YIELD RESPONSES OF OATS TO FERTILIZER NITROGEN AS INFLUENCED BY CERTAIN NITROGEN FRACTIONS IN SELECTED QUEBEC SOILS

by

John Hilarion Elwin

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Department of Agronomy,
Macdonald College of
McGill University,
Montreal.

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INTRODUCTION

Soil nitrogen is important from an agronomic viewpoint, because nitrogen is essential in the synthesis of complex organic substances such as proteins, which are an important source of food for man and feed for animals. The total nitrogen present in most soils is relatively small, and is constantly undergoing many transformations, both chemical and microbiological. However, only a significantly small fraction of the total soil nitrogen is in a form that is available to plants. The ease with which available inorganic nitrogen compounds may be lost from the soil through leaching, erosion and crop removal is an indication of the importance of the study of nitrogen in soils.

A deficiency of soil nitrogen is an important chemical factor limiting crop yields in Quebec soils and nitrogen fertilizer has been recommended for maximum production (Stobbe, 1950)[1]. Field experiments designed to indicate appropriate rates of application of nitrogen to oats have been carried out continuously for some time

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[1] P.C. Stobbe, 1950. Soil Survey information as related to soil fertility. Unpublished report Canadian Department of Agriculture, Ottawa.

(Dionne, 1957; Macdonald College Soil Fertility Committee Reports[1]), but these experiments by themselves can only indicate average regional fertilizer requirements. Responses vary widely amongst different sites, because of differences of soil and of management (Dionne, 1957), and also from year to year because of variations in seasonal climatic conditions (DeLong, 1938). Grain yield depressions have even been observed, when large quantities of nitrogen fertilizers were applied (Dionne, 1957).

If a measure can be made of the level of soil available nitrogen for plant growth and yield, it then becomes possible to collate the results of district experiments for the calculation of nitrogen fertilizer requirements in relation to the soil nitrogen level. For this purpose, the value of a number of laboratory measurements of soil nitrogen fractions, has been assessed by correlating these measurements with the absolute grain yield and yield responses of oats to nitrogen fertilizers in sixteen field experiments. The experiments were carried out during two successive growing seasons in 1962 and 1963 and covered a range of selected soils found in Quebec.

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1 Unpublished Reports on file in Agronomy Department, Macdonald College, McGill University.

LITERATURE REVIEW

According to Black (1957) nitrogen occurs in soils in many different forms, both inorganic and organic. Inorganic forms include traces of nitrous and nitric oxide and nitrite, ammonium and nitrate. The two latter ions are the main sources of inorganic nitrogen utilized by plants (Russell, 1961). Nitrate is present in the soil solution. Ammonium may occur partly in the soil solution (Russell, 1961), but it is largely adsorbed on the exchange colloids or fixed within the clay lattice (Rodrigues, 1954; Stevenson *et al.*, 1958; Bremner, 1959).

The ionic forms of nitrogen in the soil solution, ammonium, nitrite and nitrate usually constitute about 1 to 2 per cent of the total nitrogen according to Sowden (1962). Young (1962) contends that such a generalization, if restricted to the surface horizons appears valid for most mineral soils. If on the other hand soils are regarded as more than the surface horizons, the inorganic nitrogen content is more of the order of 2 to 20 per cent of the total nitrogen. This takes into account ammonium fixed by the clay minerals as well as nitrates leached deep into the soils. The remainder, organic nitrogen, therefore, accounts for the greater part of soil nitrogen, the ultimate source of which is plant and animal remains (Sowden, 1962).

Some of the organic nitrogen may be of a protein nature (Bremner, 1950). For some time, some workers including Hobson and Page (1932), Waksman and Iyer (1932) speculated that the protein was probably condensed with lignin. The latter workers suggested the reaction was similar to a tanning process, the carbonyls of the lignins condensing with the amino groups of the protein. They also showed that such compounds were resistant to further decomposition. Russell (1961) stated that the only alteration that could be made to this theory was that only a part of the humic nitrogen can be present as proteins and the tanning polyphenols must be much more complicated than lignin and may themselves contain nitrogen. He concluded that it has not been possible to prove that there was a protein moiety in humus and it was more probable that it was amino acids rather than proteins which have reacted with the polyphenols.

Investigations of these nitrogenous organic complexes have shown the presence of combined amino acids (Bremner, 1949; Bremner and Shaw, 1954; Stevenson, 1957b). Although these amino acids may be ammonified and nitrified before assimilation, it also may be possible for the plants to use them directly (Ratner *et al.*, 1957). Free amino acids probably exist in soils (Bremner, 1952; Simonart and Peeters, 1954), but these are decomposed rapidly by microorganisms, and hence do not occur in more than trace amounts, although Sowden (1957) succeeded in determining significant quantities.

The quantities of amino acids obtained on hydrolysis of soil residues have been reported by several workers. Kojima (1947) found that about 37 per cent of the total nitrogen of a muck soil was accounted for as α-amino acid nitrogen. Sowden (1962) showed that 34 per cent of the total nitrogen of a podsol was in the form of amino acid nitrogen. Rendig (1951) noted that the nonbasic amino nitrogen accounted for 15 per cent of the total nitrogen in a cultivated soil, whereas in a virgin soil adjoining the same field the nonbasic amino nitrogen constituted 27 per cent of the total nitrogen.

Investigations of organic nitrogen complexes in soil have also revealed the presence of amino sugars. Bremner (1952) found that 6 to 14 per cent of the total nitrogen in six soils examined was in the form of 2-amino sugars. Stevenson (1957) examined soils which contained 7.6 to 24 per cent of their total nitrogen as amino-sugar and also recorded the amino-sugar distribution in acid hydrolysates of soils. The percentage of amino-sugar nitrogen varied with horizon, increasing with depth. Sowden (1959) reported similar observations.

Sowden (1958) found that amide nitrogen accounted for a certain percentage of the total nitrogen in soil, but these amides were readily converted to the corresponding acids on hydrolysis. Their relative importance in contributing to the total nitrogen in soil was not fully evaluated by the methods of soil analysis.

There remained 50 to 70 per cent of the organic nitrogen in soils, which was resistant to acid hydrolysis and the nature of which was highly speculative (Russell, 1961). Some workers have suggested that this fraction was in the form of heterocyclic nitrogen compounds (Shorey, 1930; Kojima, 1947). Mattson and Koutler-Adersson (1943) speculated that this non-hydrolysable nitrogen was in the form of lignin ammonia complexes. Bremner (1955) also subscribed to the latter view, since ammonia lignin preparations were shown to be resistant to hydrolysis with 6 N hydrochloric acid.

The estimation of the ability of a soil to supply nitrogen therefore is not as straight forward as assessing the availability of potassium and phosphorus (Williams, 1962), since nearly all soil nitrogen is organic, whereas crops depend almost entirely on inorganic nitrate and ammonia. Nitrogen is ordinarily released from soil organic matter to cultivated crops to the extent of about 1 to 3 per cent during each growing season. Sandy soils, however, may yield somewhat higher percentages (Salter and Green, 1933; Woodruff, 1949 and Bremner, 1949).

Yield response to applied fertilizer materials has been one of the accepted standards for assessing the availability of soil nutrient elements (Vandecaveye, 1948). However, Vandecaveye explained that it must be recognized that the true value of the nutrient may not be accurately measured in this way, because of adverse growth conditions. In view of the expense and time involved in field plot experiments, laboratory indices have been proposed for measuring the nitrogen release from the soil. They include:-

(a) mineral-N content. (Cook et al., 1957),
(b) total nitrogen or total organic matter (Allison and Sterling, 1949; Smith, 1952),
(c) mineral nitrogen released by (i) moist incubation (Munson and Stanford, 1955) or (ii) chemical treatment (Leo, 1960; Richard et al., 1960; Purvis and Leo, 1961).

The chief uncertainty with respect to chemical methods concerns the effectiveness of chemical reagents in liberating the same portion of the soil nitrogen that natural agencies release to the crop (Allison, 1956). Actually it is well known that no chemical agent can duplicate the activities of numerous and ever-changing biological agents (Piper, 1942). Allison (1956) maintained that any chemical method must necessarily be an empirical one and will be affected by types of organic nitrogen present, amounts and types of clay and quantity of fixed ammonia held by the clay minerals within the clay lattice.

Hanway (1963) suggested that the only satisfactory way of developing laboratory tests, which can predict crop responses to fertilizer involves:-

(1) conducting field experiments on soils of the type to be tested,

(2) testing samples of the soils from these experimental sites and

(3) developing the desired relationship between the laboratory test results and the crop response obtained in the field from the fertilizer application.

There are two approaches to the problem of relating quantitative plant growth or more specifically crop yield, with laboratory measurements of soil nutrient elements (Russell, 1961). One approach, Russell explained involved the setting-up of a hypothesis which seemed to fit the facts, which was then expressed as a mathematical equation, and this was then applied to the experimental data. The second possible solution was to study the field experimental data by statistical methods. An empirical equation or regression formula was fitted to the data, with no assumption or hypothesis being made with regards to the underlying causes. In view of the fact that plant growth was dependent on so many factors, no general solution could be expected by either method. The first procedure has been favoured by many workers (Mitscherlich, 1909, cited in Russell, 1961; Bray, 1948 and Willcox, 1955a).

Mitscherlich (1909, cited in Russell, 1961) was among the first to express the growth curves obtained in field experiments by a mathematical equation. He assumed that a plant or crop should produce a certain maximum yield if all conditions were ideal, but in so far as any essential factor was deficient there was a corresponding shortage in the yield. He further assumed that the increase of crop produced by a unit increment of the lacking factor was proportional to the decrement from the maximum, or expressed mathematically.

$$\frac{dy}{dx} = (A-y)C, \quad (1)$$

where y was the yield obtained when x was the amount of factor present, A was the maximum yield obtainable if the factor was present in excess, this being calculated from the equation, and C was a constant. On integration and assuming $y = o$ when $x = o$

$$y = A\,(1-e^{-Cx}) \quad (2)$$

This curve is everywhere concave to the axis representing the nutrient supply.

Mitscherlich claimed that the proportionality factor C was a constant for each fertilizer, independent of the crop, the soil or other conditions. If this were so an experimenter knowing its value could from a single field trial, predict the yields obtainable from any given quantities of the fertilizer. The great practical value of such an hypothesis was that it would be possible to estimate by direct pot experiment the amount of available plant nutrient in a soil. This is still today one of the most difficult of all soil problems.

