Evaluation of Soil Tests for Predicting Nitrogen Requirements of Cereals for Some Manitoba Soils

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ABSTRACT

This investigation was initiated to study the utility of the determination of the accumulated nitrate nitrogen in the soil profile to a depth of four feet at seeding time as a basis for predicting the nitrogen requirements of cereals in Manitoba. Other soil test methods that have been advocated and claimed to be promising were also investigated. The results were obtained from soils of varying profile type, texture, PH, lime and organic matter content. Fertilizer trials were laid out on stubble land using barley as the test crop in 1960 and on stubble and fallow land using oats and wheat as the test crops in 1961. A greenhouse experiment was carried out early in 1961.

The accumulated nitrate nitrogen in the soil profile to a depth of four feet at seeding time varied extremely from soil to soil and seemed to be as available as the nitrogen added as fertilizer. The determination of accumulated nitrate nitrogen in the profile appeared to have real value in predicting nitrogen needs of cereals for the soils tested in Manitoba. If the accumulated nitrate nitrogen of the 0-48 inch depth at seeding time is over 80 pounds per acre, nitrogen fertilization is not considered to be necessary for cereals. Potentially available nitrogen (PAN), nitrifying power, permanganate oxidizable nitrogen and organic matter appeared to be of questionable value in assessing nitrogen requirements of cereals for the soils tested.

Both the mineralization of nitrogen during the growing season in the fields and that during one-month growth period in the greenhouse seemed to be considerable. The loss of accumulated nitrate nitrogen due to leaching during the growing season seemed to be small. The accumulated nitrate nitrogen in the profile as well as nitrogen fertilizers applied at seeding time appeared to have a bearing on nitrogen taken up and per cent protein in grain. There was evidence that the cereals employed in the 1960 investigation removed accumulated nitrate nitrogen and moisture from the depth of 36-48 inch. It is suggested that if the accumulated nitrate nitrogen of the 0-48 inch depth at seeding time is over 70 pounds per acre, the soil is not suitable for growing Canadian 6-Row barley to be used for brewing purposes. In the 1960 experiment, it was found that there was not much difference between heading stage and harvest time insofar as the accumulated nitrate nitrogen and available moisture in the 0-48 inch depth are concerned. PAN and nitrifying power of the soils tested were similar in magnitude and highly correlated with each other.

INTRODUCTION

In the past decade in Manitoba increased attention has been paid to the application of nitrogenous fertilizers to cereal crops, due to the occurrence of nitrogen deficiencies in arable soils. However, the response of cereals to fertilizer nitrogen has shown extreme variability. In the absence of a suitable soil test, nitrogen fertilizer recommendations are arrived at by indirect and often erroneous means. Therefore, the following facts and assumptions that can be drawn from previous research and observations are taken into account.

(1) Cereals do not respond or respond very little to nitrogen on summerfallow land. Cereals usually respond to nitrogen when grown on land that has grown a crop the previous year and this response is usually greater when more than one successive crop has been grown.

(2) In general, there is a large difference in nitrate content of stubble land and summer fallow land.

(3) In other studies in Manitoba, large variation in the amount of nitrate nitrogen in the soil profile to a depth of four feet was found.

(4) The mineral nitrogen in the soil is present as ammonium or nitrate ions. Generally, arable soils have a fairly constant but low content of ammonium nitrogen, but a very variable and higher nitrate content. The nitrates are dissolved in the soil solution and are extremely available unless the soil dries out. Therefore, the nitrate nitrogen is the form plants use almost exclusively.

(5) Nitrate can be leached by rainfall and accumulate down in the

soil profile. Thus accumulated nitrates could be very considerable and moreover could be very available for the crops.

On considering these facts and assumptions, this investigation was initiated to study the practicability of the prediction of nitrogen requirements of cereals in Manitoba by determining nitrate nitrogen in the soil profile to a depth of four feet at seeding time. Other soil test methods that have been advocated and claimed to be promising were also investigated.

REVIEW OF LITERATURE

A. Methods of Determining Available Soil Nitrogen.

Considerable effort has been expended toward developing a procedure for estimating available soil nitrogen. Recourse has been had to plant-physiological methods and soil test methods. In so far as soil test methods are concerned, the determination of ammoniacal and nitrate nitrogen in the surface soil is the earliest method. This method proved unsatisfactory, however, because the quantities of ammoniacal and nitrate nitrogen in the surface soil are ordinarily small and rather variable and do not necessarily reflect the total quantity of nitrogen that will be at the disposal of the crop during growing season.

There are two types of methods that have been most intensively investigated.

The first type is to estimate the amount of the potentially available soil nitrogen by various methods of extracting the soil nitrogen fraction more nearly like that utilized by the crop. Konig, Coppenrath and Hasenbaumer (34) heated soils in an autoclave at 5 atmospheres pressure for 5 hours and determined the quantity of nitrogen extracted. Results obtained by this method did not correlate well with the yield or the nitrogen content of plants grown in pot experiments. The possibilities of the method were not adequately tested, however, because the crops appeared to have ample nitrogen in all cases. Tyurin (61) and Tyurin and Kononova (62, 63) determined the quantity of nitrogen liberated from the soil organic matter upon hydrolysis with dilute sulfuric acid and claimed that this procedure distinguished organic matter decomposable by microorganism from organic matter stable in that respect. The quantity of nitrogen in the acid hydrolysate was correlated with the nitrogen needs of crops in field experiments. The method was tested further by Gracie and Khalil (27) who found likewise that the acid-hydrolyzable nitrogen was related to the nitrogen needs of crops in field experiments. In 1961, Leo (39) developed a rapid procedure for estimating potentially available soil nitrogen under greenhouse conditions. He treated the soil with very dilute sulfuric acid and brought this mixture to dryness on a steam bath. The soil was then extracted and the ammonia released was determined. The data obtained indicated that the correlations between the potentially available nitrogen determined by the described method of hydrolysis and yield of wheat and nitrogen removed by wheat were all significant at the 1 per cent level. Truog (64) developed an alkaline permanganate method for measuring soil available nitrogen . Munson and Stanford (42) reported that when the available nitrogen determined by Truog's method was related to the nitrogen response of crops, only a low correlation was obtained. Kresge and Merkle (35) modified the procedure adopted for determining active organic nitrogen in fertilizers (3) to determine the permanganate oxidizable nitrogen. Results indicated that a very poor correlation was obtained between response of crops to nitrogen and the quantity of permanganate oxidizable nitrogen. Tolton (65) found that available nitrogen as determined by a modification of Truog's method correlated significantly with the check yields of oats in seven field experiments. In samples taken from a similar number of barley fields no correlation was obtained.

The second type of approach is the biological mineralization of nitrogen during controlled incubation of soil samples. This method has the advantage of being less artificial than are the various extraction methods, but has the disadvantage that more time is required. Bogdanov (8, 9) was one of the first to use the incubation method. He incubated soils for 48 hours at 30°C and then determined the quantity of ammonia and nitrate nitrogen present in the soils. The results obtained correlated favorably with the yield of crops in pot experiments. Varallyay (66) and Varallyey and Fejer (67) recommended that an incubation period of at least a month should be used. Varallyay (66) reported that the incubation method for determining available nitrogen furnished a satisfactory estimate of the nitrogen needs of soils in Hungary. Hardy (29) found that the quantity of nitrate nitrogen produced in soil samples during incubation for 4 weeks at 30°C was inversely related to the responsiveness of cotton to nitrogen fertilizer in field experiments in British West Indies. Waksman (69), Burgess (10), Brown (11), Gowda (28) and Fraps (20, 21) have shown that usually the more productive soils yield the larger amounts of nitrate, but there have been many exceptions. In using nitrate formation as a measure of availability of soil nitrogen, many factors that limit nitrate formation were investigated and reported by Fraps and Sterges (22, 23, 24) and Waksman (69).

During 1944 to 1947 in Western Iowa, Pritchett et al.(45) measured the mineralizable nitrogen in soil samples taken from various experimental fields by determining the increase in ammonia, nitrate and nitrate nitrogen present in the soil as a result of the incubation for 3 weeks at 30°C. The data from wheat and oats plots showed that the quantity of nitrogen mineralized in the soils during incubation was directly related to the yield of unfertilized wheat on the plots that received no nitrogen fertilizer, and was inversely related to the increase in yield produced by the application of nitrogen. It was concluded that a regression equation relating response of oats to nitrogen fertilization with mineralizable soil nitrogen can be used as a means of prediction, provided the regression equation represents the average of several years data. They also stated that the mineralizable nitrogen content of the soil served as a better index of the probable response to nitrogen fertilizer in Iowa than information on past management alone.

Allison et al. (2) reported that, in a given soil type and under similar climatic conditions, thoroughly humified soil organic matter was fairly uniform in quality regardless of past agronomic treatment and the total nitrogen content under these conditions appeared to be a rough index of the nitrate-forming powers of variously treated soils. It was reported that nitrification studies, if conducted under optimum conditions would furnish additional information on nitrogen availability. They also found that the differences in nitrification rates among samples from rotation plots at Mandan, North Dakota, were as apparent after three weeks incubation as after six or eight weeks.

Fitts et al. (25, 26) stated that nitrate production during incubation should give the most reliable results because of the similarity between the incubation and soil processes. Furthermore, these workers attempted to simplify the nitrification determination procedure to adapt the laboratory procedure to mass production in soil testing laboratories. Stanford et al. (56) stated that despite the simplification of the procedure modified by Fitts et al.(26), there still remained the problem of devising a suitable means for achieving comparable moisture contents in the soils prior to incubation. Since the optimum moisture content for nitrification depends, in large part, on texture and organic matter content of soils, nitrification rate is expected to vary widely among samples. They developed a simplified technique for determining relative nitrate production in soils, that is, simpler and more rapid than existing procedures. They also reported that under controlled greenhouse conditions, both "N-values" and nitrogen uptake by the plants were highly correlated with the nitrate nitrogen released during a two-week period of incubation.

Cook et al. (15) reported that a high correlation between the yield ratios which are a measure of the response to nitrogen and nitrate accumulation was obtained in the field experiment in Saskatchewan. They suggested the determination of nitrate accumulation values as a means of predicting the need for nitrogenous fertilizers by cereal crops in Saskatchewan. Eagle et al. (17) stated that the results of an incubation method for measuring the capacity of Ontario soils to accumulate nitrate were extremely variable. They modified the incubation method by storing all samples in the moist state at 10°C for two weeks before analysis in order to reduce the wide fluctuation in results due to prolonged air-dry storage before analysis or to time of sampling during the growing season. They reported that the correlation between the logarithm of the per cent yield which is a measure of crop response to nitrogen and nitrate-supplying power as measured by the modified incubation method was highly significant for winter wheat, oats and potatoes. Synghal et al. (57) stated that the use of some type of incubation test for producing nitrates in soils appeared to offer the most promise in assessing the nitrogen requirements of Alberta soils, and that none of the other laboratory determinations -- total nitrogen, nitrate nitrogen originally present, permanganate oxidizable nitrogen, or "N-values" -- appear to be as potentially useful for predicting the nitrogen needs of Alberta soils. It was also mentioned that in spite of the superiority of the incubation methods, they are not infallible.

In 1957, Tolton (65) reported that there was a significant correlation between the available nitrogen as measured by the alkaline permanganate method and that obtained by an incubation method in samples from both oat and barley fields. However, the yield ratio did not correlate with available nitrogen as determined by either the alkaline permanganate or the incubation methods.

Andharia *et al.* (4) stated that in attempting to evaluate the relative nitrogen status of soils, it must be realized that the cropping systems affect not only the chemical nature and amounts of soil nitrogen but also the physical characteristics which in turn influence nutrient availability. It was also stated that these and other soil factors interact with climatic factors (temperature and rainfall in particular) to determine the relative nitrogen-supplying power which may be reflected, for example, in the total nitrogen content of the soil or in the ability of a soil to release nitrate under controlled conditions in the laboratory. They finally stated that there is also the actual available soil nitrogen status under uncontrollable field conditions. Hanway *et al.* (30) reported that regardless of the crop, a single set of samples from a field may provide a reliable indication of the potential nitrogen supplying power of the soil, which will hold for a period of years. However, they qualified their statement saying that the interpretation of the incubation test as a basis for making fertilizer recommendations must differ, depending on the previous crop and the crop to be grown. It was also mentioned that the relationship involved in their study was limited to the nitrogen needs of corn following crops other than leguminous hay. Harmsen and Van Schreven (31) stated that reliable available nitrogen results sufficiently correlated with the nitrogen requirement of field crops can be expected only when the incubation technique is restricted to one soil type, one climatic zone, one farming system and when all samples are collected within one season, preferably during the early spring. They stated further that the results and their interpretation will vary from one year to another due to uncontrollable and unpredictable variations in the weather conditions.

Several other methods have been advocated. Richer and White (53) reported a highly significant correlation between nitrifying capacity and cellulose decomposing capacity; and stated that it is logical to expect that the rate of decomposition of organic material low in nitrogen should correlate with the level of supply of nitrates to be utilized. Andrews (5) had used mannite in place of cellulose and shortened the incubation period to 24 hours. He reported a highly significant correlation between crop yields and CO_2 production as measured by absorption in ascarite. Richer and Holben (50) incubated soils with nitrogen free medium containing glucose, nutrient salts, and yeast, and then measured the amount of CO_2 produced after a 24-hour fermentation period. They reported that although the method appeared to be promising, further study was warranted. Munson et al.(42) reported that the relation between total nitrogen uptake by the crop and level of applied nitrogen was linear for all soils studied; and extrapolation of the linear regressions provided "N-values" which reflected the relative contents of available nitrogen in the soils. They further stated that "N-values" were correlated highly with the total nitrogen uptake of the check plots. Woodruff (70) stated that the rate at which nitrogen was delivered to crops from the organic matter supplies of soils provided a basis for estimating the amounts of nitrogen fertilizer required to produce a desired yield of crop on the soil. They further stated that the annual rate of delivery of nitrogen from the soil to the crop was a function of the amount of nitrogen in the soil and of the kind of crop. It was also reported that in so far as the changes in the nitrogen content of the soil were concerned there was no significant difference between continuous cropping and rotation cropping.

B. Accumulation and Movement of Nitrates in the Soil Profile.

Many investigators have studied or observed the accumulation of nitrates and their movement with soil moisture in the soil profile. Numerous workers have established the fact that nitrates can be readily leached from fallow lysimeters, even when clay soils are used (33). However, in cases where crops were grown on the lysimeters the leaching losses reported have been relatively smaller. In 1900, King and Whitson (37, 38) found that, in fallow land, there was more nitric nitrogen in the soil in the spring than in the previous summer and fall. They stated that the leaching must be such as to leave the large amount of nitrate nitrogen in the soil in the next spring. These workers also found that there was much more nitric nitrogen in fallow ground in the spring, in comparison with that not in fallow. They stated that Belz found that considerable nitrification may go on even at as low a temperature as 35°F and if this is true, late fall and even early winter may contribute not a little to the development of nitrates in their soils, in the lower part of the surface foot and the upper portion of second foot. They also mentioned that it at least could not be said that nitrification did not take place in the field soils to depths as great as four feet. In 1902, these workers carried out excellent laboratory studies on the upward movement of nitrates in cylinders of fallow soil. They reported some extremely high accumulations of nitrate in the surface inch.

