An Evaluation of some Laboratory Methods of Assessing the Availability of Nitrogen in Agricultural Soil

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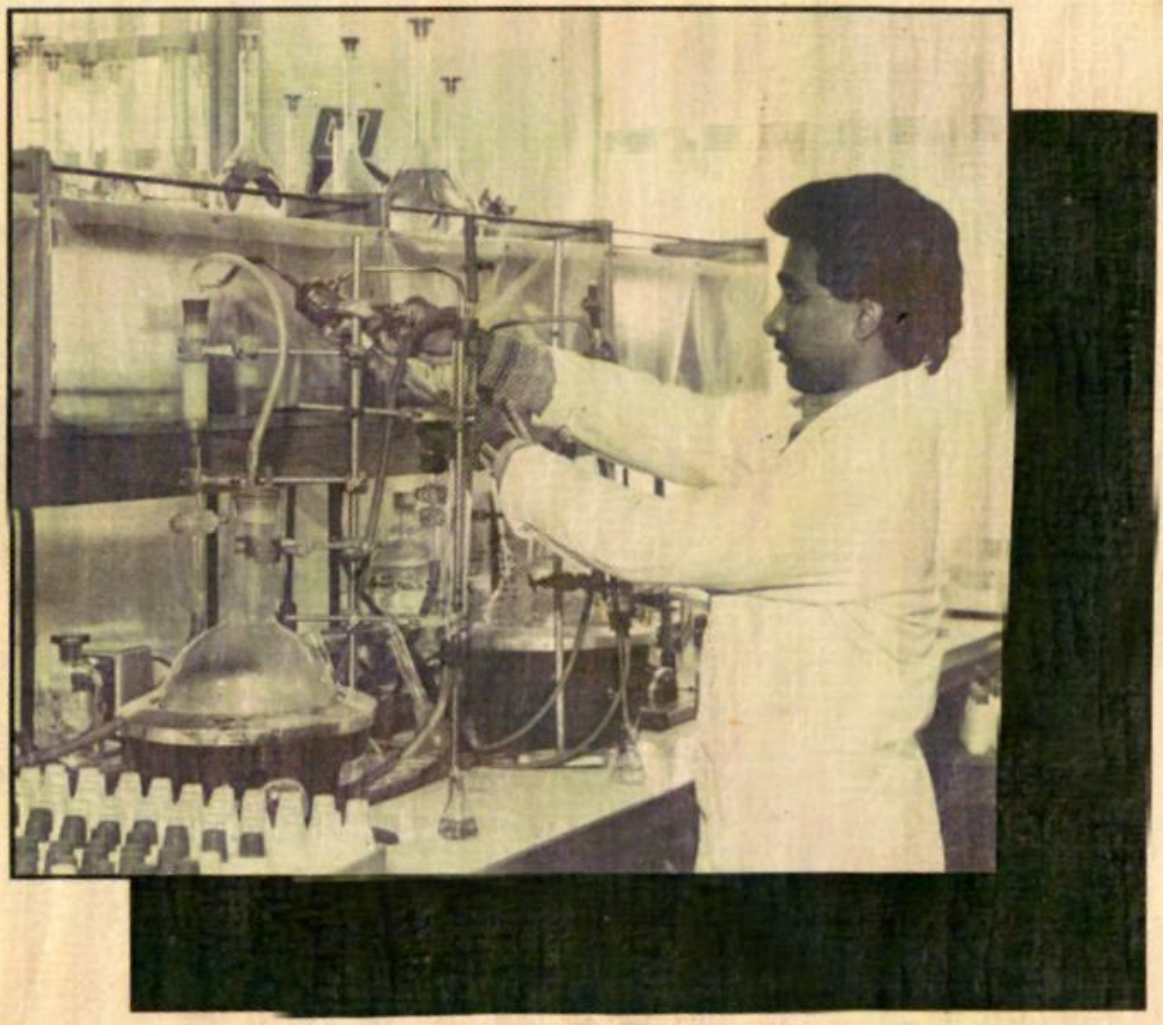

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AN EVALUATION OF SOME LABORATORY METHODS OF ASSESSING THE AVAILABILITY OF NITROGEN IN AGRICULTURAL SOILS

A Report to

The New Zealand Fertiliser Manufacturers' Research Association Inc.

The Ravensdown Fertiliser Co-operative

and

The Petrochemical Corporation of New Zealand Ltd

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SUMMARY

Soil samples were obtained from various cereal growing sites in Canterbury via the Ravensdown Fertiliser Co-operative and from MAF nitrogen fertiliser field trials in the South and North Islands. These samples were used to compare the current Ravensdown Fertiliser Co-operative soil test(s) and some selected laboratory methods of assessing soil nitrogen (N) availability viz.:

chemical methods

(i) field-moist/air-dry soil residual mineral nitrogen
(ii) acid $KMnO_4$ oxidisable nitrogen
(iii)1N H_2SO_4 extractable nitrogen
(iv)boiling KCI hydrolysable nitrogen
(v) percent soil organic carbon
(vi)percent total soil nitrogen and.

biological methods

(i) 7-day field-moist soil aerobic incubation
(ii) 14-day air-drv soil aerobic incubation
(iii) 7-day field-moist/air-dry soil anaerobic incubation
(iv) Steele *et al* (1982) "maize test"

Measurements of residual mineral-N (NH_4^+-N + NO_3^--N) showed that NO_3^--N was the dominant form (60-80%) of mineral-N in most of the soils tested. Correlation analysis indicated that residual NO_3^--N values could be used to predict the total residual mineral-N levels of all the soils studied. For the 1985 spring it was also possible to predict the mineral-N levels of the full soil profile (0-60 cm) from the NO_3^--N contents of the surface soils (0-15 cm).

The majority of soils studied had higher organic carbon and total nitrogen contents (mean values being 3.7 and 0.31 percent respectively) than most of the reported values in the literature indicating that these soils are rich in organic nitrogen. Although the total-N and organic-C contents gave statistically significant correlations with most of the chemical and biological methods tested, organic-C and total-N content determinations are not recommended for routine soil-N analysis because of the amount of time and cost involved in soil sample preparation and further analytical procedures.

Of the chemical extractants studied, acid $KMnO_4$ extracted the highest amount of mineral-N in the form of NH_4^+-N (maximum value of 330 $\mu g\ g^{-1}$) following the chemical breakdown of some soil organic nitrogen. Nevertheless, in general, this method did not correlate well to any of the chemical or biological tests performed on the surface soils (0-15 cm).

The inexpensive and rapid 1 *N* H_2SO_4 extractable-N method gave good correlations with soil mineral-N and other chemical methods tested. The study showed that 1 *N* H_2SO_4 extractable N values can be used to predict the amount of total soil-N % (r=0.993) of the organic-N-rich North Island soils collected by MAF without performing expensive and laborious Kjeldahl analysis.

The recently developed, simple and economical boiling KCI hydrolysable-N method established strong correlations with the incubation tests (biological methods) for a wide range of soils studied. This test is therefore strongly recommended as a routine chemical test for soil-N availability.

Of the short-term incubations investigated, both the 7 and 14-day aerobic incubations yielded some negative net mineralisation values, questioning the reliability of short-term aerobic incubation tests used to predict soil-N availability for crops. Similarly, the Steele *et al*., (1982) "maize test" (16 hours forced air-drying at 33°C) was also found to be unreliable for the soils tested in this study due to immobilisation of N which was originally available during the air drying process.

There was poor reproducibility of results between the Ravensdown 7-day aerobic incubation test and the same test conducted at the Lincoln College laboratory. Differences in sample handling, soil moisture contents, incubation conditions and to a lesser extent, the use of different methods to determine mineral-N levels were believed to be the causes for the poor relationship. Although the 14-day aerobic incubation decreased these effects, this test was however, considered to be unsuitable for routine analysis due to the laborious pre-treatments involved.

Of all the incubation tests studied, the 7-day anaerobic incubation method was best suited for routine analysis performed at any soil testing laboratory. The amount of NH_4^+-N mineralised from field-moist and air-dried soils of MAF North Island by this method showed good agreement ($r = 0.734$). With the numerous merits mentioned in the study, this method also gave a good correlation ($r = 0.852$) with the 14-day aerobic incubation for the MAF South Island air-dried soils.

Although the grain yield values of barley and wheat obtained from fertilised and unfertilised plots of MAF North Island correlated significantly with residual mineral-N levels of field-moist and air-dried soils, the low number of observations used in the yield study (wheat $n = 9$ and barley $n = 7$) were insufficient to permit further conclusions.

Unfortunately, for the Canterbury (Ravensdown) soils, the wide range of fertiliser rates used by different farmers and the high incidence of crop lodging in 1985 made it difficult to test for the relationship between crop yield and soil-N availability. The 7-day anaerobic test gave a correlation of $r = 0.562$ ($n = 20$) with yield and is recommended for use in future studies.

It is suggested that the current Ravensdown 7-day aerobic incubation test be discontinued and that the following methods be adopted for routine assessment of the N supplying capacity of a wide range of cropping soils:

(i) measurement of field-moist soil residual N levels and
(ii) field-moist soil boiling KCI hydrolysable N or
(iii)7-day field moist soil anaerobic incubation.

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1. INTRODUCTION

Surface soils commonly contain between 0.08 and 0.4% total nitrogen (N) of which more than 90% is in the organic form. If 1 to 3% of this N is mineralised in a growing season, from 8 to 120 Kg of N ha^{-1} may become available for crop utilisation (Keeney, 1982). Often this amount of N is not sufficient to meet the crops' N requirement. Moreover, such N is released slowly whilst the crops demand for N is high early in the growing season. Thus accurate assessment of N supplying capacity of the soil becomes necessary for efficient N fertiliser management.

The method must be able to predict reliably the N supplying capacity of soil in more than one soil type and climatic condition so that N fertiliser recommendations will be economical and environmentally sound. In the past three decades, various laboratory, glasshouse and field methods have been used to assess soil N availability, but with varying success. Research conducted on these methods up to 1982 has been summarised and evaluated by Stanford (1982). Some of the methods currently used are outlined in the following sections.

1.1. Laboratory methods

Considering the time, effort and expense involved in field and pot trials, emphasis has been placed on the development of laboratory methods of assessing soil N supplying capacity. Laboratory methods are usually inexpensive and rapid. Both incubation (biological methods) and chemical extraction methods have been used. Incubation methods determine the amount of N mineralisation under specified artificial conditions whereas chemical methods extract all, or some fraction of the organic and inorganic N pools.

1.1.1. Biological indices

Biological indices generally involve a short-term incubation (6-25 days) under aerobic or anaerobic conditions. However, a few long-term incubation tests have also been used under optimum soil water conditions for 14-210 days at 24-35°C temperature range (Gallagher and Bartholomew. 1964; Lathwell. *et al*. 1972 and Stanford & Smith, 1972). In the past, however, short and long-term incubations have been criticised because they are laborious, expensive and time-consuming. Moreover, the reliability of the results obtained from extremely long incubations in static, closed systems is questionable (Stanford, 1982). The latest long-term incubation techniques involve,

1) pre-leaching of the soil to remove initial nitrate nitrogen (NO_3^--N).
2) use of vermiculite to improve soil leaching properties and aeration.
3) the adjustment of soil water content by suction.
4) and the addition of $CaCO_3$ or nutrient solutions.

Such techniques are believed to produce mineralisation rates different from those occurring in the field (Keeney. 1982). Nevertheless, long-term incubations are still used as a quantitative estimate of N supplying capacity of soils and thus assist in evaluating other soil availability indices.

Although short-term aerobic incubations have often been used, they have been criticised because they are sensitive to incubation conditions and soil sample pre-treatment. The following factors have been regarded as affecting the results of short-term incubations:

1) sampling (time, weather conditions).
2) freezing (temperature of cold storage).
3) air-drying (duration, drying temperature and thickness of drying soil).
4) grinding/crushing (degree of grinding/crushing, type of grinder).
5) sieving (sieve size).
6) storage of air-dried soil (type of container, duration, moisture and ammonia content in the laboratory atmosphere) and
7) rewetting (amount of water used, degree of mixing).

Stanford and Smith (1972) were in favour of long-term incubation because their research showed that the results of a first incubation period (1-2 weeks) were virtually meaningless with regard to N mineralisation potential *(No),* indicating that the true rate of N mineralisation was established only after the effects of residues and sample pre-treatment had been overcome.

Nevertheless, short-term incubations are widely used and evaluated because they are more convenient and economical than any of the long-term incubations. To obtain comparable results from short-term incubations in a laboratory or among laboratories, it is necessary to rigorously standardise the methods of sample pre-treatment as well as the incubation conditions (Bremner, 1965).

Short-term anaerobic incubations have been found to be less sensitive to sample pre-treatment or incubation conditions than aerobic incubations. Keeney (1982) for instance indicated that the conditions in anaerobic incubations (6 to 14 days at 30 to 40°C) have generally been satisfactory and considered this approach to be more attractive for routine laboratory analysis. Some advantages of anaerobic incubations over aerobic tests are:

(i) only NH_4^+-N need be measured.
(ii) problems with establishment of optimal water content and loss of water during incubation are avoided.
(iii) more N is mineralised under anaerobic conditions.
(iv) more N is mineralised in a given period due to the higher incubation temperatures which have been generally used (e.g. 40^{o}C).

It is believed thai the anaerobic incubation of field moist soil provides a more accurate assessment of N availability than the incubation of air-dried soil. Air drying, grinding and sieving have considerable effect on soil N mineralisation and can result in a quicker and increased release of NH/-N (Chalk and Waring. 1970: Sahrawat. 1980: Powlson. 1980). The reasons for quicker rates and increased amounts of N mineralisation are:

(i) air drying is believed to kill the majority of the soil biomass.
(ii) grinding of soil sample further destroys the existing biomass resulting in more minerlisation (Powlson, 1980).
(iii) grinding exposes the clay-organic matter complex which was previously inaccessible to soil microbial attack (Sahrawat, 1980). and,
(iv) grinding and sieving provide a uniform distribution of biomass and organic matter throughout the sample which enables the acceleration of mineralisation.

1.1.2 Chemical indices

Numerous chemical indices of soil N availability have been proposed since they are more rapid, precise, economical and convenient than most of the biological soil N availability tests. Several chemical extractants have been proposed and these have been reviewed in detail by Keeney (1982). They can be divided into 3 broad groups:

a) weak extractants (e.g. 1 *M* KCl)
b) intermediate extractants (e.g. acid $KMnO_4$)
c) strong extractants (e.g. 6 *N* H_2SO_4).

A range of such extractants is shown in Table 1.

Generally, mild extractants of NH_4^+-N or total mineral N such as hot 0.01 *M* $CaCl_2$, cold 1 *N* K_2SO_4 and hot or cold 1 *M* KCl have given results that have been closely correlated with greenhouse tests of plant uptake of N and with biological availability indices. Often the relatively large amounts of N extracted by intermediate extractants such as acid permanganate or 1 *N* H_2SO_4 show little correlation with biological indices of N availability.

In contrast, strong extractants remove a substantial proportion of total soil N and the amounts of N extracted are often correlated with the total N content of soil. These extractants remove more N than would normally be mineralised in the short term and are not generally reliable indices of N availability.

The question remains as to which of the above mentioned chemical methods is suitable for predicting the N supplying capacity of the soil? It is intrinsically unlikely that any simple chemical method can measure the organic nitrogen about to be mineralised throughout the growing season. The most serious objection to chemical tests as distinct from biological tests, is that no single chemical extraction is likely to give a reasonable reflection of both the processes leading lo minerlisation and immobilisation (Jenkinson. 1982).

Table 1. A range of chemical methods

Extractant	Temperature	Time	Form of N measured
	(°C)	(h)	
Mild Extractants			
Water	100	1	Total N^+
0.01 *M* $CaCl_2$	100	64	Total N or NH_4^+-N
0.01 *M* $CaCl_2$	121 (autoclave)	1	NH_4^+-N
0.01 *M* $NaHCO_3$	Room	0.25	Total N, UV absorbance
1 *M* KCl	100	1	Total N
1 *M* KCl	Room	1	Total N
2 *M* KCl	100	4	Total N or NH_4^+-N
2 *M* KCl	Room	1	Total N
0.01 *M* $CaCl_2$	121 (autoclave)	16	Glucose
0.1 *N* $Ba(OH)_2$	Room	0.5	Glucose
0.1 *N* Na_2CO_3	Room	18	NH_4^+-N
0.25 *N* $NaHCO_3$ + 0.25 *N* Na_2CO_3	Room	0.5	NH_4^+-N
Solid $Ca(OH)_2$	100 (distillation)	0.5	NH_4^+-N
Neutral 0.5 *N* $Na_4P_2O_7$	100	6	Total N
0.05 *N* $Na_4P_2O_7$ pH 9	Room	0.5	Total N
1 *N* K_2SO_4	Room	1	Total N
0.05 *M* K_2SO_4	100	1	Glucose
Solid MgO (aqueous suspension)	100 (distillation)		NH_4^+-N
Intermediate extractants			

Alkaline $KMnO_4$	100 (distillation)	0.25	NH_4^+-N
Acid $KMnO_4$	Room	1	NH_4^+-N
0.5 *N* H_2SO_4	Room	1	Total N
1*N* H_2SO_4	Room	1	NH_4^+-N
1 *N* H_2SO_4	Room	28	NH_4^+-N
0.1*N* HCl	Room	26	NH_4^+-N
1 *N* HCl	Room	26	NH_4^+-N
1 *N* NaOH	Room (microdiffusion)	4.2	NH_4^+-N
1 *N* NaOH	100 (distillation)	0.5	NH_4^+-N
$Na_2Cr_2O_4 + H_3PO_4$	100	2	NH_4^+-N with CO_2 evolved
$K_2Cr_2O_4 + H_3PO_4$	Room	2	NH_4^+-N with CO_2 evolved
$CrO_3 + H_3PO_4$	Room	20	NH_4^+-N with CO_2 evolved
Strong extractants			
5 *N* HCl	Room	26	NH_4^+-N
6 *N* H_2SO_4	Room	28	NH_4^+-N
4.5 *N* NaOH	distillation		NH_4^+-N
$K_2Cr_2O_4 + H_2SO_4$	Walkley-Black oxidation		NH_4^+-N

+Total N - total inorganic N (NH_4^+-N + NO_2^--N + NO_3^--N) in the extract or distillate.

Adapted from Bremncr (1965) and Keeney (1982)

A soil with a large chemically oxidisable or hydrolysable N content, may in fact mineralise no nitrogen if immobilisation is vigorous. Nevertheless, such soil tests may be successful for soils with low immobilisation rates. The most successful tests, however, are likely to be those that reflect the quantity of microbial biomass present rather than the larger but relatively inert fractions (Jenkinson, 1982).

Nevertheless, the reliability of a biomass method is also questionable due to the assumption that fumigation of the soil will kill the entire soil microbial population. The amount of biomass killed depends on the active phase of microbial growth. For example the majority of the microbial propagules cannot be killed by a single fumigation if the microbial population is at a reproductive phase at the time of 'killing' (which is possible under certain soil-climatic conditions). Thus, often, the actual amount of biomass is believed to be underestimated. An attempt to develop a method which made allowance for the "energy material" available in soils (e.g. Jenkinson's (1968) extractable "glucose") failed to receive wide acceptance. Nevertheless, evaluation of chemical soil availability indices is still considered worthwhile due to the numerous practical advantages over biological methods.

1.2 Some methods currently used for assessing soil N availability and making N fertiliser recommendations

(a) Previous cropping history

Soil N indices used for advisory purposes in the U.K. are based on previous cropping history. The success of this method depends on other factors such as climate and management practices and is therefore highly empirical and subjective. Furthermore, such an approach without quantitative soil and/or plant analysis can only be approximate. Nevertheless, the continued use of this method in the U.K. and its proposed introduction by the MAF in N.Z. indicates the practical nature of the approach and that the approximate results may in many cases be sufficiently accurate for routine use.

(b) Residual NO_3^--N or mineral N

Prediction of the N supplying capacity of soil has also been based on the measurement of soil profile NO_3^--N or mineral N (NO_3^--N + NH_4^+-N) in spring. Although residual mineral N in the soil profile can arise from the mineralisation of soil organic N, especially in crop-fallow systems, it usually arises from previous fertilisation (Keeney, 1982). This method is particularly suitable for a region where leaching and denitrification losses are negligible before planting or during the growing season. The depth of sampling needed to sufficiently assess the quantity of residual mineral N available or accessible to crop roots is dependent on the effective rooting depth (Stanford, 1982). Evidently, the quantity of residual mineral N in the rooting zone significantly influences crop responses to applied fertiliser nitrogen (Olsen and Kurtz, 1982). Thus, assessment of residual mineral N usually involves sampling depths up to 180 cm. However, for practical reasons, it would be desirable to sample to the minimal depth required to establish a suitable relation between crop N uptake and amount of residual mineral N in the soil. Moreover, Russel (1973) stated that arable soils in the temperate regions have a fairly constant but low content of NH_4^+-N but a variable and often high NO_3^--N content. Thus, measurements of only residual NO_3^--N are more widespread and currently in use for advisory purposes in pans of West Germany and France (Jenkinson, 1982).

The method is called "the deep nitrate" test in New Zealand and assumes that no fertiliser N is required when the amount of soil NO_3^--N within at 0-60 cm depth in August-September exceeds 60 kg N ha^{-1}. Below this level, the N requirement of autumn sown wheat increases linearly with the decrease in soil NO_3^--N up to a maximum requirement of 85 kg N ha^{-1} (Stephen, 1980). Recently, Walker and Ludecke (1982) found a strong correlation between wheat grain response (Y) and soil nitrate (X):

$$Y = 1967 - I8.5X$$

The deep nitrate method is relatively easy to conduct since only soil NO_3-N is measured, however, there are many factors which influence the outcome:

(i) time, depth and number of individual soil samples
(ii) spatial variability of nitrate in soils
(iii)sample pre-treatments such as storage, sieving etc and
(iv)problems of obtaining samples in stony soils.

Use of a mineralisable N index in conjunction with profile NO_3^--N could further improve the accuracy of prediction of N fertiliser needs.

(c) Residual and mineralisable soil N

This method assesses the mineral N and soil organic N reserves. Stanford (1973) presented a direct approach in estimating N needs of crops:

$$N_c = N_i + N_m + N_f$$

where N_c = N uptake by a crop associated with a specified maximum or attainable economic yield

N_i = measured initial quantity of N in soil profile

N_m = estimated N mineralised during the cropping season

N_f = amount of N fertiliser needed

Quin *et al* (1982) incubated soil samples (0-15 cm depth) at 37°C to estimate the change in mineral N level (i.e. ΔN).

$$Y_o = 1 + 0.0417 (IN + \Delta N)$$

where Y_o = expected yield without N fertiliser or zero N (t ha^{-1})

IN = initial mineral N

ΔN = final mineral N after incubation (7-days at 37°C) minus initial mineral N.

Nitrogen to apply (kg ha^{-1}) = $(Y_p - Y_o) \times 40$

where Y_p = estimated yield potential (t ha^{-1})

40 = amount of N required/tonne of grain response for Canterbury region.

The method suffers from the same problems as the "deep nitrate" method. In addition, the amount of mineralisable N determined by the incubation method is sensitive to even small variations in incubation conditions and sample pre-treatment.

(d) Mineralisable N

The mineral N released from soils after incubation is called mineralisable N. Various models have been developed using this biological method. In New Zealand. Steele *et al.* (1982) found that amount of mineral N released by forced air drying the soil samples for 15h at 33°C (a short-term incubation) gave a good relationship with maize yield. For example, the correlation for the Waikato region is given by:

$$Y = 1.13 + 0.122X - 0.0004\ I8X^2$$

where Y = maize grain yield t ha^{-1} (20 kg N ha^{-1} basal dressing)

X = mineral soil N in air-dried soil at 0-60 cm depth (kg N ha^{-1})

This method is attractive because it is less time consuming and less expensive than other biological methods of measuring mineralisable nitrogen.

(e) Plant analysis

Plant analysis is a useful means of diagnosing nutrient deficiencies and has been used as a method of predicting fertiliser requirements. Nitrate analysis of the xylem sap of wheat stem is used as a routine procedure in Germany and has been recommended for use in New Zealand (Cornforth, 1980). Kjeldahl analysis of total plant N has also been widely used as an index. However, the concentration of N in the plant is greatly affected by genotype, the growth stage and environmental conditions, thus it is difficult to make a general recommendation even for different regions.

1.3 Objectives of this study

The quest for a soil test for available soil N has been long and for many regions, relatively unfruitful (Magdoff *et al*., 1984). However, the need to develop better methods has taken new urgency in the last decade. A local soil testing service offered by the Ravensdown Fertiliser Co-operative makes N fertiliser recommendations based on field mineral N content, the mineral N released after 7-day aerobic incubation at 37°C, yield potential and paddock history. Although this method is by no means perfect, it is generally believed that the recommendations are reasonably accurate when carefully followed under normal conditions.

The objectives of the present investigation are:

(i) to compare the current Ravensdown Fertiliser Co-operative method with other biological and chemical indices: and
(ii) to compare some selected chemical and biological indices which are currently being used in soil nitrogen availability research.

2. MATERIALS AND METHODS

2.1 Soils and soil sample preparation

(a) Ravensdown Fertiliser Co-operative

Surface soil samples (0-15 cm) were collected from Canterbury cropping farms during July 1985 by the Ravensdown Fertiliser Co-operative. A selection of about 250 samples were used in the present study. The majority of the soil samples were collected from cultivated paddocks sown either with wheat or barley. The paddocks were either irrigated or rain fed and some had N fertiliser applied, the amounts ranged from 25-100 kg N ha^{-1}. Soil sub-samples were obtained from the Ravensdown laboratory and stored in polyethylene bags at 4°C for a maximum of 4-5 weeks before analysis at the Lincoln College laboratory.

(b) MAF South Island

Soil samples were collected by the MAF from a number of fertiliser nitrogen trials in Canterbury. The control plots were sampled at 15 cm intervals to a depth of 75 cm during August and September 1985. About 5 cores were collected from each site and bulked according to depth. Composite soil cores were transported in polyethylene bags and stored overnight at 4°C crushed and mixed thoroughly before analysis.

(c) MAF North Island

Soil samples were also collected by the MAF from a number of fertiliser nitrogen trials throughout pan of the North Island at 0 to 15 cm depths. The soils were all from paddocks with 0-10 years previous cropping. One sub-sample was used for conducting N tests on the field-moist soil and the other sub-sample was air-dried at 30-33°C for 18 hours (Steele *et al.*, 1982). Sub-samples of the air-dried soil were placed in unsealed polyethylene bags and dispatched to the Lincoln College laboratory where they were stored at room temperature (10-20^{o}C) for approximately 6 months before analysis.

2.2 Analysis performed at Ravensdown and MAF North Island laboratories

(a) Ravensdown laboratory

The Ravensdown laboratory measured the initial mineral nitrogen level (initial NH_4^+-N and NO_3^--N) and conducted a 7-day aerobic incubation test (Quin *et al.*, 1982) on field-moist soil. Initial mineral N and 7-dav mineral N (7-day NH_4^+-N and NO_3^--N) were extracted from the soil using a potassium fluoride solution for 30 minutes. The extractable NH_4^+-N and NO_3^--N were measured by an electrode method.

(b) MAF North Island laboratory

The initial mineral N test (Method 1. detailed in the next section), the 7-day anaerobic incubation at 40°C (Keeney and Bremner, 1966) and the 7-day aerobic incubation at 37°C (Quin *et al*., 1982) were all performed on field-moist soils. Final mineral N (air-dried NH_4^+-N and NO_3^--N) was measured according to Method 2 which is detailed below.

2.3 Chemical methods

2.3.1 Moist soil analysis

Method 1 Estimation of initial exchangeable NH_4^+-N and NO_3^--N extracted with 2 *M* KCl (Keeney and Nelson, 1982).

A 28 g sample of moist soil was shaken in duplicate with 50 ml 2 *M* KCI in a 100 ml polycarbonate centrifuge tube on an end-over-end mechanical shaker for 30 minutes. This was then centrifuged for 10 minutes at 2000 rpm; filtered through Whatman No. 541 and the filtrate stored in 100 ml plastic bottles at 4°C. Exchangeable NH_4^+-N (Weatherburn, 1967) and NO_3 -N (Grasshoff. 1969) were measured using the autoanalyscr and the values obtained were corrected for moisture content.

2.3.2 Air-dry soil analysis

Moist soil samples were spread on plastic trays at 2 cm thickness and placed in a cabinet provided with forced air circulation at room temperature (about 10-15°C) for 48 hours. The air dried samples were then gently crushed, passed through a 2 mm sieve and stored in unsealed polyethylene bags at room temperature.

Method 2 Estimation of exchangeable NH_4^+-N and NO_3^--N extracted with 2*M* KCl.

Similar to Method 1 but using 25 g of air dry soil.

Method 3 Estimation of total soil nitrogen (Bremner and Mulvaney, 1982).

A sub-sample of air-dry soil (< 2 mm) was ground to pass through a 0.15 mm (100-mesh) screen, thoroughly mixed and stored in plastic vials. Duplicate samples of 0.5g of ground soil were mixed with l.5g of K_2SO_4-Se catalyst mixture (100:1 ratio) and digested for 5 hours at 350-400^{o}C in 100 ml Kjeldahl flasks containing 5 ml of concentrated H_2SO_4. The flasks were supported at 45°C on a sand bath in order to provide even heating and to prevent loss of N during digestion. After digestion, the contents were allowed to cool at room temperature and transferred completely into a 30 ml vial by rinsing the digest ion flask with distilled water. The final volume of the suspension was made up to 25 ml with distilled water. The analysis of N was performed using an autoanalyser method (Weatherbum. 1967). This analysis method was checked against the steam distillation method of Bremner and Mulvaney (1982) and showed excellent agreement ($r=0.98$ $p<0.01$). Thus it was decided to use the more rapid autoanalyser analysis method.