Mitscherlich (1923) cited in Russell (1961) has used this formula for this purpose. Several workers (Crowther and Yates, 1941; Bray, 1948; Willcox, 1955b; Bullen and Lessels, 1957) have shown how this formula or modifications of it can be used to work out fertilizer requirements for crops. The Mitscherlich equation according to Russell (1961) was not exact. The proportionality factor for a particular nutrient was not a constant. Bray (1948) demonstrated how this constant varied with phosphorus and potassium and with different crops. Further the response curve was often sigmoid, fertilizer in excess decreased the crop yield, and the calculated maximum yield of crop was sometimes far in excess of anything that could be obtained. Willcox (1955b) claimed that when nitrogen for example was increased out of proportion to the other nutrients, the plants were overloaded with nitrogen causing more or less severe plasmolysis of the cells with cumulative effects, that depressed the incremental yields below normal.

Bray (1948) proposed certain modifications of the Mitscherlich equation which were embodied in the following equation:-

$$\log (100-y) = \log 100 - c_1 b \quad (3)$$

where b = soil test value

c_1 = a constant for a particular crop.

100 = maximum possible yield (100 per cent) when all nutrients are present at the optimum level,

y = per cent of maximum yield possible, obtained at nutrient level b, the levels of other nutrients remaining constant.

By solving c on each field and for each crop, then averaging the values, a mean c_1 value could be obtained for each crop. Bray (1948) also showed that all crops did not all have the same or similar curves. But each crop appeared to follow the percentage yield concept of both Mitscherlich and Baule; that is, the percentage yield of the untreated plot varied directly as the level of the nutrient present in the soil. Employing this modified Mitscherlich equation of Bray (1948), Hanway and Dumenil (1955) showed that nitrate production rate in the laboratory was significantly correlated with yield increases obtained from different rates of application of nitrogen fertilizer on corn. Eagle and Matthews (1958) furnished a similar example of the use of this equation. They obtained a significant correlation between the logarithm of percentage yield decrement, which is a measure of crop response, and nitrate supplying power as measured by incubation.

Willcox (1956) supported the hypothesis approach in relating quantitative plant growth with laboratory measurements of soil nutrient elements. His agrobiologic percentage method of evaluating fertilizer tests was derived from the Mitscherlich yield equation (Willcox, 1955a, 1955b). One obvious objection to the Mitscherlich and Willcox methods was that the soil test value, represented by (x) in the equation (2) was not measured directly. In the former case mathematical procedures were used (Mitscherlich, 1949, cited in Willcox, 1955a); while in the latter a "standard yield diagram" was employed to obtain the soil test values in a particular experiment (Willcox, 1947).

Willcox's (1955a) thesis was based on:
(i) The principle of the reproducibility of natural phenomena and
(ii) The law of diminishing increments of yield in agriculture.
By the first principle he claimed that when a certain kind of plant was grown under fixed conditions it would give a certain yield of vegetable substance. When the same kind of plant was grown again on the same or a similar area of the same soil under identical conditions, the same yield of vegetable substance would be obtained as many times as the same operation was repeated. In other words, he continued, there was a priori a constant relation between the yield of a crop and the sum total of the factors of plant growth resident in and around the area of soil concerned. This relation was indefinitely reproducible when no change had been made in the kind of plant or the qualitative and quantitative composition of the environment.

The second principle was embodied in the Mitscherlich equation, and could be enunciated in the form, that it was a characteristic of every kind of plant that it could not produce an unlimited yield on a limited area of soil in one cycle of plant growth, no matter how well it may have been supplied with growth factors (Willcox, 1955a).

Willcox (1956) summarized his hypothesis regarding the approach to the problem of relating soil test laboratory values with field test responses to fertilizer thus.... The analysis of variance method had one inherent defect; that being abstract, the method had no concrete base in the specific natures of either plants or fertilizers, which were under the exclusive control of a general law of the vegetable kingdom; the law of diminishing increments of yield.

In spite of Willcox's strong case for the agrobiologic percentage method, the empirical approach to the solution of nutrient yield relationships has found favour with many workers. Saunder *et al.* (1957) used linear regressions to correlate nitrogen released on incubation with crop responses to fertilizer nitrogen in Rhodesia. Cooke *et al.* (1957) also used curvilinear regressions with much success to correlate laboratory measurements of soil nitrogen with wheat yield responses to nitrogenous fertilizer. On the whole the interest in exact equations has died down because the response of a crop to a fertilizer depends on many factors, such as the level of other nutrients present and on the environmental conditions, so that no simple exact quantitative relation between the supply of a fertilizer and the crop response can exist (Russell, 1961).

The usefulness of the yield response method in assessing the availability of soil nutrient has already been discussed with reference to the Mitscherlich equation. The value of laboratory indices in measuring "available" soil nitrogen must now be thoroughly examined. Among the methods of assessing the nitrogen status of soils was the determination of the total nitrogen content or total organic matter (Allison and Sterling, 1949; Carpenter, Haas and Miles, 1952). These workers have shown that for a given soil series, there was usually a fairly close correlation between total nitrogen and the quantity made available to plants annually. They concluded that there was a similarity in composition of the native organic matter regardless of past cropping practices. Olson et al. (1960); Pritchett et al. (1960); Richard et al. (1960) and Gasser (1961) reported significant correlations between total soil nitrogen and crop yield and crop response. On the otherhand, nonsignificant correlations have been reported by Synghal et al. (1959). Total nitrogen is likely to be most significant where the general level is low, but it does not provide the differentiation required in soil testing (Williams, 1962).

A substitute procedure is the determination of soil organic matter, which usually had a fairly constant carbon nitrogen ratio in a given climatic zone (Olson and Rhoades, 1953). Smith (1952) observed that the total organic matter gave reliable estimates of the amount of nitrogen supplied by soils in Missouri. Woodruff (1949); Saunder et al.(1957) have reported instances where the total organic matter determinations have been proposed as a basis for making broad manurial adjustments.

The nitrate nitrogen existing in the surface soil at seeding time has proved of little value in estimating the nitrogen delivery of soils (Olson and Rhoades, 1953; Cook et al., 1957; Synghal et al., 1959 and Singh, 1961). The total nitrate nitrogen content of the soil profile on the otherhand, has been a good indicator of the response of wheat and sorghum respectively to nitrogen fertilization (Legett, 1960;

Mathers, 1960). Soper and Huang (1963) reported similar results for barley.

The nitrate produced may be protected to some extent inside soil crumbs (Russell, 1961), but it was subject to losses by leaching. So was the ammonium ion, which might also be fixed in relatively unavailable non-exchangeable forms in clay minerals. The mineral nitrogen content, therefore, showed pronounced seasonal changes and was normally too variable to be a reliable criterion of nitrogen status (Williams, 1962). However, where rainfall was light and does not penetrate deeply into the subsoil, initial nitrate values for samples from the seed-bed may give some guidance (Cook et al., 1957; Gasser, 1961).

Moist incubation methods measure the release of nitrate and ammonia during controlled incubation. Harmsen and van Schreven (1955) have reviewed fully the work carried out before 1955 on the mineralization of organic nitrogen in soil. They concluded that the results of laboratory incubation experiments are in no way comparable with mineralization process under field conditions. Such incubation experiments provide information about the potential mineralization powers of the soils, whereas under field conditions the real mineralization capacity prevails. Conditions in the laboratory are entirely artificial. The aim since then has been to establish conditions which give reproducible results which correlate with crop performance (Eagle and Matthews, 1958). Such relationships may be seriously restricted by variations in nitrogen release (Eagle, 1961). It was also apparent that incubation values might not adequately reflect the effects of leguminous crop residues because although more nitrate was supplied to the crop succeeding the legume it was found that nitrate produced when soil was incubated was not similarly increased (Hanway and Dumenil, 1955; Saunder et al., 1957; Olson et al., 1960). In spite of these limitations, many significant correlations with field crop responses have been obtained for maize (Hanway and Dumenil, 1955), potatoes and barley (Eagle, 1961; Olson et al., 1960 and Pritchett et al., 1960). There have been nevertheless, a few nonsignificant correlations with field response values (Kresge and Merkel, 1957; Mathers et al., 1960).

In view of the time involved in carrying out incubation tests, attempts have been made to obtain useful nitrogen release values by simple and rapid treatment of soil with chemicals. Alkaline permanganate has been used by Synghal *et al*.(1959); dilute acids by Richards *et al*. (1960); Leo (1960); and Purvis and Leo (1961); concentrated acids by Singh (1961) and dilute alkali by Cornfield (1960). The results obtained by these chemical methods are rather conflicting and inconclusive (Williams, 1962). Significant correlations with field tests have been reported by Leo (1960). Singh (1961) as quoted in Dissertation Abstracts (1962) found that a very low percentage of the crop yield variance was associated with the hydrolysable nitrogen by strong acid. Iswaran *et al*. (1962) reported that values of nitrogen obtained by oxidation of soil with alkaline permanganate were significantly correlated with crop responses.

Summary

Soil nitrogen exists in both inorganic and organic forms: the organic form being the more abundant. The determination of the inorganic nitrogen present in the surface soil at any one time is a poor indicator of nitrogen fertilizer requirements. On the otherhand, the total mineral nitrogen in the profile may have some predictive value.

Regarding the organic nitrogen, the total amount present may be a useful basis for making broad manurial adjustments. However, the nitrifiable organic nitrogen would appear to be a more valuable determination for making fertilizer recommendations.

The organic nitrogen fractions released on mild and severe hydrolysis have not been fully explored as criteria of nitrogen availability. Results to date are conflicting and inconclusive. Not many of these hydrolysable fractions have been correlated with fertilizer response values.

EXPERIMENTAL PROCEDURE

A. Field Experiments

(i) Sites

Field experiments were conducted under the auspices of the Macdonald College Soil Fertility Committee on six Quebec farms in 1962 and ten farms in 1963, to determine oat grain response to nitrogen, phosphorus and potassium. The locations of the experimental sites and a brief description of the soils are given in Table 1. These soils have been described in detail by Cann and Lajoie (1942); Lajoie and Stobbe (1950); Mailloux and Godbout (1954); Lajoie and Baril (1956); and Lajoie (1960).

(ii) Materials

The fertilizer sources used in 1962 were ammonium nitrate, 33.6% N; superphosphate, 20% P_2O_5; muriate of potash, 60% K_2O; 0-16-8, and 0-20-20. Similar sources of nitrogen and potassium were used in 1963, but the superphosphate was replaced by triple superphosphate, 46% P_2O_5.

The variety of oats used varied with each site to conform to that sown by the farmer. Information on varieties is provided in Appendix Table 1.

Table 1. Description of soils at experimental sites -- 1962 and 1963.