In 1917, Russell and Appleyard (51) investigated the level of nitrate nitrogen in the top 18 inches of soil, throughout the growing season of 1915, of two parts of the Broadbalk plot at Rothamsted which received farmyard manure annually, one part being cropped to wheat and one part fallowed. They stated that the fallow soil accumulated nitrate during the spring and summer, whereas the cropped soil did not, and that the fallow soil appeared to have lost all its accumulated nitrate by early winter, presumably due to it being leached down into the subsoil. Russell (52) stated that Mills gave a report stating that over 400 p.p.m. nitrate nitrogen had accumulated to the 3rd foot depth in a Kawanda (Uganda) soil. He also stated that well-structured loams and clays can, however, hold appreciable quantities of nitrates against leaching. This is because the percolating water moves down principally through the cracks and coarse pores between the crumbs, and most of the nitrates are found in the crumbs, so the nitrate can only get into this water by diffusion, which is a slow process. He further stated that this holding of nitrates against leaching is of considerable agricultural importance in British soils, as for example, the Rothamsted clay loam. They concluded that part of the nitrates produced in a previous summer fallow is available for the succeeding crop, even if the autumn and winter is wet.

Millar (43) found that on fallow soils soluble salts tended to accumulate at the surface, especially during dry periods. During a dry summer, Malpeaux and Lefort (44) found that nitrates placed at the depth of 10 inches appeared in the surface 3 inches within 11 days and nitrates placed 20 inches deep appeared in the surface 3 inches within a month. They concluded that this rapid upward movement of nitrates was chiefly dependent on capillary movement rather than diffusion. Puchner (47), in studying the relationship between the movement of soluble salts and the capillary rise of water in soils, concluded that the accumulation at the surface increased with the rapidity of evaporation. This does not fully agree with Lebedev (41) who stated, "where film and gravitational water exist, salt movement is toward the area of lower concentration which may correspond or oppose the direction of movement of the water".

While this is true, the net effect will be determined by the relative rates of ion diffusion and water movement. Krantz et al.(36) reported that, during seasons of prolonged drought, nitrate moved upward in the soil to accumulate at the surface due to the net upward movement of soil moisture, however, any moderate rainfall moved the nitrates back into the main root zone and made them available again to plants. They also stated that these findings help to explain the very erratic and inconsistent responses which have been obtained in Indiana.

C. The Extending of Roots of Cereals into the Lower Soil Profile.

Russell (52) stated that Weaver gave an example from the Great Plains of North America of the effect of amount of rainfall on the depth of rooting of wheat, reporting that as the rainfall decreased from 26 to 32 inches to 16 to 19 inches the root system decreased in depth from about 5 feet to 2 feet and the height of the wheat from just over 3 feet to just over 2 feet. Recently, Power et al. (48) made observations on excavations of selected plots and stated that wheat penetrated into the lower soil profile to a depth of 3½ feet under suitable moisture conditions but did not penetrate a dry layer with moisture tensions of about 15 atm. or greater. In 1961, Racz (54) investigated the P^{32} injection method of studying root development. It was indicated in his investigational results that the extending of the roots of wheat to a depth of four feet in the soil profile was evident.

METHODS AND MATERIALS

A. Determination of Nitrate Nitrogen in Soils

The colorimetric phenoldisulphonic acid method modified by Harper (32) was used. The nitrate nitrogen to a depth of four feet was determined and converted to pounds per acre from bulk density data.

B. Determination of Available Moisture in Soils

The available moisture in soils was calculated by the difference between moisture percentage and permanent wilting percentage (40, 55). The difference of per cent moisture by weight was converted to inches of water from bulk density data.

C. Determination of Organic Matter in Soils

The method described by Peech *et al*, (46) was used.

D. Determination of Permanganate Oxidizable Nitrogen in Soils

The alkaline permanganate method modified by Kresge and Merkle (35) was used.

E. Determination of Potentially Available Nitrogen (PAN)

The rapid procedure for estimating potentially available soil nitrogen developed by Leo (39) was used.

F. Determination of Nitrifying Power of Soils

A simplified technique developed by Stanford and Hanway (56) was modified as follows:

A pyrex wool pad 5 mm. in thickness was placed in the bottom of plastic vials. About $\frac{1}{2}$ inch of plaster grade vermiculite was added and tapped down gently. Ten grams of air dry soil were weighed out and mixed with an approximately equal volume of vermiculite and were transferred to the vial. Twenty ml. of 0.01 per cent Krilium 6 solution was added to the sample and allowed to stand for 15 minutes before applying suction. The mixture of soil and vermiculite was leached with two 20 ml. portions of distilled water and incubated at 30°C for 14 days. The nitrate nitrogen present in the incubated soil was determined by the colorimetric phenoldisulphonic acid method modified by Harper (32).

G. Determination of PH of Soils

The method described by Atkinson *et al*. (1) was used.

H. Determination of $CaCO_3$ in Soils

The method used is a modification of the ones given by Adams (7) and by Waynick (71). A 2 gm. sample of less than 2 m.m. air dry soil was digested in 60 ml. of 1: 10 Hcl for 10 minutes. The carbon dioxide evolved was drawn by suction through a drying and absorption train consisting of concentrated H_2SO_4 , a tube of Dehydrite and calcium chloride. The carbon dioxide was adsorbed by the Ascarite in a Nesbitt tube.

I. Determination of Soil Texture

The hand texturing method adopted by the Manitoba Soil Survey was used.

J. Determination of Total Protein in the Grain

The improved Kjeldahl's method described by A.O.A.C. (3) was used.

1960 FIELD EXPERIMENT

A. Experimental Procedure

In 1960, nine fertilizer trials on stubble land were conducted on Red River, Lakeland and Portage soil associations, using barley as the test crop. The description of the soil type has been given by Ehrlich et al. (18, 19) and Pratt et al. (49). The dates of seeding and harvest are listed in Table I. Some characteristics of the soils tested are outlined in Table II.

A randomized block design with six replications was used. The plots were 0.11 acre (70 x 70 feet) in size and contained treatments consisting of various rates of nitrogen and phosphate, that is, 0-0, 60-0, 60-10, 60-20, 60-40, 60-60, 10-40, 20-40, 40-40, 80-40. The first figure refers to the pounds of nitrogen per acre and the second figure to the pounds of phosphate (P_2O_5) per acre applied. The nitrogen was applied in the form of 33.5-0-0 and the phosphate as 11-48-0 since 11-48-0 is the usual source of phosphate used in Manitoba. All phosphate was applied in a band with the seed; and also nitrogen up to a rate of 20 pounds per acre. Nitrogen in excess of 20 pounds per acre was hand broadcast uniformly over the area. A fallow area was located adjacent to each of the plots at Anderson's, Barg's and McDonald's.

The plots were seeded with a six furrow opener, double disc, V-belt rod row seeder mounted on a Bolens ridemaster tractor. The treatments were seeded in rows of 7 inch spacing and 20 feet long. All plots were seeded with barley at a rate of 2 bus. per acre. Each treatment constituted six rows, the central two rows of 10 feet length only being taken for yield determinations. The grain samples were taken at maturity, air dried, threshed and weighed. Response of nitrogen fertilization was determined by the per cent yield suggested by Bray (13). Because 11-48-0 fertilizer was used as the phosphate source, the per cent yield was calculated as follows:

$$\text{Per cent yield} = \frac{\text{yield in bu./ac. from 10 lb. N + 40 lb. } P_2O_5 \text{ treatment}}{\text{yield in bu./ac. from 60 lb. N + 40 lb. } P_2O_5 \text{ treatment}} \times 100$$

The grain taken from the 0-0, 10-40, 60-0 and 60-40 treatments was analyzed for nitrogen.

Soil samples at farm locations were taken at intervals of 0-6, 6-12, 12-24, 24-36 and 36-48 inches from all plot sites at seeding time, heading stage and harvest time and oven dried at 100^{o}C for nitrate nitrogen and available moisture determinations. Other soil samples were taken from the 0-6 inch depth from all plots at seeding time and air dried. Organic matter, permanganate oxidizable nitrogen, potentially available nitrogen (PAN), PH, $CaCO_3$, soil texture determinations and incubation studies were made on the air dried soils sampled from the 0-6 inch depth. The soils were also sampled from the fallow areas at harvest time and analyzed for nitrate nitrogen and available moisture.

B. Results and Discussion

The results of the 1960 field experiment are summarized in Tables III to VII and Figures I to V.

The yields of barley in bushels per acre (Table II) indicate a large variation in yields of checks and a wide range of response to fertilizers. Barley grown on some of the soils responded well to both nitrogen and phosphate while barley grown on others only responded well to one nutrient. However, the differential in the productivity of the various soils tested was greatly reduced as a result of the application of 60 pounds of nitrogen and 40 pounds of phosphate per acre.

The results obtained by various methods of estimating available soil nitrogen are shown in Table IV. PAN was similar to nitrifying power in magnitude: while permanganate oxidizable nitrogen was much higher. In general, the levels of nitrate nitrogen in the soil profiles to a depth of four feet were much lower than those of PAN, nitrifying power and permanganate oxidizable nitrogen. The correlation coefficients as shown in Table V indicate that except for permanganate oxidizable nitrogen, the amounts of nitrogen determined by various methods were not highly correlated with organic matter content. Permanganate oxidizable nitrogen, PAN and nitrifying power were closely correlated with each other. Correlation coefficients for any pair of these were significant at the 1 per cent level. However, neither organic matter nor the nitrate nitrogen content in the soil profile to a depth of four feet at seeding time .

Per cent yield (Table VI) was used to demonstrate the response of barley to nitrogen fertilizer. The data indicate that barley responded differently to nitrogen fertilizer on the various plots. When the soils were low in nitrate nitrogen, the per cent yields were low and the per cent protein and the nitrogen taken up in the grain in the 10-40 treatment were also low. When the soils were high in nitrate nitrogen, the per cent yields were high and the per cent protein and the nitrogen taken up in the grain in the 10-40 treatment were high. In general, the per cent protein and the nitrogen taken up in the grain in the 60-40 treatment were increased in comparison with those in the 10-40 treatment. However, the increases were only slight or there was no increase in the case of soils high in nitrate nitrogen in the profile, for instance, the plots at Anderson's and Stanger's: while there was considerable increase in the case of soils low in nitrate nitrogen content, for instance, the plots at McDonald's and Dick's. This was particularly true for nitrogen uptake in grain. This is evidence of the availability of the accumulated nitrate nitrogen in the soil profiles tested.

The correlations of the logarithms of results obtained by various methods of estimating available soil nitrogen with per cent yield and nitrogen uptake in the grain in the 10-40 treatment are presented in Table VII. There was no significant correlation between organic matter content and per cent yield and nitrogen uptake in the grain. The correlations between permanganate oxidizable nitrogen and per cent yield and nitrogen uptake in the grain were only significant at the 5 per cent level; while PAN, nitrifying power were highly correlated with both per cent yield and nitrogen uptake in the grain. However, the correlation coefficients between PAN, nitrifying power and per cent yield and nitrogen uptake in the grain were considerably lower than the values of 0.95 and 0.94 respectively obtained where nitrate nitrogen in the 0-48 inch depth was correlated with per cent yield and nitrogen uptake in the grain. The data indicate that organic matter content appeared to be of little value in assessing nitrogen requirements of the soils tested and that permanganate oxidizable nitrogen level appeared to be not as promising as PAN and nitrifying power levels. However, nitrate nitrogen in the soil profile to a depth of four feet at seeding time showed the best indication for the response of barley to added nitrogen.

The correlation coefficients between per cent yield and the logarithm of the amount of accumulated nitrate nitrogen of the 0-6, 0-12, 0-24, 0-36 and 0-48 inch depths were 0.80, 0.91, 0.93, 0.95 and 0.95 respectively. These correlations were all significant at the 1 per cent level. With respect to the relationship between the nitrogen taken up in the grain in the 10-40 treatment and the logarithm of the amount of accumulated nitrate nitrogen of the 0-6, 0-12, 0-24, 0-36, and 0-48 inch depths plus 10 pounds of nitrogen added as fertilizer at seeding time, the correlation coefficients were 0.68, 0.85, 0.91, 0.94 and 0.95, respectively. Excepting that the correlation between the nitrogen uptake in the grain and the accumulated nitrate nitrogen in the 0-6 inch depth was only significant at the 5 per cent level, these correlations were all significant at the 1 per cent level. Nevertheless, these "r" values show that the deeper the soil was sampled, the higher the correlation coefficient was. In general, the nitrate nitrogen content in the surface soil is rather low and variable. Therefore, it does not seem to be advisable to determine the nitrate nitrogen content of the surface soil for predicting nitrogen requirements. Further investigation is needed to determine how deep the soil should be sampled for this prediction purpose.

The relationships between the response to nitrogenous fertilizers and the nitrate nitrogen in the 0-6, 0-12, 0-24, 0-36 and 0-48 inch depths at seeding time are expressed in the following equations. The relationships were linear. Let Y represent per cent yield and X amount of accumulated nitrate nitrogen in pounds per acre.

(A) 0-6 inch depth
$Y = 106 \log X - 27$
When $Y = 100$ $X = 16$
When $Y = 90$ $X = 13$

(B) 0-12 inch depth
$Y = 104 \log X - 51$
When $Y = 100$ $X = 28$
When $Y = 90$ $X = 23$

(C) 0-24 inch depth
$Y = 92 \log X - 55$
When $Y = 100$ $X = 50$
When $Y = 90$ $X = 39$

(D) 0-36 inch depth
$Y = 73 \log X - 39$
When $Y = 100$ $X = 78$
When $Y = 90$ $X = 57$

(E) 0-48 inch depth
$Y = 90 \log X - 73$
When Y = 100   X = 86
When Y = 90   X = 66

The equations show that when the accumulated nitrate nitrogen of the 0-6, 0-12, 0-24, 0-36 and 0-48 inch depths was 16, 28, 50, 78 and 86 pounds per acre respectively, there would be no response, that is, the per cent yield would be 100. However, from the standpoint of economics, the per cent yield of 90 is considered to be reasonable for predicting nitrogen needs. When the accumulated nitrate nitrogen of the 0-6, 0-12, 0-24, 0-36 and 0-48 inch depths was 13, 23, 39, 57 and 66 pounds per acre respectively, the per cent yield would be 90. Therefore, insofar as the 0-48 inch depth is concerned, approximately 70 pounds of nitrate nitrogen was considered as the inflection point of response and non-response to nitrogen fertilization. The relationship between the per cent yield and the accumulated nitrate nitrogen in the 0-48 inch depth is shown in Figure I.

The relationships between per cent yield and PAN, nitrifying power, permanganate oxidizable nitrogen and organic matter are also expressed in the following regression equations, where Y represents per cent yield and X amount of organic matter or amount of nitrogen determined by various methods.

(a) Regression equation representing the relationship between per cent yield and PAN (p.p.m.)

$Y = 114 \log X - 152$
When Y = 100   X = 162
When Y = 90   X = 131

(b) Regression equation representing the relationship between per cent yield and nitrifying power (p.p.m.)