Method 4 Estimation of soil organic carbon. Walkley-Black procedure (Nelson and Sommers, 1982).

The pre-treatment of soil subsamples was similar to Method 3. About 0.3 g soil sample was placed in a 500 ml Pyrex conical flask and 10 ml of 1 *N* $K_2Cr_2O_7$ was added using a 50 ml burette. The soil-reagent mixture was mixed thoroughly by swirling the flask and 20 ml of conc. H_2SO_4 added. The flask was swirled for 1 minute and allowed to stand for 30 minutes after which time 20 ml of water, 10 ml of conc. H_3PO_4 and 7 drops of diphenylamine indicator were added. The unreacted $K_2Cr_2O_7$ was titrated with 0.5 *N* ammonium ferrous sulphate. Organic carbon was calculated using a correction factor of 1.30 (Nelson and Sommers, 1982). Ammonium ferrous sulphate solution was standardised on each day of the analysis by running two blank solutions of 10 ml 1 *N* $K_2Cr_2O_7$.

Method 5 Estimation of acid permanganate extractable soil N (Stanford and Smith. 1978)

Two grams of sieved soil (< 2 mm) were placed in a 100 ml polycarbonate centrifuge tube in duplicate, and 50 ml of freshly prepared 0.2 *N* $KMnO_4$ and 1 *N* H_2SO_4 mixture was added. The tubes were closed tightly with rubber stoppers, lined with a piece of thin polyethylene sheet, and mixed for 30 minutes on an end-over-end mechanical shaker. After extraction the lubes were centrifuged for 10 minutes at 2000 rpm. The NH_4^+-N content was determined on a 25 ml aliquot of supernatant which was steam distilled with 10 ml of 10 *N* NaOH solution. The NH_3-N dissolved in H_3BO_3 indicator was titrated with standard 0.01 *N* H_2SO4.

Method 6 Estimation of acid extractable soil N (Stanford and Smith, 1978).

This method was employed by Stanford and Smith (1978) to subtract acid extractable N from combined acid and oxidant extractable N as in Method 5. The method is similar to Method 5 but 50 ml 1 *N* H_2SO_4 alone was used as the extractant.

Method 7 Estimation of oxidative release of potentially mineralisable soil N by acid permanganate extraction (Stanford and Smith, 1978).

The NH_4^+-N values obtained from the 1 *N* H_2SO_4 extraction (Method 6) were subtracted from that of the combined acid and the potassium permanganate (Method 5).

Method 8 Estimation of NH_4^+-N extracted from soil by boiling in 2 *M* KCl (Gianello and Bremner, 1986).

Three grams of soil were placed in a 25 ml Universal bottle in duplicate, and heated in a boiling water bath with 20 ml of 2 *M* KCl for 4 hours. The bottles were tightly closed during the boiling period. After boiling, the water was siphoned from the water bath and the bottles were allowed to cool for 10 minutes. The bottles were shaken by hand for few seconds and then centrifuged for 10 minutes at 2000 rpm. The supernatant solution was transferred into a 100 ml plastic bottle and stored at 4°C for NH_4^+-N analysis. Ammonium-N was measured by steam distilling 10 ml aliquot with 0.2 g MgO for 5 minutes. The ammonia received in H_3BO_3 indicator was titrated against standard 0.005 *N* H_2SO_4.

Method 9 Estimation of KCI hydrolysable organic N (Gianello and Bremner, 1986).

The NH_4^+-N values obtained from 2 *M* KCl extraction at room temperature (Method 2) were subtracted from that of Method 8.

2.4 Biological Methods

2.4.1 Moist soil analysis

Method 10 Estimation of mineralisable N at 37°C for 7-days (Quin *et al*., 1982).

A 28 g (approximate) sub-sample of soil was placed in an unsealed polyethylene bag and incubated at 37°C for 7-days. The NH_4^+-N and NO_3^--N amounts were measured according to Method 1. Incubation of the Ravensdown Fertiliser Co-operative soil samples was performed in duplicate while MAF samples were in quadruplicate for 3 soil depths (0-15, 15-30 and 30-45 cm). The mineralisable N was calculated as the difference between mineral N amounts from the initial extraction (Method 1) and that after 7-days incubation (Method 10).

2.4.2 Air-dry soil analysis

Method 11 Estimation of mineralisable N at 30°C for 14 days after rewetting the air-dry soil (Keeney and Bremner, 1967).

This method involved determination of the NH_4^+-N and NO_3^--N produced when 10 g of air-drv sieved soil (< 2 mm) was mixed with 30 g of autoclaved, acid washed quartz sand, moistened with 6 ml of distilled water and incubated in an unsealed polyethylene bag at 30°C for 14 days. After incubation the contents of the bags were emptied into 100 ml polycarbonate centrifuge tubes and extracted with 25 ml 2 *M* KCl for 30 minutes on an end-over end mechanical shaker.

The rest of the procedures are as described in Method 1. Mineralisable N was calculated as the difference between mineral N amounts from Method 11 and Method 2.

Method 12 Estimation of NH_4^+-N production under anaerobic conditions (Keeney and Bremner, 1966).

This method involves incubating 5 g of soil under waterlogged conditions at 40°C for 7 days. Ten ml of air free distilled water was dispensed into 30 ml plastic vials and mixed with the air-dry soil, in duplicate. Oxygen-free N_2 was bubbled at the bottom of the vials containing soil-water mixture for a few seconds which were then immediately closed and placed in desiccators. The air in the desiccators was flushed out by using O_2 free N_2, and placed in the incubator for 7 days at 40°C. After 7 days about 10 ml of 4 *M* KCl was dispensed into each vial and shaken by hand for a few seconds. The contents of the vials were transferred into 100 ml distillation flasks and washed down with 10 ml of distilled water. The rest of the procedure is as described in Method 8.

All the results of soil analysis reported are average results of duplicate analysis (or quadruplicate - only for Method 10 tested in MAF South Island soils at 0-15, 15-30 and 30-45 cm depth intervals) and are expressed on an oven dry basis, moisture being estimated from the loss in weight following drying at 105°C for 12-18 hours. Table 2 gives a summary of the methods performed on each soil.

Table 2. Experimental summary

Sources of soil samples	Soil Depth (cm)	No. of Samples	Methods performed
Ravensdown (Canterbury)	0-15	159	1, 2, 10
	0-15	85	1-12
MAF (South Island)	0-15	15	1-12
	15-30	15	1-12
	30-45	15	1, 2, 10
	45-60	13	1, 2
	60-75	13	1, 2
MAF (North Island)	0-15	36	2-9, 11 and 12

3. RESULTS AND DISCUSSION

The terms and abbreviations used in the tables, appendices and discussion are given in Table 3. The linear correlation analysis was performed between: (i) each of the chemical methods, (ii) each of the biological methods and (iii) all of the chemical and biological methods together. The correlation coefficient (r) values obtained between chemical methods are provided in Tables 5, 6, 7 and 8 and the r values obtained between biological methods are given in Tables 10, 11, 12 and 13 for all the soils tested at 0-15 and 15-30 cm soil depths. Tables 14, 15, 16 and 17 indicate the relationship between chemical and biological methods. The r values obtained for the relationship between different soil depths are included in the Appendix. The Appendix also gives the individual N values obtained for all the methods used for all the soils

and soil depths, the basic statistical details and the regression equations obtained for some selected methods tested in this study.

It should be noted that some of the negative correlation coefficient values are statistically significant. Such values are not highlighted in the Tables or Appendices. Most of these statistically significant negative correlation values have been obtained due to subtraction of one variable from another. For example, KCl hydrolysable N (KCl-AD) gave a correlation of -0.826 with air-dried soil NH_4^+-N (AD NH_4) content (Table 6). KCl hydrolysable N values were obtained by subtracting initial NH_4^+-N values from the final NH_4^+-N extracted after boiling with 2 *M* KCl solution (see Method 9 and Table 3 for further information). Thus KCl hydrolysable N values negatively but significantly correlated with air dried NH_4^+-N, NO_3^--N and mineral N (0.826, -0.831 and -0.864 respectively) because the correlation of air-dried NH_4^+-N with NO_3^--N and mineral N was (0.833 and 0.939 respectively (Table 6).

3.1 Comparison of chemical methods

(a) Chemical extraction of soil N

All of the soil samples used in this study were collected from areas that were being cropped. Table 4 shows the mean, minimum and maximum N values obtained by each chemical method. The residual NH_4^+-N and NO_3^--N levels in the Ravensdown soils were higher than those of the rest of the soils indicating that these soils may have been fertilised in recent years.

Air drying of the Ravensdown and MAF (South Island) soils at the Lincoln College laboratory (Section 2.3.2) did not increase the mineral N content significantly (Table 4). The air drying test (Steele *et al.*, 1982) was also conducted on the MAF (North Island) soils and for over 40% of these resulted in mineral N values lower than the initial

Table 3.

The terms used in the text and their respective abbreviations in the Tables and Appendices and discussion

Method	Term(s) used in the text	Abbreviation(s) used in the Tables and Appendices
Chemical methods		
1.	Initial/Field-moist soil/ residual NH_4^+-N, NO_3^--N and mineral N (NH_4^+-N + NO_3^-N)	lniNH4, IniNO3 and IniMinN
2.	Air-dried soil/Air dried soil residual NH_4^+-N. NO_3^--N and mineral N (NH_4^+-N + NO_3^--N)	AD NH4, AD NO3 and AD MinN
3.	Total soil N %	Tot N%
4.	Organic carbon %	Org C%
5.	Acid $KMnO_4$ extractable N	HOx
6.	1 *N* H_2SO4 hydrolysable/ extractabl	H_2SO_4/H
7.	Acid $KMnO_4$ (HOx-H_2SO_4) oxidisable N	$KMnO_4$
8.	Boiling KCl extractable N	KCl

9.	Boiling KCl hydrolysable N (KCl-AD NH4	KCl-AD
MAF North Island	Air-dried soil mineral N after 18 h air drying at 33ºC	MFADMi/InADMin
Biological methods		
10.	(i) Final NH_4^+-N, NO_3^-N and mineral N obtained after 7-day aerobic incubation	7dNH4, 7dNO3 and 7dMinN
	(ii)7-day mineralisable N (7dMinN-IniMinN)	7dPotN
11.	(i) Final NH_4^+-N, NO_3^-N and mineral N obtained after 14-day incubation	14dNH4, 14dNO3 and 14MinN
	(ii) 14-day mineralisable N (14dMinN-ADMinN)	14dPotN
12.	(i) Total NH_4^+-N distilled after 7-day anaerobic incubation of air dry soil	Anaerob
	(ii) Anaerobically mineralisable N (Anaerob-ADNH4)	Ana-AD
Ravensdown	(i) Final NH_4^+-N, NO_3^-N and mineral N values obtained by Electrode method after 7-day aerobic incubation	El 7dNH4 El 7dNO_3 and El 7dMinN
	(ii) 7-day mineralisable N values (El7dMinN-ElIniMinN) obtained by electrode method	El 7dPotN
MAF North Island	(i) Total NH_4^+-N distilled after 7-day anaerobic incubation of field-moist soil	MFAnae
	(ii) Field-moist soil anaerobically mineralisable N (MFAnae-IniNH4)	An-NH4
Soil depths	0-15 cm	15
	15-30 cm	30
	30-45 cm	45
	45-60 cm	60

TABLE 4

MEAN MINIMUM AND MAXIMUM VALUES OBTAINED BY CHEMICAL METHODS FOR DIFFERENT LOCATIONS AND SOIL DEPTHS ($\mu gN\ g^{-1}$).

Location/Depth	Sample No.	Ini.NH_4	Ini.NO_3	Ini.Min.	ADNH_4N	ADNO_3N	ADMinN	$KMnO_4$	H_2SO_4
Ravensdown (0-15cm)	244	6 [1-66]	29 [5-99]	35 [8-107]					
Ravensdown (0-15cm)	82	5 [1-27]	29 [9-99]	34 [12-103]	6 [3-11]	29 [6-163]	35 [10-171]	227 [136-330]	35 [17-71]
MAF South (0-15cm)	15	5 [2-11]	9 [3-22]	14 [6-29]	7 [2-22]	12 [4-29]	19 [5-51]	212 [178-316]	28 [18-47]
MAF South (15-30cm)	15	2 [0-8]	10 [2-24]	12 [3-25]	5 [1-20]	12 [2-37]	17 [4-49]	170 [138-215]	22 [17-30]
MAF South (30-45cm)	15	2 [0-6]	10 [2-18]	12 [3-24]	3 [0-11]	11 [1-32]	14 [3-44]		
MAF South (45-60cm)	13	0 [0-2]	10 [1-23]	10 [1-23]	1 [0-3]	10 [1-22]	11 [1-22]		
MAF South (0-60cm)kg/ha	13	19 [7-52]	79 [25-131]	98 [39-184]	28 [11-63]	89 [33-161]	117 [48-217]		
MAF North (0-15cm)	35	7 [0-17]	6 [0-23]	13 [0-39]	10 [6-28]	19 [6-50]	29 [13-79]	224 [146-336]	54 [23-235]

TABLE 4 (contd.)

Location/Depth	Sample No.	KCl-AD	ElIniNH$_4$	ElIniNO$_3$	ElMinN	OC%	Tot.N%	C:N
Ravensdown (0-15cm)	82	26 [17-49]	5 [1-21]	28 [4-90]	33 [8-102]	3.6 [2.2-6.7]	0.30 [0.18-0.57]	12
MAF South (0-15cm)	15	25 [10-41]				3.3 [2.6-3.9]	0.27 [0.21-0.33]	12
MAF South (15-30cm)	15	15 [3-25]				2.3 [0.9-2.9]	0.19 [0.12-0.28]	12
MAF North (0-15cm)	35	30 [18-59]				4.3 [2.9-9.1]	0.37 [0.24-0.79]	11

Values in parenthesis are minimum-maximum values and others are mean values.

Methods $KMnO_4$ oxidisable, 1N H_2SO_4 extractable and boiling KCl hydrolysable N are in NH_4^+-N values ($\mu g\ g^{-1}$).

El-Ravensdown laboratory electrode method .

mineral N values (i.e. a negative AN value was calculated) (Appendix 18 and Table 4). The mean mineral N values before and after air drying of these soils were 13 and 12 μgN g^{-1} respectively. These findings indicate that with air drying net immobilisation was taking place in many of the soils and this questions the usefulness of this test for estimating N availability.

The oxidative release of soil N by 0.2 *N* $KMnO_4$ in 1 *N* H_2SO_4 was higher (maximum value of 330 μg g^{-1} of NH_4^+-N) than the reported values (maximum value of 220 μg g^{-1} of NH_4^+-N) of Stanford and Smith (1978) despite the reduction in shaking time by 30 minutes. This shows the readily mineralisable nature of the soils used in this study. However, results obtained using the other two chemical indices (1 *N* H_2SO_4 extractable N and boiling KCl hydrolysable N) generally agreed with the reported values of Stanford and Smith (1978) and Gianello and Bremner (198b). Nevertheless, some of the MAF North Island soils yielded extremely high N values (reported maximum values for 1 *N* H_2SO_4 and boiling KCl were 61 and 48 μg g^{-1} NH_4^+-N respectively). The main reason for these higher values is probably because the MAF North Island soils contained higher amounts of total soil nitrogen (mean = 0.37 %N) than the Ravensdown (0.30 N%) or MAF South Island soils (0.27 N%).

The acid $KMnO_4$ *(*0.2 *N* $KMnO_4$ + 1 *N* H_2SO_4) extraction resulted in a 3 to 6 fold increase in NH_4^+-N compared with the amount released after 1 *N* H_2SO_4 extraction alone (Table 5). It thus appears that acid $KMnO_4$ partially oxidises the organic N, yielding more NH_4^+-N. Stanford and Smith (1978) suggested that a discrete fraction of soil organic N is susceptible to attack by acid $KMnO_4$ oxidation at room temperature (25°C). In the present study, however, it was observed that such oxidation was still continuing even when the soil-acid $KMnO_4$ mixture was placed in the refrigerator at 4°C. The longer the total time before centrifuging and steam distillation, the greater the amount of NH_4^+-N released (data not presented here). It should therefore be emphasised that with this method, in order to avoid further oxidation of soil organic matter occurring, the extract must be separated from the soil and steam distilled immediately.

All the soils studied here had higher soil total N and organic carbon content than most of the reported values (mean= 0.31 and 3.7 percent respectively) (Stanford and Smith,1978; Gianello and Bremner, 1986) indicating that these soils are rich in soil organic nitrogen.

(b) Comparison of the Ravensdown and Lincoln College residual N values

The field moist soil NO_3^--N values obtained at the Lincoln College laboratory correlated well with the Ravensdown laboratory values (r=0.828) (Table 5). Moreover. NO_3^--N and mineral N values obtained for air dried soils at the Lincoln College laboratory also agreed well with the Ravensdown field-moist soil N values (r=0.840 and 0.823 respectively). Nevertheless, the correlation between field-moist soil mineral N values obtained from both laboratories was not as strong as expected (r=0.774) because the correlation between NH_4^+-N values was very poor (r=0.140). The differences in NH_4^+-N values observed for both laboratories suggest that NH_4^+-N values changed during the period of cold storage (maximum of one month) at the Lincoln laboratory. It was suspected that even at storage temperatures of 4 to 5°C some nitrification may have still been occurring.

TABLE 5

CORRELATION COEFFICIENTS FOR THE RELATIONSHIP BETWEEN CHEMICAL METHODS FOR 82 SOIL SAMPLES OF RAVENSDOWN FERTILISER CO-OP. (0-15 cm soil).

	IniNH4	IniNO3	InMinN	AD NH4	AD NO3	AD Min	OrgC%	TotN%
IniNO3	0.243							
InMinN	0.419 §	0.982 **						
AD NH4	0.156	0.374 §	0.380 §					
AD NO3	0.014	0.886 **	0.832 **	0.374 §				
AD Min	0.021	0.887 **	0.834 **	0.417 §	0.999 **			
OrgC%	0.066	0.548 §	0.526 §	0.583 §	0.506 §	0.525 §		
TotN%	0.043	0.554 §	0.526 §	0.594 §	0.535 §	0.554 §	0.899 **	
HOx	0.125	0.416 §	0.413 §	0.504 §	0.400 §	0.418 §	0.680 §	0.657 §
H2SO4	0.048	0.674 §	0.640 §	0.602 §	0.644 §	0.662 §	0.699 §	0.734 §
KMnO4	0.128	0.269	0.277	0.392 §	0.261	0.275	0.564 §	0.526 §
C+N %	0.064	0.554 §	0.530 §	0.589 §	0.513 §	0.532 §	0.999 **	0.916 **
KCl	0.172	0.583 §	0.578 §	0.465 §	0.565 §	0.577 §	0.777 **	0.790 **
KCl-AD	0.152	0.547 §	0.541 §	0.277	0.529 §	0.532 §	0.711 §	0.722 §
ElIniNH4	0.140	0.183	0.198	-0.043	0.171	0.165	0.013	-0.006
ElIniNO3	0.015	0.828 **	0.778 **	0.221	0.840 **	0.835 **	0.348	0.373 §
ElInMinN	0.036	0.819 **	0.774 **	0.204	0.830 **	0.823 **	0.335	0.355

	HOx	H2SO4	KMnO4	C+N%	KCl	KCl-AD	ElIniNH4	ElIniNO3
H2SO4	0.567 §							
KMnO4	0.968 **	0.342						
C+N %	0.684 §	0.708 §	0.565 §					
KCl	0.579 §	0.571 §	0.487 §	0.785 **				
KCl-AD	0.514 §	0.482 §	0.439 §	0.718 §	0.980 **			
ElIniNH4	0.081	-0.026	0.101	0.011	0.049	0.063		
ElIniNO3	0.255	0.547 §	0.125	0.353	0.365 §	0.346	0.212	
ElInMinN	0.256	0.519 §	0.135	0.339	0.356	0.340	0.358	0.988 **

§ r-values above 0.357 are significant at 0.1% level

**r-values above 0.750

TABLE 6

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN CHEMICAL METHODS FOR 15 SOIL SAMPLES OF MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 0-15 CM SOIL DEPTH

	Ini NH4	Ini NO3	IniMinN	AD NH4	AD NO3	AD Min	OrgC%	TotN%
InNO3	0.565							
InMinN	0.766 **	0.963 **						
ADNH4	-0.067	0.137	0.085					
ADNO3	0.033	0.540	0.431	0.833 **				
ADMiN	-0.008	0.393	0.304	0.939 **	0.973 **			
OrgC%	0.037	-0.087	-0.056	0.013	0.009	0.011		
TotN%	0.227	0.042	0.107	-0.070	-0.142	-0.118	0.741	
C+N%	0.051	-0.080	-0.046	0.007	-0.001	0.002	0.999 **	0.772 **
HOx	-0.312	-0.367	-0.388	0.453	0.179	0.302	0.432	0.494
H2SO4	0.085	-0.241	-0.160	0.134	-0.124	-0.021	0.504	0.597
KMnO4	-0.367	-0.355	-0.396	0.475	0.228	0.341	0.368	0.416
KCl	0.205	-0.361	-0.215	-0.373	-0.545	-0.496	0.434	0.551
KCl-AD	0.164	-0.302	-0.182	-0.826	-0.831	-0.864	0.256	0.377

	C+N%	HOx	H2SO4	KMnO4	KCl
HOx	0.444				
H2SO4	0.519	0.583			
KMnO4	0.377	0.983 **	0.424		
KCl	0.449	0.226	0.700	0.094	
KCl-AD	0.269	-0.134	0.345	-0.228	0.831 **

** r-values above 0.760 are significant at 0.1% level.

Furthermore, the differences which may have occurred due to employing different methods to measure residual N values in both laboratories are of considerable importance. The potassium fluoride solution employed at the Ravensdown laboratory is a stronger extractant than KC1 solution. Thus, it is believed that the KF solution may have extracted slightly more inorganic N than that extracted by KCl. Moreover, the quicker and more convenient electrode method employed at the Ravensdown laboratory to monitor the residual N levels in the soil-KF solution mixture should have been evaluated by simultaneous analysis of a few soil samples at the Lincoln College laboratory using an autoanalyser method. Otherwise, it is difficult to arrive to a conclusion as to whether the differences in residual N values of both laboratories have merely been caused by sample handling.

The amount of N extracted using mild extractants such as 2M KCI and KF (used at Ravensdown laboratory) at room temperature did not appear to relate to the amounts extracted by boiling 2 *M* KCI and intermediate extractants such as acid $KMnO_4$ and 1 *N* H_2SO_4.

Nevertheless, the NO_3^--N values obtained at both laboratories showed a strong correlation with the mineral N content of all fresh and air-dry soils (Table 5).

(c) Comparison of residual N values

Correlation results obtained between NO_3^--N and total mineral N showed consistency for all the soils tested (Tables 5, 6, 7 and 8). The relationship is clearly demonstrated in Figure 1 and 2 for the Ravensdown soils.

These findings strongly emphasize that soil residual NO_3^--N values of these soils can be used to predict the residual mineral N values without determining the level of NH_4^+-N for field-moist and air-dried soils. The relationship for Ravensdown field-moist soils is described by the following regression equation:

Initial Mineral N = 3.14 + 1.11 x Initial NO_3^-N; R^2 = 88.7%

Apparently. NO_3^--N is the most dominant form of mineral N present (about 60-80% of total mineral N) in the soils tested. Thus strong correlations can be expected between NO_3^--N and total mineral N contents of these soils. Table 8a shows such relationship existing on all the soils tested throughout the profile. Nevertheless, dominancy of NO_3^--N over NH_4^+-N did not necessarily seem to dictate stronger correlations with total mineral N content. For example, although MAF North Island field-moist soils contained about 49% NO_3^--N, the correlation of NO_3^--N with mineral N was slightly stronger (r=0.879) than that of NH_4^+-N with mineral N (r=0.845).

The correlation values obtained for the relationship between 0-60 cm soil profile NO_3^--N and total mineral N of MAF South Island soils were conformable with that of all the surface soils tested. Table 8b indicates the vertical distribution of NO_3^--N and NH_4^+-N throughout the profile tested and the correlation values for their relationship with total mineral N at different depth intervals.

Correlation results in Appendix 16c also indicate that in the 1985 spring it was possible to predict the residual mineral N values for the total 0-60 cm profile by using the residual NO_3^--N values of the 0-15 cm for the MAF South Island N trial control plot air-dried soils.

TABLE 7

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN NITROGEN VALUES OBTAINED BY CHEMICAL METHODS FOR 15 SOIL SAMPLES FROM MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 15-30 CM DEPTH.

	InNH4	InNO3	InMin	AD NH4	AD NO3	AD MiN	OrgC%	TotN%
InNO3	0.346							
InMin	0.580	0.965 **						
AD NH4	-0.078	0.491	0.404					
AD NO3	-0.146	0.778 **	0.634	0.850 **				
AD MiN	-0.129	0.712	0.582	0.927 **	0.986 **			
OrgC%	0.496	0.453	0.532	0.182	0.208	0.206		
TotN%	0.829 **	0.453	0.626	0.114	0.060	0.080	0.607	
C+N%	0.536	0.466	0.555	0.182	0.202	0.202	0.998 **	0.655
HOx	0.596	0.452	0.560	0.204	0.213	0.217	0.607	0.841 **
H2SO4	0.244	0.348	0.371	-0.207	0.061	-0.023	0.480	0.203
KMnO4	0.580	0.409	0.518	0.253	0.212	0.232	0.547	0.844 **
KCl	0.710	0.145	0.325	0.054	-0.123	-0.070	0.702	0.785 **
KCl-AD	0.541	-0.282	-0.093	-0.738	-0.741	-0.765	0.334	0.442

	C+N%	HOx	H2SO4	KMnO4	KCl
HOx	0.642				
H2SO4	0.472	0.346			
KMnO4	0.585	0.984 **	0.176		
KCl	0.728	0.722	0.247	0.711	
KCl-AD	0.352	0.330	0.327	0.285	0.635

** r-values above 0.760 are significant at 0.1% level.

TABLE 8

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN NITROGEN VALUES OBTAINED BY CHEMICAL METHODS FOR 35 SURFACE SOIL SAMPLES OF MAF NORTH ISLAND. (0-15 cm depth).