Farm	Location	Soil type	Great Soil group	Description
1962				
Seed Farm	Macdonald College	Chicot s.l.	Brown podsolic	Well drained soil developed from alluvial sandy materials over calcareous till.
M. Leger	Vaudreuil	Bearbrook c.	Dark grey gleisolic	Imperfectly drained soil developed from reddish brown and grey marine clays.
M. Feeny	Huntingdon	Ste.Rosalie c.	Dark grey gleisolic	Poorly drained soil developed from thick grey marine clay deposits.
J. Berard	Dunham	Blandford. l.	Brown podsolic	Developed from firm grey to olive grey loam till derived from schist and sandstone. Internal drainage imperfect.
Oswald	St.Eustache	St.Bernard l.	Brown forest	Well drained soil developed from glacial till Beekmantown dolomitic rock.
E. Jodoin	Ste.Martine	Ste.Rosalie c.	Dark grey gleisolic	Poorly drained mottled profile, occasionally interstratified with sand.

Table 1 (cont'd).

Farm	Location	Soil type	Great Soil group	Description
1963				
Seed Farm	Macdonald College	St.Bernard l.	Brown forest	Well drained soil developed from glacial till Beekmantown dolomitic rock.
Seed Farm	Macdonald College	Chicot s.l.	Brown podsolic	Well drained soil developed from alluvial sandy materials over calcareous till.
G.Beauchamp	Grenville	St.Bernard l.	Brown forest	Well drained soil developed from glacial till Beekmantown dolomitic rock.
A.Boileau	St.Lazare	St.Amable l.s.	Ground water podsol	Developed from sandy materials washed over grey Champlain clays.
A.Vinet	Vaudreuil	Bearbrook c.	Dark grey gleisolic	Imperfectly drained soil developed from reddish brown and grey marine clays.
A.Dowbiggin	Austin	Ascot s.l.	Podsol	Developed from a greyish sandy loam to loam till derived from non-calcareous slates. Well drained soil.
M. Feeny	Huntingdon	Ste Rosalie c.	Dark grey gleisolic	Poorly drained soil developed from thick grey marine clay deposits.
Feller Institute	Grande Ligne	St.Blaise s. c.l.	Brown forest	Slow draining sandy clay loam developed from brownish grey Champlain materials.

Table 1 (cont'd.)

Farm	Location	Soil type	Great Soil group	Description
C. Martin	Dunham	Blandford l.	Brown podsolic	Developed from firm grey to olive grey loam till derived from schist and sandstone. Internal drainage imperfect.
A. Lague	Dunham	Shefford l.	Brown podsolic	Developed from sandy loam till derived principally from Ordovician shale with some sandstone material. Good internal drainage.

(iii) Methods

In 1962 the trials were of a 3 x 3 x 3 factorial design, with a plot size of .0019 acre and with two replications. Treatments were randomized within the replications. The fertilizer rates expressed as pounds per acre were:-

N - 0, 25, 50

P_2O_5 - 0, 50,100

K_2O - 0, 50,100

Seeding rate was two bushels per acre for all experiments. The fertilizers were drilled with the seed at sowing, using an experimental seed drill previously described by Beauchamp (1962). Certain modifications were made to the drill in 1963 so that both fertilizer and seed were delivered through the same shoe.

The experimental design in 1963 was that of a randomized complete block with eleven treatments in two replications. Fertilizer and seed rates were the same as for 1962. The treatments applied to oats were:-

0 - 0 - 0
1 - 0 - 0
2 - 0 - 0
0 - 2 - 2
1 - 2 - 2
2 - 0 - 2
2 - 1 - 2
2 - 2 - 0
2 - 2 - 1
2 - 2 - 2
2 - 2 - 2 + micronutrients

where 0, 1, and 2 represent the zero, low and high rates of application of the major nutrient elements, nitrogen, phosphorus and potassium. Micronutrients were added as calcium sulphate at the rate of 50 lbs. per acre, and "Fritted Trace Elements"[1] at 30 lbs. per acre.

In 1963 six of the trials were undersown with forage mixtures used by the farmer. As a weed control measure, 2-4-D.B (2-4 dichlorophenoxy butyric acid) was applied at the rate of 8 oz. per acre four weeks after seeding. Border effects were eliminated at harvest by removing the two outside rows of each plot, as well as an area three feet long from both ends of each plot.

(iv) Fertilizer Response Values

Numerous values may be calculated from the yield date of the field experiments to represent the level of "available" nitrogen in the soil and to estimate the fertilizer requirement at each site. The following values have been examined as measures representing the level of "available" nitrogen in the soil:-

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1 Canada Industries Limited 'Formula 502' containing boron 2.8%; Copper 2.0%; Iron 3.9%; Manganese 9.7%; Molybdenum .13%; Zinc 4.0%.

Check yield:- the yield of grain obtained with no fertilizer application.

"No nitrogen"yield:- the yield of grain obtained with "no nitrogen" treatment but adequate phosphorus and potassium treatments.

Percentage Yield:- the yield of the "no nitrogen" plot calculated as a percentage of the maximum treatment yield. Percentage yield was calculated as follows:-

$$\frac{0 - 2 - 2}{2 - 2 - 2} \times 100$$

where 0 - 2 - 2 = no nitrogen + 100 lbs. P_2O_5 per acre + 100 lbs. K_2O per acre

2 - 2 - 2 = 50 lbs. N per acre + 100 lbs. P_2O_5 per acre + 100 lbs. K_2O per acre.

B. Laboratory Measurements

Soil samples for laboratory analyses were collected at random from the surface horizon at the experimental sites prior to seeding in both growing seasons. In 1963 the lower horizons were sampled also, to determine on the fresh samples the nitrate nitrogen in the profile down to a depth of three feet. Bulk density measurements were also made on these samples.

The samples were air-dried. The very large aggregates were broken down with a wooden hammer and screened with a 10 mesh sieve to remove stones and debris larger than 2 mm. For organic matter and organic nitrogen determinations portions of the 2 mm. soil were further crushed to pass a 60 mesh sieve. All air-dried samples were stored in cardboard containers.

The pH of the soils was determined using 0.01 M calcium chloride solution as employed by Schofield and Taylor (1955), and also a 1:1 soil:water suspension (Jackson, 1958). The nitrate nitrogen of the soil samples was extracted with a .02 N copper sulphate solution and determined by Middleton's (1958) method using phenol sulphonic acid. Bulk density data were used to convert nitrate nitrogen content to pounds per acre of nitrogen. Organic matter was determined by the DeLong[1] method, which is a slight modification of the method described by Walkley (1935). Total nitrogen determination was done by the standard micro-Kjeldahl procedure using a modified Parnaas-Wagner micro-Kjeldahl distilling apparatus.

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[1] Macdonald College, Department of Chemistry Laboratory Mannal No. 540.

Nitrification rate was determined by incubating 20 gm. of 2 mm. soil, moistened to 50 per cent of the water holding capacity, for a two week period at 28°C. The nitrate nitrogen produced was determined using the same method as for nitrate nitrogen above.

The "amino acid nitrogen", the total hydrolysable nitrogen and the amino sugar plus ammonia nitrogen were determined by using Stevenson's (1957b) method. Amino sugar nitrogen was also determined by the alkaline decomposition method of Tracey (1952), after hydrolysing the soil with 6 N HCl acid for 6 hours in a sealed test tube (1:5 soil to acid ratio).

Amide nitrogen was determined by the method described by Pucher _et al_. (1935) with the following modifications. 2 gm. of 60 mesh soil were hydrolysed with 20 ml. of 1 N H_2SO_4 in a stoppered boiling tube with a short piece of a capillary tube attached. After heating for three hours in boiling water, the hydrolysate was diluted down to 50 ml. with 1.7 M KCl and shaken for 24 hours. Two ml. of the extract were then analysed for ammonia by a micro-diffusion technique of Conway using modified micro-diffusion units (Bremner and Shaw, 1955).

C. Statistical Analyses

The relationships between soil nitrogen measurements were analyzed by simple linear correlations. These laboratory measurements of soil nitrogen were also correlated with the fertilizer response values mentioned earlier. The more promising of these correlations have been examined more fully by multiple correlation and regression analyses.

Three treatments that were common to the two different experimental designs, and which gave a measure of oat grain response to nitrogen fertilizer in the field were examined by an analysis of variance procedure for a split plot design in space (Steel and Torrie, 1960).

RESULTS AND DISCUSSION

The soil analytical data are summarized in Appendix Table 2 and the yield data of the field experiments are given in Appendix Table 3. Only mean values for the check yield, "no nitrogen" yield and maximum yields are shown.

Values of "available" nitrogen

A fairly consistent amount of nitrogen was hydrolysed from these soils, ranging from 45 to 71 per cent of the total soil nitrogen (Table 2.). Proportionally less nitrogen was found in the acid hydrolysates of the clay soils than of the loams and sandy loam soils. This was probably due to the fixation of ammonium by the clay soils as clay-ammonium complexes (Stevenson et al., 1958). The amounts of nitrogen present in the different fractions did not truly reflect the absolute values, since some of the fractions were obtained by a difference procedure. The values obtained for amide nitrogen ranged from 3.8 per cent to 7.3 per cent (Table 2.). These were below the value of 10 per cent reported by Sowden (1958).

Table 2. Chemical distribution of soil nitrogen

Soil type	Total soil-N %	Amide -N	Amino-Sugar-N	Amino-N	Amino Sugar-N + Ammonia	Total Hydro-lysable N
		Per cent of total soil nitrogen				
Chicot s.l.	.19	7.3	10	47	17	64
Bearbrook c.	.21	5.2	19*	36	13*	50
Ste Rosalie c.	.22	5.0	9.1	40	11	51
Blanford l.	.49	6.1	8.6	47	18	65
St.Bernard l.	.22	5.5	11	48	22	71
Ste Rosalie c.	.26	4.6	7.3	33	12	45
St. Bernard l.	.21	6.7	11	46	20	66
Chicot s.l.	.14	5.0	12	46	22	67
St.Bernard l.	.24	3.8	10	48	17	65
St.Amable l.s.	.22	5.0	11	50	17	66
Bearbrook c.	.27	4.4	19*	42	13*	54
Ascot s.l.	.38	5.0	7.9	42	15	56
Ste Rosalie c.	.18	6.1	10	43	17	59
St. Blaise s.c.l.	.19	5.3	10	43	16	58
Blanford l.	.48	4.4	8.9	42	19	61
Shefford l.	.49	4.5	10	37	15	51

* The higher values obtained for amino sugar nitrogen than for amino sugar plus ammonia nitrogen were probably the result of discrepancies arising from the different methods of determination.