$Y = 112 \log X - 142$
When Y = 100   X = 141
When Y = 90   X = 115

(c) Regression equation representing the relationship between per cent yield and permanganate oxidizable nitrogen (p.p.m.)

$Y = 128 \log X - 245$
When $Y = 100$ $X = 501$
When $Y = 90$ $X = 416$

(d) Regression equation representing the relationship between per cent yield and organic matter (per cent)

$Y = 39 \log X - 42$
When $Y = 100$ $X = 30$
When $Y = 90$ $X = 17$

Comparing the above mentioned results and the field experimental data as shown in Tables IV and VI, it was found that the determinations of PAN and nitrifying power seemed to be promising for the prediction of nitrogen needs of cereals. The utility of the determination of permanganate oxidizable nitrogen was not as good as that of PAN and nitrifying power; while the determination of organic matter did not appear to be promising.

The nitrogen uptake in the grain in the 10-40 treatment and the 60-40 treatment plotted against the logarithm of the amount of accumulated nitrate nitrogen in the 0-48 inch depth plus nitrogen added as fertilizer at seeding time in Figure II, gives a linear relationship with a correlation coefficient of 0.90 which was significant at the 1 per cent level. The regression equation was $Y = 47 \log X - 54$, where Y represented the nitrogen uptake in the grain and X the amount of the accumulated nitrate nitrogen plus nitrogen added as fertilizer. This line shows that the accumulated nitrate nitrogen in the soil profile to a depth of four feet was as available as the nitrogen added as fertilizer at seeding time.

The per cent protein in the grain in the 10-40 treatment was highly correlated with the logarithm of the amount of the accumulated nitrate nitrogen in the soil profile at seeding time at the 1 per cent level with an "r" value of 0.94. Even the correlation coefficient between the logarithm of the amount of the accumulated nitrate nitrogen plus nitrogen added as fertilizer and the per cent protein in the grain in the 10-40 and the 60-40 treatments was 0.80 which was significant at the 1 per cent level. These correlations further support the evidence of the availability of the accumulated nitrate nitrogen in the profile and also reveal the tendency that the per cent protein in grain did increase as a result of nitrogen fertilization. From the standpoint of brewing beer, a high protein content in grain is undesirable. About 10-12.8 per cent of protein is considered to be adequate for Canadian 6-Row barley (60). The correlation between the per cent protein in the grain in the 10-40 treatment and the accumulated nitrate nitrogen in the 0-48 inch depth plus 10 pounds of nitrogen added as fertilizer at seeding time was significant at the 1 per cent level with an "r" value of 0.95. The relationship is expressed by the regression equation, $Y = 6.1 \log X + 1.6$, where Y represents the per cent protein in grain, X the amount of nitrate nitrogen in pounds per acre. When Y is equal to 10, X is approximately 24; while when Y is equal to 12.8, X is approximately 68. In view of the results, as shown in Tables IV and VI, if the accumulated nitrate nitrogen in the 0-48 inch depth plus 10 pounds of nitrogen added as fertilizer at seeding time was below 68 pounds per acre, the protein content in the grain in the 10-40 treatment did not exceed 12.8 per cent. Therefore, it is suggested that if the nitrate nitrogen content in the soil profile to a depth of four feet is over 70 pounds per acre, the soil is not suitable for growing barley to be used for brewing purposes. Moreover, in the case of the 60-40 treatment, the protein content of the grain was all above 12.8 per cent except for the grain from the plots at McDonald's, Dick's, and Barg's.

The amounts of nitrate nitrogen in the soil profiles of all plots at the three stages are plotted in Figure III. The figure indicates that the nitrate nitrogen in the soil profile to a depth of four feet was very considerable in some cases and varied extremely from soil to soil. In general, the amount of the accumulated nitrate nitrogen at each depth at heading stage and at harvest time was considerably lower than that at seeding time. Of course, there were some exceptions, since upward and downward movements could occur. The differences between the accumulated nitrate nitrogen content at heading stage and at harvest time were very small. In some plots, for example, in the plots at Anderson's and Stanger's , the amount of the accumulated nitrate nitrogen in the soil profile to a depth of four feet was even higher at harvest time than at heading stage.

Figure IV shows the amount of available moisture in the soil profile to a depth of four feet at the three stages. As indicated in this figure, the amount of available moisture in the profile at seeding time varied from soil to soil and that at heading stage and harvest time was much lower than that at seeding time. However, there was not much difference between the amount of the available moisture at heading stage and that at harvest time. It was found that there was no significant correlation between the amount of available moisture in the profile to a depth of four feet at seeding time and the nitrogen uptake in the grain in the 10-40 treatment. This is not considered to be unreasonable, since the soil high in available moisture does not necessarily contain large amount of nitrate nitrogen, and moreover, all of the soils contained adequate available moisture at seeding time. It was found that in fallow area there was not much increase in available moisture during the growing season and in the fallow area adjacent to the plot at Anderson's, the available moisture at harvest time was lower than that at seeding time.

From Figure III it will be seen that there was less nitrate nitrogen in the soils at seeding time than in the soils at harvest time which were kept fallow and free from weeds. Since we do not know how much nitrate nitrogen was formed during the whole growing season, we do not know how much leaching, if any, might have occurred, We do know, however, that the amount of leaching during the growing season was such as to leave large amounts of nitrates in the fallow area.

The distribution of the nitrate nitrogen and available moisture in the soil profile of the nine plots at three stages are summarized in Figure V. The figure shows that the distribution of nitrate nitrogen was extremely similar to that of available moisture in the soil profile to a depth of four feet, except that there was higher available moisture at harvest time than at heading stage. This was not the case with nitrate nitrogen. This may be due to rainfall shortly before the harvest time. Though Figure V does not indicate the amount of water taken up, yet it does show the amount and distribution of available moisture in the soil profile at the three stages. As is shown in this figure, the amounts of nitrate nitrogen and available moisture in the soil profile at heading stage and at harvest time were much lower than those at seeding time. The loss of available nitrogen may be due to crop removal, erosion, leaching, denitrification and immobilization. Insofar as the climatic and topographic characteristics of the soils on which the field experiment was conducted are concerned, the loss of nitrate nitrogen due to erosion was not likely. The leaching effect on the loss of available nitrogen was also not likely since the leaching effect appeared to be such as to leave large amounts of nitrates in the fallow areas in this field experiment. Denitrification might take place in the surface soil but this was unlikely in subsoil low in organic matter content. Immobilization also might be proceeding to a certain extent. However, the loss of nitrate nitrogen during the growing season did seem to be mainly due to the removal by the crop. Thus the availability of the accumulated nitrate nitrogen in the soil profile is further substantiated. However, there was not much difference between the heading stage and the harvest time insofar as the amount and distribution of the nitrate nitrogen and available moisture are concerned. This might indicate that the barley did not take up a considerable amount of nitrogen from soil after the heading stage or that the mineralization rate was high enough to supply the available nitrogen needed by barley after the heading stage.

In short, it would seem from the data in this experiment that the nitrate nitrogen in the profile at seeding time greatly affected the response of barley to nitrogenous fertilizers and also was the major factor in determining the yields of the 10-40 treatment though mineralization seemed to be considerable. Since there is no evidence to suggest that the rate of mineralization of nitrogen under field conditions did not closely parallel the amount of accumulated nitrate nitrogen in the profile, it is impossible to assess the relative importance to the crop of the available nitrogen in soil profile at seeding time and of that mineralized during the growing season. However, it is considered that the amount of accumulated nitrate nitrogen offers promise of being a superior indication of the response of barley to nitrogen fertilization.

TABLE I List of Farmer Cooperators and the Dates of Seeding and Harvest of Barley in 1960.

Cooperator	Date of Seeding	Date of Harvest
McDonald	May 31	August 30
Dicks	May 31	August 31
Campbell	May 31	August 30
Barg	June 6	September 2
Yuill	May 13	August 11
Kroeker	June 7	September 2
Ferris	May 30	August 22
Stanger	May 24	August 11
Anderson	June 7	September 2

TABLE II Some Characteristics of the Soils Used in the Field Experiment, 1960.

Cooperator	Soil Association or Soil Series	Profile Type**	Texture	PH	$CaCO_3$ %	Organic Matter %
McDonald	Balmoral*	Calcareous Meadow	Silty Clay	7.9	42.2	5.2
Dicks	Balmoral*	Calcareous Rego Black	Very Fine Sandy Loam	7.8	11.5	5.3
Campbell	Balmoral*	Calcareous Meadow	Clay Loam	7.9	26.0	7.8
Barg	Red River	Rego Black	Clay	7.6	2.6	5.1
Yuill	Portage	Orthic Black	Loam	7.5	0.3	8.6
Kroeker	Red River	Rego Black	Clay	6.6	0.2	6.4
Ferris	Portage	Orthic Black	Loam	7.3	0.5	8.5
Stanger	Portage	Orthic Black	Loam	7.8	6.2	4.3
Anderson	Red River	Rego Black	Clay	7.3	3.8	7.5

* soil series

** based on the report of the meeting of the National Soil Survey Committee of Canada, held at Ontario Agricultural College, Guelph, February, 1960.

TABLE III <u>Yields of Barley in Bushels per Acre, 1960.</u>

Cooperator	Crop	Treatment $N-P_2O_5$ in lbs. per acre											
		0-0	60-0	60-10	60-20	60-40	60-60	10-40	20-40	40-40	80-40	L.S.D. 0.05	L.S.D. 0.01
McDonald	Barley	10.5	23.9	31.4	34.2	39.2	41.7	14.4	24.8	31.6	43.7	4.6	6.2
Dicks	"	13.1	31.4	34.1	29.4	36.6	36.4	20.4	25.8	31.7	40.0	5.1	6.9
Campbell	"	25.8	33.5	38.1	43.9	50.1	48.2	33.7	40.9	44.7	48.3	4.4	5.8
Barg	"	14.1	19.9	35.3	37.5	40.2	40.2	28.4	32.1	37.5	40.5	6.0	8.0
Yuill	"	32.4	48.7	46.3	48.9	54.5	55.2	38.7	41.3	46.3	54.3	8.2	10.9
Kroeker	"	25.0	27.3	36.0	33.0	33.3	36.4	27.0	27.0	33.0	36.0	5.5	7.3
Ferris	"	25.5	32.0	45.6	42.5	44.2	47.9	37.5	43.6	46.4	47.5	9.6	12.8
Stanger	"	23.1	23.6	32.3	37.9	45.4	48.8	41.6	45.2	45.2	46.6	6.0	8.0
Anderson	"	46.4	40.9	44.8	45.0	52.3	54.2	50.6	52.0	51.8	49.4	6.5	9.4

TABLE IV Amount of Organic Matter and Amount of Nitrogen Determined by Various Methods, 1960.

Cooperator	Organic Matter % (0-6 inch depth)	Permanganate Oxidizable Nitrogen p.p.m (0-6 inch depth)	PAN p.p.m. (0-6 inch depth)	Nitrifying Power (NO_3-N) p.p.m. (0-6 inch depth)	Nitrate Nitrogen lb./ac. (0-48 inch depth)
McDonald	5.2	232	56	40	15
Dicks	5.3	214	63	72	19
Campbell	7.8	341	80	92	38
Barg	5.1	274	94	72	29
Yuill	8.6	351	102	87	48
Kroeker	6.4	348	111	107	43
Ferris	8.5	390	135	93	72
Stanger	4.3	281	87	83	102
Anderson	7.5	394	138	111	104

TABLE V Correlations of Results Obtained by Various Methods of Estimating Available Soil Nitrogen, 1960.

Method		Correlation Coefficient			
		Organic Matter	Permanganate Oxidizable Nitrogen	PAN	Nitrifying
Permanganate Oxidizable Nitrogen	(0-6 inch depth)	0.81 **			
PAN	(0-6 inch depth)	0.60 *	0.89 **		
Nitrifying Power	(0-6 inch depth)	0.54	0.82 **	0.82 **	
Nitrate Nitrogen	(0-48 inch depth)	0.18	0.59 *	0.72 *	0.62 *

** significant at the 1 per cent level

* significant at the 5 per cent level

TABLE VI <u>Per Cent Yield, Nitrogen Uptake and Per Cent Protein in Grain, 1960.</u>

Cooperator	Per Cent Yield	Nitrogen Uptake in Grain (Lb./ac.) Treatment – N – P_2O_5 in lbs. per acre				Per Cent Protein in Grain Treatment – N – P_2O_5 in lbs. per acre			
		0-0	60-0	10-40	60-40	0-0	60-0	10-40	60-40
McDonald	37	8.1	18.7	10.2	28.6	10.8	10.9	9.9	10.2
Dicks	56	10.6	27.8	15.6	32.4	11.0	12.5	10.8	12.4
Campbell	67	22.7	33.5	30.2	49.7	12.3	14.0	12.6	13.9
Barg	71	11.2	18.6	21.3	33.3	11.2	13.1	10.5	11.6
Yuill	71	28.6	45.0	34.6	50.8	12.4	12.9	12.5	13.0
Kroeker	80	22.1	25.9	24.0	31.2	12.4	13.3	12.4	13.1
Ferris	85	24.5	32.0	36.4	41.5	13.4	14.0	13.6	13.1
Stanger	92	21.5	26.3	39.5	46.2	13.0	15.6	13.3	14.3
Anderson	97	45.8	41.7	52.6	53.1	13.8	14.3	14.6	14.2

TABLE VII Correlations of the Logarithm of Results Obtained by Various Methods of Estimating Available Soil Nitrogen with Per Cent Yield and Nitrogen Uptake in Grain, 1960.