	InNH4	InNO3	InMin	ADNH4	ADNO3	ADMin	MFADMi	OC%
InNO3	0.486							
InMin	0.845**	0.879**						
ADNH4	0.162	0.548	0.424					
ADNO3	0.535	0.849**	0.812**	0.681+				
ADMin	0.459	0.818**	0.752+	0.829**	0.974**			
MFADMi	0.166	0.677+	0.506	0.466	0.517	0.539		
OC%	0.544	0.547	0.632+	0.659+	0.536	0.613+	0.359	
N% .	0.523	0.538	0.615+	0.663+	0.499	0.586+	0.397	0.987**
C+N%	0.542	0.547	0.631+	0.660+	0.533	0.611+	0.363	1.000**
HOX	0.400	0.528	0.542	0.674+	0.498	0.588+	0.388	0.842**
H2SO4	0.449	0.494	0.548	0.687+	0.483	0.581+	0.339	0.947**
KMnO4	0.278	0.462	0.435	0.536	0.419	0.486	0.363	0.583+
KCl	0.440	0.550+	0.578+	0.828**	0.573+	0.693+	0.452	0.923**
KCl-AD	0.506	0.503	0.585+	0.691+	0.482	0.581+	0.407	0.942**

	N% .	C+N%	HOX	H2SO4	KMnO4	KCl
C+N%	0.989 **					
HOX	0.852 **	0.843 **				
H2SO4	0.934 **	0.947 **	0.901 **			
KMnO4	0.614 +	0.587 +	0.909 **	0.637+		
KCl	0.943 **	0.926 **	0.856 **	0.910 **	0.644+	
KCl-AD	0.966 **	0.946 **	0.849 **	0.914 **	0.629+	0.977**

\+ r-values above 0.550 are significant at 0.1% level;

** r-values above 0.800.

Figure 1

Relationship between residual mineral N (NH_4^+-N+NO_3^--N) and NO_3^--N values obtained from field-moist soil (Ravensdown-244 soils) (0-15 cm)

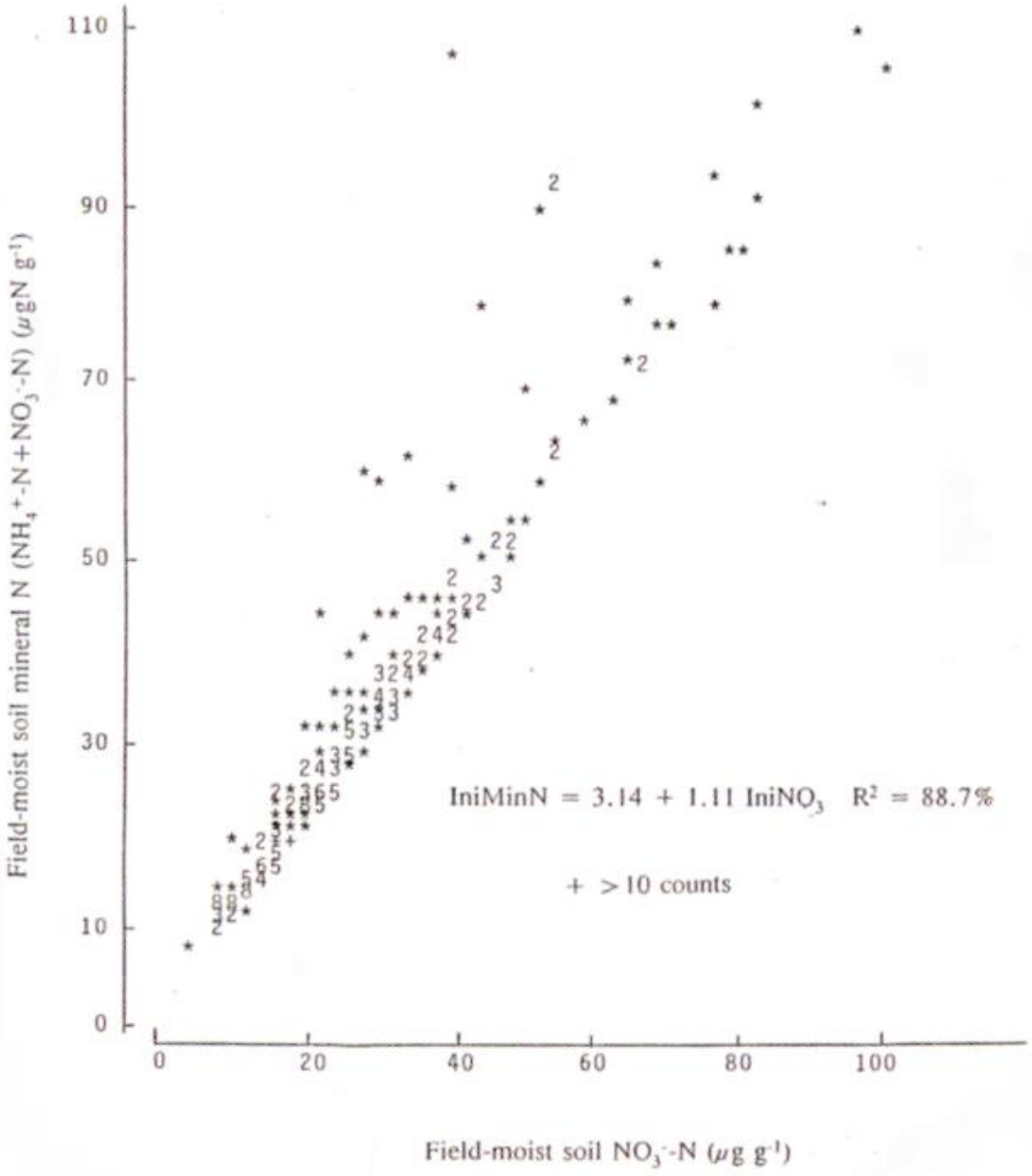
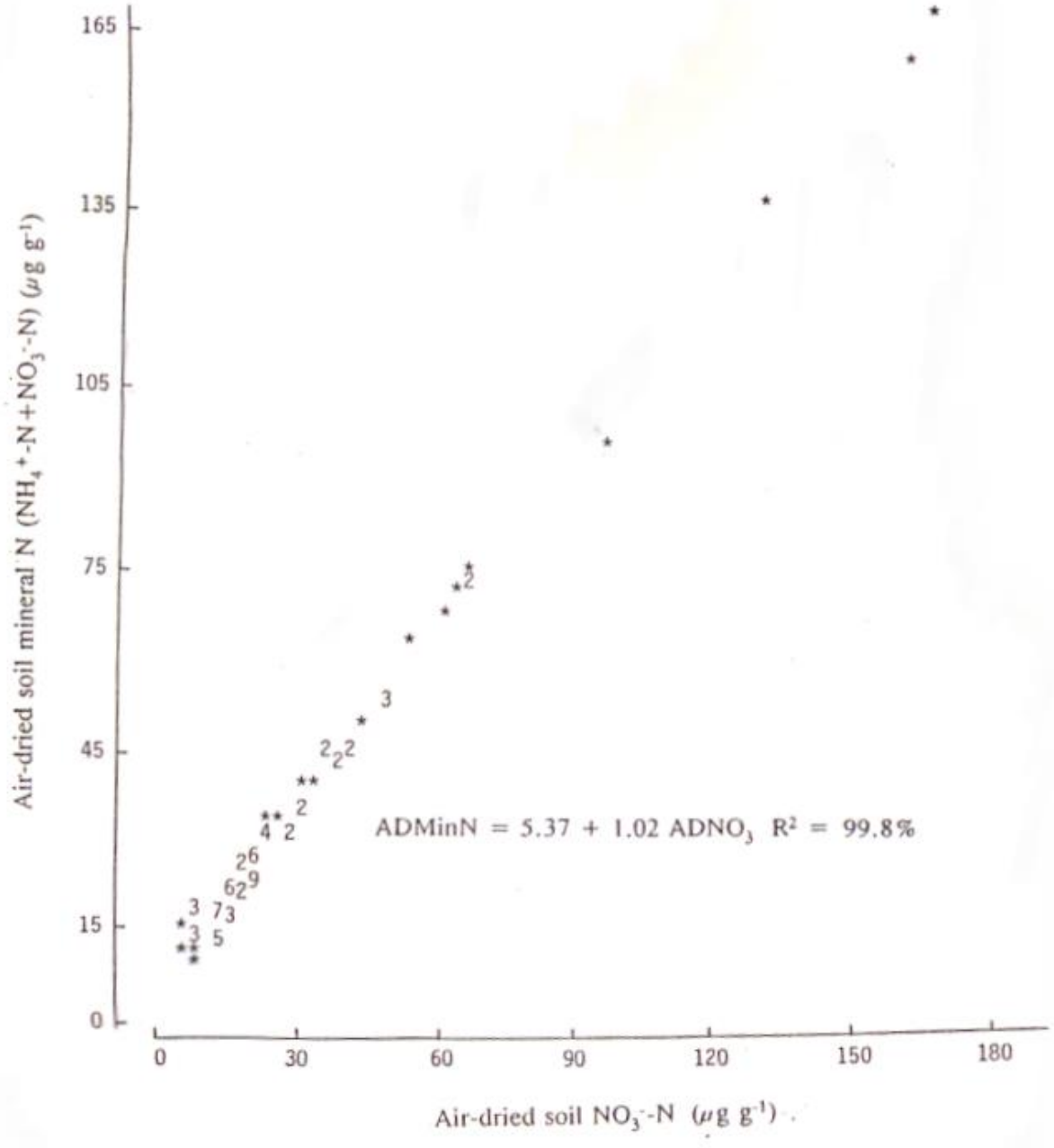


Figure 2

Relationship between residual mineral N (NH_4^+-N + NO_3^--N) and NO_3^--N values obtained from air-dried soil (Ravensdown-82 soils) (0–15 cm)



The regression equation obtained for the relationship for MAF. South Island air-dried soils is given below:

$$\text{Min.N 0-60 cm} = 36.2 + 6.47\ NO_3^-\text{-N};\quad R^2 = 80.4\%.$$

Although considerable quantities of NO_3^--N can be leached during a heavy rainfall, the amount leached depends on the soil type. It was estimated in the U.K. that the mean N losses during the winter season averaged from 85 kg N ha^{-1} for light soils in wet regions to 15 kg N ha^{-1} for heavy soils in regions where rainfall is less (Burns. 1982). Thus, it must be emphasised that heavy soils receiving low rainfall can retain considerable amounts of residual N even during the winter season, providing that denitrification losses are low.

The majority of the Canterbury soils tested in the present study are moderate to slow draining soils. These soils receive an average rainfall of only 58 mm per month (with a maximum of 71 mm rainfall occurring during May) and thus can be expected to retain most of the residual nitrogen. Therefore, for Canterbury soils, in an 'average year' it may be possible to use the residual N values as an availability index for N fertiliser recommendations.

Although soil sampling for N availability studies is not recommended soon after a heavy rainfall, the readily nitrifying nature of these soils may be able to replenish the leached NO_3^--N quicker than is expected. Although the soil incubation tests in the present study clearly demonstrated such ability (see Section 3.2.(c)), there are no microbiological evidence available for South Island soils to support this statement. Sarathchandra (1978), however, reported that significant number of nitrifying bacteria (10^4-10^7 g^{-1}) were found in some North Island soils. It is believed that extensive nitrification studies could enable the South Island soil N availability investigations to be more meaningful due to better understanding of N transformations in agricultural soils.

Air drying the soil samples normally results in increased release or extraction of mineral nitrogen. The problem is further accentuated if the air-dried soil samples arc crushed or ground, sieved and stored for a period of lime. Such soil sample preparation procedures lead to increased chemical extraction, hydrolysation or partial oxidation of soil organic and/or inorganic nitrogen. It should be noted that the main objective of any chemical test is to perform accurate and inexpensive analysis within the shortest possible time. The experience obtained from the present study emphasises that such tests should be conducted on field-moist soils. The advantage and importance of analysing field-moist soil have already been emphasised in Section 1.1.1. Further emphasis on the possibility of using field-moist soil for reliable results will be placed on incubation tests in the forthcoming sections.

(d) Comparison of acid $KMn0_4$-N values with that obtained from other chemical tests.

The acid $KMnO_4$ method (Stanford and Smith. 1978), did not correlate well with any of the chemical methods tested in this study. It was stated earlier that the acid $KMnO_4$ oxidises a certain fraction of the soil organic N yielding NH_4^+-N. These amounts appeared to be unrelated to the amounts obtained by the other extraction techniques, such as 1 *N* H_2SO_4 extractable N (Stanford and Smith. 1978).

Table 8a

The correlation coefficient values for the relationship of NH_4^+-N and NO_3^--N with total mineral N and percent NH_4^+-N and NO_3^--N present in the total mineral N obtained from field-moist and air-dried surface soils (0-15 cm depth)

		Field-moist soil		Air-dried soil	
Location	No. of Soils	Ini.NO3 vs IniMinN	Ini.NH4 vs IniMinN	AD NO3 vs ADMinN	AD NH4 vs ADMinN
Ravensdown	244	0.942 **82%**	0.577 **18%**	- -	- -
	82	0.982 **85%**	0.419 **15%**	0.999 **83%**	0.417 **17%**
MAF SI	15	0.963 **66%**	0.766 **34%**	0.973 **64%**	0.939 **36%**
MAF NI	35	0.879 **49%**	0.845 **51%**	0.974 **65%**	0.829 **35%**

Note: All the r values are significant at 0.1% level.
Numbers quoted in **bold** are percent NH_4^+-N or NO_3^--N present in total mineral nitrogen.

Table 8b

The correlation coefficient values for the relationship of NH_4^+-N and NO_3^--N with total mineral N and percent NH_4^+-N or NO_3^--N content in total mineral N obtained from 0-60 cm profile field-moist and air-dried MAF South Island soils

		Field-moist soil		Air-dried soil	
Depth(cm)	No. of Soils	Ini.NO3 vs IniMinN	Ini.NH4 vs IniMinN	AD NO3 vs ADMinN	AD NH4 vs ADMinN
0-15	15	0.963 **66%**	0.766 **34%**	0.973 **64%**	0.939 **36%**
15-30	15	0.965 **79%**	0.580* **21%**	0.986 **71%**	0.927 **29%**
30-45	13	0.955 **85%**	0.579* **15%**	0.985 **79%**	0.877 **21%**
45-60	13	0.995 **93%**	-0.314* **7%**	0.987 **88%**	0.155* **12%**
0-60	13	0.967 **81%**	0.628 **19%**	0.994 **76%**	0.940 **24%**

Note: All the r values are significant at the 0.1% level except those indicated by * which are not significant.

Numbers quoted in **bold** are percent NH_4^+-N and NO_3^--N present in total mineral nitrogen.

The only significant correlation obtained was with total N percentage at the 15-30 cm depth for the MAF; South Island N trial control plot soils (r=0.844) (Table 7). This may be due to the strong relationship between total soil N content and the acid $KMnO_4$ oxidisable fraction of organic nitrogen present in the sub-surface soils.

(e) Comparison of 1 *N* H_2SO_4 extractable N values with the N values obtained from other chemical methods.

Although this simple method yielded statistically significant correlations with residual N values and total N and organic C contents for the Ravensdown soils (Table 5), the relationships with boiling KCl nitrogen values, total N (Figure 3a) and organic C percentages were stronger for North Island soils (Table 8). These findings show that it may be possible to predict the total soil N and organic C contents from 1 *N* H_2SO_4 extractable N values for these organic N rich soils (N% > 0.214 and OC% > 2.59). The following equations could be used for the soils studied:

Figure 3a
Relationship between percent total nitrogen and 1N H_2SO_4 extractable N values (NH_4^+-N $\mu g\ g^{-1}$) (MAF North Island-35 soils)(0-15 cm depth)

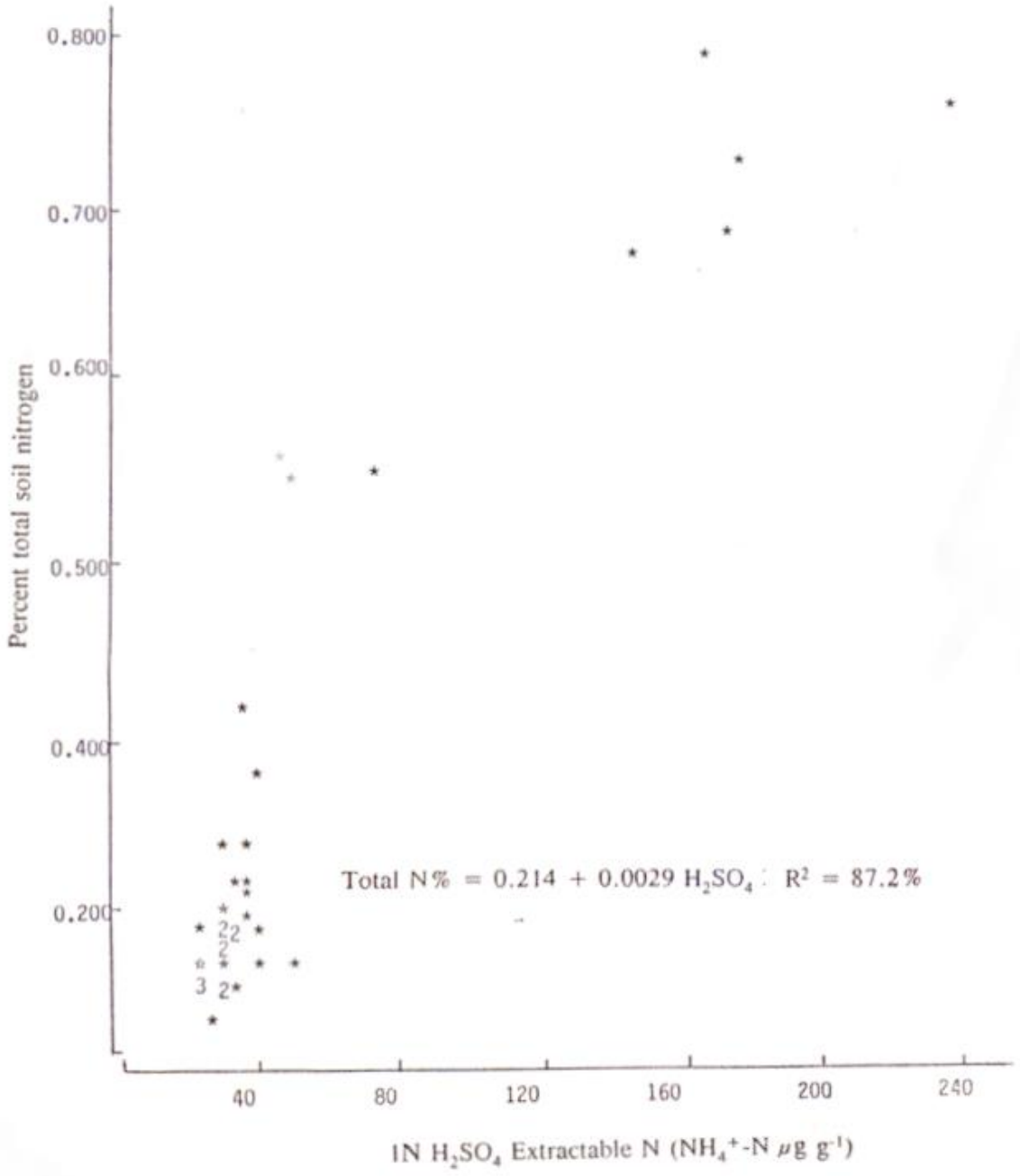
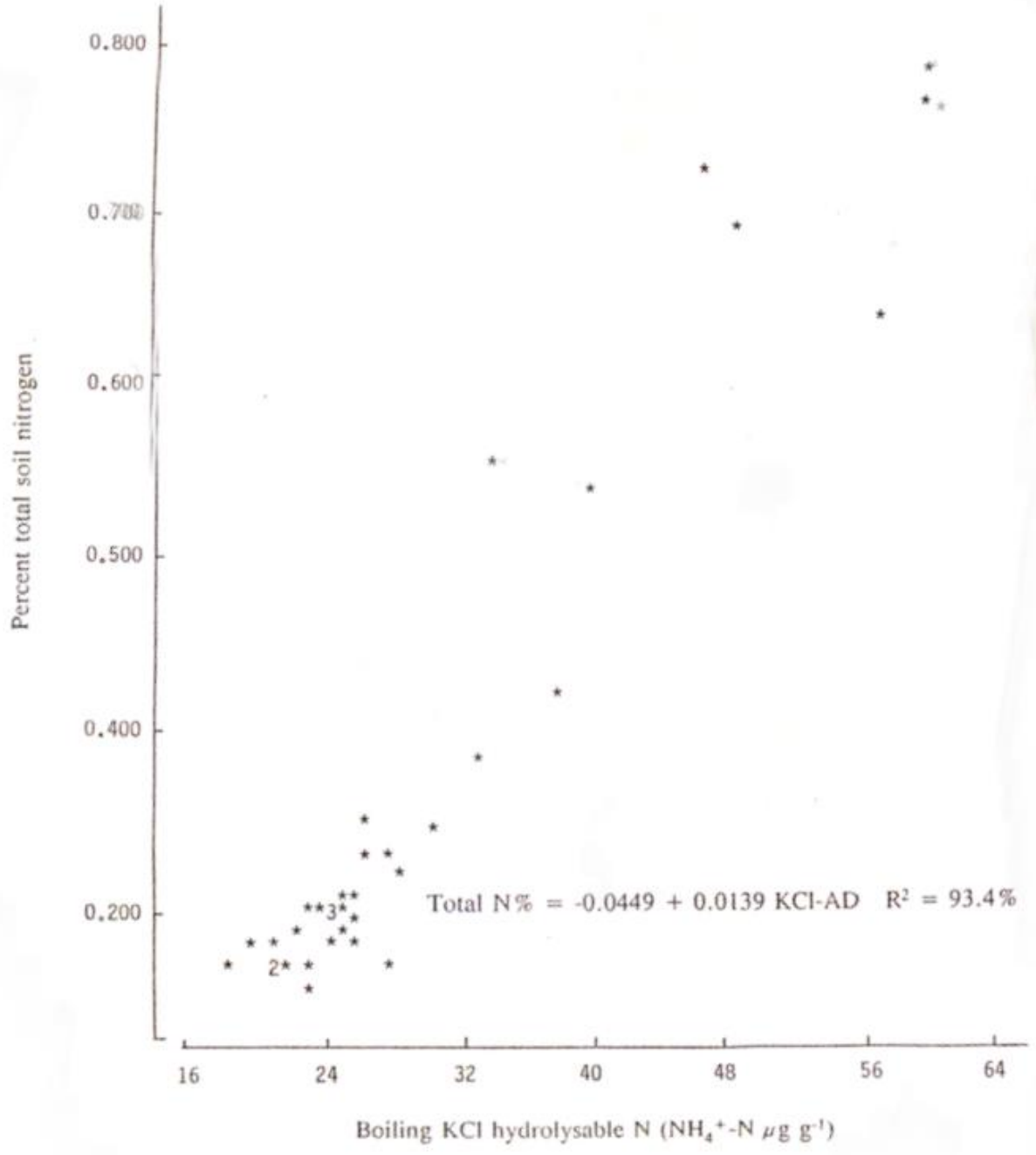


Figure 3b

Relationship between percent total soil nitrogen and boiling KCl hydrolysable N values (NH_4^+-N $\mu g\ g^{-1}$) (MAF North Island-35 soils) (0-15 cm depth)



Tolal N% = 0.214 + 0.0029 H_2SO_4; R^2 = 87.2%

Organic C% = 2.59 + 0.0308 H_2SO_4; R^2 = 89.6%

(f) Comparison of boiling KC1 hydrolysablc N values with (hat of other chemical methods

The boiling KCl method has been recommended by Gianello and Bremner (1986) as the best chemical method thus far developed for laboratory assessment of potentially available organic N *(No)* in soil. Although acid $KMnO_4$ oxidisable N gave them a good correlation (r = 0.85) with potentially available organic N *(No),* the relationship was not as strong as with boiling KCl N values (r=0.95). It was indicated that the pre-extraction of soil N by 1 *N* H_2SO_4 before the actual acid $KMnO_4$ extraction resulted in twice the amount of NH_4^+-N than boiling KCl. The reason given for relatively lower correlation obtained between acid $KMnO_4$ N values and *No* was that the organic N which was readily hydrolysed by 1 *N* H_2SO_4 was not recovered by the subsequent extraction with acid $KMnO_4$ solution. However. Gianello and Bremner (1986) did not attempt to show any relationship between KCl hydrolysable N and 1 *N* H_2SO_4 hydrolysable N. The present investigation of this method clearly demonstrates that there was a good correlation between N values obtained by 1 *N* H_2SO_4 and the boiling KCl extraction (r=0.914) for the North Island soils tested. The correlation coefficient value obtained between acid $KMnO_4$ and boiling KCl N values, however, was lower (r = 0.629).

The high statistically significant correlation values obtained for boiling KCl hydrolysable N with soil mineral N values and all the other chemical methods for North Island (Table 8) and Ravensdown soils (Table 5) suggests that boiling KCl method is suitable for a range of soils. The regression equation obtained for the relationship with total N content indicates that this method can also be used to predict the soil total N content for the North Island soils (Figure 3b) using the following equation:

Total N% = 0.0449 + 0.0139 KCl-AD; R^2 = 93.4%

In contrast, the method did not show significant correlation with any of the chemical methods tested for MAF South Island soils at 0-15 and 15-30 cm soil depth. It should be noted that the MAF South Island soils were slightly lower in organic C and total N content compared to the Ravensdown and North Island soils (Table 4). Moreover, the lower standard deviation values obtained for MAF (South Island) organic C and total soil N contents (0.4 and 0.03 respectively) than that of Ravensdown (0.8 and 0.08 respectively) and MAF North Island (1.7 and 0.2 respectively) suggests that the MAF South Island soils also had a narrow range of organic carbon and total soil N contents.

3.2 Comparison of biological methods

(11) Amount of mineralisation

Of the three biological methods employed the order of efficiency of mineralisation based on the amount of N released by incubation was anaerobic > 14-day > 7-dav aerobic incubation (Table 9). The North Island soils yielded more mineralisable N followed by the Ravensdown soils and lastly the MAF South Island soils. The MAF South Island soils appeared to respond better for the anaerobic incubation than for the other two incubation methods.

It should be noted that the 7-day and 14-day aerobic incubations of the Ravensdown soils yielded some negative mineralisation values indicating that short-term incubation does not always result in net mineralisation. This finding may even question the reliability of the positive net mineralisation values obtained in the short-term aerobic incubation studies. Such values may not purely represent the actual mineralised amounts obtained during the incubation period because it is likely that the final mineral N values obtained are the sum of the amount of mineral N involved in mineralisation-nitrification-denitrification-immobilisation interactions.

The anaerobic incubation performed on field-moist soil at the MAF North Island laboratory mineralised 74 µg g^{-1} of NH_4^+-N (mean value). However, when the soils were anaerobically incubated at the Lincoln College laboratory (after being air-dried and stored for about 6 months) the mineralised NH_4^+-N value increased to 108 µg g^{-1} (mean value) (for explanation see Section 1.1.1.).

(b) Comparison of 7-dav aerobic incubation test performed at the Ravensdown Fertiliser Co-operative and Lincoln College laboratories.

There was a very poor correlation (r = -0.073) observed between the mineralised N values obtained using the 7-day incubation method at both laboratories (Figure 4). Although the mean N values were similar, the variation in maximum and minimum values was high (Table 9) indicating that the values obtained from both laboratories for a particular soil sample may not relate to each other.

A thorough analysis of Figure 4 reveals the following findings and questions the reliability of the 7-day aerobically minerlisable N method:

(i) Minimum and maximum 7-day aerobically minerlisable N values obtained at the Ravensdown laboratory were 10 and 80 µg N g^{-1} whereas values of 3 and 177 µg N g^{-1} were obtained at the Lincoln College laboratory.
(ii) Although the majority of the values lie between 0-80 µg N g^{-1} range, only about 10 soils of the total 82 Ravensdown soil samples show approximately similar values.
(iii) The majority of the samples produced entirely different mineral N values when they were incubated in both laboratories. For example, a soil sample which minerlised only 30 µg N g^{-1} at the Ravensdown laboratory produced 176 µg N g^{-1} at the Lincoln College laboratory. In contrast, a sample which produced 50 µg N g^{-1} at the Ravensdown laboratory mineralised only 2 µg N g^{-1} at the Lincoln laboratory.
(iv) Although the soils incubated at the Lincoln College laboratory appeared to have produced more mineral N than at the Ravensdown laboratory (see (i) the mean mineralised N values were approximately similar for both laboratories (50 and 45 µg N g^{-1} respectively (Appendix 4)).

When this method was studied by Quin *et al.,* (1982) it was concluded that "the disadvantage of the time required for the incubation (7 days) is more than made up for by the flexibility in the timing of the test, and its reduced susceptibility to errors due to small changes in the mineral N content during storage of the sample prior to analysis". However, the present study has shown that sample handling and storage must have had a large effect on the N values obtained using the 7-day incubation test in the Ravensdown and Lincoln College laboratories. Keenev (1982) cautioned that the results of any short-term incubation must be treated with care because mineralised N values would be affected by sample pre-treatments and handling. This has also been emphasised in Section 1.1.1.

TABLE 9

MEAN, MINIMUM AND MAXIMUM VALUES OBTAINED BY BIOLOGICAL METHODS FOR DIFFERENT LOCATIONS AND SOIL DEPTHS ($\mu gN\ g^{-1}$).

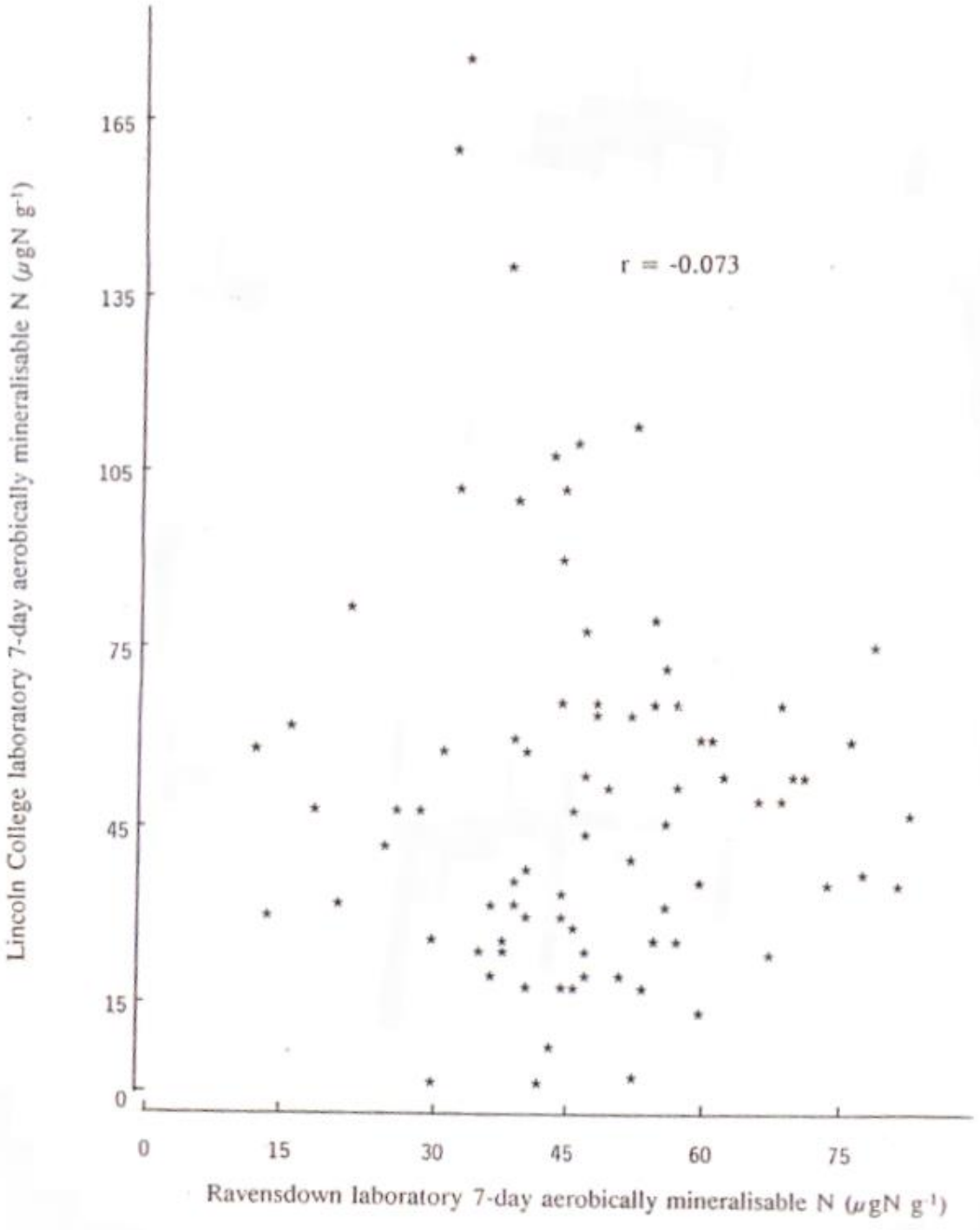
Location/Depth	Sample No.	7dNH_4N	7dNO_3N	7dMin.N	7dPot.N	E17dNH_4	E17dNO_3	E17dMin	E17dPot
Ravensdown (0-15cm)	244	13 [1-79]	69 [25-206]	82 [27-266]	47 [-38-178]				
Ravensdown (0-15cm)	82	14 [1-80]	71 [35-206]	85 [39-206]	51 [3-177]	6 [1-18]	73 [34-106]	79 [38-122]	45 [10-80]
MAF South (0-15cm)	15	6 [1-14]	37 [25-59]	43 [27-73]	29 [15-46]				
MAF South (15-30)	15	4 [1-13]	26 [15-39]	30 [16-47]	17 [8-34]				
MAF South (30-45cm)	15	4 [1-12]	13 [5-25]	17 [7-36]					
MAF North (0-15cm)	35			62 [28-128]	48 [10-107]				

TABLE 9 (contd.)