Amino sugar nitrogen ranged from 7.3 per cent to 19 per cent. Bremner (1952) reported values of 6 to 14 per cent for surface soils and Cheng and Kurtz (1963) obtained amounts ranging from 6 to 15 per cent. It was observed that the two Bearbrook clay soils included in the study had rather high values of 19 per cent amino sugar nitrogen in the surface soils, while the range excluding these two, was of the order of 7.3 per cent to 12 per cent. Such a range for surface soils was more consistent with the findings of Bremner (1952), Sowden (1959) and Cheng and Kurtz (1963). These high values may have been the result of the release of fixed ammonium ion by acid hydrolysis. Bremner (1959) observed that 50 to 90 per cent of the fixed ammonium may be released in this way. The "amino acid" nitrogen accounted for 33 to 50 per cent of the total nitrogen. These values may seem high according to the findings of Sowden (1962) who obtained a figure of about 34 per cent of the total nitrogen. Having regard to the fact that this fraction was determined by a difference method (Stevenson, 1957b) the values did reflect the relative importance of this soil nitrogen component.

If the above measures of soil nitrogen reflect in any way the ability of the soil to supply nitrogen to the crop, one would have expected the nitrification rate, which was determined by incubation, to correlate with some of these fractions. Correlation coefficients (Table 3.) showed that all laboratory measurements of soil nitrogen failed to reach significance with the nitrate nitrogen accumulated on incubation. The nitrogen fractions that released their ammonia with the more drastic hydrolysis conditions showed the highest correlation. One might have thought that the easily hydrolysable amide fraction, for example, would have been most closely related to nitrogen released on incubation. As a matter of fact, Cornfield (1960) found a significant correlation between nitrogen released on incubation and the ammonia liberated by mild alkaline hydrolysis. However, it is extremely difficult for a chemical reagent to duplicate the activities of the extremely variable micro-organisms involved. Total nitrogen, which required rather severe digestion before all or most of the organic nitrogen can be released as ammonia showed the highest correlation with incubation nitrogen or nitrification rate. This suggested that the proportion of mineralisable nitrogen was reasonably constant, and that the

Table 3. Correlation coefficients between laboratory measurements of soil nitrogen (1962 and 1963 samples).

	Total-N	Organic matter	Amide-N	Amino sugar-N	Amino -N	Amino sugar plus ammonia -N	Total hydro-lysable - N
Nitrification rate	.355	.348	.197	.326	.327	.266	.309
Total - N		.977**	.923**	.739 **	.962**	.915**	.956**
Organic matter			.900**	.672**	.945**	.867**	.929**
Amide - N				.632*	.940**	.899 **	.936**
Amino sugar - N					.681**	.605 *	.663**
Amino - N						.958 **	.996**
Amino sugar plus ammonia - N							.979**

* Significant at the 5 per cent level
** Significant at the 1 per cent level

total nitrogen was likely to give a useful general indication of the nitrogen supplying ability of these soils. Allison and Sterling (1949) found this relationship was true of a given soil series, irrespective of the past cropping practices. All the other measures of soil nitrogen showed significant correlations among themselves (Table 3). This indicated that the chemical methods of assessing soil nitrogen were all fairly satisfactory in liberating the organic nitrogen of soil, but did not duplicate the action of micro-organisms, as evidenced by the poor correlations with nitrification rate.

Field Experiments

The analysis of variance on the pooled data of selected treatment grain yields for the six sites in 1962 is given in Table 4.

Table 4. Analysis of variance of pooled results of oat grain yields from 0-2-2; 1-2-2; and 2-2-2 treatments -- 1962.

Source of Variation	d.f.	S.S.	M.S.	F.	5%	1%
Replications	1	507.00				
Sites	5	11,423.37	2,284.67	13.60**	5.05	10.97
Error (a)	5	839.99	168.00			
Treatments	2	953.90	476.95	11.02**	4.75	9.33
Linear	1	56.43	56.43	1.30	6.61	16.26
Quadratic	1	897.47	897.47	20.73**		
Interaction (Treatment x Sites)	10	2,579.87	257.99	5.96**	2.76	4.30
Error (b)	12	519.65	43.30			
Total	35	16,823.78				

**Significant at the 1 per cent level.

A highly significant treatment response was obtained as well as a significant difference between sites. There was also the suggestion of a strong interaction of treatment with sites. This indicated that the effects of the treatments on grain yield were strongly influenced by conditions prevailing at each site. A comparison of the means[1] of the three

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[1] See Appendix Table 4 for required differences for significance between means.

treatments over all sites indicated that the treatment consisting of 25 lbs. -N + 100 lbs. P_2O_5 + 100 lbs. K_2O per acre (1 - 2 - 2) was superior to the other two treatments in 1962, and that the higher rate of nitrogen application was not significantly different from the untreated plot (Table 5.).

Table 5. Grain yields in bushels per acre of treatment means over all sites -- 1962.

Treatment	Mean yield (bush./acre).
0 - 2 - 2	40.3 a
1 - 2 - 2	52.4 b
2 - 2 - 2	43.4 a

Any two treatment means followed by the same letter are not significantly different at the 5 per cent level and vice-versa.

There were two sites at which a significant difference was observed between treatments, namely, the Seed Farm and Feeny experiments (Appendix Table 3.).

An analysis of the treatment effects into linear and quadratic components demonstrated that the oat grain response to nitrogen was non-linear. In other words, increasing rates of nitrogen fertilizer application resulted in decreasing yield increments. In actual fact the mean treatment yields over all sites showed a depression for the highest rate of nitrogen applied (Table 5.). Such yield depressions have been reported by Dionne (1957). A possible explanation here was the adverse effect of lodging on yield at the higher rates of nitrogen. Mulder (1954) has demonstrated how lodging depresses grain yield of oats with heavy nitrogen fertilizer applications. Another factor which may have contributed to this phenomenon was the abundant growth of weeds on three of the sites. It was found that the nitrogen fertilized plot and weed growth were strongly associated. The significant interaction of treatment with sites indicated that environmental factors other than the fertilizer nitrogen applied played a major part in determining grain yield. These factors may be soil-moisture, variety, and soil nitrogen among others.

A similar analysis of variance on the pooled results for 1963 showed a highly significant linear response to nitrogen fertilizer application (Table 6.).

Table 6. Analysis of variance of pooled results of oat grain yields from 0-2-2; 1-2-2; and 2-2-2 treatments -- 1963.

Source of Variation	d.f.	S.S.	M.S.	F.	5%	1%
Replications	1	11.53				
Sites	9	17,951.61	1,994.62	202.09**	3.18	5.26
Error (a)	9	88.82	9.87			
Treatments	2	714.57	357.29	8.89**	3.49	5.85
Linear 1		696.39	696.39	17.31**	4.35	8.10
Quadratic 1		18.18	18.18	.45		
Interaction (Treatment x Sites)	18	919.54	51.09	1.27	2.15	2.99
Error (b)	20	803.50	40.18			
Total	59					

** Significant at the 1 per cent level.

There was also a significant difference between sites. A comparison of the treatment means[1] over all sites indicated that the treatments containing nitrogen were not significantly different from each other, but either was different from the "no nitrogen" plot at the 5 per cent level (Table 7.).

Table 7. Grain yield in bushels per acre of treatment means over all sites -- 1963.

Treatment	Mean yield (bush./acre)
0 - 2 - 2	32.0 a
1 - 2 - 2	37.3 b
2 - 2 - 2	40.3 b

Any two treatment means followed by the same letter are not significantly different at the 5 per cent level and vice-versa.

There were three sites at which significant differences were observed between treatments. These were the two Seed Farm experiments and the Beauchamp experiment (Appendix Table 3.).

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[1] See Appendix Table 5 for required differences for significance between means.

It was remarkable, however, that the treatment with site interaction was non-significant. This may have been a reflection of an adequate moisture supply throughout the growing season, and the smaller incidence of weeds on the experimental sites due to the use of weed killer. The linear response to nitrogen suggested that nitrogen fertilizer applied to the oat crop was inadequate in 1963.

It was difficult to reconcile these two opposing yield trends to fertilizer nitrogen application in two successive years. It is for this reason that the soil nitrogen and other environmental factors, such as soil moisture,should be measured before attempting to resolve the problem of nitrogen responses. Any explanations based on the effects of variable environmental conditions would have been highly speculative, since adequate measures were not available of the environmental factors other than the soil nitrogen at each site.

Correlation of fertilizer response values with laboratory measurements

(i) Check yield and "no nitrogen" yield

In 1962 the mean yield of grain on the check plots varied from 20.3 bushels/acre to 64.9 bushels/acre. These yield values gave an approximate assessment of the relative availability of nitrogen in these soils. This would have been particularly true of the "no nitrogen" grain yields, since nitrogen would have been the only limiting nutrient in the fertilizer applied. Correlation of these values with the results of the incubation method of measuring soil nitrogen yielded negative linear correlations (See Figures 1 and 2 or Table 8.). The negative linear relationship with incubation nitrogen was significant at the 5 per cent level ($r = -.830$). Such an observation was contrary to the findings of Pritchett et al. (1960), Eagle (1961) and Gasser (1961). The scatter diagram (Figure 1.) showed that there were three soils which were associated with this negative trend. These were the very soils on which excessive weed growth was observed and may have accounted for reduction in yields, thereby vitiating the relationship. It was also worthy of mentioning that the soil which had the

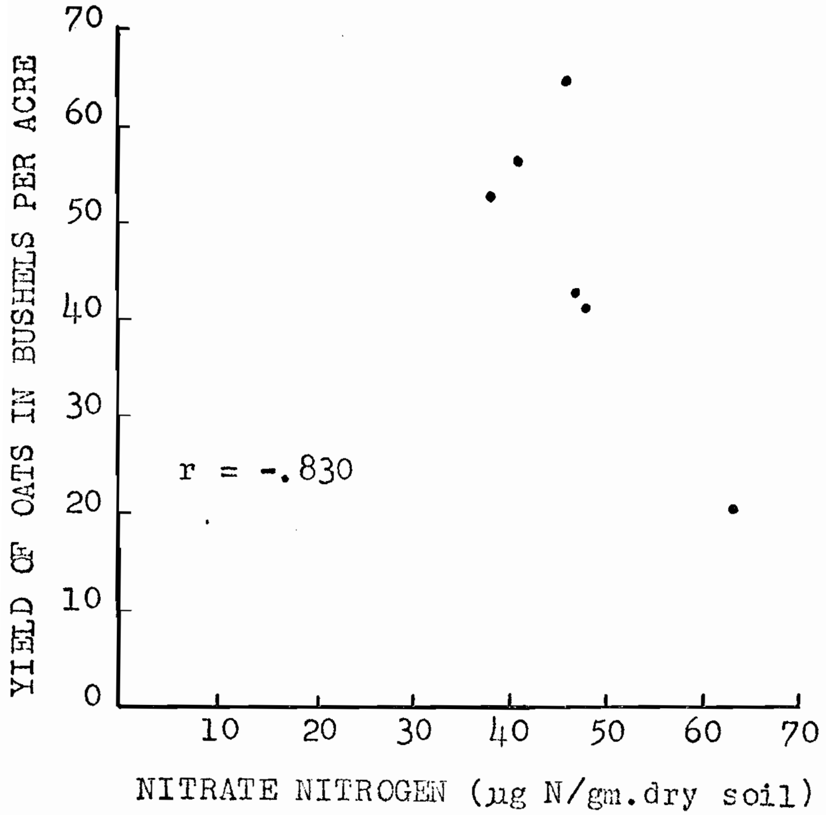

FIG.1. Relationship between check yield of oats and the nitrate nitrogen accumulated on incubation -- 1962.