Method		Correlation Coefficient	
		Per Cent Yield	Nitrogen Uptake in Grain (10-40 treatment)
Organic Matter	(0-6 inch depth)	0.24	0.44
Permanganate Oxidizable Nitrogen	(0-6 inch depth)	0.69*	0.75*
PAN	(0-6 inch depth)	0.84**	0.77**
Nitrifying Power	(0-6 inch depth)	0.83**	0.80**
Nitrate Nitrogen	(0-48 inch depth)	0.95**	0.94**

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

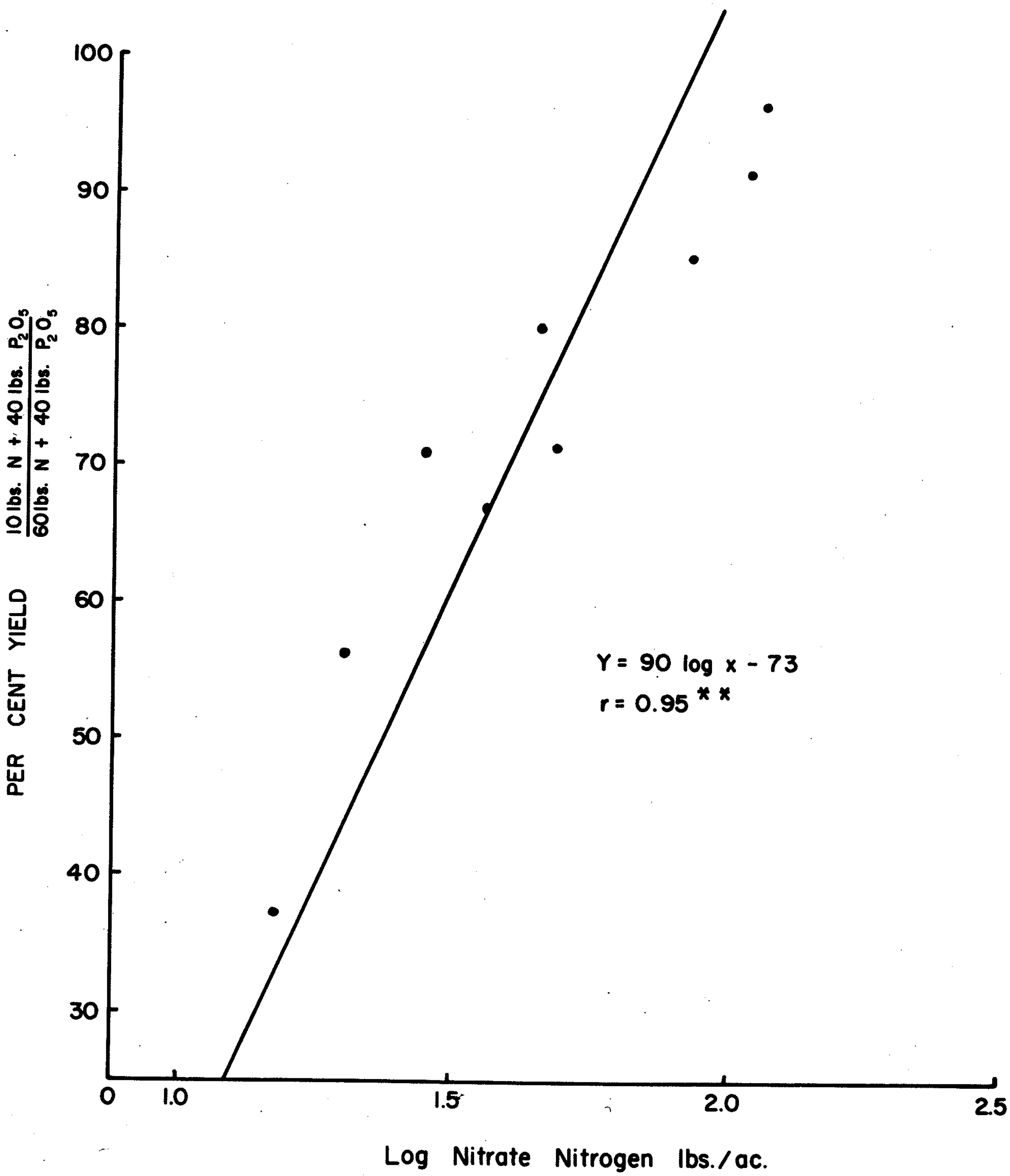

FIGURE I Relationship between per cent yield and accumulated nitrate nitrogen in the 0 - 48 inch depth of soils cropped the previous year.

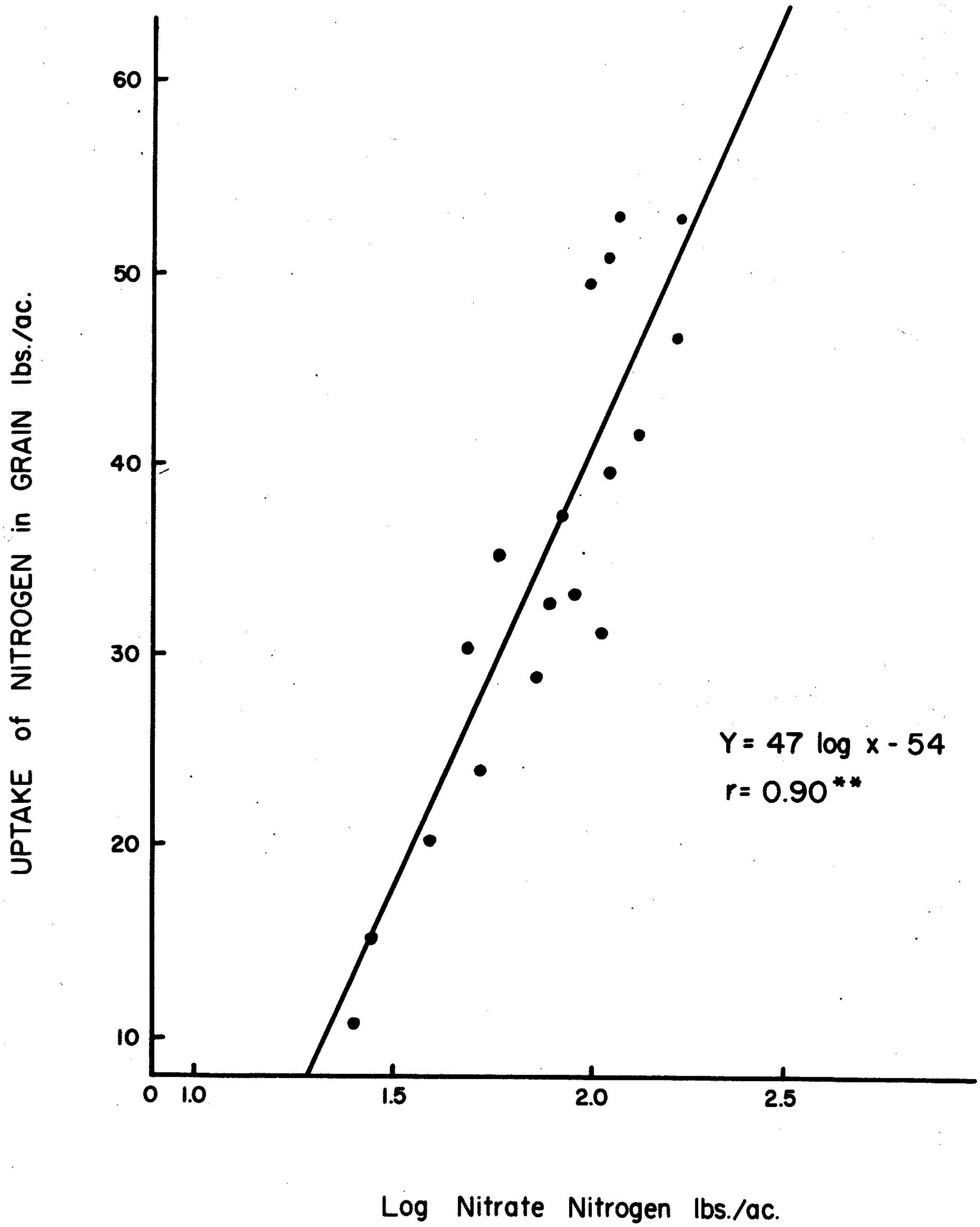

FIGURE II Relationship between uptake of nitrogen in grain and accumulated nitrate nitrogen in the 0-48 inch depth plus nitrogen added as fertilizer at seeding time.

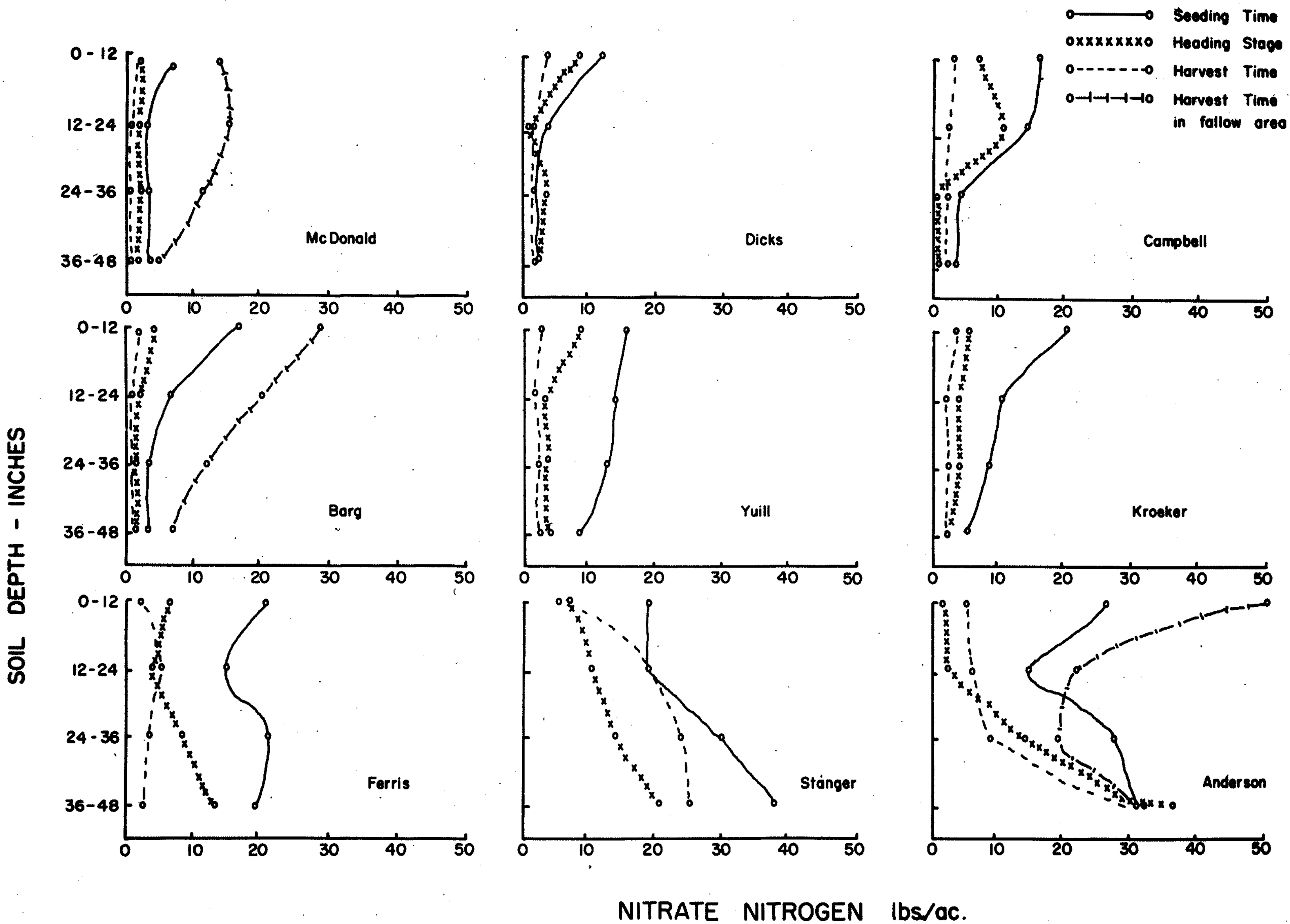

FIGURE III The distribution and amount of nitrate nitrogen in the soil profile

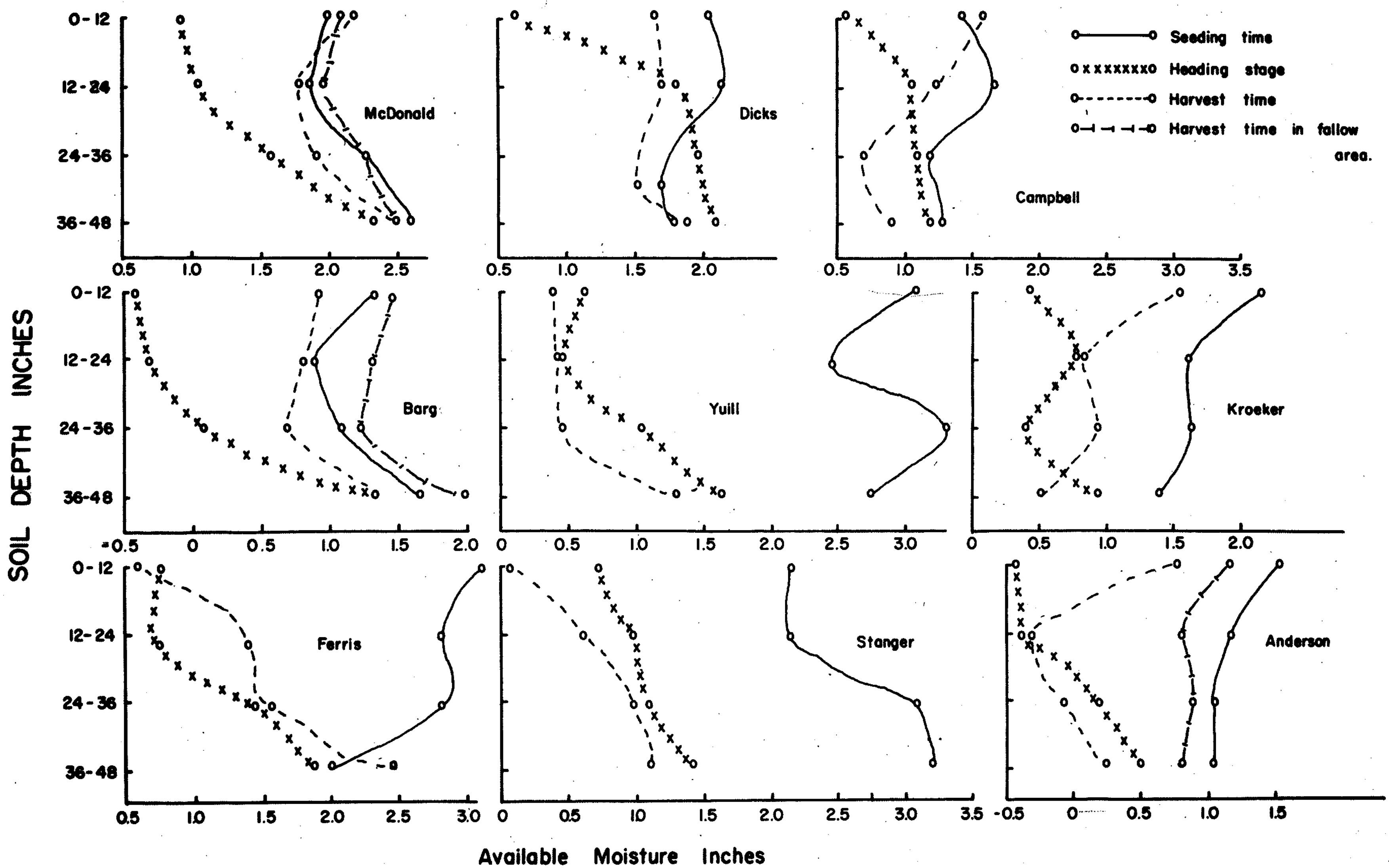

FIGURE IV The distribution and amount of available moisture in the soil profile at seeding time, heading stage and harvest time, 1960.