Location/Depth	Sample No.	14dNH_4N	14dNO_3N	14dMinN	14dPotN	Anaer-AD	Anaer-NH_4
Ravensdown (0-15cm)	82	3 [1-43]	102 [58-215]	105 [60-221]	70 [-13-162]	83 [49-176]	
MAF South (0-15cm)	15	3 [1-7]	72 [38-85]	76 [40-86]	56 [10-77]	80 [49-119]	
MAF South (15-30cm)	15	6 [1-15]	57 [40-78]	63 [46-82]	45 [10-68]	49 [30-84]	
MAF North (0-15cm)	35	14 [3-80]	104 [57-175]	119 [62-179]	89 [37-138]	108 [43-163]	74 [22-136]

Method Anaer-AD : 7d anaerobically mineralised NH_4^+-N from air-dried soil;
Method Anaer-NH_4 : 7d anerobically mineralised NH_4^+-N from field-moist soil.
Values in parenthesis are minimum-maximum values and others are mean values.

Figure 4
Relationship between 7-day aerobically mineralisable N values obtained from the Ravensdown and Lincoln College laboratories (82 soils) (0-15 cm depth)



The following treatments are believed to have caused the poor correlation observed between the 7-day aerobically mineralisable (Pot N) values obtained from both laboratories:

(i) Soil samples were incubated after one month storage in the refrigerator at the Lincoln College laboratory.

(ii) Soil moisture content which is considered as one of the major factors influencing the soil N minerlisation was not adjusted to optimum amounts (field capacity) during the incubation. Note that the soils tested had a wide range of field moisture contents (minimum, 9.5 and maximum 31.5 % wet weight basis).

(iii) It is believed that the provision of an aerobic condition for the incubation was not satisfactory in both laboratories. Soil samples were placed in unsealed polyethylene bags and incubated after simply folding the bags once. It is suspected that high incubation temperature (37°C) could have caused excess evaporation of soil water which was condensed in the bag and subsequently stopped the air circulation by sealing some of the bags completely at the folded area. Consequently, soil samples with good air circulation were mineralised and nitrified well. This was evident with the significant differences observed among the duplicates and quadruplicates of some of the soil samples incubated at the same time. These differences may also have been caused by an uneven distribution of potentially mineralisable soil N in the wet soil samples which were difficult to mix uniformly before placing in the bags for incubation.

(iv) Different methods of analysis of mineral N have been employed at both laboratories. Although this may also have contributed to the different values obtained from both laboratories the errors involved should be relatively small compared to those introduced by sample handling.

Note that the 7-day aerobically minerlisable N values were obtained by subtracting the initial mineral N value from final mineral N value measured after 7 days incubation. The correlation between initial mineral N values of both laboratories was, however, not as strong as expected ($r = 0.774$) (Table 5) (section 3.1b). On the other hand, a statistically significant but poor correlation value ($r = 0.374$) was obtained between final mineral N (7-day mineral N) value of both laboratories (Table 10). Consequently, the correlation analysis for the 7-day minerlisable N values from each laboratory gave a lower coefficient ($r = -0.073$).

Moreover, it should be noted that soils which are incubated aerobically over short time periods are sensitive to the level of aeration. Sufficient aeration should be provided during the incubation period. If the soil samples are incubated in the open containers, a device may be set up to humidify the incubator to prevent water loss from the soil samples. It is also suggested to adjust the soil moisture content to field capacity and mix the moist soil sample with acid washed-sterilised quartz sand before the incubation. This will enable the soil samples to be mixed thoroughly and thus is expected to provide uniform and maximum aerobic mineralisation and nitrification conditions. The use of short-term aerobic incubations is only possible if the conditions of sample preparation and incubation are rigidly standardised and controlled. Otherwise, the values obtained may be inaccurate and misleading.

(c) Comparison of 14 day aerobic incubation with other biological tests.

There was only a very poor correlation obtained between the 14-day and the 7-day aerobically mineralisable N values of all the soils tested (Tables 10, 11, 12 and 13). Figure 5 shows the poor correlation ($r = 0.004$) between 7-day and 14-day aerobically mineralisable N values for

the Ravcnsdown soils. This is thought to be due to the errors involved in the 7-day incubation test, as described previously (section 3.2(b)). However, the 14-dav method showed a good relationship with NH_4^+-N released after 7-day anaerobic incubation of the 0-15 and 15-30 cm MAF South Island soils (r=0.852 and 0.840 respectively) (Tables 11 and 12).

The 14 day mineralisable N values of 0-15 cm soils correlated well with 15-30 cm 14-day mineralisable N values (r=0.868) (Appendix 9b) indicating that there was a strong relationship between mineralising capacity of both surface and sub-surface soils. The present study of two aerobic incubation tests also revealed that measurement of the final amount of NO_3^--N produced was adequate to predict final mineral N released (Figures 6 and 7). The NO_3^--N relationship with mineral N clearly demonstrated that Canterbury soils have high nitrifying capacity. Evidently. NH_4^+-N values were found to be continuously unstable due to their consistently lower values obtained during the whole growing season for Canterbury soils (personal communication with MAF. Lincoln). Similar behaviour was observed in the laboratory incubation tests indicating that the NH_4^+-N mineralised from organic N was readily nitrified.

The strong correlation between the 14-day incubation and the anaerobically mineralisablc N values agreed with the similar relationship obtained by Waring and Bremner (1964). When this anaerobic method was developed it was performed for 2 weeks at 30°C. Later. Keeney and Bremner (1966) modified it to incubating for only 1 week at 40°C. Their findings showed that the relationship between the two anaerobic methods and 14-day incubation technique was strong.

(d) Comparison of anaerobic incubation method with other biological tests.

The amount of NH_4^+-N mineralised from field-moist soil after 7-days anaerobic incubation was highly correlated with the 7-day anaerobic incubation of air-dried (and stored for 24 weeks) North Island soils (r=0.734) (Table 13). Keeney and Bremner (1966) obtained a better correlation between field-moist and stored (up to 48 weeks) air-dried soil anaerobic incubations ($r > 0.95$) than is reported here. The high correlation coefficients obtained for field-moist soils is promising and requires more investigation.

The anaerobic incubation method has several advantages over the 7-day aerobic incubation test. Thus it can be strongly recommended for routine measurement of N-supplying capacity of the soils for the following reasons:

(i) It is rapid and precise.
(ii) Only NH_4^+-N need to be measured.
(iii) Only a small sample of soil is needed (5 to 10 g).
(iv) The problems of establishing an optimal water content and the loss of water during the incubation are avoided.
(v) With the addition of a nitrifying inhibitor special precautions or equipment is not necessary to provide anaerobic conditions.
(vi) The effect of sample pre-treatment is less than with the short-term aerobic incubations.
(vii) With the addition of 4 *N* KCl and a few seconds shaking, the sample is ready for NH_4^+-N analysis.
(viii) Nitrogen mineralisation under submerged conditions is usually not limited. Therefore the net result is positive mineralisable N values. The present study also indicates that

TABLE 10

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN BIOLOGICAL METHODS FOR 82 SOIL SAMPLES OF RAVENSDOWN FERT. CO-OP. (0-15 cm depth)

	7D.NH4	7D.NO3	7dMinN	PotMiN	14dNH4-N	14dNO3-N	14dMin-N	14dPotN
7D.NO3	0.411 §							
7dMinN	0.677 §	0.949 **						
PotMiN	0.847 **	0.724 §	0.877 **					
14dNH4-N	-0.060	0.309	0.228	-0.005				
14dNO3-N	0.010	0.645 §	0.524 §	0.270	0.271			
14dMin-N	0.001	0.658 §	0.531 §	0.256	0.396 §	0.991**		
14dPotN	0.003	-0.006	-0.004	0.004	0.189	0.589§	0.588§	
Anaerob	0.129	0.533 §	0.474 §	0.371 §	0.138	0.703§	0.690§	0.385§
Ana -AD	0.123	0.519 §	0.462 §	0.363 §	0.126	0.699§	0.684§	0.386§
El 7dNH4	-0.078	0.130	0.078	-0.045	0.178	0.183	0.199	-0.016
El 7dNO3	-0.052	0.485 §	0.373 §	0.186	0.138	0.445§	0.443§	-0.032
El7dMinN	-0.064	0.490 §	0.374 §	0.172	0.164	0.461§	0.462§	-0.033
ElPotMin	-0.107	-0.255	-0.243	-0.073	-0.193	-0.036	-0.061	0.272

	Anaerob	Ana -AD	El7dNH4	El7dNO3	El7dMinN
Ana -AD	0.998 **				
El 7dNH4	0.092	0.082			
El 7dNO3	0.236	0.236	0.117		
El7dMinN	0.243	0.242	0.288	0.985 **	
ElPotMin	0.004	0.008	0.065	0.374 §	0.371 §

§ r-values above 0.357 are significant at .1% level;

** r-values above 0.750.

Figure 5
Relationship between 7 and 14-day aerobically mineralisable N values (μg g^{-1}) obtained at the Lincoln College laboratory (Ravensdown-82 soils) (0-15 cm)

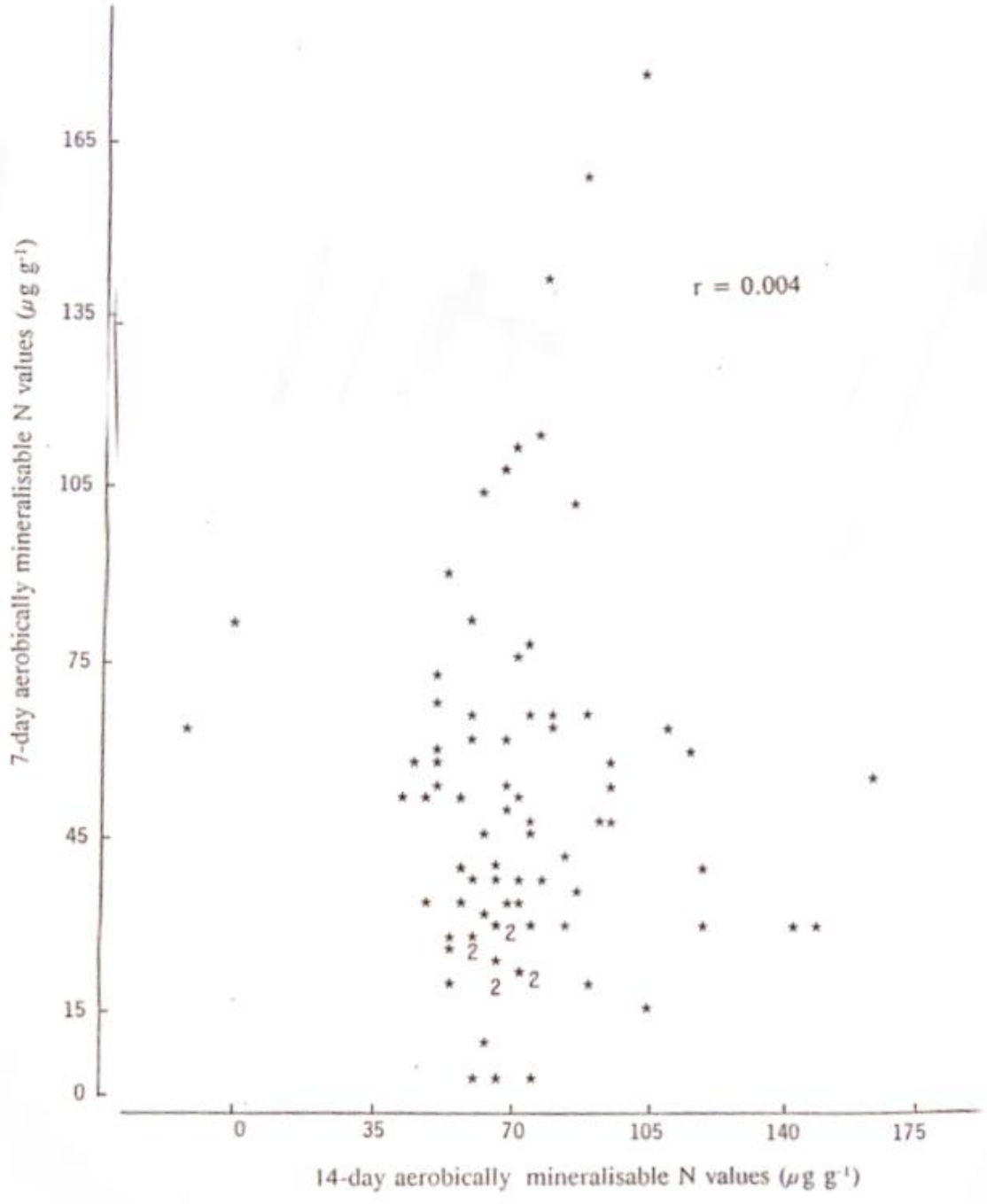


TABLE 11

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN BIOLOGICAL METHODS FOR 15 SOIL SAMPLES FROM MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 0-15 CM SOIL DEPTH.

	7dNH4	7dNO3	7dMinN	PotN	14dNH4	14dNO3	14dMin	14dPot
7dNO3	0.643							
7dMinN	0.847 **	0.952 **						
PotN	0.733	0.634	0.733					
14dNH4	-0.401	-0.426	-0.456	-0.193				
14dNO3	-0.010	0.080	0.052	-0.274	0.092			
14dMin	-0.070	0.013	-0.019	-0.297	0.242	0.988**		
14dPot	-0.408	-0.372	-0.421	-0.551	0.467	0.811**	0.861**	
Anaero	-0.667	-0.324	-0.492	-0.579	0.375	0.571	0.613	0.741
Ana-AD	-0.670	-0.400	-0.546	-0.641	0.484	0.600	0.658	0.852**

	Anaero
Ana-AD	0.970 **

** r-values above 0.760 are significant at 0.1% level.

TABLE 12

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN BIOLOGICAL METHODS FOR 15 SOIL SAMPLES FROM MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 15-30 CM SOIL DEPTH.

	7dNH4	7dNO3	7dMin	PotN	NH414d	NO314d	Min14d	Pot14d
7dNO3	0.589							
7dMin	0.787 **	0.962 **						
PotN	0.899 **	0.456	0.651					
NH414d	-0.445	-0.467	-0.507	-0.254				
NO314d	-0.038	0.533	0.394	-0.196	-0.537			
Min14d	-0.245	0.412	0.232	-0.343	-0.177	0.925 **		
Pot14d	-0.802	-0.452	-0.615	-0.804	0.170	0.415	0.561	
Anaero	-0.290	0.120	-0.006	-0.388	-0.247	0.820 **	0.846 **	0.667
Ana-AD	-0.524	-0.094	-0.248	-0.598	-0.112	0.710	0.778 **	0.840 **

	Anaero
Ana-AD	0.956 **

** r-values above 0.760 are significant at 0.1% level.

all the anaerobically mineralisable N values obtained were positive whilst both aerobic incubations yielded some negative values.

(ix) The ammonium electrode method can be used very conveniently.

If the Ravensdown 7-day aerobic incubation method was replaced by the more accurate anaerobic test, the accuracy of fertiliser recommendations would be improved.

3.3 Chemical vs Biological methods

Only one chemical method that of boiling KCI hydrolysable N. yielded good correlations with the biological methods tested (Tables 14, 15, 16 and 17). Boiling KCl hydrolysable N showed good correlations with mineralisable N values obtained from all the biological methods studied (Table 17a).

Table 17a Correlation coefficients obtained for the relationship between boiling KCl hydrolysable N and selected biological N indices

Soil	Number of soils	Biological N indices	r^+
MAF South Island			
0-15 cm	15	14 d aerobic N	0.779
		7 d anaerobic N	0.828
15-30 cm	15	14 d aerobic N	0.921
		7 d anaerobic N	0.881
MAF North Island			
0-15 cm	35	7 d fresh anaerobic N	0.581
		7 d aerobic N	0.544
Ravensdown Fert. Co-op.			
0-15 cm	82	7 d anaerobic N	0.524

+ All r-values reported are significant at 0.1% level

This clearly explains the selective extractability of soil organic N by boiling KCl and its relationship with biologically available soil N after incubation. This simple chemical method also appears to be a possible alternative to the 7- day aerobic incubation method. The method if used in routine analysis would save space, time and reduce the likelihood of sample pre-treatment errors which are associated with short-term incubation tests. However, further evaluation is necessary using field moist rather than using air-dried soil. Field trials to relate this test to crop yield and N uptake are also seen as the next priority.

Figure 6

Relationship between 7-day mineral N (NH_4^+-N + NO_3^--N) and 7-day NO_3^--N values (μgN g^{-1}) (Ravensdown-244 soils) (0-15 cm depth)

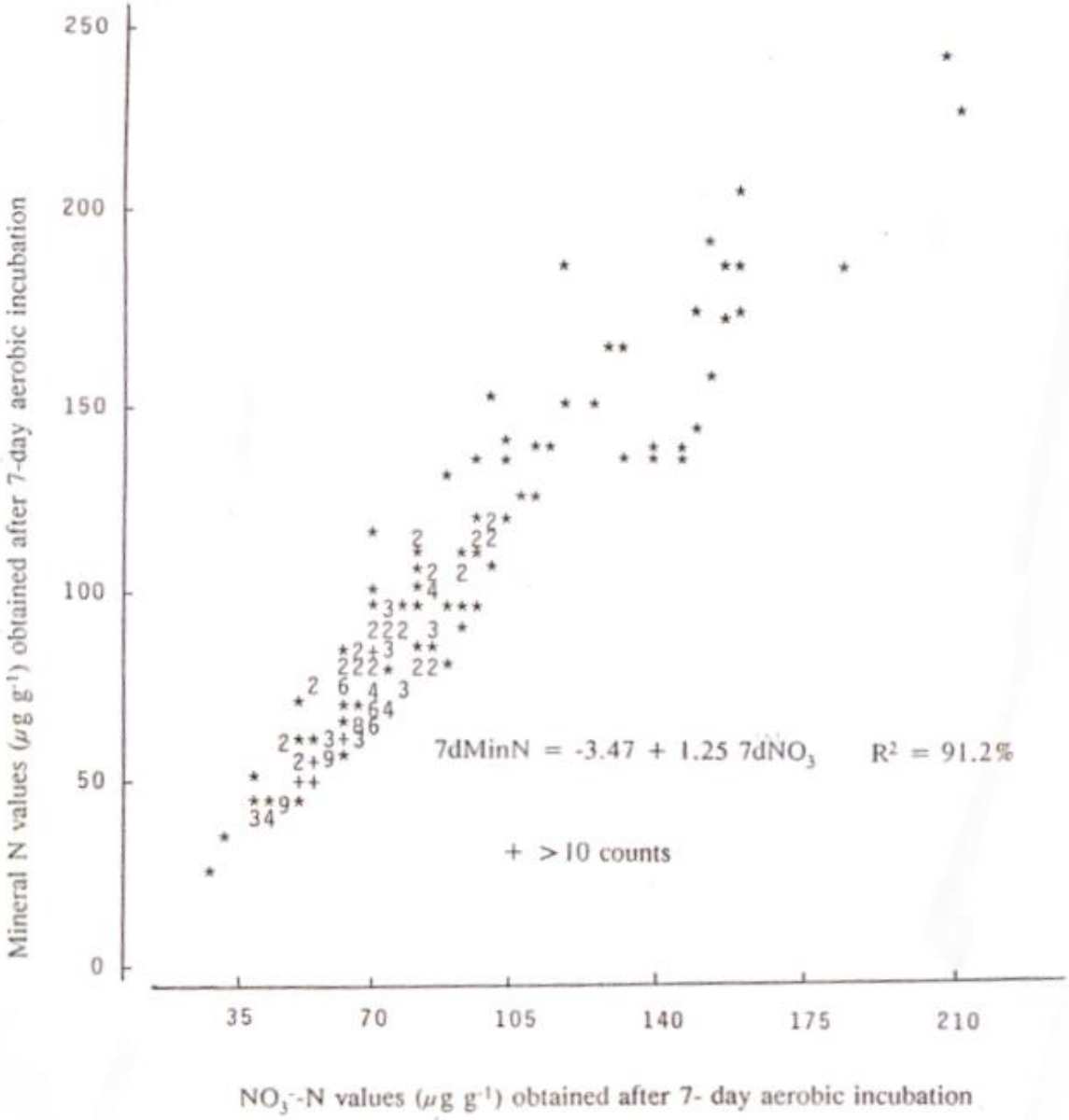


Figure 7

Relationship between 14-day mineral N (NH_4^+-N + NO_3^--N) and 14-day NO_3^--N values ($\mu g\ g^{-1}$) (Ravensdown-82 soils)

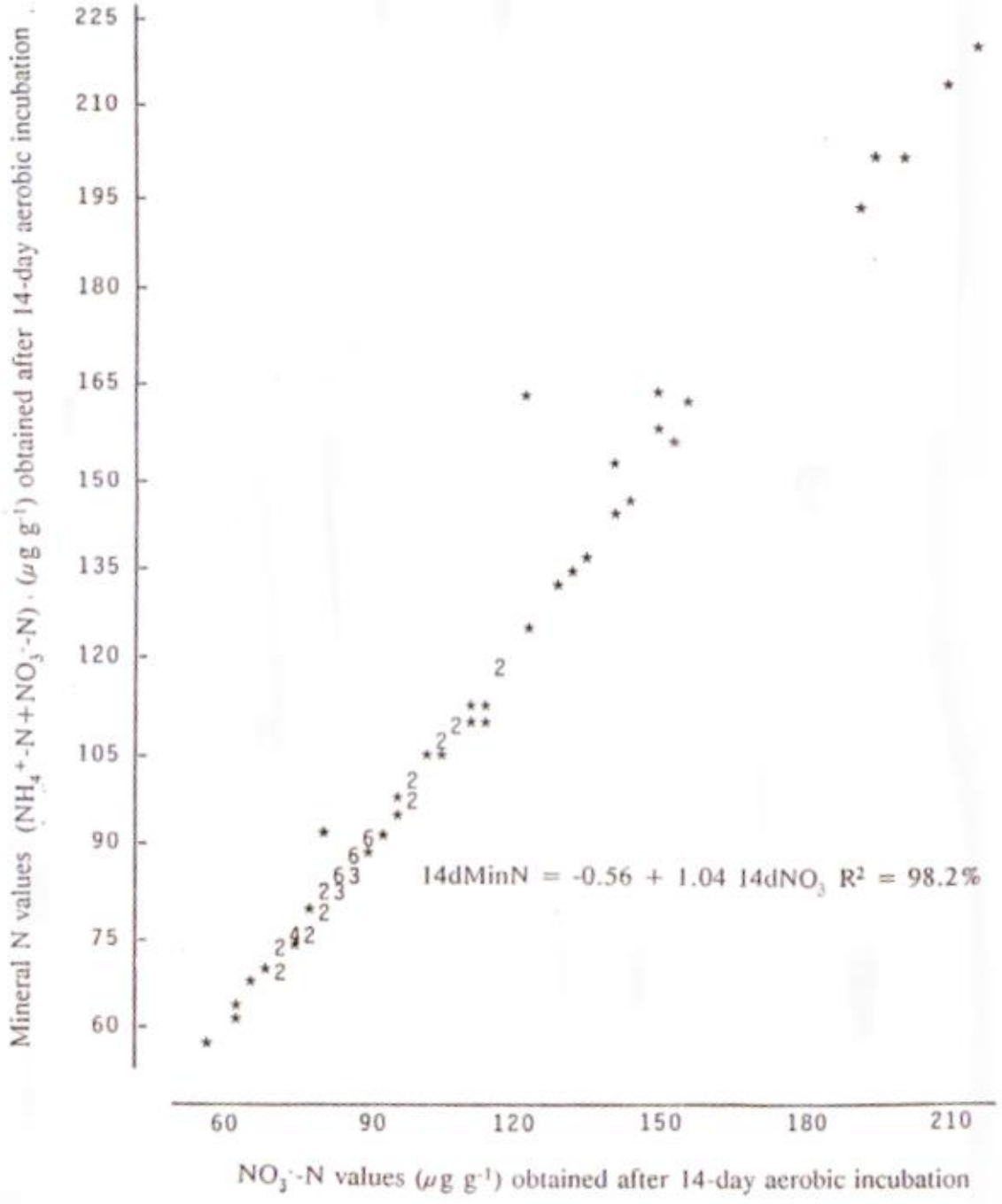


TABLE 14

CORRELATION COEFFICIENTS FOR THE RELATIONSHIP BETWEEN BIOLOGICAL AND CHEMICAL METHODS FOR 82 SOIL SAMPLES OF RAVENSDOWN FERTILISER CO-OP. (0-15 cm depth).

	IniNH4	IniNO3	InMinN	AD NH4	AD NO3	AD Min	OrgC%	TotN%
7D.NH4	-0.003	0.012	0.011	0.153	-0.009	-0.001	0.127	0.120
7D.NO3	0.074	0.806 **	0.769 **	0.494 §	0.800 **	0.809 **	0.597 §	0.618 §
7dMinN	0.059	0.654 §	0.624 §	0.451 §	0.643 §	0.652 §	0.525 §	0.540 §
PotMiN	-0.183	0.222	0.172	0.335	0.299	0.310	0.339	0.357 §
14dNH4-N	0.312	0.445 §	0.476 §	0.263	0.313	0.320	0.357 §	0.365 §
14dNO3-N	0.014	0.677 §	0.636 §	0.472 §	0.689 §	0.699 §	0.730 §	0.724 §
14dMin-N	0.057	0.707 §	0.672 §	0.486 §	0.700 §	0.711 §	0.746 §	0.741 §
14dPotN	0.055	-0.027	-0.015	0.204	-0.165	-0.152	0.444 §	0.404 §
AnaerobN	-0.078	0.410 §	0.369 §	0.598 §	0.488 §	0.508 §	0.631 §	0.606 §
AnaN-ADN	-0.092	0.401 §	0.357 §	0.552 §	0.481 §	0.499 §	0.615 §	0.589 §
El 7dNH4	0.091	0.230	0.233	0.191	0.253	0.258	0.216	0.241
El 7dNO3	-0.163	0.528 §	0.463 §	0.134	0.574 §	0.569 §	0.239	0.272
El7dMinN	-0.141	0.549 §	0.487 §	0.163	0.598 §	0.594 §	0.268	0.305
ElPotMin	-0.219	-0.361	-0.379	-0.058	-0.314	-0.311	-0.093	-0.074

	HOx	H2SO4	KMnO4	C+N%	KCl	KCl-AD	ElIniNH4	ElIniNO3	ElInMinN
7D.NH4	0.296	0.125	0.300	0.127	0.180	0.160	-0.024	0.027	0.022
7D.NO3	0.569 §	0.677 §	0.442 §	0.604 §	0.651 §	0.594 §	0.140	0.687 §	0.679 §
7dMinN	0.561 §	0.590 §	0.461 §	0.531 §	0.588 §	0.535 §	0.105	0.564 §	0.555 §
PotMiN	0.454 §	0.351	0.411	0.344	0.385 §	0.342	0.011	0.234	0.225
14dNH4-N	0.241	0.492 §	0.126	0.361 §	0.184	0.140	0.179	0.298	0.312
14dNO3-N	0.457 §	0.683 §	0.313	0.736 §	0.652 §	0.600 §	0.013	0.497 §	0.477 §
14dMin-N	0.469 §	0.719 §	0.316	0.751 §	0.647 §	0.592 §	0.037	0.515 §	0.498 §
14dPotN	0.178	0.249	0.128	0.444 §	0.245	0.220	-0.137	-0.237	-0.248
Anaerob	0.503 §	0.526 §	0.413 §	0.634 §	0.607 §	0.523 §	-0.043	0.251	0.233
Ana -AD	0.488 §	0.505 §	0.402 §	0.618 §	0.599 §	0.524 §	-0.042	0.246	0.228
El 7dNH4	0.118	0.277	0.051	0.220	0.046	0.006	0.047	0.232	0.229
El 7dNO3	0.172	0.444 §	0.061	0.244	0.227	0.216	0.112	0.676 §	0.663 §
El7dMinN	0.186	0.476 §	0.068	0.274	0.227	0.209	0.116	0.692 §	0.679 §
ElPotMin	-0.095	-0.070	-0.087	-0.092	-0.172	-0.173	-0.310	-0.399	-0.429

§ r-values above 0.357 are significant at .1% level;

** r-values above 0.750.

TABLE 15

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN BIOLOGICAL AND CHEMICAL METHODS FOR 15 SOIL SAMPLES FROM MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 0-15 CM SOIL DEPTH.