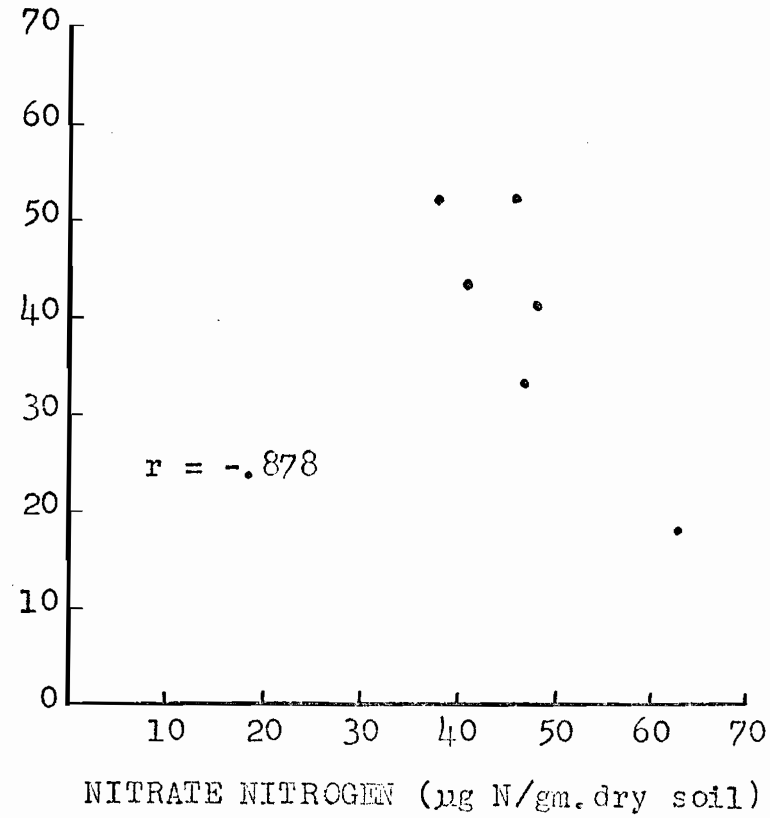

FIG.2. Relationship between "no nitrogen" yield of oats and the nitrate nitrogen accumulated on incubation -- 1962.

Table 8. Correlation coefficients relating laboratory measurements of soil nitrogen with yield and log. per cent yield decrement -- 1962.

Laboratory measurement vs.	No fertilizer grain yield	No nitrogen grain yield	Maximum grain yield	Log per cent yield decrement
Nitrification rate	-.830*	-.878*	-.272	+.232
Total nitrogen	-.208	-.317	-.296	-.991
Organic matter	-.125	-.233	-.228	-.980
Amide nitrogen	-.133	-.274	-.161	-.974
Amino sugar nitrogen	-.008	-.014	-.280	-.987
Amino nitrogen	-.235	-.413	-.229	-.992
Amino sugar and ammonia	-.390	-.527	-.420	-.995
Total hydrolysable -N	-.276	-.435	-.227	-.997*

*Significant at the 5 per cent level

highest nitrification rate in the laboratory yielded the smallest amount of grain. A factor which may have contributed to the high nitrification rate was the application of manure to the field in the preceding fall. Eagle and Matthews (1958) have pointed out that such fall applications of manure increase the nitrogen produced on incubation of soils sampled in the spring, without affecting appreciably the soil nitrogen status for the growing crop in the field. It followed therefore, that environmental factors other than the level of soil nitrogen may have influenced yield under the prevailing conditions.

Statistically significant positive linear correlations were obtained between check plot yields and "no nitrogen" yields and incubation nitrogen in 1963 (Table 9. or Figures 3 and 4). This was consistent with the observations of several workers (Hanway and Dumenil, 1955; Munson and Stanford, 1955; Olson et al., 1960). It followed from these observations that the higher the nitrification rate in the laboratory, the greater was the expected yield when no fertilizer nitrogen was applied. The other laboratory measurements of "available" soil nitrogen showed rather poor relationships with absolute crop yields (Table 9.). There was a slight indication, however, that the total hydrolysable nitrogen (r = .487) might have some value in assessing the "available" nitrogen of soil. Singh (1961) however, has demonstrated that this nitrogen fraction accounts for a very small percentage of the crop yield variance. So the trend projected here requires further investigation.

Table 9. Correlation coefficients relating laboratory measurements of soil nitrogen with yield and log. per cent yield decrement -- 1963.

Laboratory measurement vs.	No fertilizer grain yield	No nitrogen grain yield	Maximum grain yield	Log per cent yield decrement
Nitrification rate	.692 *	.644*	.413	- .364
Total nitrogen	.282	.434	.175	- .443
Organic matter	.217	.360	.098	- .364
Amide nitrogen	.202	.327	.094	- .421
Amino sugar nitrogen	.401	.386	.162	- .274
Amino nitrogen	.298	.483	.214	- .473
Amino sugar and ammonia	.194	.439	.224	- .517
Total hydrolysable - N	.276	.487	.226	- .493
Initial nitrate (0 - 36")	.361	.412	.649*	.493

* Significant at the 5 per cent level

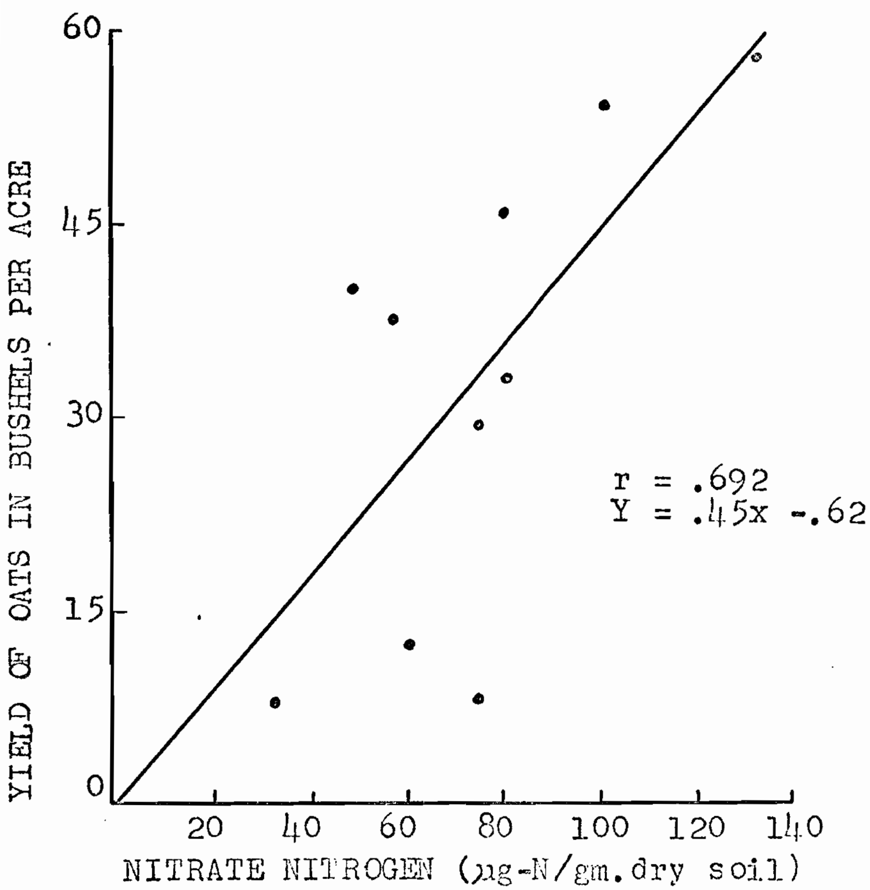

FIG. 3. Relationship between check yield of oats and the nitrate nitrogen accumulated on incubation -- 1963

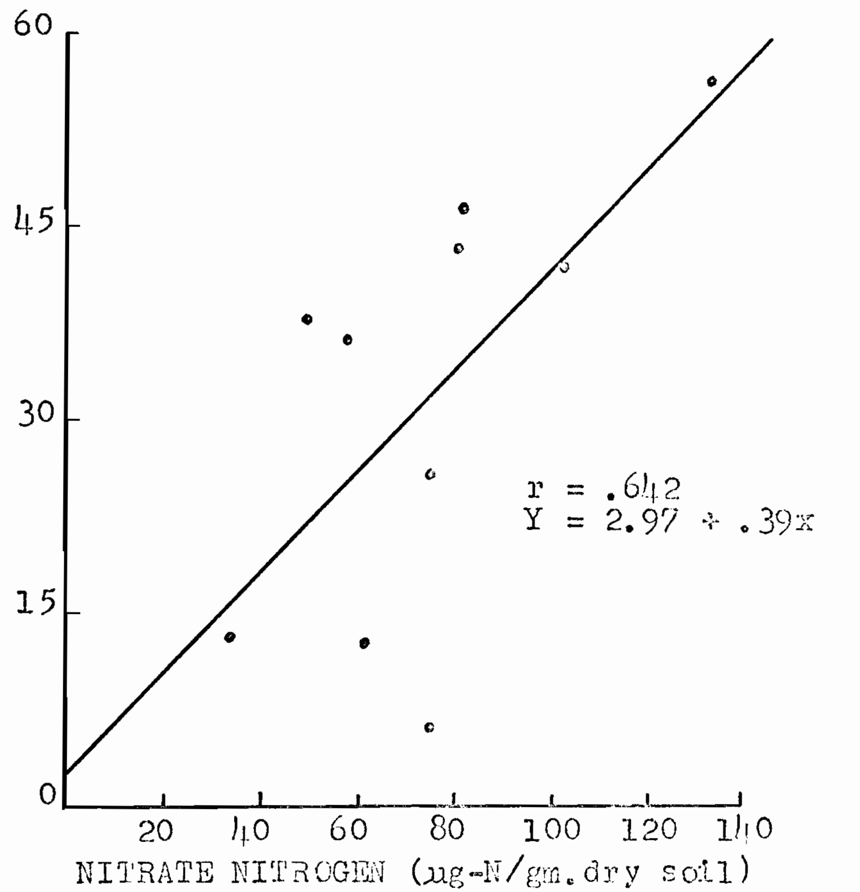

FIG. 4. Relationship between "no nitrogen" yield of oats and the nitrate nitrogen accumulated on incubation -- 1963.