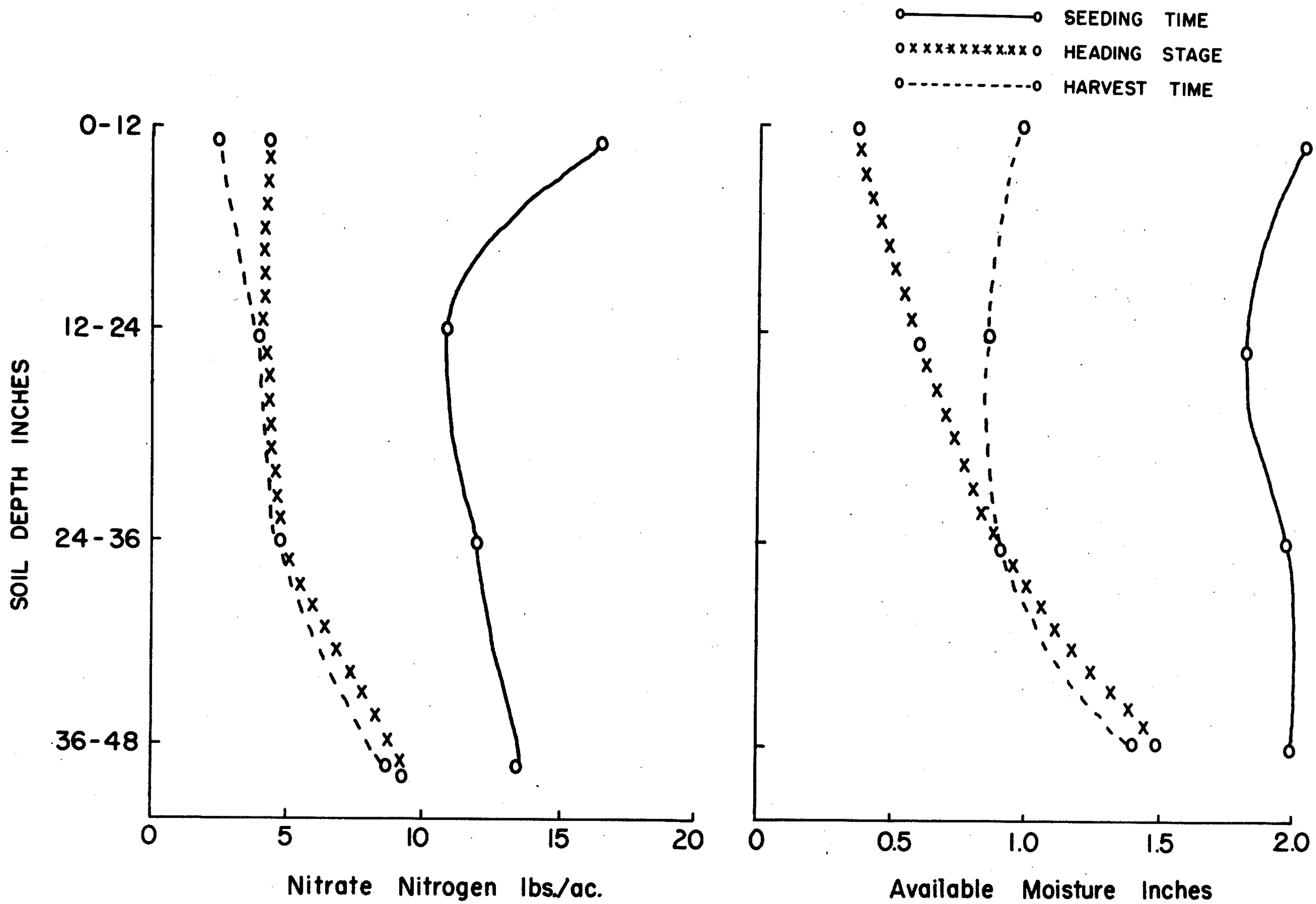

FIGURE V The distribution of nitrate nitrogen and available moisture in the soil profile (average of the nine plots). 1960

1961 FIELD EXPERIMENT

Results from the 1960 experiment show that barley grown in small plots had a wide range of response in yield, nitrogen taken up and per cent protein in grain to the application of nitrogenous fertilizers. It was also found that the accumulated nitrate nitrogen in the 0-48 inch depth appeared to be a good indication of the response of barley to nitrogenous fertilizers.

In order to investigate further the results obtained in 1960 and to study the mineralization rate of nitrogen in the fields, a similar experiment was conducted in 1961.

A. Experimental Procedure

In 1961, thirteen fertilizer trials using wheat and oats as test crops, were placed on Altona, Lakeland and Red River soil associations on summerfallow and stubble land. The description of these soil types has been given by Ehrlich et al. (18) and Pratt et al. (49). The dates of seeding and harvest are shown in Table VIII. Some characteristics of the soils used in this experiment are outlined in Table IX.

A randomized block design with six replications was used. Summerfallow plots were 0.11 acre (70 x 70 feet) and stubble plots 0.14 acre (70 x 87 feet) in size. Each treatment consisted of 6 rows which had 7 inch spacing and the length of each row was 20 feet. The seeding procedure was the same as that of the previous year. This year a fallow strip of 10 feet wide and 70 feet long was located in the middle of each stubble plot. The summerfallow plot design was the same as the stubble plot, except that there was no fallow strip and guard rows in the middle of the plot.

The plots contained treatments consisting of various rates of nitrogen and phosphate, that is, 0-0, 60-0, 60-10, 60-20, 60-40, 0-40, 10-40, 20-40, 40-40, 80-40. The first figure refers to the pounds of nitrogen per acre and the second figure to the pounds of phosphate (P_2O_5) per acre applied. Except that phosphate was added in the form of 0-45-0 in the 0-40 treatment, 11-48-0 was used as the source of phosphate in the other treatments. Ammonium nitrate 33.5-0-0 was used as the source of nitrogen in the 60-0 treatment and also used to bring the nitrogen to the level required in the other treatments. All phosphate was applied with the seed and also nitrogen up to a rate of 20 pounds per acre. Nitrogen in excess of 20 pounds per acre was hand broadcast uniformly over the area.

Soil samples were collected at depths of 0-6, 6-12, 12-24, 24-36, and 36-48 inches at seeding time, and harvest time and oven dried at 100°C for nitrate nitrogen and available moisture determinations. Other soil samples were collected from the 0-6 inch depth at seeding time and air dried. The incubation studies and the determinations of organic matter, permanganate oxidizable nitrogen, PAN, PH, $CaCO_3$ and soil texture were made on the 0-6 inch air dried soils samples at seeding time. The soils were also sampled from the fallow strip in the stubble plots at harvest time and analyzed for nitrate nitrogen and available moisture. The difference between the amount of accumulated nitrate nitrogen in the 0-48 inch depth of the fallow strip at harvest time and that at seeding time is considered to be approximately equal to field mineralization rate of nitrogen during the growing season.

Ten feet of crop was harvested from the central two rows of each treatment of all plots at maturity and air dried, threshed and weighed. Response to nitrogen fertilization was determined by the per cent yield suggested by Bray (13)

$$\text{Per cent yield} = \frac{\text{Yield in bu./ac. from 0 lb.N - 40 lb.}P_2O_5\text{ treatment}}{\text{Yield in bu./ac. from 60lb.N - 40 lb.}P_2O_5\text{ treatment}} \times 100$$

The analyses for nitrogen were made on the grain collected from the 0-0, 0-40, 60-0 and 60-40 treatments.

B. Results and Discussion

Although 13 small plots were set out on summer fallow and stubble land, seven of these plots were lost due to poor germination as a result of severe drought conditions prevailing during the summer. The other six plots germinated very well and also received local showers during the growing season. Among the six plots, the plots at Skinner's, Cook's and Campbell's were stubble and those at Last's, Goulet's and Catellier's were summerfallow.

The results for the 1961 field experiment are summarized in Tables X to XIV and Figures VI to X.

The yields of oats and wheat as influenced by treatment were presented in Table X. The data indicate a large variation in yields of checks and a wide range of response to fertilizers. Except for the plot at Campbell's, oats grown in the stubble plots responded well to both nitrogen and phosphate. Except for the plot at Goulet's wheat grown in the summerfallow plots only responded slightly to phosphate.

As indicated in Table XI, the amount of organic matter and the amount of nitrogen determined by various methods were quite variable from soil to soil. PAN was again similar in magnitude to nitrifying power: while permanganate oxidizable nitrogen was much higher. In general, the amounts of the accumulated nitrate nitrogen in the 0-48 inch depth in the fields which had been fallowed the previous year were much higher than in the fields which had been cropped. As shown in Table XII, except for permanganate oxidizable nitrogen, none of the nitrogen determined by various methods was significantly correlated with organic matter at the I per cent level. Permanganate oxidizable nitrogen, PAN and nitrifying power were all highly correlated with each other at the 1 per cent level. Organic matter, nitrogen determined by various methods were not significantly correlated with accumulated nitrate nitrogen in the soil profile to a depth of four feet at seeding time.

The 1960 results suggested that the per cent yield would not be less than 90 if the test for nitrate nitrogen revealed over 66 pounds of the accumulated nitrate nitrogen per acre and that there would be no response to nitrogen if the accumulated nitrate nitrogen was over 86 pounds per acre. With this in mind, it could be expected that a response to nitrogen would not occur in the plots at Last's and Catellier's and a small response in the plot at Goulet's. That was essentially what occurred. The data from the stubble plots also agreed with the predictions from this soil test. The plot at Campbell's which had a very high value for nitrate nitrogen for stubble land did not respond to the addition of nitrogen. The plot at Cook's had a very low value for nitrate nitrogen and a response was obtained with the application of nitrogen. The plot at Skinner's also had a fairly low value for nitrate nitrogen and a response to nitrogen was also obtained. These plots were oats and wheat, but the values obtained in the 1960 field experiment were for barley. However, as shown in Tables XI and XIII, the response of oats and wheat to nitrogen fertilization did seem to be predictable by these values. Therefore, the value "70 pounds of the accumulated nitrate nitrogen in the 0-48 inch depth per acre" may be used as a criterion for predicting the response of all cereals to nitrogenous fertilizers.

Per cent yield (Table XIII) was used to demonstrate the response to nitrogen fertilization. Where there was no response to nitrogen, the accumulated nitrate nitrogen was over 86 pounds per acre. The per cent protein and the nitrogen taken up in the grain in the 0-40 and the 60-40 treatments also support the evidence of the variation of response to nitrogen on the various plots. In the plots at Skinner's, Cook's and Goulet's, the per cent yields were 70, 74 and 90 respectively. The nitrogen uptake and the per cent protein in the grain in the 60-40 treatment in these three plots were all higher than those of the 0-40 treatment. This was particularly evident in the nitrogen uptake in the grain in the plots at Skinner's and Cook's which had low levels of nitrate nitrogen. However, there was not much difference in nitrogen uptake and per cent protein in grain between the 0-40 and the 60-40 treatments in the plots at Last's, Catellier's and Campbell's which had a very high amount of accumulated nitrate nitrogen. Therefore, as a result of the application of nitrogenous fertilizers in the soils low in available nitrogen, not only the yield was increased but also the quality of oats and wheat was improved.

The correlations of the logarithms of results obtained by various methods of estimating available soil nitrogen with per cent yield and nitrogen uptake in the grain in the 0-40 treatment are listed in Table XIV. From the standpoint of statistics, the level of significance below the 5 per cent level is considered to be not significant. There was no significant correlation between the per cent yield and organic matter and permanganate oxidizable nitrogen, while PAN, nitrifying power and the accumulated nitrate nitrogen in the 0-48 inch depth were only correlated with the per cent yield at the 5 per cent level, with "r" values of 0.80, 0.83 and 0.89, respectively. The "r" value was highest when the accumulated nitrate nitrogen was correlated with the per cent yield. None of the results obtained by various methods for estimating available soil nitrogen was significantly correlated with the nitrogen taken up in the grain in the 0-40 treatment. The reason for the poorer correlation may be due to the three facts. In the first place, severe drought conditions prevailed during the summer, although the plots did receive local showers during the growing season .

The severe drought condition would limit the crop growth and the amount of nitrogen required for the crop growth would thus be lower than in a normal year. This explanation is well supported by the report given by Power _et al_. (48), stating that correlation coefficients between plant growth, nutrient uptake and moisture use were extremely high as the crop approached maturity. Moreover, the severe drought condition prevailing during the growing season did seem to have greater limiting effect on the crop growth in the stubble plots than in the fallow plots. In the second place, the stubble and fallow plots were put together for the correlations. The levels of organic matter, permanganate oxidizable nitrogen, PAN and nitrifying power, which could be used as criteria for the prediction of the response of cereals to nitrogen in stubble fields, might not be applicable for this purpose in fallowed fields, since, generally speaking, the amount of accumulated nitrate nitrogen is higher in the field which has been fallowed the previous year than in the field which has been cropped. It has been reported by Cook _et al_. (15), that a significant response of wheat to nitrogen can be expected when nitrifying power is below 50 p.p.m. N in stubble soils or 40 p.p.m. N in fallow soils. Moreover, the level of the accumulated nitrate nitrogen which could be used as the criterion for the prediction of the response of cereals to nitrogen in stubble soils might be different than that used for fallow soils. Since even if the stubble soil and the fallow soil have the same amount of accumulated nitrate nitrogen at seeding time, the mineralization rate of nitrogen during the growing season in the fallow soil and that in the stubble soil might not be comparable. In the third place, oats and wheat were used as test crops and their per cent yield and nitrogen uptake in grain were used to correlate with amounts of organic matter and nitrogen determined by various methods.

This could make the correlations poorer and is particularly true in the nitrogen uptake correlation, since the per cent protein and the yield of grain of oats and wheat are not quite comparable.

The relationships between the response of oats and wheat to nitrogenous fertilizers and organic matter, permanganate oxidizable nitrogen, PAN and nitrifying power are expressed in the following equations, where Y represents per cent yield and X amount of organic matter or amount of nitrogen determined by various methods.

(A) Regression equation representing the relationship between per cent yield and PAN (p.p.m.)

$Y = 117 \log X - 114$
When $Y = 100$ $\quad$ $X = 68$
When $Y = 90$ $\quad$ $X = 56$

(B) Regression equation representing the relationship between per cent yield and nitrifying power (p.p.m.)

$Y = 82 \log X - 50$
When $Y = 100$ $\quad$ $X = 67$
When $Y = 90$ $\quad$ $X = 51$

(C) Regression equation representing the relationship between per cent yield and permanganate oxidizable nitrogen (p.p.m.)

$Y = 93 \log X - 137$
When $Y = 100$ $\quad$ $X = 350$
When $Y = 90$ $\quad$ $X = 274$

(D) Regression equation representing the relationship between per cent yield and organic matter (per cent)

$Y = 49 \log X - 51$
When $Y = 100$ $\quad$ $X = 9.7$
When $Y = 90$ $\quad$ $X = 6.1$

In view of the field experimental data as shown in Tables XI and XIII and the above mentioned results, the response of oats and wheat to nitrogen did seem to be more predictable by the levels of PAN and nitrifying power than by those of organic matter and permanganate oxidizable nitrogen.

The relationships between the response to nitrogenous fertilizer and the accumulated nitrate nitrogen in the 0-6, 0-12, 0-24, 0-36 and 0-48 inch depths are expressed by the following regression equations, where Y represents per cent yield and X accumulated nitrate nitrogen in lb./ac.