	InNH4	InNO3	InMinN	ADNH4	ADNO3	ADMiN	OrgC%	TotN%
7dNH4	-0.070	0.574	0.425	0.463	0.698	0.629	-0.292	-0.414
7dNO3	0.308	0.757	0.690	0.476	0.723	0.650	-0.122	-0.003
7dMinN	0.186	0.756	0.649	0.516	0.781 **	0.703	-0.202	-0.168
PotN	-0.440	0.132	-0.041	0.602	0.641	0.652	-0.215	-0.316
14dNH4	-0.464	-0.390	-0.455	-0.617	-0.488	-0.563	0.318	0.193
14dNO3	0.369	0.337	0.383	-0.487	-0.339	-0.416	-0.282	0.176
14dMin	0.289	0.269	0.304	-0.568	-0.404	-0.491	-0.226	0.201
14dPot	0.170	-0.075	-0.003	-0.874	-0.800	-0.865	-0.136	0.184
Anaero	0.204	-0.182	-0.075	-0.580	-0.677	-0.665	0.341	0.688
Ana-AD	0.182	-0.186	-0.086	-0.762	-0.788	-0.811	0.267	0.568

	C+N%	HOx	H2SO4	KMnO4	KCl	KCl-AD
7dNH4	-0.305	-0.250	-0.293	-0.212	-0.667	-0.683
7dNO3	-0.116	-0.111	-0.008	-0.122	-0.345	-0.495
7dMinN	-0.203	-0.177	-0.123	-0.169	-0.507	-0.617
PotN	-0.225	0.114	-0.018	0.131	-0.474	-0.648
14dNH4	0.314	0.093	0.172	0.065	0.435	0.634
14dNO3	-0.255	-0.319	-0.129	-0.327	0.165	0.392
14dMin	-0.200	-0.297	-0.099	-0.309	0.227	0.478
14dPot	-0.116	-0.347	-0.045	-0.377	0.420	0.779 **
Anaero	0.370	0.051	0.312	-0.014	0.627	0.729
Ana-AD	0.292	-0.096	0.208	-0.154	0.611	0.828 **

** r-values above 0.760 are significant at 0.1% level.

TABLE 16

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN BIOLOGICAL AND CHEMICAL METHODS FOR 15 SOIL SAMPLES FROM MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 15-30 CM SOIL DEPTH.

	InNH4	InNO3	InMin	AD:NH4	AD NO3	AD MiN	OrgC%	TotN%
7dNH4	-0.106	0.391	0.310	0.874 **	0.737	0.806 **	0.065	0.094
7dNO3	0.321	0.932 **	0.898 **	0.677	0.845 **	0.820 **	0.454	0.477
7dMin	0.209	0.843 **	0.790 **	0.812 **	0.894 **	0.898 **	0.368	0.396
PotN	-0.378	0.180	0.050	0.823 **	0.672	0.743	-0.059	-0.129
NH414d	-0.341	-0.422	-0.462	-0.372	-0.287	-0.324	-0.531	-0.615
NO314d	0.801 **	0.521	0.677	0.108	0.111	0.114	0.791 **	0.801**
Min14d	0.782 **	0.419	0.583	-0.042	0.001	-0.013	0.684	0.658
Pot14d	0.537	-0.359	-0.161	-0.790	-0.815	-0.835	0.206	0.296
Anaero	0.766 **	0.105	0.305	-0.171	-0.264	-0.243	0.686	0.700
Ana-AD	0.716	-0.052	0.155	-0.453	-0.493	-0.497	0.566	0.600

	C+N%	HOx	H2SO4	KMnO4	KCl	KCl-AD
7dNH4	0.069	0.151	-0.178	0.192	-0.089	-0.737
7dNO3	0.468	0.455	0.207	0.439	0.232	-0.368
7dMin	0.381	0.399	0.098	0.400	0.147	-0.529
PotN	-0.066	-0.043	-0.299	0.011	-0.163	-0.748
NH414d	-0.553	-0.545	-0.042	-0.564	-0.518	-0.063
NO314d	0.814 **	0.623	0.436	0.571	0.820**	0.471
Min14d	0.701	0.481	0.490	0.413	0.723	0.521
Pot14d	0.219	0.085	0.289	0.035	0.457	0.920 **
Anaero	0.706	0.658	0.476	0.601	0.885**	0.700
Ana-AD	0.585	0.534	0.493	0.468	0.785**	0.881 **

** r-values above 0.760 are significant at 0.1% level.

TABLE 17

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN NITROGEN VALUES OBTAINED BY BIOLOGICAL AND CHEMICAL METHODS FOR 35 SURFACE SOIL SAMPLES OF MAF NORTH ISLAND. (0-15 cm depth).

	InNH4	InNO3	InMin	ADNH4	ADNO3	ADMin	MFADMi	OC%
7dMin	0.137	0.490	0.376	0.746 +	0.472	0.590 +	0.479	0.657 +
PotN	-0.251	0.113	-0.068	0.602 +	0.124	0.280	0.277	0.409
14dNH4	-0.299	-0.311	-0.354	-0.154	-0.285	-0.265	-0.138	-0.282
14dNO3	0.387	0.553 +	0.550 +	0.625 +	0.526	0.595 +	0.523	0.680 +
14dMin	0.213	0.386	0.353	0.577 +	0.376	0.465	0.476	0.547
14dPot	-0.053	-0.087	-0.083	0.119	-0.199	-0.115	0.191	0.224
Anaer	0.107	0.065	0.099	0.538	0.206	0.323	0.076	0.407
An-AD	0.089	-0.018	0.038	0.418	0.112	0.214	0.006	0.332
MFAnae	0.110	0.142	0.147	0.628 +	0.240	0.377	0.160	0.629 +
An-NH4	-0.105	0.038	-0.034	0.594 +	0.125	0.278	0.125	0.513

	N% .	C+N%	HOX	H2SO4	KMnO4	KCl	KCl-AD
7dMin	0.704 +	0.662 +	0.703 +	0.669 +	0.605 +	0.809 **	0.762 +
PotN	0.468	0.414	0.501	0.462	0.445	0.598 +	0.544
14dNH4	-0.251	-0.279	-0.224	-0.211	-0.194	-0.205	-0.206
14dNO3	0.728 +	0.685 +	0.636 +	0.587 +	0.564 +	0.786 +	0.779 +
14dMin	0.620 +	0.554 +	0.539	0.495	0.481	0.718 +	0.709 +
14dPot	0.323	0.233	0.230	0.185	0.230	0.364	0.425
Anaer	0.446	0.411	0.429	0.385	0.392	0.577 +	0.541
An-AD	0.373	0.336	0.354	0.304	0.336	0.488	0.471
MFAnae	0.672 +	0.633 +	0.537	0.581 +	0.395	0.725 +	0.698 +
An-NH4	0.560 +	0.517	0.452	0.485	0.335	0.631 +	0.589 +

+ r-values above 0.550 are significant at 0.1% level;

** r-values above 0.800 .

3.4 Grain yield

An attempt was made to investigate the relationships between wheat/barley grain yield and the chemical and biological indices studied. Owing to the low number of yield values available from the MAF South Island N trial plots (wheat, 6 and barley, 6), it was decided to not to use these grain yields in the present study.

(a) Ravensdown Fertiliser Co-operative

For the Ravensdown soils 32 Canterbury farms were selected on the basis of 'better than average management'. Of the 26 yield values received 20 were for wheat and 6 for barley. Only the wheat grain yield values were used in the present study. Grain yield values (t ha^{-1}) of wheat are given in Table 18a. The yield values ranged between 2.0 and 6.8 t ha^{-1}, the mean value being 5.2 t ha^{-1}. The correlation coefficient values obtained for the relationship between wheat grain yield values and the laboratory N test values are presented in Table 18b .

While the soil N tests such as total N content and anaerobically mineralisable N showed positive significant correlations (r=0.544 and 0.562 respectively), both residual mineral N and NO_3^--N measured by the electrode method gave negative but significant correlations (r=-0.565 and -0.561 respectively) with grain yield values. It appears that the previous growing season may have left a considerable amount of residual N in the soil and further addition of fertiliser N during the 1985 season (amount applied ranges from 25 to 100 kg N ha^{-1}), associated with high rainfall were believed to have resulted in crop lodging. Note that the Canterbury 1985 season grain yield survey showed that lodging was one of major causes for the season's low grain yield. Consequently, a negative correlation was obtained between the residual mineral N levels and grain yield values in the present study.

On the other hand, the significant correlation observed between the anaerobically mineralisable N and grain yield indicates that more future investigation on the anaerobic test and hence its application as a soil N availability index for the Canterbury cropping soils is warranted.

(b) MAF North Island

The grain yield values (t ha^{-1}) of wheat and barley obtained from North Island zero N and 40 kg N ha^{-1} plots are given in Table 19a. Note that the addition of 40 kg N ha^{-1} did not increase the yield significantly. Correlation analysis was performed on yield values of wheat and barley and N values obtained from the chemical and biological N availability indices (Table 19b). Table 19b clearly demonstrates that the relationships of grain yield values with residual N levels of field moist and air-dried soils hold the highest correlation values. Similar relationships have been reported by several workers (Gasser. 1961; Soper *et al*., 1971; Walker and Ludecke. 1982). Note that the highest correlation value r=0.847 was obtained for the relationship between air-dried soil NO_3^--N (air-dried at 33°C for 18 h; passed through 2 mm sieve and stored in unsealed polyethylene bags for 6 months before analysis) and barley yield values from unfertilised plots. Practically, it is not possible to use such NO_3^--N values for any N availability index experimental purpose due to the unusual length of storage period. Thus similar studies must include sample pre-treatments which can be easily adapted for future investigations and recommendations.

TABLE 18a

YIELD VALUES (t grain ha^{-1}) OF WHEAT OBTAINED FROM SOME CATERBURY CROPPING FARMS BY THE RAVENSDOWN FERTILISER CO-OPERATIVE.

Soil No.	Yield	Soil No.	Yield
1	6.5	43	6.4
10	5.0	47	6.8
32	6.5	48	2.6
33	4.0	53	2.5
34	6.5	58	2.0
37	4.5	65	6.1
38	5.7	69	6.0
40	6.0	71	3.4
41	5.7	78	4.3
42	6.2	82	6.5

TABLE 18b

CORRELATION COEFFICIENTS FOR THE RELATIONSHIP BETWEEN WHEAT GRAIN YIELDS AND N VALUES OBTAINED FROM CHEMICAL AND BIOLOGICAL METHODS (RAVENSDOWN).(0-15 cm depth).

OC%	0.351	
Tot.N%	0.544	*
H2SO4	0.176	
KMnO4	-0.051	
KCl-AD	0.315	
IniNH4	-0.214	
IniNO3	-0.050	
IniMin	-0.101	
ElIniNH4	-0.401	
ElIniNO3	-0.561	**
ElIniMin	-0.565	**
ADNH4	0.318	
ADNO3	-0.128	
ADMin	-0.073	
7dPotN	0.001	
14dPotN	0.298	
Anaer-AD	0.562	**
ElPotN	-0.283	

* r-values significant at 5% level; ** r-values significant at 1% level.

TABLE 19a

YIELD VALUES (t grain/ha) OF WHEAT AND BARLEY OBTAINED FROM MAF NORTH ISLAND N TRIAL PLOTS.

W H E A T			B A R L E Y		
Soil No.	0-N	40kgN/ha	Soil No.	0-N	40kgN/ha
7	6.57	7.94	9	5.9	5.5
8	5.97	6.27	11	5.0	4.9
14	5.90	6.10	21	3.9	3.9
15	5.34	5.47	22	4.5	4.5
19	5.30	5.30	26	3.6	3.7
30	5.98	5.98	32	5.8	6.7
31	5.90	5.70	35	4.2	4.3
33	5.54	6.29			
34	5.58	6.04			

TABLE 19b

CORRELATION COEFFICIENTS FOR THE RELATIONSHIP BETWEEN WHEAT & BARLEY YIELDS AND N VALUES OBTAINED FROM CHEMICAL AND BIOLOGICAL METHODS (MAF NORTH ISLAND).

	0-N Wheat	40N Wheat	0-N Barley	40N Barley
40N Wheat	0.845			
40N Barley			0.926	
OC%	-0.314	-0.316	0.337	0.164
Tot.N%	-0.306	-0.295	0.152	0.121
H2SO4	-0.367	-0.310	0.234	0.173
KMnO4	0.217	0.206	-0.664	-0.395
KCl-AD	-0.292	-0.238	-0.137	-0.086
IniNH4	0.435	0.517	0.762 *	0.527
IniNO3	0.659	0.618	0.483	0.490
IniMin	0.660	0.669 *	0.791 *	0.611
IniADMin	0.564	0.608	0.490	0.779 *
ADNH4	-0.081	0.043	-0.517	-0.365
ADNO3	0.434	0.354	0.847 **	0.657
ADMin	0.295	0.278	0.695	0.552
7dPotN	-0.554	-0.489	-0.349	-0.163
14dPotN	-0.092	0.015	0.018	0.041
Anaer-NH4	-0.613	-0.496	-0.562	-0.496
Anaer-AD	-0.462	-0.215	0.188	-0.015

* r-values significant at 5% level;

** r-values significant at 2% level.

In contrast, all the other chemical and biological indices tested in our study gave low correlation values with grain yield. Obviously, biological indices yielded negative correlation values because mineralisable N values were obtained by subtracting initial mineral N level of either field-moist or air-dried soil.

4. CONCLUSIONS

(a) Residual mineral nitrogen

Nitrate nitrogen was the dominant form (60-80%) of mineral nitrogen in most surface soils (0-15 cm). Study of the MAF South Island soil profiles indicated that the contribution of NO_3^--N to total mineral N content increased with depth. Correlation results obtained for the relationship between NO_3^--N and mineral N emphasise that.

(i) for the soils studied residual NO_3^--N values could be used to predict the level of NH_4^+-N in field-moist and air-dried samples.
(ii) such prediction was even possible for the soils which contained as much as 50% of the total mineral N as NH_4^+-N since there was still a high correlation between NO_3^--N and mineral N, and
(iii) for the 1985 spring, it is possible to predict the residual mineral N values for the total 0-60 cm profile using the 0-15 cm soil NO_3^--N content of the MAF South Island soils.

The following points are believed to be important for planning similar residual mineral N studies in Canterbury:

(i) The majority of the Canterbury soils tested in the present study are moderate to slow draining soils and receive only an average rainfall of 58 mm per month. Thus in an "average year" these soils may be able to retain most of their residual mineral nitrogen. Nevertheless, soil sampling is not recommended soon after a heavy rainfall. It must be emphasised that such prediction should only be used with reservations when the annual/monthly rainfall significantly exceeds the average rainfall.
(ii) The readily nitrifying nature of these soils is believed to replenish any leached NO_3^--N quickly. Although our chemical and incubation tests conclusively proved such occurrence, a microbiological approach (e.g. determination of the population and the activity of the microorganisms such as ammonifiers, nitrifiers and denitrifiers for various seasons) would assist in obtaining a better understanding of N transformations in Canterbury cropping soils.
(iii) Since the soil mineral N content did not increase significantly after air drying (some of the MAF North Island soil mineral N contents were reduced after air drying due to immobilisation), measurement of field-moist soil mineral N alone is considered to be sufficient.

The electrode method used to measure mineral N levels in field-moist soil at the Ravensdown laboratory was the most rapid method investigated in the present study. Although initial NO_3^--N levels measured at both laboratories correlated well (0 =0.828), the correlation results obtained for initial NH_4^+-N and total mineral N (r=0.140 and r=0.774 respectively) were not satisfactory. It is believed that future evaluation of the Ravensdown electrode method should be carried out for the soils subjected to standard sample pre-treatments.

(b) Chemical methods

(1) Acid $KMnO_4$ oxidisable N

Of the chemical extractants studied, acid $KMnO_4$ extracted considerably greater amounts of soil organic N (maximum value 330 μg g^{-1} of NH_4^+-N), than boiling KCl and H_2SO_4 (maximum values of 59 and 235 μg g^{-1} respectively). Nevertheless, in general, the acid $KMnO_4$ oxidisable N method did not correlate with any of the chemical or biological methods tested. Thus this method is not recommended for future N availability studies for the soils tested. However, if this method is evaluated in future, it is suggested that the extraction should be separated from the extractant-soil mixture and steam-distilled immediately because the oxidation process of soil organic N does not cease until the extraction is steam-distilled.

(2) 1 *N* H_2SO_4 extractable N

This method has been found to be simple, quick and inexpensive. Although the method yielded statistically significant correlations with soil residual N values and other chemical methods tested, the correlation was stronger with total N and organic C contents for the organic N rich North Island soils. This suggests that the amount of NH_4^+-N extracted by 1 *N* H_2SO_4 may be used to predict the total N content of such soils without performing expensive and laborious kjeldahl analysis. Nevertheless, H_2SO_4 extractable N is not recommended as a soil test because routine soil N indices do not require total N content determinations.

(3) Boiling KCl hydrolysable N

This rapid and inexpensive chemical method provided the strongest correlations with the biological methods tested in this study. This new chemical method may be used to replace the laborious and rather expensive biological N tests. There are number of advantages of using this method for routine soil N tests:

(i) Only a small amount of soil sample (3-5 g) is needed.
(ii) Field moist or air-dried soils can be used.
(iii) Only standard laboratory equipment is needed.
(iv) Although a 4 hour boiling time is required, several hundreds of samples can be boiled at once, depending on the capacity of the waterbath used.
(v) If centrifuged no nitration is necessary.
(vi) Only NH_4^+-N needs to be measured.
(vii) The NH_4^+-N can be measured by a rapid autoanalyser method.
(viii) Analysis of NH_4^+-N need not to be done immediately after boiling. The extractions can be stored in the refrigerator for several days before determination of the NH_4^+-N because the 4 hour boiling can be expected to kill most of the ammonifying and nitrifying organisms.
(ix) The high statistically significant correlation values obtained with soil mineral N values and all the other chemical methods for the North Island and Ravensdown soils suggest that this method is also suitable for a range of soils.

(4) Total soil N and organic C contents

All the soils studied had higher soil total N and organic carbon contents than most of the reported values (e.g. Stanford and Smith (1978), Gianello and Bremner (1986)) indicating that

these soils are rich in soil organic nitrogen. Although these two indices provided statistically significant correlations with the other chemical and biological N indices, for most of the soils studied, both methods are considered to be expensive and laborious. Thus these methods are not recommended for routine soil N analysis. Nevertheless, these methods are important in any detailed soil N studies.

(c) Biological methods

Of the short-term incubations employed both aerobic incubations (7 and 14-day) yielded negative mineralisation values (i.e. -AN) for some of the soils tested. This is attributed to the occurrence of a vigorous immobilisation process during the short-term aerobic incubation. This finding may also question the reliability of the positive net mineralisation values obtained in any of the short-term incubation studies. In contrast, anaerobic incubation mineralised the highest amount of N and never yielded negative mineralisation values.

(1) The 7-day aerobic incubation test performed at the Ravensdown and Lincoln College laboratories

Sample handling, differences in soil moisture contents, incubation conditions and to a lesser extent, employing two different methods to determine mineral N levels were believed to have caused the poor correlation (r=-0.073) observed between the 7-day mineralisable N values obtained at each laboratory. Future studies should consider the following points:

(i) Soil samples collected for aerobic incubations studies should be analysed for mineral N levels and incubated as soon as possible. Although the samples can be stored in the refrigerator overnight, prolonged cold storage is believed to affect the final mineralisation results considerably. This is particularly important when soil N tests (especially field-moist soil mineral N levels or short-term incubations) are carried out in different laboratories on similar soil samples.
(ii) Sufficient aeration should be provided during the incubation period since improper aeration can affect the mineralisation and nitrification processes significantly.
(iii) Soil sample moisture content should be adjusted to field capacity.
(iv) If the soil sample is incubated in open containers a device may need to be set up to humidify the incubator while the incubation temperature is constantly maintained.
(v) It is also believed that mixing quartz sand with field-moist soil would enable uniform mineralisation and provide further aeration needed during the incubation.

The problems outlined above appear to be too difficult to solve in a routine method of analysis. Therefore the results from a routine 7-day aerobic test are likely to be inaccurate and it is recommended that the Ravensdown 7-day test be discontinued.

(2) The 14-day aerobic incubation

The 14-day aerobic incubation method cannot be recommended for routine soil N analysis because soil samples need to be air-dried, ground, sieved, mixed with sand and rewetted before being incubated. These pre-treatments were found to affect the mineralisation process.

(3) The 7-day anaerobic incubation

The 7-day anaerobic incubation method is highly recommended as a routine test for the following reasons:

(i) It is a relatively rapid incubation.
(ii) Field-moist soils can be used and thus the effects of sample pre-treatments (air drying, grinding, sieving etc.) on mineralisation arc minimised.
(iii) Only a small sample of soil is needed (5-10 g).
(iv) Problems of establishing optimal water content and loss of water during incubation are avoided.
(v) The net mineralisation value obtained is positive due to more vigorous mineralisation than immobilisation occurring under anaerobic conditions.
(vi) More net N is mineralised because the loss of NO_3 -N due to denitrificalion is reduced by preventing the nitrification process under anaerobic conditions.
(vii) More N is mineralised in a given period due to the higher incubation temperatures used (e.g. 40°C).
(viii) No special provision (such as the precautions taken in the present study) of anaerobic condition is needed if nitrifying inhibitors are added before the incubation.
(ix) Only the NH_4^+-N released needs to be measured.
(x) With the addition of 4 *N* KCI and a few seconds of shaking by hand, the sample is ready for NH_4^+-N analysis.
(xi) The electrode method employed at the Ravensdown laboratory can be used to measure the NH_4^+-N released

(d) Grain yield

Grain yield values of wheat and barley obtained from the MAF North Island fertilised and unfertilised plots showed consistently good correlations with residual N levels of field-moist and air-dried soils. This indicates the usefulness of residual N level measurement in N availability studies. Although the number of observations used in the grain yield correlation analysis (wheat n=9 and barley n=7) were not sufficient to derive any further conclusions, similar findings have often been reported in the literature.

The wide range in amount of fertiliser N used (25-100 kg N ha^{-1}), the high residual mineral N accumulated in the past growing seasons, high rainfall for the 1985 growing season and the consequently high incidence of crop lodging were believed to be the main factors influencing the grain yield values obtained from the Canterbury cropping farms studied. Consequently, there was an inverse relationship between residual mineral N levels (electrode method) and the yield values observed.

On the other hand, the positive significant correlation (r=0.562) obtained between anaerobically minerlisable N and grain yields indicates that this incubation method may be of use for a wide range of Canterbury soils. It is believed that a fertiliser N trial designed to evaluate the anaerobic incubation test for some of the major cropping soil types may provide the basis for using this test as a soil N index for wheat and barley.

(e) Recommendations

From the results of the present study the following methods of assessing N availability can be recommended for a wide range of soils:

(i) measurement of field-moist soil residual N levels **and**
(ii) boiling KCl hvdrolysable N **or** 7-day field-moist soil **anaerobic** incubation

These methods possess numerous advantages over the other methods evaluated and are suitable for making routine soil N availability measurements. It is also recommended that the Ravensdown Fertiliser Co-operative should discontinue the current 7-day aerobic incubation test and replace it with the anaerobic test. It is believed that the laboratory measurements of both the residual mineral N and anaerobically mineralisable N may provide a better soil N availability index for the Canterbury cropping soils.

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APPENDIX 1

NITROGEN VALUES OBTAINED BY CHEMICAL AND BIOLOGICAL METHODS FOR 244 RAVENSDOWN FERTILISER CO-OP. SOIL SAMPLES ($\mu gN\ g^{-1}$). (0-15 cm depth)

Sample no.	H20%ww	NH4-N	NO3-N	Min-N	7d NH4-N	7d NO3-N	7d Min-N	7d Pot-N
1	9.5	10	10	20	4	49	53	32
2	20.0	2	42	45	1	67	68	23
3	22.7	2	18	20	2	68	70	49
4	22.3	5	35	41	3	79	82	41
5	23.8	4	24	29	4	76	80	51
6	28.7	2	13	15	2	48	50	34
7	20.9	5	17	22	3	55	58	36
8	23.0	4	14	18	3	42	45	27
9	21.6	3	49	52	53	95	149	96
10	25.8	3	40	44	7	95	102	58
11	22.2	4	26	31	2	68	71	40
12	27.4	23	20	44	10	81	91	47
13	26.1	3	4	8	2	49	51	43
14	10.1	1	43	45	1	61	62	16
15	21.1	2	32	34	3	65	69	34
16	26.4	2	12	14	1	39	41	26
17	21.6	4	7	11	1	25	27	15
18	25.1	2	12	14	2	33	35	20
19	25.5	7	15	22	8	57	66	43
20	24.7	2	16	18	29	57	86	67
21	25.9	3	11	14	2	43	45	30
22	24.1	2	21	24	2	50	53	28
23	30.1	4	30	35	2	71	74	39
24	22.8	3	11	14	2	41	43	28
25	19.4	3	16	20	8	57	66	46
26	25.2	3	32	36	6	76	82	45
27	18.9	11	34	45	2	68	70	25
28	21.7	2	18	21	2	46	48	27
29	20.6	2	38	40	2	62	64	24
30	22.2	3	11	15	23	53	76	61
31	25.6	2	14	16	2	55	57	40
32	26.5	3	34	38	11	80	92	53
33	21.3	2	16	18	2	41	43	24
34	24.8	2	16	18	2	51	53	34
35	27.4	4	35	39	26	69	96	56
36	27.4	3	20	23	8	73	81	57
37	23.0	3	18	22	2	51	53	31
38	23.1	12	20	32	1	62	64	31
39	23.4	2	11	13	2	49	51	38
40	26.2	2	15	18	2	49	51	33
41	20.7	2	30	32	3	54	58	26
42	22.7	1	35	37	1	58	60	22
43	24.6	5	37	42	4	66	70	27
44	25.7	1	11	12	6	46	52	39
45	24.8	1	31	33	2	69	72	39
46	26.6	1	46	47	2	82	84	36
47	30.3	4	79	83	17	206	223	140
48	27.9	14	76	91	10	128	138	47
49	26.0	2	7	9	3	46	50	41
50	24.2	8	53	62	3	88	91	29
51	24.3	2	28	31	4	68	72	41
52	25.9	2	38	41	14	73	87	46
53	27.7	2	40	43	4	68	73	29
54	20.4	2	32	34	22	61	84	50
55	29.6	2	40	42	4	90	94	52
56	28.3	4	37	41	2	66	68	27

sample	H2O%ww	NH4-N	NO3-N	Min-N	7dNH4	7dNO3	7dMin	7dPot
57	29.6	5	61	67	6	139	145	78
58	19.8	4	27	31	3	50	53	22
59	29.9	4	99	103	9	174	183	80
60	30.5	10	96	107	9	148	157	50
61	23.9	3	15	18	4	49	53	35
62	24.3	6	15	22	4	59	63	41
63	25.8	7	64	71	3	133	137	65
64	23.9	1	34	35	3	63	66	31
65	27.3	4	23	27	4	61	66	38
66	27.4	2	24	26	3	56	60	33
67	27.2	2	12	15	4	47	51	36
68	22.1	2	12	15	4	37	41	26
69	21.7	2	28	30	3	55	58	28
70	23.2	3	75	78	5	135	140	61
71	26.3	5	24	30	19	67	86	56
72	23.5	27	30	57	16	66	82	24
73	28.1	6	65	71	33	140	173	102
74	23.3	6	32	38	18	87	105	67
75	21.3	7	51	58	16	98	114	56
76	28.2	8	67	75	36	129	166	90
77	22.4	13	64	77	21	146	168	90
78	28.1	6	29	36	18	65	83	47
79	24.2	5	29	34	14	71	85	51
80	24.5	6	33	39	21	105	127	87
81	24.8	4	19	24	17	68	86	62
82	30.8	6	65	72	19	155	174	102
83	24.0	5	37	43	17	88	105	62
84	24.3	5	19	25	15	67	82	57
85	30.1	7	82	89	73	193	266	177
86	23.7	3	45	48	46	121	167	118
87	23.0	6	26	32	34	113	148	115
88	25.6	2	21	24	40	77	117	93
89	22.6	5	70	76	39	145	185	108
90	23.7	3	26	29	39	99	138	108
91	21.7	2	23	25	35	71	106	81
92	25.2	5	11	16	46	81	128	112
93	21.5	3	8	12	34	69	103	91
94	21.3	6	8	15	32	65	97	82
95	25.3	2	7	10	37	69	107	97
96	24.2	2	25	28	79	107	186	150
97	23.6	4	14	19	33	75	108	89
98	22.5	4	12	17	33	66	99	87
99	22.3	1	45	47	33	104	137	97
100	24.1	2	47	49	37	96	134	72
101	22.2	1	44	45	22	90	112	54
102	20.7	4	48	52	41	91	133	57
103	26.7	17	81	99	43	145	189	89
104	26.6	6	20	27	54	150	204	177
105	22.1	2	16	19	39	76	116	97
106	21.9	4	18	23	26	68	95	72
107	23.6	2	14	17	13	57	71	54
108	24.6	4	21	25	17	66	83	57
109	23.3	2	11	14	30	91	122	107
110	25.9	2	10	12	24	66	90	78
111	24.9	1	10	11	20	65	85	74
112	22.3	2	11	13	21	58	79	66
113	24.9	3	12	16	5	44	50	34
114	23.1	3	15	19	6	58	64	45
115	23.9	6	25	31	2	48	50	19