(ii) Maximum yield

The maximum yield *per se* does not give a measure of crop response nor the level of soil nitrogen that is present at any one time. However, the relationship of the maximum grain yield with the laboratory measurements of soil nitrogen was examined. All 1962 values were negatively correlated with maximum yield (Table 8.) although the coefficients were non-significant. In view of the apparent predominant influence of environmental variation on grain yield in the 1962 experiments, it would be unwise to attach any significance to the relationships obtained.

Examination of the 1963 coefficients, however, showed that initial nitrate in the profile was significantly linearly correlated with the maximum yield ($r = .649$) (Figure 5.). The other measures of "available" nitrogen were also linearly correlated, but were non-significant. Of the other measures, nitrification gave the highest correlation coefficient ($r = .413$) (Table 8.).

It seemed rather odd that the initial nitrate showed no significant relationship with the check yield nor with the "no nitrogen" yield. This was what one would have expected, as Mathers (1960); Soper and Huang (1963) have

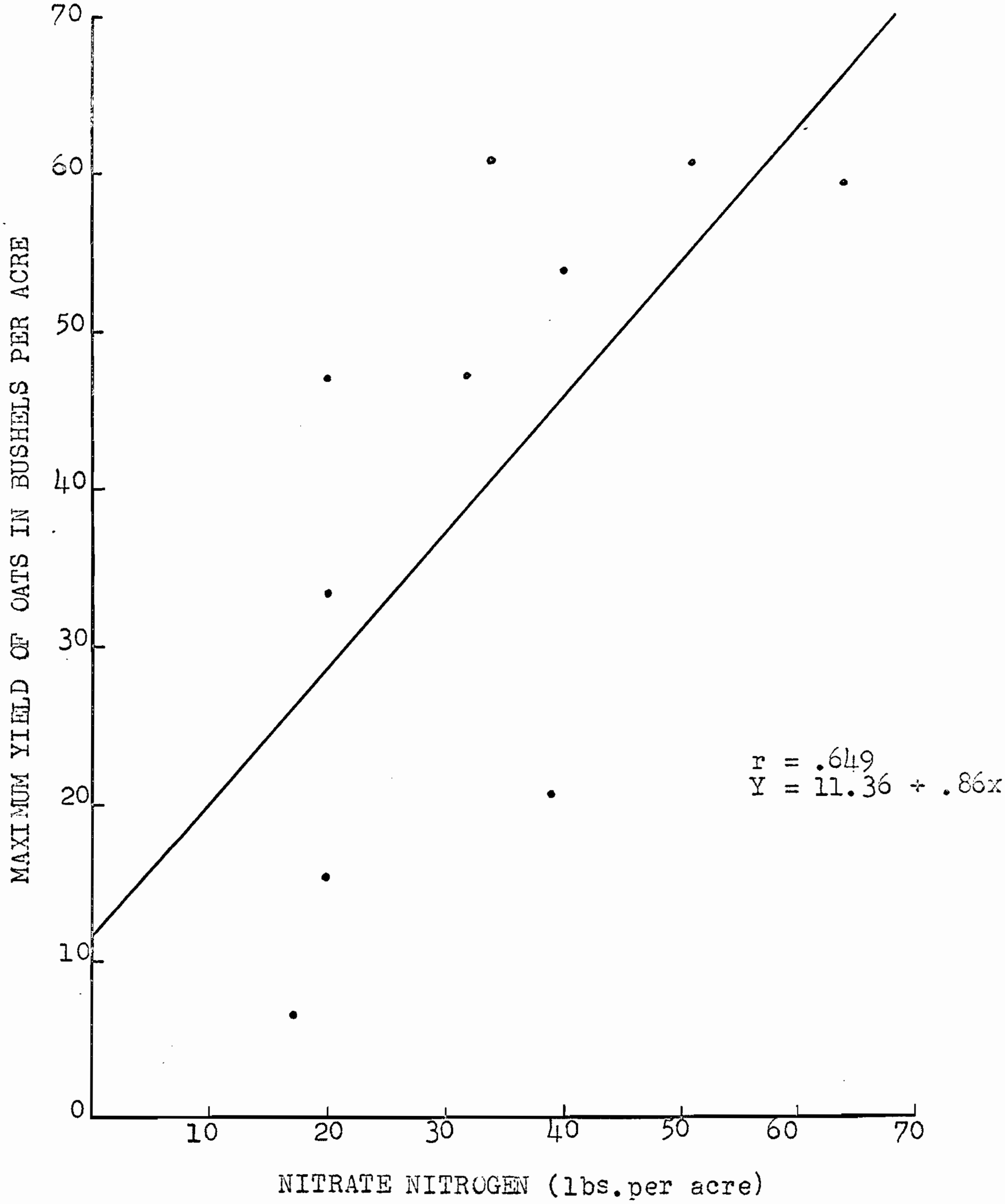

FIG. 5. Relationship between maximum yield of oats and the initial nitrate nitrogen in the profile.

demonstrated. A possible explanation would be that the initial nitrate alone was insufficient to influence the yield, but with the addition of nitrogen fertilizer the initial nitrate became operative. Bearing in mind that the analysis of variance of the treatment effects showed a linear response, this explanation is not untenable. The present relationship obtained might also have been a reflection of more complete utilization of subsoil moisture with added nitrogen. Although this explanation is highly speculative, the findings of Knock _et al_. (1957) of such treatment effects with winter wheat, provide a basis for this speculation.

(iii) Percentage yield

The percentage yield values as opposed to the absolute yield, could give a measure of crop response to applied nitrogen fertilizer. Bray (1948) argued that the yield of crop and soil nitrate content should have been related by Liebig's Law of the Minimum. Bray considered nitrate as a mobile nutrient, since it was completely soluble in the soil solution. Soil phosphorus and potassium on the otherhand, being relatively insoluble were considered to be immobile and therefore, should be related to crop yield by the modified Mitscherlich equation (equation 3). The incubation method and the hydrolysable nitrogen methods employed in this study, measured the nitrogen-supplying characteristics of soils and not the nitrate content of the soil at any particular moment. It is undoubtedly true that an increase in the size of the root system for foraging may not increase the amount of nitrate capable of being absorbed from a given soil, as much as it does the amount of phosphorus and potassium capable of being absorbed. However factors such as temperature, moisture supply and plant nutrients that influence the size of plants, and hence crop yield, have a similar effect on microbial activity and hence the nitrate supplying power. Although the same factors were not involved in the hydrolysis of organic nitrogen in the laboratory by chemical reagents, it was reasonable, therefore to apply the percentage yield concept and regression analysis to relate the results of the nitrification and hydrolysis methods to the percentage yield decrement, Log (100-y) where y = percentage yield on plot from which nitrogen has been omitted. Since these correlations were worked out between percentage yield decrement and laboratory measurements of soil nitrogen, all values greater than 100 per cent yield for the untreated plot had to be omitted. This left as a result only three sets of values for the calculation of the correlation coefficients. These are indicated in Table 8. The available soil nitrogen determined by the incubation method showed the poorest relationship with percentage yield decrement. Although this was inconsistent with the work of Eagle and Matthews (1958); Gasser (1961), it was not unique. Kresge and Merkel (1957) have reported similar unsatisfactory correlations for nitrification rate and yield response to nitrogen. While the other measurements of nitrogen-supplying ability showed rather high correlation coefficients, only that obtained with total hydrolysable nitrogen was significant at the 5 per cent level.

Evidently the expression of yield of the untreated plot as a percentage of the maximum yield reduced the variations due to differences in levels of yield associated with environmental conditions. The negative correlations obtained with percentage yield decrement indicated that as the values of "available" soil nitrogen increased the response from applied nitrogen became smaller. The anomalous situation that arose when absolute yield was correlated with measures of soil nitrogen in 1962 was clarified by applying the percentage yield concept. No improvement in the relationship between nitrification rate and percentage yield decrement or yield response was obtained (Table 8.). This indicated that probably some correction was required in the soil test method itself, or in the calculation before the test would give a satisfactory correlation with yield response under such variable field conditions.

The correlations between percentage yield decrement, Log(100-y) and laboratory measurements of soil nitrogen in 1963 showed no significance (Table 9.). However, certain trends were indicated by the values obtained. It would appear that percentage yield decrement decreased with increasing nitrogen incubation values for these soils. Initial nitrate nitrogen in the profile, however, indicated a very poor relationship with yield response. Although Bray (1948) considered that nitrate nitrogen should not be related to crop yield according to the percentage yield concept, it was attempted here to corroborate the findings of Soper and Huang (1963). They obtained a significant correlation between percentage yield and nitrate nitrogen in the profile.

The 1962-63 data were pooled to determine the relationships between percentage yield decrement and soil nitrogen (Table 10). Three of the laboratory

Table 10. Correlation coefficients relating laboratory measurements of soil nitrogen with log. per cent yield decrement . (Pooled results -- 1962 and 1963)

Laboratory measurement	vs.	Log. per cent yield decrement
Nitrification rate	vs.	- .308
Total nitrogen	"	- .563 *
Organic matter	"	- .515
Amide nitrogen	"	- .549
Amino sugar nitrogen	"	- .452
Amino nitrogen	"	- .187
Amino sugar + ammonia	"	- .602*
Total hydrolysable -N.	"	- .598*

* Significant at the 5 per cent level.

measurements of soil nitrogen showed a significant correlation with percentage yield decrement at the 5 per cent level (Figures 6, 7, 8). Similar relationships have been reported with total nitrogen and yield response by Pritchett et al.(1960); Richard et al.(1960). There was no evidence in the literature that total hydrolysable nitrogen in strong acid was significantly correlated with yield response. Singh (1961) has however, reported a non-significant correlation. "Amino-sugar" plus ammonia nitrogen showed the highest correlation with yield response. The amino sugar and ammonia nitrogen determined here represented the more easily hydrolysable nitrogen fractions together with that portion of the organic nitrogen that was rendered soluble by slightly more drastic hydrolysis conditions. To what extent it gave a reliable estimate of potentially "available" nitrogen cannot be corroborated by other evidence.