(A) 0-6 inch depth
$Y = 26 \log X + 57$
When $Y = 100$ $\quad X = 44$
When $Y = 90$ $\quad X = 19$

(B) 0-12 inch depth
$Y = 28 \log X + 51$
When $Y = 100$ $\quad X = 59$
When $Y = 90$ $\quad X = 26$

(C) 0-24 inch depth
$Y = 27 \log X + 48$
When $Y = 100$ $\quad X = 80$
When $Y = 90$ $\quad X = 35$

(D) 0-36 inch depth
$Y = 27 \log X + 46$
When $Y = 100$ $\quad X = 94$
When $Y = 90$ $\quad X = 41$

(E) 0-48 inch depth
$Y = 27 \log X + 44$
When $Y = 100$ $\quad X = 111$
When $Y = 90$ $\quad X = 48$

The correlation coefficients between per cent yield and accumulated nitrate nitrogen in the 0-6, 0-12, 0-24, 0-36 and 0-48 inch depths were 0.75, 0.80, 0.85, 0.89 and 0.89, respectively. Except that the relationship between per cent yield and accumulated nitrate nitrogen in the 0-6 inch depth was not significant, the other correlations were significant at the 5 per cent level. As shown in these "r" values, the deeper the soil was sampled the better the correlation between the per cent yield and the accumulated nitrate nitrogen was. This further indicates that the determination of the nitrate nitrogen in the soil profile was more reliable than that in the surface soil, insofar as the prediction o f nitrogen needs of cereals is concerned. These results agree with the results obtained in 1960. However, the correlation coefficients between the nitrogen taken up in the grain in the 0-40 treatment and the accumulated nitrate nitrogen in the 0-6, 0-12, 0-24, 0-36 and 0-48 inch depths were 0.77, 0.74, 0.69, 0.67 and 0.64, respectively. None of these correlations was significant.

These regression equations show that when the accumulated nitrate nitrogen was over 44, 59, 80, 94 and 111 pounds per acre in the 0-6, 0-12, 0-24, 0-36, and 0-48 inch depths respectively, there would be no response to nitrogen; while if the accumulated nitrate nitrogen was 19, 26, 35, 41 and 48 pounds per acre in the five soil depths respectively, the per cent yield would be 90.

Therefore, as far as the 0-48 inch depth is concerned, the amount of accumulated nitrate nitrogen which gave 90 per cent yield in the 1961 experiment was approximately 50 pounds per acre. The relationship between the response to nitrogenous fertilizers and the accumulated nitrate nitrogen in the soil profile to a depth of four feet at seeding time is shown in Figure VI. The smaller response to nitrogen is considered to be quite reasonable since the plant growth and nutrient uptake were related to the moisture condition during the growing season.

The distribution and amount of nitrate nitrogen and available moisture in the soil profiles of the fields on which the experiment was conducted in 1961 are plotted in Figures VII and VIII and summarized in Figures IX and X.

The amounts of available moisture in each depth of the soil profiles of the stubble and the summerfallow plots at harvest time were considerably lower than those at seeding time. These results are in agreement with the results obtained in the 1960 field experiment. This decrease in the amount of available moisture is considered to be due to the uptake of water by roots and the evaporation during the growing season. Percolation was not likely to take place in the soils on which the field experiment was conducted, since the growing season was very dry in 1961. As far as the difference between the amount of available moisture in the fallow strip of the stubble plot at seeding time and that at harvest time is concerned, there was not much difference in the plot at Skinner's. However, the amounts of available moisture in the 0-48 inch depth of the fallow strips in the plots at Campbell's and Cook's at harvest time were lower than those at seeding time by 2.49 and 2.04 inches, respectively. It was intended to keep the fallow strips free from weeds, however, some weeds did grow. Therefore, the decrease in the amount of available moisture in the profile of the fallow strip at harvest time might be partially due to the uptake of water by weeds and the evaporation from surface soil. However, it is not safe to say that upward movement of soil moisture did not take place, since the plot at Campbell's was nearly free from weeds in the fallow strip during the growing season.

The amount of accumulated nitrate nitrogen in the 0-48 inch depth in the six plots at harvest time was considerably lower than that at seeding time with one exception; the plot at Last's had a higher amount of accumulated nitrate nitrogen at harvest time than at seeding time. This erratic result may be partially explained by the fact that the amount of accumulated nitrate nitrogen in the 0-48 inch depth of the four places where the soil was sampled was quite variable and also the mineralization rate in the field during the growing season might be very high. There was more nitrate nitrogen in the fallow strips of the stubble plots at harvest time than at seeding time. The differences in the amount of accumulated nitrate nitrogen in the 0-48 inch depth between seeding time and harvest time in the fallow strips of the plots at Campbell's and

Skinner's and Cook's were 34, 24, and 28 pounds per acre respectively. Therefore the mineralization of nitrogen during the growing season appeared to be considerable. However, in view of the nitrifying power of those soils as shown in Table XI, the field mineralization rate of those soils did not seem to correlate very well with their nitrifying power. This is not considered to be unreasonable, since the incubator conditions are not comparable with field conditions. It is also difficult to conclude how deep the nitrification did take place in the soil profile, since the upward and downward movement could occur during the growing season.

TABLE VIII **List of Test Crops and the Dates of Seeding and Harvest, 1961**

Cooperator	Crop	Date of Seeding	Date of Harvest
Skinner	Oats on Stubble	May 20	August 10
Cook	Oats on Stubble	May 19	August 10
Goulet	Wheat on Summerfallow	June 8	August 30
Last	Wheat on Summerfallow	June 7	August 30
Catellier	Wheat on Summerfallow	June 9	August 30
Campbell	Oats on Stubble	May 18	August 23

TABLE IX Some Characteristics of the Soils Used in the Field Experiment, 1961.

Cooperator	Soil Series	Profile type *	Texture	PH	$CaCO_3$ %	Organic Matter %
Skinner	Balmoral	Calcareous Meadow	Loam	7.9	13.9	7.0
Cook	Lakeland	Calcareous Rego Black	Very fine sandy loam	7.8	9.4	3.5
Goulet	Osborne	Orthic Meadow	Clay	7.7	1.5	4.4
Last	Osborne	Orthic Meadow	Clay	7.6	5.1	8.6
Catellier	Osborne	Orthic Meadow	Clay	7.5	0.9	5.9
Campbell	Balmoral	Calcareous Meadow	Clay loam	8.0	21.2	9.8

* Based on the report of the meeting of the National Soil Survey Committee of Canada, held at Ontario Agricultural College, Guelph, February, 1960.

TABLE X <u>Yields of Oats and Wheat in Bushels per Acre, 1961.</u>

Cooperator	Crop	Treatment – N-P_2O_5 lbs. per acre 0-0	60-0	60-10	60-20	60-40	0-40	10-40	20-40	40-40	80-40	L.S.D. 0.05	L.S.D. 0.01
Skinner	Oats	31.0	28.7	31.5	31.7	40.3	28.4	34.8	33.5	33.2	37.1	6.2	8.2
Cook	Oats	26.9	41.7	43.3	41.4	51.5	37.9	42.5	43.0	50.7	53.3	11.3	15.0
Goulet	Wheat	28.8	29.9	34.4	35.6	36.9	33.2	37.2	37.2	35.8	38.8	4.4	5.8
Last	Wheat	20.6	21.1	21.7	24.9	24.9	24.8	24.8	26.3	23.4	25.9	3.6	N.S.
Catellier	Wheat	32.1	28.8	37.1	36.2	35.6	36.0	36.0	36.4	36.1	37.5	N.S.	
Campbell	Oats	53.0	47.8	57.2	55.9	51.2	54.7	51.8	53.2	55.3	57.6	N.S.	

TABLE XII Correlations of Results Obtained by Various Methods of Estimating Available Soil Nitrogen, 1961.

Method		Organic Matter	Permanganate Oxidizable Nitrogen	PAN	Nitrifying Power
Permanganate Oxidizable Nitrogen	(0-6 inch depth)	0.96 **			
PAN	(0-6 inch depth)	0.84 *	0.93 **		
Nitrifying Power	(0-6 inch depth)	0.89 *	0.96 **	0.94 **	
Nitrate Nitrogen	(0-48 inch depth)	0.73	0.67	0.58	0.76

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

TABLE XIII Per Cent Yield, Nitrogen Uptake and Per Cent Protein in Grain, 1961.

Cooperator	Per Cent Yield	Nitrogen Uptake in Grain (lb./ac.) Treatment - N-P_2O_5 in lbs.per acre				Per Cent Protein in Grain Treatment - N-P_2O_5 in lbs.per acre			
		0-0	60-0	0-40	60-40	0-0	60-0	0-40	60-40
Skinner	70	20.3	19.1	19.1	29.9	12.9	13.7	14.3	14.8
Cook	74	15.9	29.0	23.4	37.3	11.7	13.8	12.2	14.3
Goulet	90	40.6	44.1	48.0	55.4	14.8	15.4	15.1	15.7
Last	100	30.9	31.3	36.7	37.7	15.7	15.5	15.4	15.9
Catellier	101	47.3	42.9	54.1	54.8	15.4	15.6	15.7	16.1
Campbell	107	37.7	33.1	39.4	36.6	14.1	13.7	14.4	14.1

TABLE XIV Correlations of the Logarithm of Results Obtained by Various Methods of Estimating Available Soil Nitrogen with Per Cent Yield and Nitrogen Uptake in Grain, 1961.

Method		Correlation Coefficient	
		Per Cent Yield	Nitrogen Uptake in Grain (0-40 treatment)
Organic Matter	(0-6 inch depth)	0.56	0.06
Permanganate Oxidizable Nitrogen	(0-6 inch depth)	0.67	0.27
PAN	(0-6 inch depth)	0.80 *	0.42
Nitrifying Power	(0-6 inch depth)	0.83 *	0.49
Nitrate Nitrogen	(0-48 inch depth)	0.89 *	0.64

* Significant at the 5 per cent level

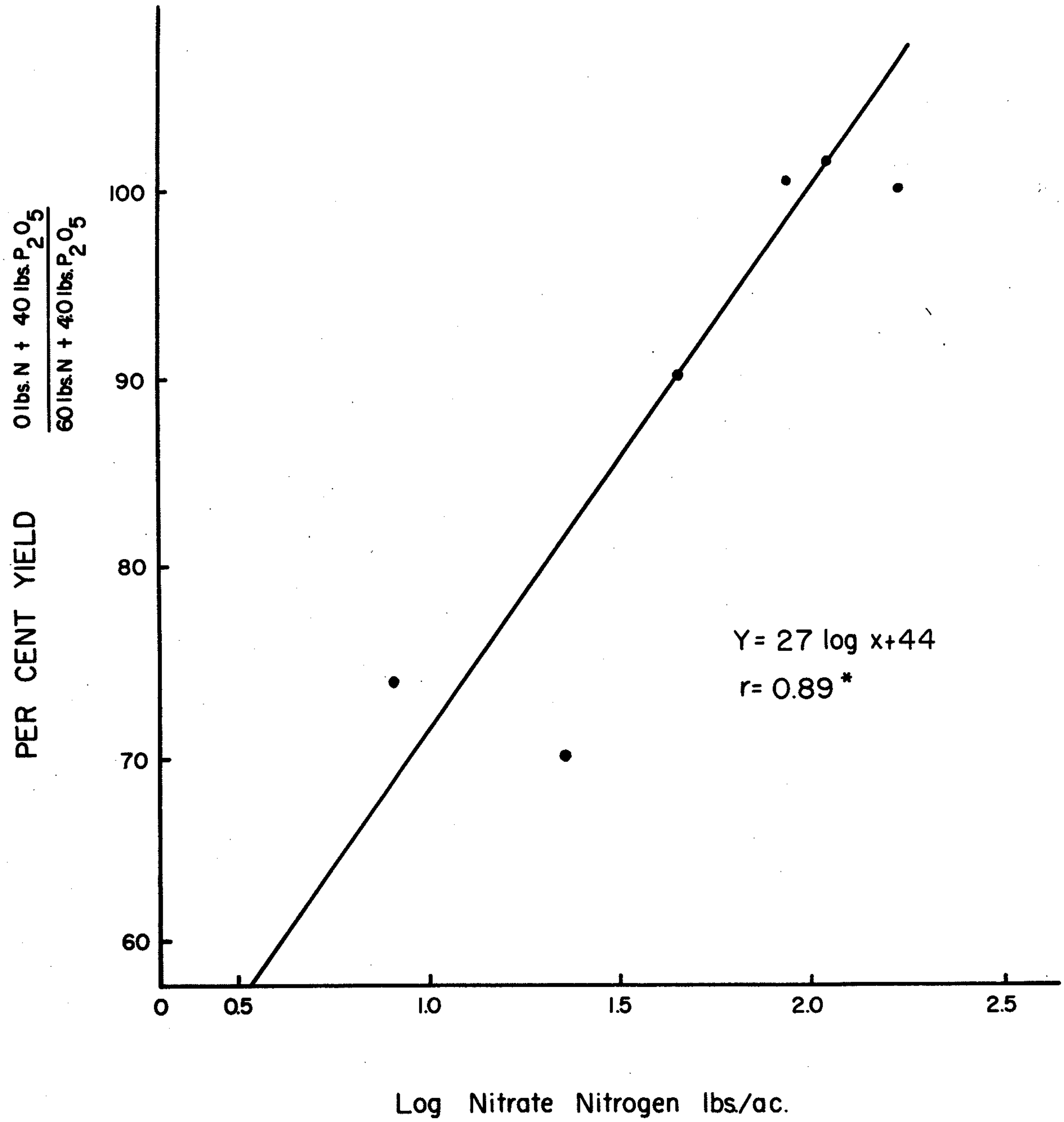

FIGURE VI Relationship between per cent yield and accumulated nitrate nitrogen in the 0 - 48 inch depth of fallowed soils and previously cropped soils.

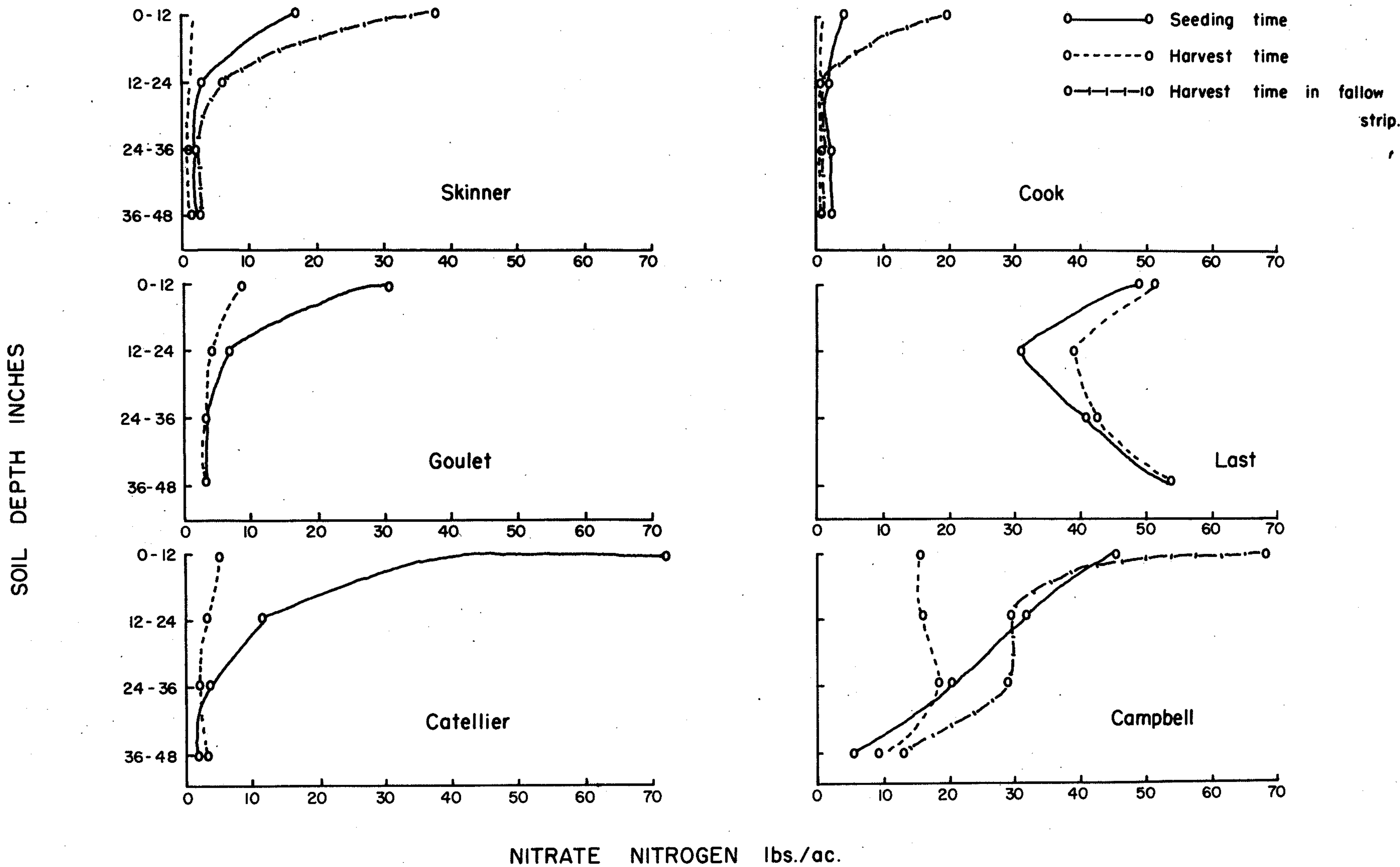

FIGURE VII The distribution and amount of nitrate nitrogen in the soil profile at seeding time and hdrvest time, 1961.