sample	H2O%ww	NH4-N	NO3-N	Min-N	7dNH4	7dNO3	7dMin	7dPot
116	22.5	7	32	40	3	47	51	11
117	21.2	35	43	78	4	44	48	-29
118	24.3	36	54	91	3	55	58	-33
119	23.9	37	54	92	3	61	64	-28
120	22.4	35	51	87	3	45	49	-38
121	23.1	3	19	22	21	61	83	61
122	22.9	2	17	19	21	65	87	67
123	23.3	3	13	17	16	56	72	55
124	26.6	3	20	24	22	71	93	69
125	22.4	3	14	17	19	54	73	56
126	25.0	13	26	40	22	70	93	52
127	25.2	6	20	27	23	78	102	74
128	21.9	5	34	39	21	87	109	69
129	21.1	1	13	15	16	43	60	44
130	23.2	13	28	42	15	65	80	38
131	24.2	4	22	26	24	69	94	68
132	25.7	4	17	22	19	58	78	56
133	21.0	2	11	14	18	41	59	45
134	25.0	4	17	21	18	56	75	53
135	24.6	2	21	24	21	69	91	66
136	19.8	3	16	19	18	55	74	54
137	21.7	5	32	38	18	81	100	61
138	28.9	6	78	84	30	153	183	99
139	25.3	4	31	35	19	72	91	56
140	27.8	4	32	36	24	94	118	81
141	18.6	2	16	19	16	51	68	48
142	19.9	5	37	42	18	80	99	56
143	21.5	5	30	35	25	79	105	69
144	23.6	66	39	106	31	108	140	34
145	24.9	5	15	20	18	64	82	62
146	25.4	4	19	24	22	85	107	83
147	21.9	3	15	18	15	34	50	31
148	21.7	11	15	26	17	62	80	53
149	23.8	5	30	35	19	78	98	62
150	22.7	5	14	20	16	53	70	50
151	21.6	3	10	13	16	62	79	65
152	21.2	7	22	29	19	65	84	54
153	29.1	7	54	61	28	120	149	88
154	24.2	3	24	28	4	56	61	33
155	22.1	3	24	27	3	56	60	33
156	22.2	3	22	25	3	51	54	28
157	25.5	4	22	26	3	47	51	24
158	25.2	4	13	17	3	43	46	28
159	22.9	3	18	22	3	40	43	21
160	23.8	6	59	65	11	50	61	-4
161	25.8	4	41	45	12	83	95	49
162	23.8	3	21	24	4	48	52	28
163	23.5	13	20	34	23	79	102	68
164	29.5	3	38	42	25	93	118	75
165	20.9	7	28	36	21	71	93	56
166	22.6	9	26	35	25	78	103	68
167	22.6	3	16	19	20	66	86	66
168	22.3	4	41	45	22	101	123	77
169	22.7	2	16	19	20	53	74	54
170	21.9	3	26	29	18	63	82	52
171	22.6	4	22	26	20	67	87	61
172	23.9	3	21	25	5	48	53	28
173	21.9	5	20	26	50	61	112	86

sample								
174	24.2	3	19	22	14	58	72	49
175	22.3	5	22	27	21	66	87	60
176	22.8	5	16	22	15	57	72	50
177	23.9	4	20	24	19	76	95	71
178	26.4	4	29	33	24	92	117	83
179	25.9	3	23	26	20	64	85	58
180	21.9	3	17	20	16	55	72	52
181	21.7	2	26	29	2	49	51	22
182	25.1	3	28	31	19	70	90	58
183	26.3	6	39	45	8	78	86	41
184	26.2	4	29	34	19	81	100	66
185	29.3	3	21	25	12	65	78	52
186	26.0	3	15	19	3	50	54	35
187	25.3	7	22	30	4	62	66	36
188	25.0	5	19	24	5	70	75	50
189	24.6	4	15	20	4	57	62	42
190	22.2	6	21	27	4	59	63	36
191	31.3	13	68	81	8	124	133	51
192	17.4	3	23	26	3	45	48	22
193	23.2	3	14	18	4	42	47	28
194	18.0	3	39	42	3	54	58	15
195	27.7	7	40	47	8	73	81	34
196	18.7	2	18	21	3	34	37	16
197	27.1	4	17	21	22	46	68	47
198	23.3	4	50	54	4	53	58	3
199	24.3	3	17	21	3	45	48	27
200	24.1	3	17	21	4	50	54	33
201	22.7	2	23	26	6	46	53	27
202	24.4	3	25	29	4	39	43	14
203	21.9	12	23	36	3	35	39	2
204	25.5	6	26	32	4	52	56	24
205	22.9	6	17	23	3	38	41	18
206	25.4	31	27	59	17	69	87	27
207	24.5	4	20	24	17	52	69	44
208	17.2	6	24	31	4	47	51	19
209	22.4	9	20	29	3	48	52	22
210	26.2	3	17	20	5	56	61	40
211	26.4	3	20	23	3	57	61	37
212	21.6	6	23	30	3	46	49	19
213	22.7	8	15	24	8	63	71	47
214	22.9	4	7	12	3	38	42	30
215	24.3	7	18	26	3	49	53	27
216	23.8	7	19	26	3	35	38	12
217	25.1	8	16	25	3	43	47	21
218	25.5	9	22	31	3	44	48	16
219	22.0	6	21	27	3	45	49	22
220	23.9	17	50	68	4	50	54	-13
221	19.7	8	22	30	3	47	51	20
222	23.0	6	23	30	3	51	54	24
223	25.6	4	44	49	4	40	44	-4
224	26.5	7	40	47	4	65	69	21
225	24.8	9	41	51	4	62	66	15
226	29.5	6	21	27	9	36	46	18
227	19.5	9	36	46	3	50	54	8
228	24.5	6	26	33	3	52	55	22
229	26.3	11	53	64	5	89	94	30
230	25.2	11	32	44	3	58	62	18
231	20.3	6	46	52	3	55	58	6

232	26.1	6	48	54	3	43	47	-7
233	24.0	6	28	34	3	54	58	23
234	24.6	28	33	62	4	59	64	1
235	18.3	6	31	37	3	46	49	12
236	19.1	7	45	52	5	60	66	13
237	21.2	8	29	37	3	55	58	20
238	22.3	8	29	38	3	53	57	19
239	23.4	5	25	30	4	51	55	25
240	23.5	12	30	43	3	54	58	15
241	24.8	9	25	34	3	53	57	22
242	23.2	6	35	42	3	56	60	18
243	27.5	18	39	58	16	46	62	4
244	24.0	7	26	34	3	44	48	14

APPENDIX 2

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN CHEMICAL AND BIOLOGICAL METHODS FOR 244 RAVENSDOWN FERTILISER CO-OP. SOIL SAMPLES. (0-15 cm depth).

	IniNH4	IniNO3	IniMin	7dNH4	7dNO3	7dMin
IniNO3	0.268 §					
IniMin	0.577 §	0.942 **				
7dNH4	-0.018	0.130	0.104			
7dNO3	0.085	0.733 **	0.652 §	0.535 §		
7dMin	0.059	0.607 §	0.536 §	0.762 **	0.955 **	
7dPotN	-0.294	0.125	0.004	0.838 **	0.720 **	0.846 **

§ r-values above 0.181 are significant at 1% level;

** r-values above 0.700.

	N	MEAN	MIN	MAX	STDEV	SEMEAN
H20 %ww	244	23.920	9.500	31.300	2.912	0.186
IniNH4	244	6.328	1.318	66.201	6.904	0.442
IniNO3	244	28.87	4.91	99.09	16.77	1.07
IniMin	244	35.20	8.05	107.29	19.78	1.27
7dNH4	244	13.440	1.350	79.041	13.074	0.837
7dNO3	244	68.74	25.23	206.70	28.45	1.82
7dMin	244	82.18	27.13	266.28	37.13	2.38
7dPotN	244	46.97	-38.16	177.64	31.35	2.01

APPENDIX 3

NITROGEN VALUES OBTAINED BY CHEMICAL METHODS FOR 82 SOIL SAMPLES OF RAVENSDOWN FERTILISER CO-OP.($\mu gN\ g^{-1}$). (0-15 cm depth).

Sample	NH4N	NO3N	MinN	ADNH4N	ADNO3N	ADMinN	OC%	N%
1	2	42	44	6	47	53	3.6	0.32
2	2	18	20	5	20	26	2.9	0.24
3	3	40	44	7	41	49	5.4	0.53
4	1	43	45	5	46	52	2.8	0.29
5	2	32	34	5	36	41	3.3	0.27
6	2	12	14	5	14	20	4.4	0.35
7	4	30	35	5	30	36	3.4	0.33
8	2	38	40	5	39	45	3.0	0.28
9	2	11	13	6	14	20	3.2	0.26
10	2	15	18	6	18	24	3.8	0.29
11	1	35	37	5	34	39	2.9	0.18
12	5	37	42	6	55	62	4.2	0.21
13	1	31	33	7	36	44	3.6	0.28
14	4	79	83	10	126	137	5.5	0.46
15	14	76	91	7	64	72	5.0	0.41
16	2	40	43	6	46	53	4.5	0.38
17	2	32	34	5	30	36	2.8	0.22
18	2	40	42	6	35	42	5.3	0.51
19	4	37	41	7	66	73	5.6	0.57
20	4	99	103	7	163	171	4.8	0.49
21	3	15	18	5	12	17	3.1	0.29
22	7	64	71	6	60	67	3.3	0.33
23	2	12	15	5	11	16	3.8	0.34
24	3	75	78	5	155	160	3.3	0.31
25	27	30	57	6	21	27	3.2	0.29
26	6	65	71	5	65	70	4.1	0.37
27	6	65	72	7	62	69	6.1	0.54
28	5	37	43	8	31	39	3.6	0.33
29	5	19	25	6	12	19	3.1	0.29
30	7	82	89	8	92	100	6.7	0.53
31	6	26	32	8	23	32	3.2	0.27
32	3	26	29	6	17	24	3.3	0.30
33	5	11	16	7	7	14	4.0	0.32
34	3	8	12	4	9	13	3.0	0.27
35	2	25	28	6	22	28	3.2	0.30
36	4	12	17	8	9	18	2.9	0.32
37	4	18	23	6	18	24	3.2	0.26
38	2	10	12	7	9	16	3.8	0.32
39	1	10	11	5	8	13	3.2	0.31
40	2	11	13	4	8	12	2.7	0.25
41	3	12	16	4	6	11	3.5	0.32
42	3	15	19	11	16	27	4.3	0.38
43	6	25	31	4	13	18	3.0	0.27
44	3	19	22	5	13	19	3.3	0.26
45	2	17	19	4	13	18	3.6	0.29
46	1	13	15	3	10	14	2.7	0.23

47	4	17	22	5	13	18	3.7	0.31
48	3	16	19	5	17	22	3.1	0.24
49	2	16	19	4	10	14	2.2	0.20
50	5	30	35	5	21	27	3.6	0.29
51	5	14	20	4	11	15	4.0	0.30
52	3	10	13	2	7	10	2.9	0.22
53	7	22	29	4	21	26	2.9	0.23
54	3	24	28	4	19	23	4.0	0.31
55	3	22	25	4	17	22	2.9	0.25
56	4	13	17	3	11	15	3.6	0.28
57	3	18	22	3	13	17	3.3	0.23
58	7	28	36	4	22	26	3.1	0.22
59	3	16	19	4	10	15	3.3	0.27
60	3	26	29	4	24	29	3.0	0.22
61	4	22	26	7	17	24	3.7	0.27
62	3	21	25	4	17	21	3.7	0.28
63	5	22	27	4	15	20	3.4	0.26
64	3	17	20	5	15	20	3.0	0.24
65	3	21	25	8	17	26	4.7	0.41
66	7	22	30	6	18	24	3.2	0.26
67	6	21	27	7	22	29	3.8	0.28
68	7	40	47	6	36	43	3.6	0.27
69	4	17	21	5	13	19	3.8	0.29
70	4	50	54	4	19	24	3.5	0.27
71	12	23	36	4	12	17	2.7	0.21
72	3	17	20	4	12	17	3.0	0.25
73	8	15	24	6	13	19	3.1	0.25
74	7	40	47	4	26	30	3.0	0.25
75	9	41	51	5	26	31	3.7	0.31
76	6	21	27	4	10	15	3.3	0.28
77	9	36	46	4	26	31	2.8	0.23
78	11	53	64	5	38	43	4.1	0.37
79	8	29	37	6	19	25	3.6	0.26
80	8	29	38	7	22	29	3.8	0.28
81	5	25	30	5	18	24	3.3	0.26
82	18	39	58	8	10	18	3.7	0.33

APPENDIX 3 (contd.)

NITROGEN VALUES OBTAINED BY CHEMICAL METHODS FOR 82 SOIL SAMPLES OF RAVENSDOWN FERTILISER CO-OP. ($\mu gN\ g^{-1}$).(0-15 cm depth).

Sample	HOx	H2SO4	KMn04	KCl	KCl-AD	ElNH4	ElN03	ElMinN
1	212	40	172	37	31	8	44	52
2	198	41	157	28	22	5	13	18
3	295	40	255	46	38	2	32	34
4	177	41	136	23	17	2	58	61
5	217	37	180	28	23	2	34	37
6	270	42	228	32	27	2	18	21
7	248	52	196	31	25	4	18	22
8	225	37	188	27	21	4	69	73
9	230	38	192	28	22	6	26	33
10	242	38	204	30	24	4	16	20
11	214	38	176	24	19	1	29	30
12	261	47	214	32	25	2	30	33
13	230	46	184	29	21	2	36	38
14	359	58	301	46	36	5	68	73
15	310	67	243	36	28	10	61	72
16	267	47	220	33	27	2	26	29
17	210	42	168	24	19	2	34	37
18	305	54	251	40	34	2	28	30
19	329	58	271	44	36	5	44	49
20	354	68	286	37	29	12	90	102
21	329	33	296	29	23	2	5	8
22	240	40	200	32	25	5	66	72
23	256	39	217	37	32	4	4	8
24	264	35	229	50	44	8	85	93
25	250	36	214	40	33	5	16	21
26	270	43	227	54	49	8	58	66
27	384	69	315	54	47	5	58	64
28	269	40	229	34	26	5	28	33
29	246	38	208	33	27	6	14	21
30	398	71	327	54	46	6	72	78
31	265	34	231	31	23	8	6	14
32	263	37	226	30	24	4	14	18
33	261	38	223	37	30	4	9	13
34	240	29	211	26	21	2	13	16
35	284	38	246	29	23	4	30	34
36	308	44	264	29	21	2	21	24
37	371	41	330	31	25	2	22	25
38	354	41	313	32	25	4	9	13
39	230	34	196	28	23	5	18	24
40	239	23	216	26	22	2	12	14
41	224	29	195	42	38	2	10	13
42	283	40	243	30	19	8	12	20
43	216	27	189	29	24	2	17	20
44	292	18	274	30	24	5	14	20
45	260	22	238	31	26	6	17	24
46	224	24	200	27	23	5	24	29

47	234	22	212	32	26	6	10	17
48	257	31	226	28	23	9	33	42
49	187	27	160	22	18	2	14	17
50	261	32	229	31	25	10	21	32
51	282	29	253	29	25	2	16	18
52	221	17	204	23	20	5	14	20
53	245	29	216	24	19	6	36	42
54	292	33	259	33	29	10	17	28
55	251	35	216	26	22	21	30	52
56	246	24	222	29	25	6	12	18
57	220	18	202	27	23	6	17	24
58	234	25	209	24	20	10	44	54
59	250	25	225	33	28	6	17	24
60	231	24	207	25	20	9	53	62
61	232	26	206	28	21	8	21	29
62	246	22	224	28	23	6	21	28
63	274	27	247	31	26	5	24	29
64	231	25	206	28	22	6	21	28
65	299	28	271	43	35	6	8	14
66	262	23	239	31	25	8	14	22
67	265	31	234	33	26	8	18	26
68	276	33	243	29	23	8	56	64
69	235	33	202	31	26	6	26	33
70	273	31	242	31	26	2	29	32
71	235	21	214	22	17	5	22	28
72	241	29	212	28	23	5	32	37
73	292	27	265	28	22	6	25	32
74	332	34	298	30	26	9	26	36
75	253	34	219	36	31	8	12	20
76	239	31	208	32	27	8	8	16
77	239	29	210	29	24	9	22	32
78	262	35	227	37	31	4	26	30
79	258	27	231	30	24	4	28	32
80	259	30	229	32	25	2	26	29
81	268	31	237	27	21	2	25	28
82	266	37	229	33	25	5	20	25

	N	MEAN	MIN	MAX	STDEV	SEMEAN
IniNH4	82	5.150	1.320	27.560	3.849	0.425
IniNO3	82	29.73	8.76	99.09	18.75	2.07
InMinN	82	34.88	11.73	103.21	20.03	2.21
AD.NH4.N	82	5.915	2.900	11.400	1.471	0.162
AD.NO3.N	82	28.76	6.40	163.40	28.90	3.19
AD.Min.N	82	34.67	10.40	171.00	29.49	3.26
OrgC%	82	3.6001	2.1600	6.7400	0.8095	0.0894
TotN%	82	0.30356	0.17900	0.57200	0.08106	0.00895
HOx	82	262.45	177.00	398.00	42.95	4.74
H2SO4	82	35.48	17.00	71.00	11.45	1.26
KMnO4	82	226.98	136.00	330.00	37.66	4.16
C+N%	82	3.9037	2.3560	7.2730	0.8831	0.0975
KCl	82	32.416	22.400	54.600	7.029	0.776
KCl-AD	82	26.500	17.100	49.000	6.478	0.715
ElIniNH4	82	5.756	1.333	21.333	3.042	0.336
ElIniNO3	82	28.07	4.00	90.67	18.70	2.07
ElInMinN	82	33.82	8.00	102.67	19.57	2.16

APPENDIX 4

NITROGEN VALUES OBTAINED BY BIOLOGICAL METHODS FOR 82 SOIL SAMPLES OF RAVENSDOWN FERTILISER CO-OP. ($\mu gN\ g^{-1}$).(0-15 cm depth).

Sample	7dNH4	7dNO3	7dMinN	7dPotN	14dNH4	14dNO3	14dMinN
1	4	67	71	26	2	102	105
2	2	68	70	49	2	91	94
3	7	95	102	58	5	155	161
4	1	61	62	16	1	112	114
5	3	65	69	34	2	91	93
6	1	39	41	26	2	76	79
7	2	71	74	39	11	141	153
8	2	62	64	24	2	103	106
9	2	49	51	38	2	73	76
10	2	49	51	33	2	90	92
11	1	58	60	22	2	88	90
12	4	66	70	27	2	201	203
13	2	69	72	39	2	107	110
14	17	206	223	140	4	210	214
15	10	128	138	47	42	122	165
16	4	68	73	29	2	122	125
17	22	61	84	50	2	80	82
18	4	90	95	52	9	195	204
19	2	66	68	27	6	215	221
20	9	174	183	80	14	151	165
21	4	49	53	35	2	86	89
22	3	133	137	65	2	140	143
23	4	47	51	36	2	90	92
24	5	135	140	61	2	145	147
25	16	66	82	24	1	86	88
26	33	140	173	102	2	131	134
27	19	155	174	102	2	151	154
28	17	88	105	62	1	116	118
29	15	67	82	57	2	61	64
30	73	193	266	177	3	192	196
31	34	113	148	115	2	105	107
32	39	99	138	108	2	87	89
33	46	81	128	112	2	82	84
34	34	69	103	91	2	63	65
35	79	107	186	158	2	110	112
36	33	66	99	82	2	75	77
37	26	68	95	72	2	73	75
38	24	66	90	78	2	86	88
39	20	65	85	74	2	80	82
40	21	58	79	66	2	82	84
41	5	44	50	34	2	78	80
42	6	58	64	45	2	98	100
43	2	48	50	19	2	80	82
44	21	61	83	61	1	76	78
45	21	65	87	67	1	77	78
46	16	43	60	44	1	71	73
47	19	58	78	56	2	110	112
48	18	55	74	54	2	86	88

APPENDIX 4

NITROGEN VALUES OBTAINED BY BIOLOGICAL METHODS FOR 82 SOIL SAMPLES OF RAVENSDOWN FERTILISER CO-OP. ($\mu gN\ g^{-1}$).(0-15 cm depth).

Sample	7dNH4	7dNO3	7dMinN	7dPotN	14dNH4	14dNO3	14dMinN
1	4	67	71	26	2	102	105
2	2	68	70	49	2	91	94
3	7	95	102	58	5	155	161
4	1	61	62	16	1	112	114
5	3	65	69	34	2	91	93
6	1	39	41	26	2	76	79
7	2	71	74	39	11	141	153
8	2	62	64	24	2	103	106
9	2	49	51	38	2	73	76
10	2	49	51	33	2	90	92
11	1	58	60	22	2	88	90
12	4	66	70	27	2	201	203
13	2	69	72	39	2	107	110
14	17	206	223	140	4	210	214
15	10	128	138	47	42	122	165
16	4	68	73	29	2	122	125
17	22	61	84	50	2	80	82
18	4	90	95	52	9	195	204
19	2	66	68	27	6	215	221
20	9	174	183	80	14	151	165
21	4	49	53	35	2	86	89
22	3	133	137	65	2	140	143
23	4	47	51	36	2	90	92
24	5	135	140	61	2	145	147
25	16	66	82	24	1	86	88
26	33	140	173	102	2	131	134
27	19	155	174	102	2	151	154
28	17	88	105	62	1	116	118
29	15	67	82	57	2	61	64
30	73	193	266	177	3	192	196
31	34	113	148	115	2	105	107
32	39	99	138	108	2	87	89
33	46	81	128	112	2	82	84
34	34	69	103	91	2	63	65
35	79	107	186	158	2	110	112
36	33	66	99	82	2	75	77
37	26	68	95	72	2	73	75
38	24	66	90	78	2	86	88
39	20	65	85	74	2	80	82
40	21	58	79	66	2	82	84
41	5	44	50	34	2	78	80
42	6	58	64	45	2	98	100
43	2	48	50	19	2	80	82
44	21	61	83	61	1	76	78
45	21	65	87	67	1	77	78
46	16	43	60	44	1	71	73
47	19	58	78	56	2	110	112
48	18	55	74	54	2	86	88

49	16	51	68	48	2	85	87
50	20	78	98	62	2	134	136
51	16	53	70	50	2	70	73
52	16	62	79	65	2	58	60
53	19	65	84	54	2	74	76
54	4	56	61	33	2	104	106
55	3	51	54	28	2	83	85
56	3	43	46	28	2	95	96
57	3	40	43	21	2	83	85
58	21	71	93	56	2	74	76
59	20	66	86	66	2	99	101
60	18	63	82	52	2	70	72
61	20	67	87	61	2	88	91
62	5	48	53	28	2	83	85
63	21	66	87	60	2	67	69
64	16	55	72	52	2	90	92
65	12	65	78	52	3	116	120
66	4	62	66	36	2	83	85
67	4	59	63	36	2	86	88
68	8	73	81	34	2	90	92
69	22	46	68	47	4	106	111
70	4	53	58	3	2	83	86
71	3	35	39	2	2	73	75
72	5	56	61	40	2	96	98
73	8	63	71	47	1	86	88
74	4	65	69	21	2	98	100
75	4	62	66	15	2	129	131
76	9	36	46	18	2	100	102
77	3	50	54	8	2	90	92
78	5	89	94	30	6	151	158
79	3	55	58	20	2	85	87
80	3	53	57	19	2	81	83
81	4	51	55	25	2	85	86
82	16	46	62	4	11	80	92

APPENDIX 4 (contd.)

NITROGEN VALUES OBTAINED BY BIOLOGICAL METHODS FOR 82 SOIL SAMPLES OF RAVENSDOWN FERTILISER CO-OP. ($\mu gN\ g^{-1}$).(0-15 cm depth).

Sample	14dPotN	AnaeN	NetAna	El7dNH4	El7dNO3	El7dMinN	El7dPot
1	51	84	78	2	77	80	28
2	67	74	68	5	93	98	80
3	112	120	113	12	96	108	73
4	61	65	59	6	93	100	38
5	51	70	65	2	76	78	41
6	59	71	65	6	50	57	36
7	117	107	102	6	90	97	74
8	60	79	74	2	106	109	36
9	56	73	67	2	80	82	49
10	68	101	95	10	64	74	54
11	51	67	62	8	86	94	64
12	141	122	116	8	80	88	54
13	65	97	89	2	74	77	38
14	77	186	176	2	106	109	36
15	93	95	88	5	82	88	16
16	72	99	93	14	69	84	54
17	46	120	115	10	93	104	66
18	162	122	115	6	92	98	68
19	147	130	122	10	90	101	52
20	-5	85	77	16	106	122	20
21	71	86	81	6	80	86	78
22	75	100	94	10	102	113	41
23	75	98	93	4	74	78	70
24	-13	129	123	5	101	106	13
25	60	79	72	6	48	54	33
26	63	81	76	6	92	98	32
27	85	112	105	2	102	105	41
28	79	102	94	5	74	80	46
29	45	104	97	4	46	50	29
30	96	128	119	5	104	109	30
31	75	91	83	8	57	65	50
32	65	80	74	5	54	60	41
33	70	84	77	4	53	57	44
34	52	76	72	2	54	57	41
35	83	110	104	4	61	65	30
36	59	69	61	5	70	76	52
37	50	96	90	5	73	78	53
38	72	95	88	5	53	58	45
39	68	69	64	12	88	100	76
40	72	86	82	2	58	61	46
41	69	80	76	4	46	50	37
42	72	115	103	4	61	65	45
43	64	83	79	2	58	61	41
44	58	77	71	4	53	57	37
45	60	78	74	4	73	77	53
46	58	66	63	2	80	82	53
47	93	94	88	2	53	56	38
48	65	58	53	4	98	102	60
49	72	53	49	4	40	44	26

50	108	97	91	4	77	81	49
51	57	84	80	10	62	73	54
52	50	56	53	5	66	72	52
53	50	68	63	5	106	112	69
54	83	88	84	9	37	46	18
55	63	79	75	8	82	90	38
56	81	62	58	4	58	62	44
57	68	60	56	4	65	69	45
58	50	60	55	6	58	65	10
59	86	103	98	4	86	90	66
60	43	64	60	2	106	109	46
61	66	93	86	8	80	88	58
62	64	88	83	4	34	38	10
63	48	70	66	4	82	86	57
64	71	92	87	4	86	90	62
65	94	141	132	4	56	60	45
66	61	77	71	4	56	60	37
67	58	85	77	4	80	84	57
68	49	83	76	18	80	98	34
69	92	100	94	6	52	58	25
70	62	89	84	2	69	72	40
71	58	64	59	5	80	85	57
72	81	94	89	6	54	61	24
73	69	89	83	4	72	76	44
74	70	83	79	1	69	70	34
75	100	98	93	2	74	77	57
76	87	93	88	4	62	66	50
77	61	73	68	4	70	74	42
78	114	67	61	4	69	73	42
79	62	75	69	5	74	80	48
80	53	75	68	4	69	73	44
81	62	74	69	5	68	73	45
82	74	78	70	13	40	53	28

	N	MEAN	MIN	MAX	STDEV	SEMEAN
7D.NH4	82	13.75	1.35	79.04	14.22	1.57
7D.NO3	82	71.95	35.84	206.69	33.19	3.66
7dMinN	82	85.70	39.25	266.28	41.13	4.54
PotMiN	82	50.83	2.83	176.96	32.63	3.60
14dNH4-N	82	3.428	1.700	42.880	4.956	0.547
14dNO3-N	82	101.84	58.30	215.00	34.36	3.79
14dMin-N	82	105.27	60.38	221.63	36.02	3.98
14dPotN	82	70.60	-13.62	162.38	25.64	2.83
Anaerob	82	88.92	53.80	186.60	21.82	2.41
Ana -AD	82	83.01	49.60	176.50	20.97	2.32
El 7dNH4	82	5.756	1.333	18.667	3.325	0.367
El 7dNO3	82	73.41	34.67	106.67	18.36	2.03
El7dMinN	82	79.17	38.67	122.67	19.04	2.10
ElPotMin	82	45.35	10.67	80.00	15.47	1.71

APPENDIX 5

NITROGEN VALUES OBTAINED BY CHEMICAL METHODS FOR 15 SOIL SAMPLES OF MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 0-15 CM SOIL DEPTH

Smpl	InNH4	InNO3	InMinN	ADNH4	ADNO3	ADMiN	OrgC%
1	4	8	13	9	17	27	3.86
2	2	7	9	11	14	25	2.71
3	7	22	29	11	29	40	3.08
4	3	7	11	22	28	51	3.90
5	3	6	9	14	20	34	2.62
6	6	8	14	6	6	12	2.92
7	10	17	28	4	10	14	3.33
8	5	13	18	4	8	13	2.97
9	9	7	17	4	5	10	3.42
10	2	4	6	2	6	9	3.18
11	2	3	6	2	7	9	3.17
12	4	3	7	2	3	5	3.55
13	2	4	7	2	7	9	3.37
14	2	5	8	2	4	7	3.83
15	4	21	26	5	19	24	3.39

Smpl	TotN%	C+N%	HOx	H2SO4	KMnO4	KCl	KCl-AD
1	0.260	4.120	230	25	205	27	17
2	0.252	2.962	254	33	221	29	18
3	0.258	3.338	204	23	181	26	15
4	0.311	4.211	358	42	316	33	10
5	0.214	2.834	209	18	191	25	11
6	0.245	3.165	212	26	186	27	21
7	0.308	3.638	236	31	205	32	28
8	0.269	3.239	247	26	221	31	27
9	0.283	3.703	213	33	180	45	40
10	0.247	3.427	222	22	200	29	26
11	0.266	3.436	262	21	241	31	29
12	0.276	3.826	255	47	208	43	41
13	0.271	3.641	265	27	238	35	33
14	0.328	4.158	241	32	209	36	34
15	0.265	3.655	202	24	178	28	23

	N	MEAN	MIN	MAX	STDEV	SEMEAN
InNH4	15	4.793	2.100	10.900	2.621	0.677
InNO3	15	9.41	3.00	22.30	6.28	1.62
InMinN	15	14.21	6.20	29.30	8.06	2.08
ADNH4	15	7.14	2.00	22.60	5.75	1.48
ADNO3	15	12.60	3.80	29.10	8.50	2.19
ADMiN	15	19.74	5.80	51.10	13.66	3.53
OrgC%	15	3.287	2.620	3.900	0.395	0.102
TotN%	15	0.27020	0.21400	0.32800	0.02878	0.00743
C+N%	15	3.557	2.834	4.211	0.417	0.108
HOx	15	240.7	202.0	358.0	38.9	10.0
H2SO4	15	28.67	18.00	47.00	7.88	2.03
KMnO4	15	212.00	178.00	316.00	34.87	9.00
KCl	15	32.31	25.70	45.00	5.82	1.50
KCl-AD	15	25.17	10.50	41.60	9.59	2.48

NITROGEN VALUES OBTAINED BY BIOLOGICAL METHODS FOR 15 SOIL SAMPLES OF MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 0-15 CM SOIL DEPTH ($\mu gN\ g^{-1}$)

Smpl	7dNH4	7dNO3	7dMinN	PotN	14dNH4	14dNO3	14dMin
1	6	35	42	28	2	38	40
2	12	43	55	46	1	67	69
3	14	59	73	44	2	81	83
4	7	41	48	37	2	59	61
5	7	35	42	33	2	56	58
6	6	37	43	29	2	83	85
7	4	39	43	15	1	85	86
8	2	34	36	18	2	78	80
9	1	32	34	17	2	82	84
10	9	25	34	28	4	81	86
11	1	26	27	21	6	77	83
12	1	31	32	25	7	65	72
13	1	36	37	30	6	70	76
14	1	33	35	27	5	76	82
15	14	43	57	30	5	81	86

Smpl	14dPot	Anaero	Ana-AD
1	13	66	57
2	43	69	58
3	43	78	67
4	10	80	58
5	24	63	49
6	73	94	88
7	71	99	94
8	66	94	90
9	74	100	95
10	77	88	85
11	73	91	89
12	66	94	92
13	67	89	87
14	75	121	119
15	62	75	70

	N	MEAN	MIN	MAX	STDEV	SEMEAN
7dNH4	15	6.08	1.00	14.10	4.74	1.22
7dNO3	15	37.05	25.10	59.80	8.23	2.13
7dMinN	15	43.13	27.30	73.80	11.85	3.06
PotN	15	28.93	15.60	46.20	9.02	2.33
14dNH4	15	3.607	1.750	7.250	2.050	0.529
14dNO3	15	72.39	38.30	85.00	13.13	3.39
14dMin	15	76.00	40.50	86.79	13.47	3.48
14dPot	15	56.26	10.38	77.01	23.43	6.05
Anaero	15	87.32	63.30	121.90	15.22	3.93
Ana-AD	15	80.18	49.20	119.00	19.14	4.94

APPENDIX 7

NITROGEN VALUES OBTAINED BY CHEMICAL METHODS FOR 15 SOIL SAMPLES FROM MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 15-30 CM SOIL DEPTH.