(iv) Multiple regressions and correlations

Since nitrification rate and initial nitrate nitrogen in the profile provided the best relationship with absolute yields of oats, it was thought that these relationships might be more thoroughly examined by multiple

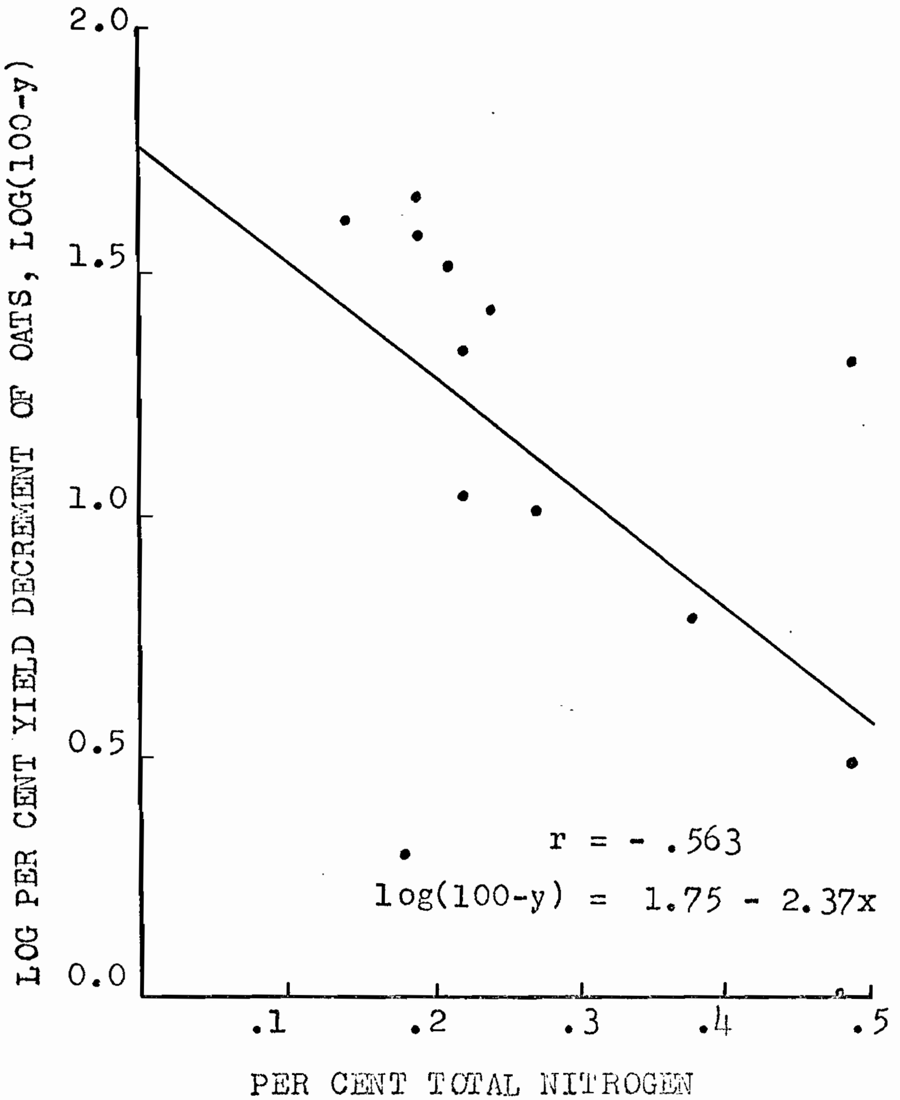

FIG.6. Relationship between log per cent yield decrement of oats log(100-y) and per cent total soil nitrogen -- 1962 and 1963.

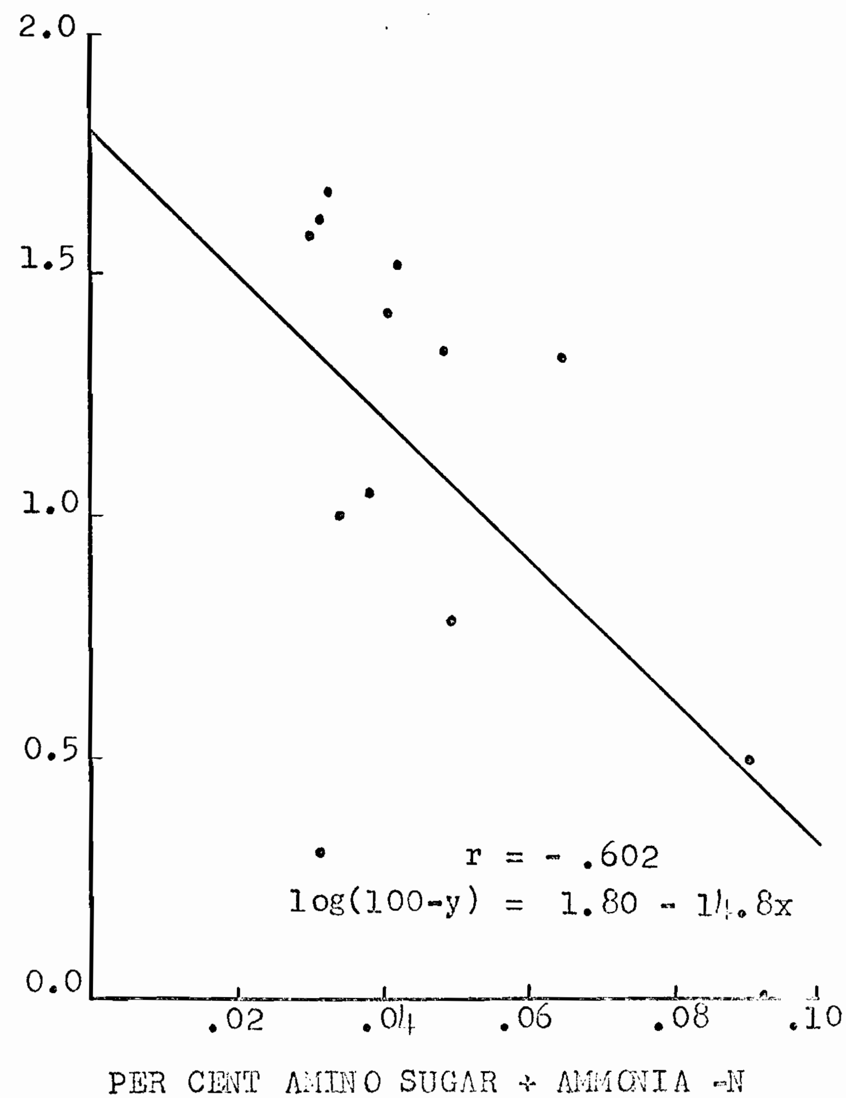

FIG.7. Relationship between log per cent yield decrement of oats log(100-y) and per cent amino sugar + ammonia -N. -- 1962 and 1963.

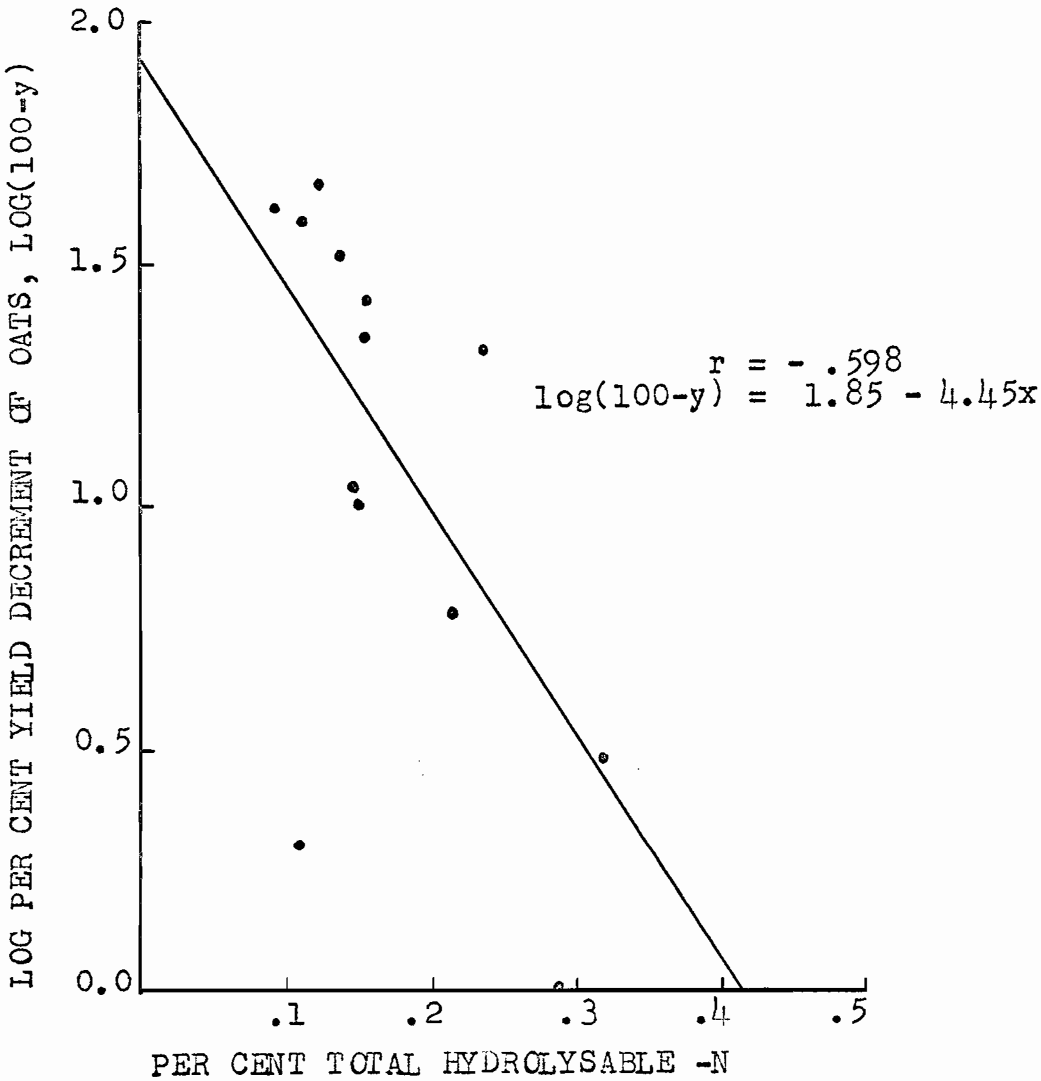

FIG. 8. Relationship between log per cent yield decrement of oats log(100-y) and per cent total hydrolysable -N -- 1962 and 1963.

regression (Appendix Tables 6, 7 and 8) and correlation analyses. A significant multiple correlation coefficient (R = .801) was obtained between the check yield and this pair of soil nitrogen measurements. The standard partial regression coefficients demonstrated that nitrification rate had a greater effect in influencing grain yield than initial profile nitrate ($b^1_{y_{1.2}} = .40$; and $b^1_{y_{2.1}} = .71$)

where $b^1_{y_{1.2}}$ = the standard partial regression of check yield on initial nitrate, when nitrification was held constant.

$b^1_{y_{2.1}}$ = the standard partial regression of check yield on nitrification, when initial nitrate was held constant.