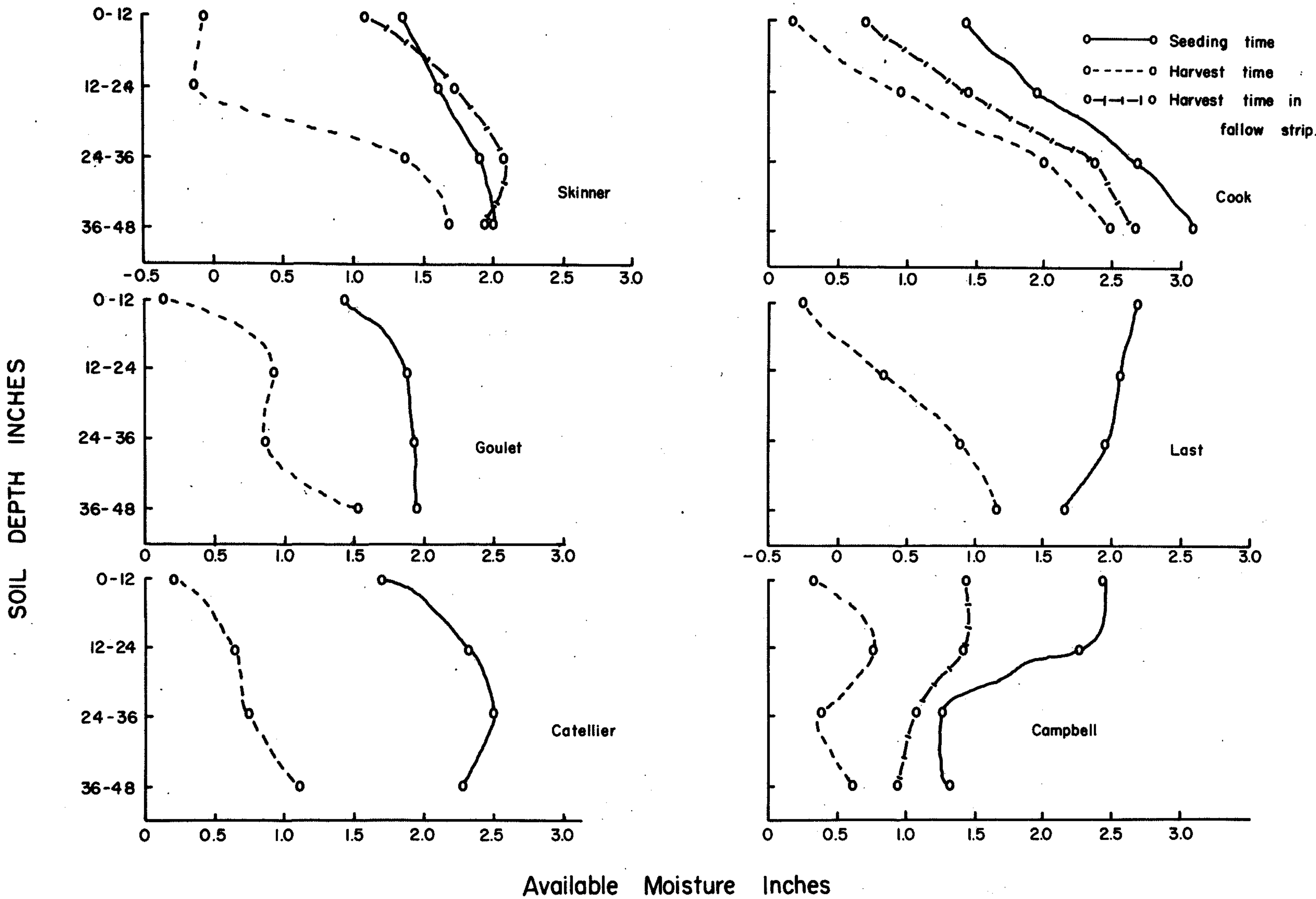

FIGURE VIII The distribution and amount of available moisture in the soil profile at seeding time and harvest time, 1961

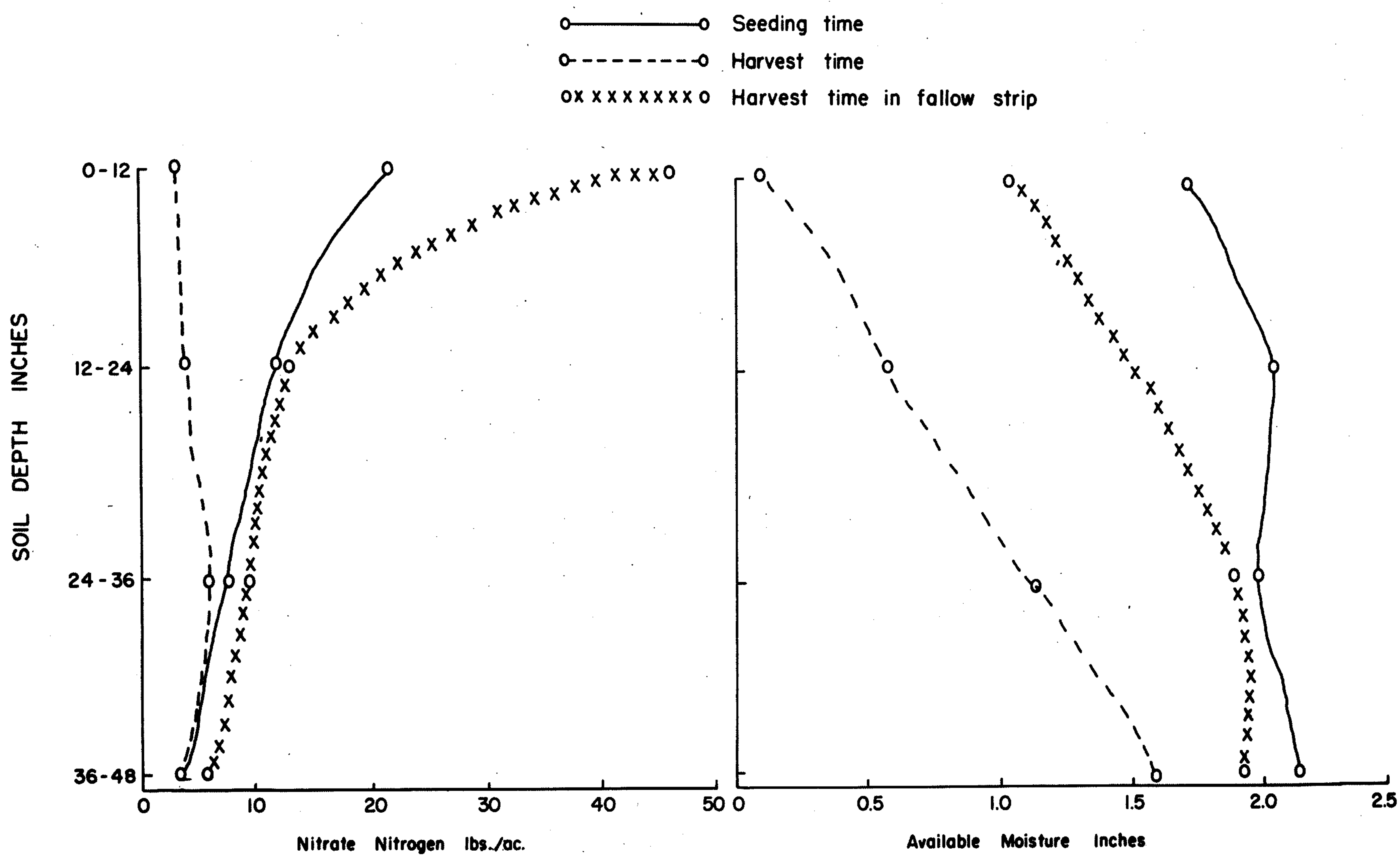

FIGURE IX The distribution of nitrate nitrogen and available moisture in the soil profile (average of the three stubble plots), 1961.

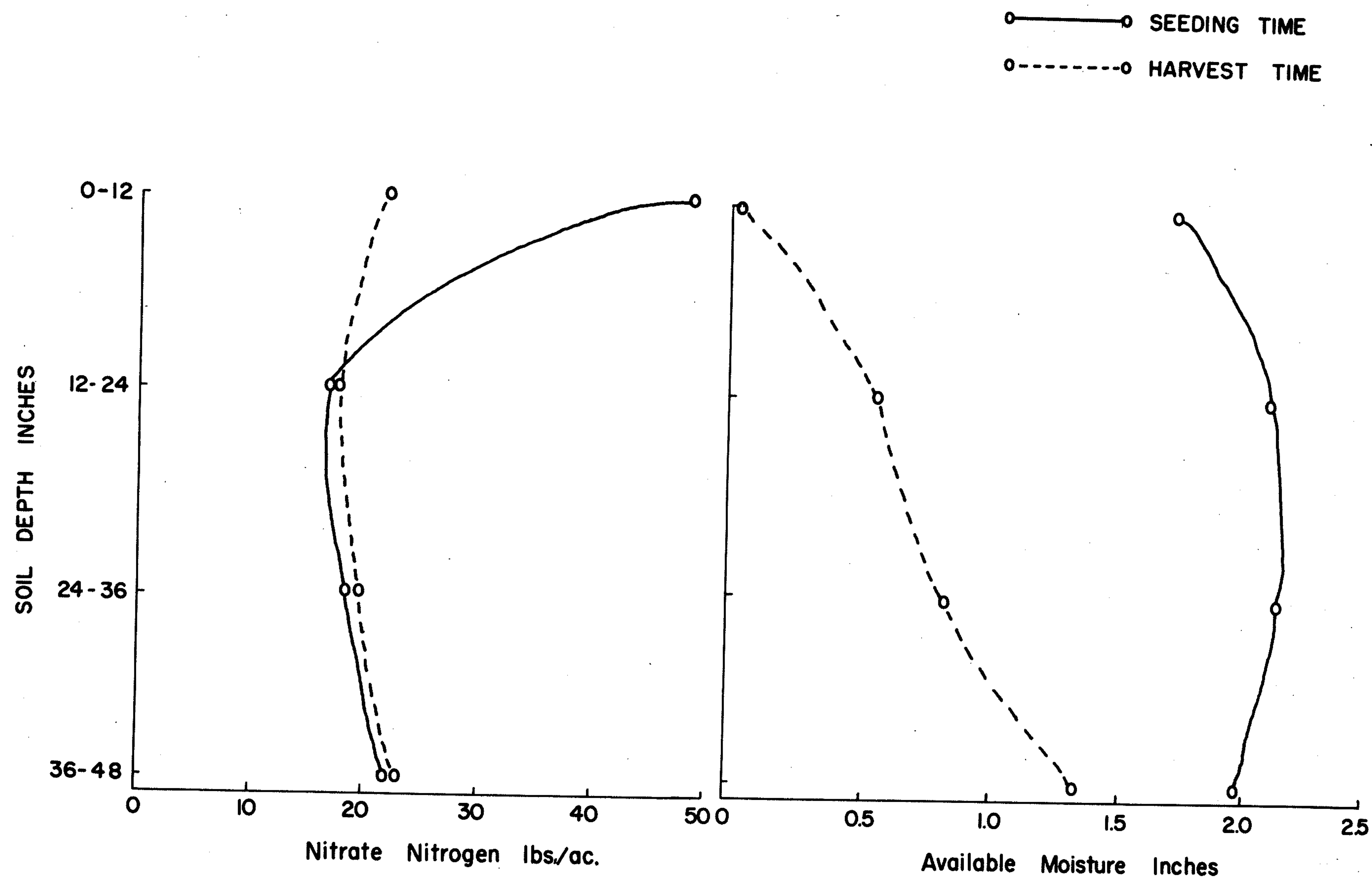

FIGURE X The distribution of nitrate nitrogen and available moisture in the soil profile (average of the three summerfallow plots), 1961

GREENHOUSE EXPERIMENT

The results of the 1960 field experiment demonstrated that the accumulated nitrate nitrogen of the soil had a bearing on the response of barley to nitrogenous fertilizers. In order to further check this effect and to further investigate the relationships between crop growth and organic matter and nitrogen determined by various methods, a greenhouse experiment was carried out early in 1961.

A. Experimental Procedure

The nine soils used in this greenhouse experiment were obtained in the fall of 1960 from the farms on which the field experiment was conducted in 1960. The samples were taken from the 0-6 inch depth. These soils were analyzed for organic matter, permanganate oxidizable nitrogen, PAN, nitrifying power and nitrate nitrogen.

A randomized block design with four replications was used in this experiment. Two series of the nine air dried soils, that is 1.7 and 1.8 Kg., were placed in the six inch high glazed crocks.

The soils in the pots containing 1.8 Kg. of air dried soil were incubated at field capacity in the greenhouse for one month. The temperature of the greenhouse fluctuated from 75° to 88°F. The incubated soils were then removed from the pots and air dried and 100 grams of air dried soil was taken from each pot for the determination of nitrate nitrogen content. The rest of the soil was placed back in the pots.

The top two inches of soil was removed from each pot containing incubated or non-incubated soil. An amount of potassium biphosphate a rate of 40 pounds of P_2O_5 per acre was applied in solution to each crock. A half inch of the soil was replaced and eight pairs of oats seeds were planted. The rest of soil was placed back uniformly in the pots and then the soil was moistened to field capacity. The amount of water needed to bring the soil moisture to field capacity was measured by weighing.

