 1970. Maize cropping. *Proceedings Ruakura Farmers' Conference 1970:* 93-106.

Douglas, J.A., Cottier, K., Kain, W.M., O'Connor, M.B., Southon, T. 1972. Advances in maize production. *Proceedings Ruakura Farmers' Conference 1972:* 121-128.

Elliott, I.L., Van Der Elst, F.C.C.H. 1956. The use of copper on Rukuhia peat. *N.Z. Journal of Agriculture 93:* 550-557.

Garcia, R., Hanway, J.J. 1976. Foliar fertilisation of soybeans during the seed-filling period. *Agronomy Journal 68:* 653-657.

Hanway, J.J. 1962. Corn growth and composition in relation to soil fertility. II. Uptake of N, P and K, and their distribution in different plant parts during the growing season. *Agronomy Journal 54:* 217-222.

Hanway, J.J., Dumenil, L. 1965. Corn leaf analysis. *Plant Food Review 11:* 5-8.

Harder, H.J., Carlson, R.E., Shaw, R.H. 1982. Corn grain yield and nutrient response to foliar fertiliser applied during grain fill. *Agronomy Journal 74:* 106-110.

Harris, P.M., Douglas, J.A. 1982. *Chemical Composition of New Zealand Feed Grains.* D.S.I.R., Palmerston North, New Zealand. 23 pp.

Johnson, M.E., Miller, L.B., Lang, A.L. 1960. Frequency of potash application. *Better Crops with Plant Food 44:* 9.

Kockler, B. 1960. Corn stalk rots in Illinois. *Illinois Agricultural Experimental Station Bulletin 658.*

Miller, M.H. 1974. Effect of nitrogen on phosphorus absorption by plants. In Carson, E.W. ed. *The Plant Root and its Environment Part II. Soil Physical and Chemical Aspects of the Root Environment.* Charlottesville, United States of America, University Press of Virginia: 643-668.

Miller, M.H., Ohlrogge, A.J. 1958. Principles of nutrient uptake from fertiliser bands. I. Effect of placement of nitrogen fertiliser on the uptake of band-placed phosphorus at different soil phosphorus levels. *Agronomy Journal 50:* 95-97.

Murdock, J.T., Stengel, P.J., Doersch, R.E. 1962. How fertility level and balance can affect corn production. *Better Crops 46:* 16-21.

Nelson, L.B. 1956. The mineral nutrition of corn as related to its growth and culture. *Advances in Agronomy 8:* New York, Academic Press Inc. 336-351.

Rahman, A. 1985. Weed control in maize in New Zealand. In: *Maize: Management to Market. Agronomy Society of N.Z. Special Publication 4:* 37-45.

Robertson, W.K., Smith, P.M., Ohlrogge, A.J., Kinch, D.M. 1954. Phosphorus utilisation by corn as affected by placement and nitrogen and potassium fertilisation. *Soil Science 77:* 219-226.

Sayre, J.D. 1948. Mineral accumulation in corn. *Plant Physiology 23:* 267-281.

Sinclair, D.P., Douglas, J.A. 1974. Maize on the Gisborne Plain. *N.Z. Journal of Agriculture 128:* 33-37.

Steele, K.W. 1981. Maize fertilisers. Estimating nitrogen fertiliser requirements. *N.Z. AgLink FPP602.* MAF 2pp.

Steele, K.W. 1983. Efficient utilisation of soil and fertiliser N to optimise maize grain yield. *Proceedings Agronomy Society of N.Z. 13:* 33-38.

Steele, K.W., Cooper, D.M. 1980. Reducing fertiliser applications to maize. *Proceedings Ruakura Farmers' Conference 1980:* 25-34.

Steele, K.W., Cooper, D.M., Dyson, C.B. 1982a. Estimating nitrogen fertiliser requirements in maize grain production. 1. Determinations of available soil nitrogen and prediction of grain yield increase to applied nitrogen. *N.Z. Journal of Agricultural Research 25:* 199-206.

Steele, K.W., Cooper, D.M., Dyson, C.B. 1982b. Estimating nitrogen fertiliser requirements in maize grain production. 2. Estimates based on ear leaf and grain nitrogen concentrations. *N.Z. Journal of Agricultural Research 25:* 207-210.

Steele, K.W., McCormick, S.J., Percival, N., Brown, N.S. 1981. Nitrogen, phosphorus, potassium, magnesium and sulphur requirements for maize grain production. *N.Z. Journal of Experimental Agriculture 9:* 243-249.

Sumner, M.E. 1977. Use of the DRIS system in foliar diagnosis of crops at high yield levels. *Communications in Soil Science and Plant Analysis 8:* 251-268.

Thom, E.R., Watkins, B.R. 1978. Effect of rate and time of fertiliser nitrogen application on total plant shoot and root yields of maize (*Zea mays* L.). *N.Z. Journal of Experimental Agriculture 6:* 29-38.

Webb, J.R., Pesek, J.T. 1958. An evaluation of phosphorus fertilisers varying in water solubility. I. Hill applications for corn. *Soil Science Society of America Proceedings 22:* 533-538.

Webb, J.R., Pesek, J.T. 1959. An evaluation of phosphorus fertilisers varying in water solubility: II. Broadcast applications for corn. *Soil Science Society of America Proceedings 23:* 381-384.

Welch, L.R., Mulvaney, D.L., Boone, L.V., McKibben, G.E., Pendleton, J.W. 1966. Relative efficiency of broadcast versus banded phosphorus for corn. *Agronomy Journal 58:* 283-287.

Yost, R.S., Kamprath, E.J., Lobato, E., Naderman, G. 1979. Phosphorus response of corn on an oxisol as influenced by rates and placement. *Soil Science Society of America Journal 43:* 338-343.