The multiple regression equation expressing check yield as a function of initial nitrate and nitrification is given by the equation

$$Y = .48\, X_1 + .47\, X_2 - 18.39$$

where Y = check yield in bushels per acre

X_1 = initial nitrate in lbs. per acre

X_2 = nitrification rate in μg.-N/gm. of dry soil.

Similar relationships were obtained between "no nitrogen" yield and the same pair of soil nitrogen measurements ($R = .780$). The standard partial regression coefficients were $b^1_{y1.2} = .44$ and $b^1_{y2.1} = .66$ respectively. The multiple regression equation expressing "no nitrogen" yield as a function of initial nitrate and nitrification was of the form

$$Y = .48X_1 + .40\ X_2 - 13.95$$

Y = no nitrogen yield in bushels per acre

X_1 = initial nitrate in lbs. per acre

X_2 = nitrification rate in µg.-N/gm. of soil

The multiple correlation coefficient between maximum grain yield and the same pair of soil nitrogen measurements was significant at the 5 per cent level ($R = .781$). It was observed that initial nitrate nitrogen had a more important effect on maximum yield than nitrification ($b^1_{y1.2} = .67$ and $b^1_{y2.1} = .44$) where

$b^1_{y1.2}$ = standard partial regression coefficients of maximum yield on initial nitrate, when nitrification was held constant.

$b^1_{y2.1}$ = standard partial regression coefficients of maximum yield on nitrification, when initial nitrate was held constant.

This was consistent with earlier analyses in which initial nitrate was correlated with maximum yield. The multiple regression equation expressing the relationship between maximum yield and the pair of soil nitrogen values is of the form

$$Y = .88\, X_1 + .32\, X_2 - 13.12$$

where Y = maximum grain yield

X_1 = initial nitrate in lbs. per acre

X_2 = nitrification rate in μg.-N/gm. dry soil.

The analysis of variance is given in Appendix Table 8. The magnitude of the correlations between the laboratory measurements of soil nitrogen and oat yield and yield response to nitrogen fertilizer depended basically on the extent to which each variable represented the soil nitrogen that was available to the growing plant. Variations either in the soil or crop data due to factors other than the available nitrogen would have represented the "deviation" in the regression analyses. The greatest source of this deviation variance was undoubtedly the effects of other environmental factors, particularly available soil moisture, soil structure and weather conditions on plant growth. The major sources of error in the laboratory results would have been inadequacies in the soil sampling technique and chemical inadequacies in assessing the available nitrogen. In view of these and other likely major sources of error, the relations established between soil nitrogen and absolute yield values indicated that the incubation method was a satisfactory measure of soil available nitrogen in the soils studied. Total hydrolysable nitrogen, amino sugar with ammonia and total nitrogen all seemed to be satisfactory measures from the favourable correlations obtained with yield response, that is, percentage yield decrement.

The effects of environmental factors other than the soil nitrogen represented by the incubation nitrogen and other forms of nitrogen were shown by the poor relationships with absolute yield obtained in 1962. The regression equations arrived at were of importance because of the estimate they provided of optimum nitrogen requirement and the likely crop yield.

SUMMARY AND CONCLUSIONS

The check and "no nitrogen" grain yields of oats were shown to be linearly correlated with soil nitrogen measured by an incubation method in 1963. In 1962, however, grain yields were inversely related to nitrification rate. It was speculated that the latter relationship might have been due to the influence of environmental factors, particularly soil moisture, weed competition and lodging of the oat plants.

Initial profile nitrate was significantly correlated with maximum yield but not with check yield or "no nitrogen" yield.

Total hydrolysable nitrogen, soluble in strong acid and released by alkaline distillation was significantly correlated with yield response in 1962.

All measures of soil nitrogen showed no significant relationships with yield response in 1963. However, the pooled results for 1962 and 1963 indicated that "amino sugar" with ammonia, total hydrolysable nitrogen and total nitrogen were satisfactory measures of soil nitrogen from the relations established with yield response.

Useful prediction equations were obtained which could be used to determine crop response from available soil nitrogen. They may also be of value in working-out optimum fertilizer requirements in relation to the level of soil nitrogen.

These equations, while they cannot be considered as exact, do project certain trends, which might be useful in future research. For example they indicated the superiority of initial profile nitrate over nitrate accumulation on incubation in determining yields when nitrogen was applied and the superiority of nitrate accumulation on incubation when no fertilizer nitrogen was applied. More work will have to be done on a greater number of experimental sites, over a longer period before valid calibrations of nitrogen soil tests can be obtained for the Province of Quebec.

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Appendix Table 1. Dates of seeding and harvesting and oat varieties used on each farm.

Farm	Variety of oats	Date of seeding	Date of harvesting
<u>1962</u>			
Seed Farm	Roxton	May 9th	August 16th
Leger	Garry	May 26th	Sept. 1st and 8th
Feeny	Garry	May 17th	August 20th
Berard	Glen	June 6th	Sept. 4th
Oswald	Garry	May 16th	August 15th
Jodoin	Garry	May 29th	September 7th
<u>1963</u>			
Seed Farm	Glen	May 3rd	July 29th
Seed Farm	Glen	May 3rd	July 28th
Beauchamp	Rodney	May 6th	August 12th
Boileau	Garry	May 27th	August 20th
Vinet	Garry	May 27th	August 26th
Dowbiggin	Garry	May 10th	August 13th
Feeny	Russell	June 3rd	August 21st
Feller Institute	Rodney	June 6th	August 26th
Martin	Glen	May 16th	August 17th
Lague	Glen	May 16th	August 9th.

Appendix Table 2. Laboratory measurements of soil nitrogen and pH.

Soil type	pH 1:1 soil: water	pH 1:2 soil: .01M $CaCl_2$	Organic matter %	Total -N %	Nitrifiable -N ug/gm.	Amino sugar -N %	Amino -N %	Amide -N %	Amino sugar + ammonia %	Total hydrolysable -N %	Initial nitrate (0-36") lbs./acre
<u>1962</u>											
Chicot s.l.	6.4	5.1	3.75	.19	46	.019	.089	.012	.033	.122	-
Bearbrook c.	5.4	4.5	3.70	.21	38	.040	.076	.011	.028	.104	-
Ste Rosalie c.	5.3	4.3	4.40	.22	41	.020	.088	.011	.024	.112	-
Blanford l.	5.6	4.7	9.85	.49	47	.042	.229	.030	.090	.318	-
St.Bernard l.	6.6	6.0	4.00	.22	63	.024	.106	.012	.049	.155	-
Ste Rosalie c.	5.2	4.4	5.60	.26	48	.019	.086	.012	.031	.116	-
<u>1963</u>											
St.Bernard l.	6.9	6.5	3.95	.21	49	.023	.097	.014	.042	.139	40
Chicot s.l.	5.4	4.8	2.70	.14	57	.017	.064	.007	.031	.094	51
St.Bernard l.	6.3	5.8	5.35	.24	80	.024	.114	.009	.041	.155	64
St.Amable l.s.	5.0	4.5	5.40	.22	33	.024	.109	.011	.038	.146	20
Bearbrook c.	6.0	5.5	5.15	.27	101	.050	.114	.012	.034	.147	20
Ascot s.l.	5.9	5.4	8.00	.38	132	.030	.159	.019	.056	.214	34
Ste Rosalie c.	5.1	4.7	3.70	.18	75	.018	.077	.011	.031	.107	17
St.Blaise s.c.l.	6.6	6.5	4.45	.19	61	.019	.081	.010	.030	.111	39
Blanford l.	5.5	4.9	8.60	.48	81	.042	.200	.021	.092	.291	32
Shefford l.	5.0	4.5	9.95	.49	75	.050	.180	.022	.071	.250	20

Appendix Table 3. Mean grain yield of selected treatment means in bushels per acre and percentage yield, values.

Farm	Treatment 0-0-0	0-2-2	1-2-2	2-2-2	Percentage Yield
1962					
Seed Farm	64.9	52.7b	97.7a	20.9a	58
Leger	52.7	52.7a	45.5a	40.9a	129
Feeny	56.2	43.8a	60.8b	31.7a	138
Berard	42.7	33.2a	43.4a	34.3a	97
Oswald	20.3	17.9a	22.1a	23.1a	78
Jodoin	41.3	41.4a	45.1a	39.3a	106
1963					
Seed Farm	40.0	36.3a	46.6a	53.6b	68
Seed Farm	37.6	35.7a	53.9b	60.7b	59
Beauchamp	45.9	43.8a	59.0b	59.3b	74
Boileau	7.8	13.4a	16.5a	15.1a	89
Vinet	54.5	42.3a	34.2a	47.0a	90
Dowbiggin	58.2	56.7a	61.8a	60.6a	94
Feeny	9.1	6.1a	6.6a	6.2a	98
Feller Institute	12.5	12.8a	16.9a	20.5a	62
Martin	33.2	46.6a	41.2a	47.2a	99
Lague	29.8	26.2a	36.7a	33.2a	79

For any one site any two means followed by the same letter are not significantly different at the 5 per cent level and vice versa. Comparisons are between 0-2-2; 1-2-2 and 2-2-2 treatment means.

Appendix Table 4. Standard error and differences required for significance between treatment means at the 5 per cent level -- 1962.

	S.E.	L.S.D.
Between two treatments at all sites	2.69	5.99
Between two treatments at one site	6.58	16.92

Appendix Table 5. Standard error and differences required for significance between treatment means at the 5 per cent level -- 1963.

	S.E.	L.S.D.
Between two treatments over all sites	2.00	4.17
Between two treatments at one site	6.34	14.34

Appendix Table 6. Analysis of variance of the regression of check yield on initial profile nitrate and nitrification rate.

Source of variation	d.f.	S.S.	M.S.	F(calc.)	F 5%
Total	9	3,036.06			
Regression	2	1,953.20	976.60	6.31*	4.74
Deviation from regression	7	1,082.86	154.61		

*Significant at the 5 per cent level.

Appendix Table 7. Analysis of variance of the regression of no nitrogen yield on initial profile nitrate and nitrification rate.

Source of variation	d.f.	S.S.	M.S.	F(calc.)	F 5%
Total	9	2,519.81			
Regression	2	1,536.02	768.01	5.47*	4.74
Deviation from regression	7	983.79	140.54		

*Significant at the 5 per cent level.

Appendix Table 8. Analysis of variance of the regression of maximum yield on initial profile nitrate and nitrification rate.

Source of variation	d.f.	S.S.	M.S.	F(calc.)	F 5%
Total	9	3,698.92			
Regression	2	2,262.37	1,131.19	6.39*	4.74
Deviation from regression	7	1,436.55			

* Significant at the 5 per cent level.