Smpl	InNH4	InNO3	InMin	ADrNH4	ADrNO3	ADrMiN	OrgC%	TotN%
1	0	10	10	7	15	22	2.04	0.183
2	1	6	8	1	7	8	1.88	0.176
3	1	24	25	10	37	48	2.21	0.184
4	0	17	17	11	31	42	2.26	0.182
5	2	10	12	20	29	49	2.42	0.199
6	4	7	12	4	6	11	2.70	0.236
7	8	16	24	3	8	12	2.90	0.283
8	5	16	22	4	9	13	2.28	0.225
9	2	5	7	2	5	8	2.33	0.203
10	2	2	4	1	3	5	0.96	0.150
11	1	2	3	1	3	5	1.96	0.164
12	1	2	3	1	2	4	2.05	0.179
13	1	4	5	1	4	5	2.38	0.193
14	1	5	6	1	6	8	2.50	0.120
15	4	19	23	5	19	24	2.89	0.218

Smpl	C+N%	HOx	H2SO4	KMnO4	KCl	KCl-AD
1	2.223	176	21	155	15	8
2	2.056	181	23	158	16	15
3	2.394	198	26	172	15	5
4	2.442	214	22	192	19	8
5	2.619	196	18	178	23	3
6	2.936	213	20	193	29	25
7	3.183	242	27	215	27	23
8	2.505	200	22	178	23	19
9	2.533	208	30	178	25	22
10	1.110	163	18	145	16	14
11	2.124	169	17	152	16	14
12	2.229	192	23	169	18	16
13	2.573	200	21	179	22	20
14	2.620	165	27	138	18	16
15	3.108	185	26	159	23	18

	N	MEAN	MIN	MAX	STDEV	SEMEAN
InNH4	15	2.613	0.000	8.600	2.282	0.589
InNO3	15	9.99	2.10	24.30	7.07	1.82
InMin	15	12.60	3.50	25.80	8.14	2.10
ADrNH4	15	5.27	1.50	20.10	5.17	1.33
ADrNO3	15	12.74	2.70	37.70	11.48	2.96
ADrMiN	15	18.01	4.20	49.40	16.11	4.16
OrgC%	15	2.251	0.960	2.900	0.472	0.122
TotN%	15	0.19300	0.12000	0.28300	0.03830	0.00989
C+N%	15	2.444	1.110	3.183	0.496	0.128
HOx	15	193.47	163.00	242.00	21.30	5.50
H2SO4	15	22.733	17.000	30.000	3.807	0.983
KMnO4	15	170.73	138.00	215.00	20.30	5.24
KCl	15	20.80	15.60	29.40	4.52	1.17
KCl-AD	15	15.53	3.20	25.20	6.68	1.72

APPENDIX 8

NITROGEN VALUES OBTAINED BY BIOLOGICAL METHODS FOR 15 SOIL SAMPLES FROM MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 15-30 CM SOIL DEPTH

SMPL	7dNH4	7dNO3	7dMin	PotN	NH414d	NO314d	Min14d	Pot14d
1	6	26	33	23	2	50	52	30
2	6	23	30	21	2	44	46	37
3	6	39	46	20	9	54	63	15
4	6	35	42	24	1	52	54	11
5	13	33	47	34	2	57	59	10
6	2	28	30	18	1	73	74	63
7	4	31	36	11	1	78	80	68
8	1	29	30	8	2	67	69	56
9	1	20	21	13	4	65	69	61
10	1	18	20	16	15	40	55	50
11	0	15	16	12	7	50	57	52
12	1	18	20	16	14	45	60	56
13	0	16	17	12	6	45	52	46
14	0	18	19	13	11	52	63	55
15	3	38	41	17	5	77	82	58

Sample	Anaero	Ana-AD
1	38	31
2	35	34
3	42	31
4	42	30
5	51	31
6	79	74
7	87	84
8	59	55
9	71	69
10	41	39
11	40	38
12	54	52
13	51	49
14	59	58
15	62	56

	N	MEAN	MIN	MAX	STDEV	SEMEAN
7dNH4	15	3.900	0.900	13.600	3.615	0.933
7dNO3	15	26.33	15.30	39.80	8.18	2.11
7dMin	15	30.23	16.20	47.10	10.72	2.77
PotN	15	17.63	8.10	34.20	6.57	1.70
NH414d	15	5.89	1.81	15.50	4.82	1.24
NO314d	15	57.05	40.00	78.80	12.50	3.23
Min14d	15	62.94	46.46	82.70	10.71	2.77
Pot14d	15	44.94	10.16	68.63	19.46	5.02
Anaero	15	54.57	35.80	87.90	15.64	4.04
Ana-AD	15	49.30	30.90	84.50	17.29	4.46

APPENDIX 9 a.

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN CHEMICAL METHOD FOR 15 SOIL SAMPLES FROM MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 0-15 AND 15-30 CM SOIL DEPTH

	InNH4.15	InNO3.15	InMinN15	ADNH4.15	ADNO3.15	ADMiN15	OrgC%15	TotN%15
30InNH4	0.632	0.508	0.601	-0.277	-0.181	-0.229	-0.356	0.044
30InNO3	0.440	0.889 **	0.836 **	0.511	0.777 **	0.698	-0.016	0.084
30InMin	0.559	0.914 **	0.894 **	0.366	0.624	0.542	-0.114	0.085
30ADrNH4	0.015	0.224	0.179	0.726	0.734	0.762**	-0.227	-0.398
30ADrNO3	0.092	0.530	0.443	0.794 **	0.948 **	0.924**	-0.027	-0.149
30ADrMiN	0.071	0.450	0.373	0.799 **	0.912 **	0.903**	-0.092	-0.234
30OrgC%	0.502	0.488	0.544	0.046	0.123	0.096	0.073	0.293
30TotN%	0.748	0.516	0.645	0.009	0.066	0.045	-0.275	-0.076
30 C+N%	0.535	0.504	0.567	0.045	0.122	0.095	0.048	0.272
30 HOx	0.755	0.367	0.531	0.252	0.166	0.209	-0.069	0.206
30 H2SO4	0.620	0.508	0.597	-0.085	0.020	-0.023	0.334	0.585
30 KMnO4	0.676	0.289	0.445	0.280	0.171	0.224	-0.135	0.107
30KCl	0.584	0.215	0.358	-0.116	-0.228	-0.191	-0.221	0.018
30KCl-AD	0.384	-0.028	0.103	-0.640	-0.722	-0.719	0.026	0.320

	C+N% 15	HOx 15	H2SO4.15	KMnO4.15	KCl15	KCl-AD15
30InNH4	-0.334	-0.328	-0.171	-0.327	-0.097	0.107
30InNO3	-0.010	-0.027	-0.121	-0.003	-0.432	-0.569
30InMin	-0.102	-0.116	-0.153	-0.094	-0.402	-0.464
30ADrNH4	-0.243	-0.039	-0.297	0.024	-0.487	-0.731
30ADrNO3	-0.036	0.068	-0.157	0.111	-0.483	-0.769
30ADrMiN	-0.103	0.036	-0.207	0.087	-0.500	-0.783
30OrgC%	0.089	-0.116	0.059	-0.143	0.037	-0.006
30TotN%	-0.266	-0.192	-0.059	-0.201	-0.120	-0.078
30 C+N%	0.064	-0.125	0.052	-0.151	0.026	-0.011
30 HOx	-0.051	0.133	0.270	0.087	0.135	-0.069
30 H2SO4	0.357	-0.183	0.387	-0.291	0.489	0.348
30 KMnO4	-0.120	0.173	0.211	0.146	0.050	-0.138

** r-values above 0.760 are significant at 0.1% level.

APPENDIX 9b.

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN BIOLOGICAL METHOD FOR 15 SOIL SAMPLES FROM MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 0-15 AND 15-30 CM SOIL DEPTH

	7dNH4.15	7dNO3.15	7dMinN15	14dNH415	14dNO315	14dMin15	14dPot15	Anaero15
307dNH4	0.499	0.407	0.482	-0.582	-0.546	-0.620	-0.808	-0.748
307dNO3	0.659	0.747	0.782**	-0.605	-0.029	-0.120	-0.522	-0.472
307dMin	0.672	0.707	0.760**	-0.658	-0.206	-0.301	-0.671	-0.613
30PotN	0.503	0.276	0.393	-0.382	-0.619	-0.661	-0.801	-0.743
30NH414d	-0.106	-0.271	-0.230	0.697	0.229	0.329	0.442	0.374
30NO314d	0.039	0.245	0.186	-0.372	0.434	0.367	0.210	0.155
30Min14d	-0.002	0.165	0.113	-0.121	0.610	0.576	0.444	0.350
30Pot14d	-0.448	-0.426	-0.475	0.343	0.606	0.643	0.868**	0.675
30Anaero	-0.330	-0.033	-0.155	-0.133	0.534	0.500	0.517	0.530
30Ana-AD	-0.408	-0.138	-0.259	0.023	0.609	0.597	0.684	0.658

	Ana-AD15
307dNH4	-0.827
307dNO3	-0.564
307dMin	-0.709
30PotN	-0.817
30NH414d	0.449
30NO314d	0.143
30Min14d	0.368
30Pot14d	0.785 **
30Anaero	0.527
30Ana-AD	0.685

** r-values above 0.760 are significant at 0.1% level.

APPENDIX 9c.

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN BIOLOGICAL AND CHEMICAL METHODS FOR 15 SOIL SAMPLES FROM MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 0-15 AND 15-30 CM SOIL DEPTH

	InNH4.15	InNO3.15	InMinN15	ADNH4.15	ADNO3.15	ADMiN15	OrgC%15	TotN%15
307dNH4	-0.040	0.165	0.116	0.771**	0.722	0,774 **	-0.310	-0.429
307dNO3	0.376	0.796**	0.743	0.628	0.823 **	0.776 **	-0.123	-0.122
307dMin	0.274	0.664	0.606	0.739	0.872 **	0.854 **	-0.199	-0.238
30PotN	-0.246	-0.050	-0.119	0.752	0.649	0.720	-0.183	-0.493
30NH414d	-0.334	-0.270	-0.319	-0.504	-0.355	-0.433	0.222	0.100
30NO314d	0.724	0.639	0.733	-0.063	0.045	0.001	-0.112	0.122
30Min14d	0.694	0.624	0.712	-0.300	-0.108	-0.193	-0.031	0.187
30Pot14d	0.324	-0.029	0.083	-0.826	-0.814	-0.854	0.059	0.297
30Anaero	0.723	0.275	0.450	-0.353	-0.394	-0.393	-0.020	0.284
30Ana-AD	0.649	0.182	0.353	-0.536	-0.576	-0.584	0.050	0.376

	7dNH4.15	7dNO3.15	7dMinN15	PotN.15	14dNH415	14dMin15	14dPot15	Anaero15	Ana-AD15
30InNH4	-0.024	0.057	0.030	-0.498	-0.295	0.496	0.418	0.202	0.244
30InNO3	0.558	0.797 **	0.777**	0.274	-0.547	-0.001	-0.408	-0.304	-0.395
30InMin	0.478	0.708	0.683	0.098	-0.558	0.138	-0.237	-0.207	-0.275
30ADrNH4	0.366	0.361	0.397	0.361	-0.480	-0.482	-0.722	-0.599	-0.695
30ADrNO3	0.593	0.712	0.732	0.566	-0.477	-0.335	-0.732	-0.547	-0.674
30ADrMiN	0.540	0.624	0.649	0.519	-0.494	-0.394	-0.753	-0.582	-0.703
30OrgC%	-0.110	0.391	0.228	-0.186	-0.124	0.144	0.027	0.171	0.122
30TotN%	0.031	0.244	0.182	-0.338	-0.455	0.173	0.073	-0.098	-0.080
30 C+N%	-0.102	0.391	0.231	-0.203	-0.153	0.150	0.031	0.155	0.110
30 HOx	-0.107	0.351	0.201	-0.211	-0.468	0.125	-0.050	0.067	-0.023
30 H2SO4	0.012	0.434	0.306	-0.132	-0.126	0.320	0.198	0.397	0.341
30 KMnO4	-0.114	0.287	0.154	-0.196	-0.467	0.071	-0.090	-0.005	-0.088
30KCl	-0.220	-0.012	-0.096	-0.446	-0.263	0.339	0.306	0.232	0.219
30KCl-AD	-0.432	-0.287	-0.372	-0.581	0.194	0.602	0.765	0.621	0.686

** r-values above 0.760 are significant at 0.1% level.

APPENDIX 10

NITROGEN VALUES OBTAINED BY CHEMICAL AND BIOLOGICAL METHODS FOR 15 SOIL SAMPLES FROM MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 30-45 CM SOIL DEPTHS ($\mu gN\ g^{-1}$).

Sample	InNH4	InNO3	InMiN	7dNH4	7dNO3	7dMin	ADNH4
1	0	17	17	1	18	20	8
2	0	15	15	2	16	19	0
3	0	10	10	11	15	27	0
4	0	14	14	12	24	36	0
5	0	15	16	7	25	32	11
6	4	10	14	1	14	15	4
7	6	17	24	5	15	20	3
8	5	18	23	4	14	18	3
9	1	5	6	1	7	9	1
10	1	2	3	2	5	7	1
11	1	3	4	1	6	8	1
12	0	2	3	2	7	10	1
13	1	6	7	2	13	16	1
14	1	5	6	3	5	8	1
15	3	10	14	4	10	14	3

Sample	ADNO3	ADMiN
1	25	33
2	16	16
3	12	12
4	13	13
5	32	44
6	9	14
7	13	17
8	14	17
9	3	5
10	2	4
11	1	3
12	4	5
13	9	10
14	2	4
15	8	12

	N	MEAN	MIN	MAX	STDEV	SEMEAN
InNH4	15	1.833	0.000	6.600	2.142	0.553
InNO3	15	10.37	2.10	18.00	5.89	1.52
InMiN	15	12.20	3.20	24.10	6.87	1.77
7dNH4	15	4.367	1.400	12.100	3.401	0.878
7dNO3	15	13.37	5.10	25.10	6.37	1.65
7dMin	15	17.73	7.40	36.50	8.87	2.29
ADNH4	15	2.993	0.200	11.700	3.142	0.811
ADNO3	15	11.45	1.90	32.40	8.71	2.25
ADMiN	15	14.45	3.70	44.10	11.34	2.93

APPENDIX 11

NITROGEN VALUES OBTAINED BY 2M KCl EXTRACTION OF MAF SOUTH ISLAND FIELD MOIST AND AIR DRY SOIL SAMPLES FROM 45-60 CM SOIL DEPTH ($\mu gN\ g^{-1}$).

SAMPLE	IniNH4	IniN03	IniMin	ADNH4	ADNO3	ADMin
1	0	21	21	0	19	20
2	0	23	23	0	22	22
3	0	1	1	0	1	1
4	0	5	5	0	5	5
5	0	14	15	3	14	17
6	0	10	10	2	14	17
7	1	7	8	1	6	8
8	0	5	6	1	8	9
9	1	3	4	1	4	6
10	1	5	6	1	8	9
11	0	12	13	1	12	13
12	0	7	7	1	6	8
13	2	6	8	2	4	7

APPENDIX 12

NITROGEN VALUES (kg/ha) OBTAINED BY 2M KCl EXTRACTION OF MAF SOUTH ISLAND FIELD MOIST AND AIR DRY SAMPLES FROM 0-60 CM SOIL DEPTH.

Smpl	NH4.0-60	N03.0-60	Min.0-60	AmAD0-60	NiAD0-60	MiAD0-60
1	8.6	120.5	129.1	50.2	161.0	211.2
2	7.0	111.0	118.1	25.1	123.7	148.9
3	15.5	114.0	129.5	42.2	155.4	197.7
4	7.2	92.1	99.3	62.9	154.6	217.6
5	52.2	131.7	184.0	29.9	97.7	127.6
6	34.2	117.9	152.1	29.6	96.6	126.2
7	27.4	50.8	78.3	21.8	42.7	64.6
8	12.8	28.3	41.1	15.0	42.7	57.7
9	12.7	26.4	39.2	15.0	33.6	48.6
10	15.0	25.8	40.8	11.0	39.0	50.1
11	11.7	58.2	69.9	13.3	68.3	81.7
12	10.1	46.3	56.5	14.8	40.3	55.1
13	29.9	113.0	143.0	33.1	101.6	134.8

	N	MEAN	MIN	MAX	STDEV	SEMEAN
60IniNH4	13	0.727	0.000	2.400	0.685	0.190
60IniN03	13	9.58	1.90	23.30	6.63	1.84
60IniMin	13	10.30	1.90	23.30	6.39	1.77
60ADNH4	13	1.385	0.100	3.100	1.026	0.285
60ADNO3	13	9.95	1.30	22.40	6.31	1.75
60ADMin	13	11.34	1.40	22.50	6.39	1.77
NH4.0-60	13	18.84	7.10	52.27	13.39	3.71
N03.0-60	13	79.7	25.8	131.8	40.9	11.3
Min.0-60	13	98.6	39.2	184.0	47.9	13.3
AmAD0-60	13	28.05	11.09	62.98	15.84	4.39
NiAD0-60	13	89.1	33.6	161.0	48.4	13.4
MiAD0-60	13	117.1	48.7	217.6	62.9	17.5

APPENDIX 13

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN CHEMICAL AND BIOLOGICAL METHODS FOR 15 SOIL SAMPLES OF MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 30-45 CM SOIL DEPTH.

	InNH4	InNO3	InMin	7dNH4	7dNO3	7dMinN	ADNH4	ADNO3
InNO3	0.312							
InMiN	0.579	0.955 **						
7dNH4	-0.182	0.358	0.250					
7dNO3	-0.104	0.800 **	0.654	0.612				
7dMinN	-0.145	0.712	0.566	0.823 **	0.953 **			
ADNH4	0.102	0.480	0.444	-0.068	0.493	0.328		
ADNO3	-0.068	0.815 **	0.677	0.328	0.871 **	0.751	0.781 **	
ADMiN	-0.024	0.759	0.644	0.233	0.806 **	0.668	0.877 **	0.985 **

** r-values above 0.760 are significant at 0.1% level.

APPENDIX 14

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN NITROGEN VALUES OBTAINED BY 2M KCl EXTRACTION OF MAF SOUTH ISLAND FIELD MOIST AND AIR DRY SOIL SAMPLES FROM 45-60 CM SOIL DEPTH (ppm).

	IniNH4	IniNO3	IniMin	ADNH4	ADNO3
IniNO3	-0.406				
IniMin	-0.314	0.995 **			
ADNH4	0.593	-0.086	-0.026		
ADNO3	-0.410	0.966 **	0.959 **	-0.006	
ADMin	-0.310	0.940 **	0.944 **	0.155	0.987 **

** r-values above 0.801 are significant at 0.1% level.

APPENDIX 15

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN CHEMICAL AND BIOLOGICAL METHODS FOR 15 SOIL SAMPLES OF MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 0-15 AND 30-45 CM SOIL DEPTH.

	InNH4.45	InNO3.45	InMiN.45	7dNH4.45	7dNO3.45	7dMinN45	ADNH4.45	ADNO3.45	ADMiN45
InNH4.15	0.579	0.261	0.405	0.118	0.037	0.072	0.060	0.013	0.027
InNO3.15	0.392	0.441	0.500	0.463	0.186	0.311	-0.004	0.166	0.126
InMinN15	0.494	0.429	0.522	0.399	0.157	0.266	0.017	0.134	0.107
ADNH4.15	-0.373	0.562	0.366	0.752	0.843**	0.894**	0.171	0.599	0.508
ADNO3.15	-0.329	0.520	0.343	0.846**	0.724	0.844**	0.145	0.548	0.462
ADMiN15	-0.362	0.560	0.367	0.843**	0.805**	0.901**	0.162	0.593	0.501
OrgC%15	-0.205	-0.201	-0.236	0.053	-0.173	-0.104	-0.257	-0.289	-0.293
TotN%15	0.151	-0.111	-0.049	0.134	-0.255	-0.132	-0.524	-0.459	-0.498
C+N% 15	-0.184	-0.198	-0.227	0.059	-0.182	-0.108	-0.280	-0.305	-0.312
HOx .15	-0.229	0.074	-0.008	0.341	0.291	0.340	-0.398	-0.074	-0.168
H2SO4.15	-0.108	-0.139	-0.152	0.081	-0.054	-0.008	-0.494	-0.290	-0.359
KMnO4.15	-0.230	0.114	0.026	0.362	0.337	0.381	-0.332	-0.018	-0.106
KCl 15	-0.012	-0.526	-0.455	-0.273	-0.497	-0.462	-0.445	-0.576	-0.566
KCl-AD15	0.216	-0.657	-0.496	-0.616	-0.807	-0.816	-0.372	-0.709	-0.648
7dNH4.15	-0.212	0.313	0.203	0.419	0.336	0.402	0.027	0.317	0.251
7dNO3.15	-0.076	0.419	0.335	0.667	0.442	0.573	-0.138	0.283	0.179
7dMinN15	-0.138	0.416	0.314	0.631	0.442	0.559	-0.085	0.323	0.225
PotN.15	-0.622	0.164	-0.054	0.472	0.440	0.497	-0.320	-0.306	0.200
14dNH415	-0.204	-0.752	-0.708	-0.381	-0.635	-0.603	-0.489	-0.601	-0.550
14dNO315	0.541	-0.366	-0.145	-0.090	-0.574	-0.447	-0.525	-0.660	-0.642
14dMin15	0.497	-0.471	-0.249	-0.146	-0.656	-0.527	-0.393	-0.734	-0.710
14dPot15	0.497	-0.597	-0.358	-0.575	-0.847	-0.829	-0.397	-0.768	-0.700
Anaero15	0.371	-0.487	-0.302	-0.292	-0.672	-0.595	-0.460	-0.722	-0.682
Ana-AD15	0.407	-0.556	-0.350	-0.458	-0.788	-0.741	-0.417	-0.754	-0.695

** r-values above 0.760 are significant at 0.1% level.

APPENDIX 16a

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN
NITROGEN VALUES (kg/ha) OBTAINED BY CHEMICAL AND BIOLOGICAL METHODS
WITH 13 SOIL SAMPLES FROM MAF SOUTH ISLAND N TRIAL CONTROL PLOTS
AT 0-15(ppm) AND 0-30 CM (kg/ha) SOIL DEPTH.

	NH4.0-30	NO3.0-30	MiN.0-30	7Amm0-30	7Nit0-30	7Min0-30	PotN0-30	AmAD0-30	NiAD0-30	MiAD0-30
ADNH4.15	-0.170	0.395	0.278	0.647	0.598	0.646	0.704	0.970 **	0.803 **	0.871 **
ADNO3.15	-0.029	0.729	0.592	0.821 **	0.863 **	0.897 **	0.723	0.915 **	0.986 **	0.984 **
ADMiN15	-0.089	0.620	0.486	0.783	0.789	0.830 **	0.746	0.977 **	0.951 **	0.979 **
InNH4.15	0.910 **	0.525	0.683	0.011	0.388	0.290	-0.377	0.087	0.156	0.138
InNO3.15	0.614	0.968 **	0.966 **	0.566	0.866 **	0.819 **	0.131	0.347	0.627	0.553
7dNH4.15	-0.048	0.591	0.473	0.958 **	0.696	0.816 **	0.739	0.504	0.667	0.630
7dNO3.15	0.202	0.805 **	0.718	0.717	0.943 **	0.923 **	0.608	0.610	0.807 **	0.762
InMinN15	0.773	0.925 **	0.974 **	0.445	0.801 **	0.733	-0.020	0.299	0.539	0.476
7dMinN15	0.121	0.794	0.687	0.879 **	0.931 **	0.966 **	0.717	0.624	0.826 **	0.780
PotN.15	-0.528	0.229	0.043	0.769	0.521	0.628	0.967 **	0.561	0.614	0.610
HOx .15	-0.359	-0.229	-0.287	-0.097	-0.081	-0.090	0.211	0.476	0.181	0.276
H2SO4.15	-0.058	-0.231	-0.206	-0.166	-0.047	-0.087	0.115	0.192	-0.041	0.030
KMnO4.15	-0.382	-0.202	-0.272	-0.070	-0.079	-0.080	0.207	0.483	0.208	0.297
OrgC%15	-0.191	-0.121	-0.152	-0.208	-0.078	-0.124	-0.012	0.248	0.135	0.173
TotN%15	0.204	0.016	0.069	-0.369	0.005	-0.113	-0.269	0.117	-0.007	0.031
C+N% 15	-0.169	-0.114	-0.141	-0.224	-0.075	-0.126	-0.029	0.245	0.129	0.167
14dNH415	-0.429	-0.547	-0.569	-0.555	-0.549	-0.581	-0.238	-0.615	-0.506	-0.550
14dNO315	0.495	0.221	0.318	-0.161	0.053	-0.011	-0.414	-0.385	-0.181	-0.248
14dMin15	0.414	0.128	0.220	-0.245	-0.035	-0.103	-0.441	-0.473	-0.257	-0.329
14dPotN	0.294	-0.303	-0.168	-0.619	-0.500	-0.565	-0.710	-0.869	-0.728	-0.786
KCl 15	0.089	-0.491	-0.379	-0.699	-0.470	-0.568	-0.452	-0.376	-0.518	-0.484
KCl-AD15	0.160	-0.546	-0.405	-0.830	-0.659	-0.749	-0.714	-0.832	-0.816	-0.837
Anae 15	0.198	-0.308	-0.199	-0.767	-0.437	-0.565	-0.672	-0.519	-0.535	-0.541
An-AD15	0.213	-0.372	-0.247	-0.819	-0.539	-0.657	-0.761	-0.723	-0.683	-0.709

** r-values above 0.801 are significant at 0.1% level.

APPENDIX 16b

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN
NITROGEN VALUES (kg/ha) OBTAINED BY CHEMICAL AND BIOLOGICAL METHODS
WITH 13 SOIL SAMPLES FROM MAF SOUTH ISLAND N TRIAL CONTROL PLOTS
AT 0-15(ppm) AND 0-45 CM (kg/ha) SOIL DEPTH.

	NH4.0-45	NO3.0-45	MiN.0-45	7Amm0-45	7Nit0-45	7Min0-45	PotN0-45	AmAD0-45	NiAD0-45	MiAD0-45
ADNH4.15	-0.245	0.484	0.322	0.776	0.727	0.762	0.752	0.912 **	0.820 **	0.856 **
ADNO3.15	-0.115	0.720	0.553	0.934 **	0.904 **	0.937 **	0.747	0.892 **	0.968 **	0.961 **
ADMiN15	-0.174	0.652	0.480	0.908 **	0.868 **	0.904 **	0.781	0.939 **	0.947 **	0.958 **
InNH4.15	0.819 **	0.502	0.651	0.090	0.340	0.269	-0.345	0.157	0.178	0.175
InNO3.15	0.570	0.894 **	0.898 **	0.620	0.764	0.738	0.063	0.390	0.616	0.564
7dNH4.15	-0.111	0.546	0.412	0.866 **	0.646	0.734	0.608	0.480	0.652	0.615
7dNO3.15	0.101	0.756	0.646	0.817 **	0.901 **	0.897 **	0.583	0.554	0.788	0.736
InMinN15	0.709	0.859 **	0.910 **	0.512	0.705	0.662	-0.062	0.355	0.538	0.496
7dMinN15	0.026	0.742	0.613	0.912 **	0.883 **	0.915 **	0.647	0.576	0.807 **	0.756
PotN.15	-0.597	0.218	0.001	0.752	0.541	0.623	0.913 **	0.447	0.590	0.560
HOx .15	-0.321	-0.111	-0.185	0.090	0.103	0.102	0.360	0.380	0.180	0.236
H2SO4.15	-0.092	-0.185	-0.178	-0.051	0.022	-0.001	0.201	0.099	-0.052	-0.013
KMnO4.15	-0.334	-0.082	-0.166	0.110	0.109	0.112	0.353	0.397	0.209	0.262
OrgC%15	-0.214	-0.121	-0.162	-0.098	-0.023	-0.048	0.114	0.324	0.119	0.176
TotN%15	0.215	0.030	0.088	-0.156	0.022	-0.035	-0.151	0.081	-0.061	-0.024
C+N% 15	-0.191	-0.114	-0.149	-0.104	-0.021	-0.048	0.099	0.316	0.110	0.167
14dNH415	-0.358	-0.680	-0.660	-0.574	-0.624	-0.625	-0.167	-0.659	-0.618	-0.638
14dNO315	0.514	0.041	0.186	-0.097	-0.128	-0.122	-0.390	-0.507	-0.353	-0.400
14dMin15	0.444	-0.067	0.076	-0.186	-0.224	-0.218	-0.406	-0.599	-0.443	-0.491
14dPotN	0.364	-0.436	-0.248	-0.660	-0.658	-0.676	-0.711	-0.918	-0.833	-0.867
KCl 15	0.067	-0.543	-0.423	-0.623	-0.492	-0.547	-0.323	-0.446	-0.591	-0.561
KCl-AD15	0.193	-0.633	-0.459	-0.863	-0.753	-0.808	-0.664	-0.839	-0.871	-0.875
Anae 15	0.254	-0.388	-0.241	-0.633	-0.527	-0.575	-0.570	-0.580	-0.641	-0.634
An-AD15	0.281	-0.464	-0.295	-0.753	-0.652	-0.701	-0.694	-0.753	-0.773	-0.778

** r-values above 0.801 are significant at 0.1% level.

APPENDIX 16c

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN NITROGEN VALUES (kg/ha) OBTAINED BY CHEMICAL AND BIOLOGICAL METHODS WITH 13 SOIL SAMPLES FROM MAF SOUTH ISLAND N TRIAL CONTROL PLOTS AT 0-15(ppm) AND 0-60 CM (kg/ha) SOIL DEPTH.

	NH4.0-60	NO3.0-60	Min.0-60	AmAD0-60	NiAD0-60	MiAD0-60
ADNH4.15	-0.305	0.472	0.318	0.876 **	0.796	0.832 **
ADNO3.15	-0.153	0.619	0.485	0.878 **	0.880 **	0.897 **
ADMiN15	-0.223	0.584	0.436	0.914 **	0.882 **	0.908 **
InNH4.15	0.798	0.429	0.589	0.221	0.154	0.174
InNO3.15	0.564	0.754	0.800	0.454	0.542	0.531
7dNH4.15	-0.116	0.510	0.403	0.467	0.623	0.596
7dNO3.15	0.065	0.670	0.590	0.540	0.725	0.693
InMinN15	0.697	0.727	0.814	0.426	0.473	0.470
7dMinN15	-0.001	0.668	0.570	0.561	0.751	0.718
PotN.15	-0.622	0.239	0.030	0.364	0.575	0.533
HOx .15	-0.353	-0.092	-0.177	0.348	0.182	0.227
H2SO4.15	-0.101	-0.161	-0.165	0.065	-0.041	-0.015
KMnO4.15	-0.367	-0.066	-0.159	0.369	0.209	0.253
OrgC%15	-0.202	-0.153	-0.187	0.328	0.053	0.123
TotN%15	0.207	-0.030	0.032	0.112	-0.116	-0.061
C+N% 15	-0.180	-0.149	-0.177	0.321	0.043	0.114
14dNH415	-0.278	-0.734	-0.703	-0.678	-0.692	-0.702
14dNO315	0.548	-0.148	0.027	-0.459	-0.474	-0.479
14dMin15	0.491	-0.261	-0.085	-0.555	-0.572	-0.579
14dPotN	0.420	-0.507	-0.315	-0.878	-0.868	-0.888
KCl 15	0.096	-0.564	-0.454	-0.459	-0.623	-0.594
KCl-AD15	0.247	-0.639	-0.475	-0.824	-0.875	-0.880
Anae 15	0.273	-0.479	-0.333	-0.549	-0.705	-0.680
Ana-AD15	0.315	-0.533	-0.367	-0.717	-0.816	-0.808

** r-values above 0.801 are significant at 0.1% level.

APPENDIX 17

NITROGEN VALUES (ppm) OBTAINED BY CHEMICAL METHODS FOR 35 SURFACE SOIL SAMPLES OF MAF NORTH ISLAND. (0-15 cm depth).

Smpl	InNH4	InNO3	InMin	ADNH4	ADNO3	ADMin	MFADMin
1	17	8	26	8	29	38	14
2	12	3	15	7	18	25	6
3	12	3	16	10	20	30	6
4	17	12	30	10	26	36	16
5	15	23	38	13	34	47	25
6	12	10	23	11	14	25	12
7	12	22	34	17	46	64	24
8	12	9	22	6	29	35	10
9	15	2	17	6	20	26	5
10	10	7	17	6	19	25	9
11	12	5	18	6	15	22	7
12	10	7	18	12	26	39	10
13	11	10	21	11	27	39	11
14	2	19	21	9	37	46	20
15	9	14	23	28	50	79	15
16	0	0	0	7	7	14	6
17	1	0	2	6	6	12	4
18	1	0	2	7	8	16	5
19	2	1	4	8	12	20	5
20	1	3	4	8	12	21	9
21	0	0	0	7	10	17	6
22	3	7	11	9	16	25	10
23	2	3	5	8	14	23	6
24	3	2	5	8	10	19	7
25	3	1	5	8	11	19	7
26	3	1	4	8	7	16	5
27	3	0	3	8	10	19	10
28	4	1	6	8	13	21	8
29	11	8	20	17	22	40	20
30	2	11	13	16	26	43	20
31	2	9	12	10	25	35	18
32	6	5	11	7	15	23	33
33	2	10	13	13	11	24	20
34	0	0	1	10	12	22	19
35	1	0	2	10	14	24	10

APPENDIX 17 (contd.)

Smpl	OC%	N%	C+N%	HOX	H2SO4	KMnO4	KCl	KCl-AD
1	5.16	0.424	5.584	231	37	194	46	37
2	4.04	0.344	4.384	220	27	193	38	30
3	4.39	0.377	4.767	236	40	196	42	32
4	8.05	0.730	8.780	490	176	314	57	47
5	8.35	0.794	9.144	470	163	307	73	59
6	7.92	0.689	8.609	461	172	289	59	48
7	3.62	0.315	3.935	327	36	291	45	27
8	2.98	0.260	3.240	359	23	336	27	21
9	3.55	0.288	3.838	180	33	147	31	24
10	3.97	0.275	4.245	218	48	170	25	19
11	3.36	0.290	3.650	202	29	173	31	25
12	5.91	0.545	6.455	234	48	186	46	33
13	3.17	0.264	3.434	198	25	173	29	18
14	3.57	0.277	3.847	207	30	177	32	22
15	9.09	0.772	9.862	555	235	320	88	59
16	3.24	0.296	3.536	179	33	146	33	25
17	3.22	0.271	3.491	172	24	148	30	23
18	3.33	0.291	3.621	342	31	311	32	24
19	3.40	0.286	3.686	255	26	229	31	22
20	3.24	0.267	3.507	226	28	198	30	21
21	3.09	0.262	3.352	222	27	195	30	22
22	3.18	0.261	3.441	253	26	227	30	20
23	3.19	0.259	3.449	227	25	202	29	21
24	3.36	0.290	3.650	257	39	218	34	25
25	3.32	0.286	3.606	236	25	211	33	24
26	3.15	0.258	3.408	266	30	236	35	27
27	2.97	0.239	3.209	260	28	232	31	22
28	2.99	0.272	3.262	230	41	189	33	25
29	6.60	0.683	7.283	466	142	324	75	58
30	5.97	0.544	6.514	362	74	288	56	39
31	3.47	0.300	3.770	235	34	201	35	25
32	3.21	0.280	3.490	237	30	207	32	24
33	3.27	0.320	3.590	245	31	214	40	27
34	3.76	0.324	4.084	231	36	195	36	26
35	3.66	0.342	4.002	249	35	214	36	26

	N	MEAN	MIN	MAX	STDEV	SEMEAN
InNH4	35	7.031	0.400	17.800	5.579	0.943
InNO3	35	6.74	0.00	23.30	6.25	1.06
InMin	35	13.77	0.40	38.90	10.21	1.73
ADNH4	35	10.359	6.300	28.800	4.367	0.738
ADNO3	35	19.51	6.00	50.80	10.84	1.83
ADMin	35	29.87	12.90	79.60	14.18	2.40
MFADMi	35	12.40	4.60	33.10	7.09	1.20
OC%	35	4.250	2.970	9.090	1.740	0.294
N%	35	0.3707	0.2390	0.7940	0.1662	0.0281
C+N%	35	4.621	3.209	9.862	1.904	0.322
HOX	35	278.2	172.0	555.0	98.6	16.7
H2SO4	35	53.91	23.00	235.00	53.42	9.03
KMnO4	35	224.31	146.00	336.00	55.54	9.39
KCl	35	40.16	25.40	88.70	14.87	2.51
KCl-AD	35	29.80	18.40	59.90	11.51	1.95

APPENDIX 18

NITROGEN VALUES (ppm) OBTAINED BY BIOLOGICAL METHODS FOR 35 SURFACE SOIL SAMPLES OF MAF NORTH ISLAND. (0-15 cm depth).

Smpl	7dMin	PotN	14dNH4	14dNO3	14dMin	14dPot	Anaer
1	77	50	14	131	145	107	133
2	46	30	6	121	127	102	132
3	53	37	4	115	119	89	112
4	81	51	4	135	139	103	109
5	98	59	5	159	165	118	153
6	58	35	3	107	111	85	90
7	72	37	26	117	143	79	130
8	42	20	3	96	100	65	74
9	33	15	27	89	116	89	140
10	28	10	4	57	62	37	49
11	38	19	4	80	84	62	103
12	53	34	5	115	120	80	148
13	43	21	4	75	80	40	80
14	66	44	5	110	115	68	82
15	122	98	5	140	145	65	188
16	64	63	52	73	126	111	98
17	55	53	27	69	96	83	89
18	71	68	50	66	117	101	150
19	72	67	17	84	101	81	141
20	60	55	21	78	99	77	145
21	39	38	5	88	94	76	112
22	76	64	5	95	101	75	120
23	53	47	6	116	123	100	131
24	51	45	6	111	117	98	119
25	54	48	5	117	122	103	133
26	36	32	7	100	107	90	128
27	38	34	5	91	96	77	121
28	71	65	80	66	146	125	116
29	128	107	4	175	179	138	181
30	100	86	8	155	163	119	128
31	54	41	5	109	115	79	86
32	52	41	5	100	105	82	104
33	74	61	21	115	137	113	114
34	63	51	47	88	135	113	114
35	45	43	7	97	104	80	88

APPENDIX 18 (contd.)

Smpl	An-AD	MFAnae	An-NH4	Pot.AD.N
1	125	92	74	-11
2	125	68	56	-9
3	102	73	61	-10
4	98	97	79	-13
5	140	106	90	-13
6	79	80	68	-11
7	112	64	51	-10
8	68	43	30	-11
9	133	69	54	-12
10	43	32	22	-8
11	97	53	40	-10
12	135	145	134	-7
13	68	61	50	-10
14	73	67	65	-1
15	159	145	135	-7
16	90	80	79	6
17	82	78	76	2
18	142	102	100	2
19	133	83	80	0
20	136	79	78	4
21	104	59	58	6
22	111	68	64	0
23	123	81	78	1
24	110	86	83	1
25	124	90	86	2
26	120	80	77	0
27	112	77	74	6
28	108	92	87	2
29	163	147	135	0
30	111	98	96	6
31	76	63	61	5
32	96	58	52	21
33	101	77	75	7
34	103	95	94	18
35	77	52	51	8

	N	MEAN	MIN	MAX	STDEV	SEMEAN
7dMin	35	61.99	28.40	128.50	23.27	3.93
PotN	35	48.22	10.70	107.70	21.62	3.65
14dNH4	35	14.74	3.50	80.00	17.67	2.99
14dNO3	35	104.42	57.50	175.00	27.39	4.63
14dMin	35	119.16	62.38	179.13	24.97	4.22
14dPot	35	89.29	37.08	138.83	22.26	3.76
Anaer	35	118.83	49.90	188.60	29.15	4.93
An-AD	35	108.48	43.60	163.60	27.05	4.57
MFAnae	35	81.63	32.80	147.70	25.97	4.39
An-NH4	35	74.60	22.60	135.90	25.96	4.39

APPENDIX 19a

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN NITROGEN VALUES OBTAINED BY CHEMICAL METHODS FOR MAF SOUTH ISLAND(15) AND RAVENSDOWN FERTILISER CO-OP(82) SURFACE SOILS (TOTAL OF 97 SAMPLES)

	Ini.NH4	Ini.NO3	IniMinN	AD.NH4	AD.NO3	AD.Min	OrgC%	TotN%
Ini.NO3	0.246							
IniMinN	0.414 §	0.984 **						
AD.NH4	0.056	0.124	0.127					
AD.NO3	0.021	0.875 **	0.826 **	0.234				
AD.Min	0.026	0.864 **	0.816 **	0.321	0.996 **			
OrgC%	0.069	0.540 §	0.520 §	0.269	0.507 §	0.519 §		
TotN%	0.055	0.556 §	0.532 §	0.264	0.538 §	0.549 §	0.896 **	
C+N%	0.068	0.547 §	0.526 §	0.270	0.515 §	0.526 §	0.999 **	0.913 **
HOx	0.087	0.405 §	0.396 §	0.340 §	0.404 §	0.425 §	0.663 §	0.644 §
H2SO4	0.057	0.654 §	0.625 §	0.284	0.629 §	0.639 §	0.694 §	0.730 §
KMnO4	0.083	0.267	0.266	0.304	0.274	0.295	0.552 §	0.519 §
KCl	0.175	0.489 §	0.492 §	0.124	0.498 §	0.497 §	0.741 §	0.756 **
KCl-AD	0.150	0.431 §	0.432 §	-0.253	0.399 §	0.365 §	0.622 §	0.639 §

	C+N%	HOx	H2SO4	KMnO4	KCl
HOx	0.667 §				
H2SO4	0.704 §	0.584 §			
KMnO4	0.553 §	0.970 **	0.369 §		
KCl	0.748 §	0.530 §	0.568 §	0.436 §	
KCl-AD	0.629 §	0.390 §	0.448 §	0.312	0.929 **

§ r-values above 0.330 are significant at 0.1% level ;

** r-values above 0.750.

APPENDIX 19b

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN NITROGEN VALUES OBTAINED BY BIOLOGICAL METHODS FOR THE COMBINATION OF MAF SOUTH ISLAND (15) AND RAVENSDOWN FERTILISER CO-OP. (82) SOILS (TOT. 97).

	7D.NH4	7D.NO3
7D.NO3	0.454 §	
7dMinN	0.694 §	0.956 **
PotMinN	0.852 **	0.744 §
14dNH4	-0.070	0.267
14dNO3	0.074	0.677 §
14dMin	0.062	0.685 §
14dPotN	0.025	0.059
Anaerob	0.101	0.472 §
Ana-AD	0.090	0.451 §

	7dMinN	PotMinN	14dNH4	14dNO3	14dMin	14dPotN	Anaerob
PotMinN	0.880 **						
14dNH4	0.193	-0.012					
14dNO3	0.571 §	0.319	0.248				
14dMin	0.573 §	0.304	0.370 §	0.992 **			
14dPotN	0.056	0.034	0.195	0.611 §	0.612 §		
Anaerob	0.414 §	0.332 §	0.148	0.665 §	0.657 §	0.416 §	
Ana-AD	0.394 §	0.313	0.144	0.658 §	0.650 §	0.445 §	0.992 **

§ r-values above 0.330 are significant at 0.1% level ;

** r-values above 0.750.

APPENDIX 19c

CORRELATION COEFFICIENT FOR THE RELATIONSHIP BETWEEN NITROGEN VALUES OBTAINED BY BIOLOGICAL AND CHEMICAL METHODS FOR MAF SOUTH ISLAND(15) AND RAVENSDOWN FERTILISER CO-OP(82) SURFACE SOILS (TOTAL OF 97 SAMPLES)

	Ini.NH4	Ini.NO3	IniMinN	AD.NH4	AD.NO3	AD.Min	OrgC%	TotN%
7D.NH4	0.002	0.101	0.095	0.093	0.047	0.055	0.142	0.138
7D.NO3	0.087	0.834 **	0.799 **	0.207	0.803 **	0.802 **	0.586 §	0.615 §
7dMinN	0.071	0.707 §	0.677 §	0.198	0.664 §	0.665 §	0.520 §	0.542 §
PotMinN	-0.173	0.296	0.246	0.179	0.342 §	0.350 §	0.349 §	0.371 §
14dNH4	0.273	0.386 §	0.412 §	0.048	0.286	0.283	0.350 §	0.354 §
14dNO3	0.039	0.708 §	0.672 §	0.113	0.688 §	0.680 §	0.701 §	0.716 §
14dMin	0.073	0.730 §	0.699 §	0.115	0.697 §	0.690 §	0.718 §	0.733 §
14dPotN	0.071	0.053	0.062	-0.193	-0.136	-0.151	0.414 §	0.402 §
Anaerob	-0.056	0.364 §	0.331 §	0.156	0.438 §	0.441 §	0.609 §	0.601 §
Ana-AD	-0.063	0.352 §	0.319	0.031	0.413 §	0.406 §	0.583 §	0.574 §

	C+N%	HOx	H2SO4	KMnO4	KCl	KCl-AD
7D.NH4	0.143	0.291	0.149	0.288	0.137	0.098
7D.NO3	0.594 §	0.548 §	0.668 §	0.427 §	0.557 §	0.466 §
7dMinN	0.526 §	0.538 §	0.588 §	0.439 §	0.495 §	0.409 §
PotMinN	0.354 §	0.452 §	0.372 §	0.407 §	0.334 §	0.259
14dNH4	0.353 §	0.222	0.459 §	0.116	0.196	0.173
14dNO3	0.709 §	0.435 §	0.664 §	0.299	0.586 §	0.529 §
14dMin	0.726 §	0.447 §	0.698 §	0.302	0.588 §	0.531 §
14dPotN	0.416 §	0.145	0.254	0.090	0.260	0.326
Anaerob	0.614 §	0.454 §	0.503 §	0.369 §	0.608 §	0.534 §
Ana-AD	0.587 §	0.416 §	0.473 §	0.335 §	0.599 §	0.573 §

§ r-values above 0.330 are significant at 0.1% level;

** r-values above 0.750.

APPENDIX 20a

CORRELATION COEFFIECIENT FOR THE RELATIONSHIP BETWEEN NITROGEN VALUES OBTAINED BY CHEMICAL METHODS FOR THE COMBINATION OF RAVENSDOWN FERT CO-OP. (82) AND MAF SOUTH ISLAND (15) AND MAF NORTH ISLAND (35) SOILS (TOT. 132)

	InNH4	InNO3	InMin	AdNH4	AdNO3	AdMin	OrgC	N%
InNO3	0.116							
InMin	0.330 §	0.976 *						
AdNH4	0.191	-0.119	-0.071					
AdNO3	0.071	0.822 *	0.797 *	0.168				
AdMin	0.096	0.776 *	0.759 *	0.308 §	0.990 *			
OrgC	0.358 §	0.213	0.281	0.541 §	0.342 §	0.409 §		
N%	0.341 §	0.216	0.280	0.546 §	0.355 §	0.422 §	0.957 *	
C+N%	0.358	0.214	0.282	0.543 §	0.344 §	0.412 §	1.000 *	0.964 *
HOx	0.274	0.213	0.263	0.517 §	0.302 §	0.367 §	0.780 *	0.776 *
H	0.336 §	0.122	0.190	0.578 §	0.258	0.333 §	0.866 *	0.859 *
KMnO4	0.165	0.227	0.253	0.352 §	0.262	0.304 §	0.535 §	0.535 §
KCl	0.355 §	0.154	0.225	0.590 §	0.332 §	0.407 §	0.868 *	0.884 *
KCl-AD	0.341 §	0.235	0.299	0.273	0.324 §	0.352 §	0.801 *	0.819 *

	C+N%	HOx	H	KMnO4	KCl
HOx	0.782 *				
H	0.868 *	0.799 *			
KMnO4	0.537 §	0.906 *	0.468 §		
KCl	0.872 *	0.734 §	0.813 *	0.504 §	
KCl-AD	0.806 *	0.652 §	0.721 §	0.450 §	0.938 *

§ r-values above 0.300 are significant at 0.1% level;

* r-values above 0.750.

APPENDIX 20b

CORRELATION COEFFIECIENT FOR THE RELATIONSHIP BETWEEN NITROGEN VALUES OBTAINED BY BIOLOGICAL METHODS FOR THE COMBINATION OF RAVENSDOWN FERT CO-OP. (82) AND MAF SOUTH ISLAND (15) AND MAF NORTH ISLAND (35) SOILS (TOT. 132)

	7dMiN	PotN
PotN	0.860 *	
14dNH4	-0.012	0.072
14dNO3	0.548 §	0.344 §
14dMin	0.520 §	0.353 §
14dPot	0.042	0.126
Anae	0.265	0.343 §
An-AD	0.260	0.329 §

	14dNH4	14dNO3	14dMin	14dPot	Anae
14dNO3	-0.036				
14dMin	0.293	0.945 *			
14dPot	0.359 §	0.582 §	0.674 §		
Anae	0.290	0.573 §	0.643 §	0.523 §	
An-AD	0.284	0.570 §	0.638 §	0.541 §	0.992 *

§ r-values above 0.300 are significant at 0.1% level;

* r-values above 0.750.

APPENDIX 20c

CORRELATION COEFFIECIENT FOR THE RELATIONSHIP BETWEEN NITROGEN VALUES OBTAINED BY BIOLOGICAL AND CHEMICAL METHODS FOR THE COMBINATION OF RAVENSDOWN FERT CO-OP. (82) MAF SOUTH ISLAND (15) AND MAF NORTH ISLAND (35) SOILS (TOT. 132)

	InNH4	InNO3	InMin	AdNH4	AdNO3	AdMin	OrgC	N%
7dMiN	0.036	0.688 §	0.662 §	0.150	0.654 §	0.653 §	0.382 §	0.404 §
PotN	-0.177	0.238	0.187	0.246	0.315 §	0.339 §	0.309 §	0.339 §
14dNH4	0.001	-0.137	-0.130	0.167	-0.010	0.015	0.017	0.049
14dNO3	0.155	0.544 §	0.551 §	0.276	0.635 §	0.653 §	0.615 §	0.643 §
14dMin	0.148	0.475 §	0.484 §	0.319 §	0.604 §	0.630 §	0.594 §	0.631 §
14dPot	0.098	-0.133	-0.105	0.113	-0.172	-0.150	0.366 §	0.401 §
Anae	0.111	-0.019	0.007	0.499 §	0.246	0.311 §	0.542 §	0.565 §
An-AD	0.090	-0.002	0.017	0.386 §	0.238	0.286	0.498 §	0.522 §

	C+N%	HOx	H	KMnO4	KCl	KCl-AD
7dMiN	0.385 §	0.441 §	0.306 §	0.432 §	0.385 §	0.394 §
PotN	0.313 §	0.399 §	0.272	0.394 §	0.352 §	0.313 §
14dNH4	0.019	-0.038	0.027	-0.075	0.069	0.011
14dNO3	0.619 §	0.462 §	0.448 §	0.362 §	0.589 §	0.583 §
14dMin	0.599 §	0.429 §	0.437 §	0.322 §	0.586 §	0.562 §
14dPot	0.371 §	0.197	0.240	0.120	0.359 §	0.380 §
Anae	0.546 §	0.435 §	0.443 §	0.326 §	0.640 §	0.547 §
An-AD	0.502 §	0.387 §	0.387 §	0.296	0.595 §	0.543 §

§ r-values above 0.300 are signfficant at 0.1% level.

APPENDIX 21

REGRESSION EQUATIONS OBTAINED FOR THE RELATIONSHIP BETWEEN DIFFERENT METHODS.

Location	Sample No.	Equation	R^2%
CHEMICAL METHODS:			
Ravensdown	244	IniMin.N =3.14+1.11 $IniNO_3$	88.7
	82	El.Min.N =4.79+1.03 $ElIniNO_3$	97.7
		AD.Min.N =5.37+1.02 $ADNO_3$	99.8
		Total N% =0.0206+0.090 OC%	80.9
MAF South	15	IniMin15cm=2.57+1.24 $IniNO_3$15cm	92.8
	15	ADMin15cm =0.04+1.56 $ADNO_3$15cm	94.6
	15	ADMin15cm =3.80+2.23 $ADNH_4$15cm	88.2
	15	IniMin30cm=1.50+1.11 $IniNO_3$30cm	93.1
	15	ADMin30cm =0.39+1.38 $ADNO_3$30cm	97.1
	15	IniMin30cm=0.80+1.21 $IniNO_3$15cm	85.5
	15	ADMin30cm =-3.92+1.6 $ADNO_3$15cm	91.8
	15	$IniNH_4$0-30cm=-0.37+2.88 $IniNH_4$15cm	82.8
	15	$IniNO_3$0-30cm=0.41+3.78 $IniNO_3$15cm	93.8
	15	IniMin0-30cm=6.06+4.59 $IniNO_3$15cm	93.4
	15	ADMin.0-30cm=-8.2+5.93 $ADNO_3$15cm	96.8
	15	Ini.MinN45cm=0.66+1.11 $IniNO_3$45cm	91.2
	15	ADMin.0-45cm=6.54+6.87 $ADNO_3$15cm	92.4
	13	ADMin.0-60cm=36.2+6.47 $ADNO_3$15cm	80.4
MAF North	35	ADMin.N =3.00+1.27 $ADNO_3$	94.9
	35	Total N% =-0.0298+0.0942 OC%	97.3
	35	Total N% =0.214+0.0029 H_2SO_4	87.2
	35	Total N% =-0.0449+0.0139 KCl-AD	93.4
	35	Organic C%=2.59+0.0308 H_2SO_4	89.6
BIOLOGICAL METHODS:			
Ravensdown	244	7d MinN =-3.47+1.25 7d-NO_3	91.2
	82	14d MinN =-0.56+1.04 14d-NO_3	98.2
MAF South	15	7dMin15cm =-7.63+1.37 7d-$NO_3$15cm	90.6
	15	14dMin15cm=2.57+1.01 14d-$NO_3$15cm	97.7
	15	7dMin30cm =-2.95+1.26 7d-$NO_3$30cm	92.6
	15	7dMin 0-45cm=-4.7+4.06 7dMin15cm	83.7
	15	7dPot.0-45cm=-10.2+3.66 7dPot15cm	83.3

Suffix 15,30 and 45cm: N values measured at depth intervals 0-15 15-30 and 30-45cm in ppm.

Suffix 0-30,45 and 60cm: N levels in kg/ha.