Ten days after seeding, the smallest plant of each pair was removed. This left eight plants in each crock.

At the end of a 30-day growth period, the crops were harvested at ground level. They were then cut in small pieces and oven dried at 60°C for twelve hours and weighed. Analyses for nitrogen were carried out on the whole plant as previously described.

B. Results and Discussion

The results from the greenhouse experiment are summarized in Tables XV to XVIII.

Except for McDonald's and Barg's soils, the weight of plant tissue, the nitrogen taken up and the per cent nitrogen in plant tissue from the incubated soils were higher than those from the non-incubated soils. This was particularly evident in the case of the nitrogen uptake in plant tissue. These findings indicate the availability of the nitrogen mineralized during one month incubation in the greenhouse.

However, the difference between the weight of plant tissue from the incubated soil and that from the non-incubated soil was small. This may be partially explained by the assumption that the nitrate nitrogen at seeding time plus that mineralized during one month growth period might be enough to supply the nitrogen requirement for the growth of oats in one month under the greenhouse conditions and under the limitations of other factors in each soil that might exist.

Organic matter and nitrogen determined by various methods again appeared to be quite variable and their levels were similar to those shown in the 1960 field experimental results. There were no significant correlations between the nitrogen mineralized in one month in the greenhouse and amount of organic matter and amount of nitrate nitrogen before incubation. Permanganate oxidizable nitrogen only correlated with the nitrogen mineralized in the greenhouse at the 5 per cent level. However, the correlations between the nitrogen mineralized in the greenhouse and PAN and nitrifying power were both significant at the 1 per cent level, with "r" values of 0.87 and 0.89 respectively. This indicates that PAN and the nitrogen released during the incubation in the incubator and those released during the incubation in the greenhouse might come from the same source.

As shown in Table XVIII, excepting that there was no significant correlation between organic matter and nitrogen taken up from non-incubated soils, all of results obtained by various methods of estimating available soil nitrogen were correlated with weight of plant tissue and nitrogen uptake fairly well. However, these findings are not considered to be surprising, since oats were growing under favorable temperature and moisture conditions.

Nitrate nitrogen in the non-incubated soils at seeding time was correlated with the weight of plant tissue and the nitrogen uptake only at the 5 per cent level. This is explained by the fact that the amount of the nitrate nitrogen of the non-incubated soils was rather small. However, insofar as the incubated soils are concerned, the correlations between the nitrate nitrogen at seeding time and the weight of plant tissue and the nitrogen uptake were all significant at the 1 per cent level. This further supports the evidence of the availability of the nitrogen mineralized during one-month incubation in the greenhouse.

In view of Tables XV and XVI, it was found that in both cases of incubated and non-incubated soils, the amount of nitrogen taken up in plant tissue was considerably higher than that of nitrate nitrogen in 1.7 Kg. of soils at seeding time. This was particularly evident in the case of non-incubated soils. Therefore, the nitrogen mineralized during one-month growth period appeared to be quite considerable and available.

Furthermore, the logarithms of the amounts of nitrate nitrogen in the non-incubated soils at seeding time plus that mineralized during one-month incubation were significantly correlated with the weight of plant tissue and the nitrogen taken up from the non-incubated soils at the 1 per cent level, with "r" values of 0.88 and 0.94, respectively. Strictly speaking, there might be some difference between the amount of nitrogen mineralized during one month of incubation and that mineralized during one-month growth period under greenhouse conditions. However, the above-mentioned correlations indicate that there might be not much difference between those two mineralization amounts under greenhouse conditions. Moreover, these correlations further indicate that not only the nitrate nitrogen of the soils at seeding time was responsible for the growth of oats but also that mineralized during the growth period in the greenhouse did not seem to be negligible.

The results shown in Table XVIII also reveal that except for the nitrogen mineralized in the greenhouse, organic matter and nitrogen determined by various methods were better correlated with the nitrogen taken up from the incubated soils than with the nitrogen taken up from the non-incubated soils.

The results obtained from this greenhouse experiment imply that the amount of accumulated nitrate nitrogen in the soil profile of fallow soil at seeding time could be better correlated with the response of cereals to nitrogen than that of stubble soil. The results also imply that the nitrogen mineralized during growing season in field cannot be completely ignored.

TABLE XV Incluence of Incubation on Yield and Nitrogen Content of Oats Grown in the Greenhouse.

Soils	Weight of Plant Tissue g./pot		Nitrogen uptake in Plant tissue mg./pot		Per Cent Nitrogen in Plant Tissue	
	Non-incubated soils	Incubated soils	Non-incubated soils	Incubated soils	Non-incubated soils	Incubated Soils
McDonald	2.8	2.4	45	46	1.6	1.9
Dicks	2.2	2.5	29	40	1.3	1.6
Campbell	2.8	3.0	50	69	1.8	2.3
Barg	2.8	2.8	45	59	1.6	2.1
Yuill	4.0	4.8	60	86	1.5	1.8
Kroeker	3.6	3.7	68	85	1.9	2.3
Ferris	4.0	4.7	68	99	1.7	2.1
Stanger	3.5	4.0	63	88	1.8	2.2
Anderson	3.8	4.3	65	90	1.7	2.1

TABLE XVI Amount of Organic Matter and Amount of Nitrogen Determined by Various Methods.

GREENHOUSE EXPERIMENT

Soils	Organic Matter % (0-6 inch depth)	Permanganate Oxidizable Nitrogen p.p.m. (0-6 inch depth)	PAN p.p.m. (0-6 inch depth)	Nitrifying Power (NO_3-N) p.p.m. (0-6 inch depth)	Nitrogen Mineralized in Greenhouse (NO_3-N) p.p.m. (0-6 inch depth)	Nitrate Nitrogen before Incubation p.p.m. (0-6 inch depth)
McDonald	5.4	225	61	43	15	5
Dicks	6.0	228	50	64	12	5
Campbell	8.0	267	77	87	25	12
Barg	5.4	250	91	70	24	6
Yuill	8.8	337	105	90	22	14
Kroeker	6.5	299	108	109	37	7
Ferris	8.6	334	120	98	29	19
Stanger	6.2	260	82	88	23	17
Anderson	7.8	348	127	115	40	8

TABLE XVII Correlations of Results Obtained by Various Methods of Estimating Available Soil Nitrogen with Nitrogen Mineralized in One Month in the Greenhouse.

Method (0-6 inch depth)	Correlation Coefficient
Organic Matter	0.43
Permanganate Oxidizable Nitrogen	0.74 *
PAN	0.87 **
Nitrifying Power	0.89 **
Nitrate Nitrogen Before Incubation	0.16

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

TABLE XVIII Correlations of the Logarithm of Results Obtained by Various Methods of Estimating Available Soil Nitrogen with Weight of Plant Tissue and Nitrogen Uptake.

Method (0-6 inch depth)	Correlation Coefficient			
	Weight of Plant Tissue		Nitrogen Uptake	
	Non-incubated soils	Incubated soils	Non-incubated soils	Incubated Soils
Organic Matter	0.68 *	0.76 *	0.54 *	0.68 *
Permanganate Oxidizable Nitrogen	0.81 **	0.83 **	0.75 *	0.81 **
PAN	0.88 **	0.83 **	0.87 **	0.89 **
Nitrifying Power	0.74 *	0.76 *	0.75 *	0.85 **
Nitrogen mineralized in greenhouse	0.68 *	0.59 *	0.80 **	0.75 *
Nitrate nitrogen at seeding time	0.66 *	0.82 **	0.61 *	0.96 **

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

FINAL DISCUSSION

The 1960 and 1961 experimental results all indicate that the determination of organic matter of soils appeared to be of little value in predicting the response of cereals for the Manitoba soils tested. This finding is considered to be logical since the bulk of soil nitrogen is thought to be combined in organic substances that are highly resistant to decomposition (14, 52).

The determination of permanganate oxidizable nitrogen of soils showed some value for predicting nitrogen needs in the 1960 experiment. However, the utility of this method appeared to be questionable in the 1961 experiment. These results are supported by the report given by Kresge and Merkle (35). They stated that alkaline permanganate method was of questionable value in determining the nitrogenous fertilizer requirements. They further stated that nitrate delivery to a given crop depends, not only upon the presence of easily ammonifiable nitrogen in the soil, but also upon the soil conditions prevailing at the moment. Moreover, the work done by Munson and Stanford (42) and Tolton (65) also support this fact.

The determination of the accumulated nitrate nitrogen in the 0-48 inch depth, PAN and nitrifying power appeared to be promising in predicting nitrogen needs of cereals for the Manitoba soils tested in each of those two experiments conducted in 1960 and 1961. Particularly, the amount of the accumulated nitrate nitrogen in the 0-48 inch depth was the best index of all that were determined in predicting the response of cereals in yield to nitrogen fertilization. Moreover, the accumulated nitrate nitrogen in the soil profile as well as nitrogenous fertilizers applied appeared to have a bearing on nitrogen taken up and per cent protein in grain. The utility of the determination of PAN as a measure of the nitrogen supplying power of soils has been reported and claimed to be promising by Leo (39) at New Jersey in 1961. With respect to the measurement of nitrifying power, its validity has been investigated and suggested by several investigators (15, 17, 26, 56, 57) as a means of predicting the needs of nitrogenous fertilizers. However, a good evaluation of their respective merits cannot be made, since the usefulness of the determination of PAN and nitrifying power in predicting the nitrogen fertilizer needs of soils under field conditions requires more field trials to confirm. Moreover, contradictory results have been found in the utility of the measurement of nitrifying power (4, 31, 35, 65).

The results obtained by various methods of estimating available soil nitrogen in the 1960 and the 1961 experiments were combined and correlated with the per cent yield and the nitrogen uptake obtained in the same two years. Because there was no 0-40 treatment in the 1960 field experiment, the yields from the 10-40 treatment and the 60-40 treatment were used in calculating the per cent yields for the two years in this final discussion. In the nitrogen uptake correlation, the grain from the 10-40 treatment in the 1960 experiment and that from the 0-40 treatment in the 1961 experiment were used, thus the 10 pounds of nitrogen applied as fertilizer was combined with the accumulated nitrate nitrogen in the 0-48 inch depth at seeding time in the 1960 experiment. As is shown in Table XIX, there was no significant correlation between organic matter, permanganate oxidizable nitrogen, PAN, nitrifying power and the per cent yield or the nitrogen taken up in the grain. While the accumulated nitrate nitrogen in the 0-48 inch depth was significantly correlated with both the per cent yield and the nitrogen taken up in the grain at the 1 per cent level. The relationship between per cent yield and accumulated nitrate nitrogen in the 0-48 inch depth of the soils tested in the two years is shown in Figure XI.

The levels of organic matter, permanganate oxidizable nitrogen, PAN and nitrifying power for predicting the response of cereals to nitrogen, obtained in the 1961 experiment were considerably lower than those obtained in the 1960 experiment. Therefore, though PAN and nitrifying power appeared to be promising for predicting the nitrogen needs in the 1960 experiment, the values obtained in the 1960 experiment were not applicable to the prediction of the response of oats and wheat to nitrogen in the 1961 experiment. While the level of accumulated nitrate nitrogen in the 0-48 inch depth, for this prediction purpose, obtained in the 1960 experiment was fairly accurately applicable to the prediction of the response of oats and wheat to nitrogen in the 1961 experiment.

Except for the determination of organic matter for predicting nitrogen needs of cereals, all methods used in the 1960 experiment appeared to be fairly good. In the 1961 experiment, all of the methods used were of more questionable value. When the results of the two years were put together, except for the determination of the accumulated nitrate nitrogen in the 0-48 inch depth, all methods used did not seem too promising for predicting nitrogen needs of cereals in Manitoba.

Furthermore, from theoretical consideration, there are many sources of nitrogen available for the growth of crops in soils. These include mineralization of organic nitrogen, nitrogenous fertilizers applied and rainfall. Therefore, the actual nitrogen-supplying power of the soil under field condition and the productivity of the soil would not likely be evaluated accurately by the soil test methods advocated so far, since the amount of organic matter and the amount of nitrogen determined by various methods do not reflect the total soil nitrogen available for the crop. Even the biological incubation method that has been used most widely is artificial since this method only indicates the mineralization rate of organic nitrogen in a certain period in an incubator. Moreover, when the soil sample is taken and removed to the laboratory for incubation study, most of the factors affecting the mineralization rate in the field, as described by Andharia et al. (4) are controlled or held constant. It was reported by Fitts et al. (26) that by first air drying the sample and then imposing optimum conditions of incubation in the laboratory, it is possible to produce as much nitrate in 2 or 3 weeks as might be produced in 1 or 2 months in the field. They further stated that soils which produce only small amounts of nitrate nitrogen under optimum conditions in the laboratory are not likely to produce much under field conditions. Nevertheless, it might be reasonable to say that soils which produce high amounts of nitrate nitrogen under optimum condition in the laboratory might not have a high mineralization rate of nitrogen under field conditions, since laboratory conditions are much more optimum for mineralization than field conditions. Of course, the accumulated nitrate nitrogen in the profile at seeding time might not reflect the total available soil nitrogen during growing season, since mineralization during the growing season appeared to be considerable. There is, however, no evidence to suggest that the rate of mineralization of nitrogen did not closely parallel the amount of nitrate nitrogen in the profile at seeding time.

It is evident from the results of this investigation that only the determination of the accumulated nitrate nitrogen in the profile at seeding time had any real value for predicting nitrogen needs of cereals for the Manitoba soils tested for the two years. On considering uncontrollable and unpredictable variations in the weather conditions, this method is considered to have a real value. Moreover, in case the culture practice is unknown, this method could be very useful.

The results of the two years all showed that the deeper the soils were sampled the higher the correlation between per cent yield and the logarithm of the amount of the accumulated nitrate nitrogen was. The amounts of accumulated nitrate nitrogen in the 0-6, 0-12, 0-24, 0-36 and 0-48 inch depth determined in the 1960 and the 1961 experiments were combined and correlated with per cent yields and the nitrogen uptake obtained in the same two years. In the nitrogen uptake correlation, the grain from the 10-40 treatment in the 1960 experiment and that from the 0-40 treatment in the 1961 experiment were used and thus 10 pounds of nitrogen added as fertilizer at seeding time was combined with the accumulated nitrate nitrogen in each depth of the profile determined at seeding time in the 1960 experiment. The correlations between per cent yield and the accumulated nitrate nitrogen in the 0-6, 0-12, 0-24, 0-36 and 0-48 inch depths were all significant at the 1 per cent level with "r" values of 0.69, 0.69, 0.66, 0.67 and 0.67, respectively. These correlations indicate that the amount of accumulated nitrate nitrogen in each soil depth determined was almost equally good as an index for predicting the response of cereals to nitrogen. However, the correlations between the nitrogen taken up in the grain and the accumulated nitrate nitrogen in the 0-6, 0-12, and 0-24 inch depths were only significant at the 5 per cent level with "r" values of 0.57, 0.59 and 0.61, respectively. While the accumulated nitrate nitrogen in the 0-36 and the 0-48 inch depths was significantly correlated with the nitrogen taken up in the grain at the 1 per cent level with "r" values of 0.65 and 0.67, respectively. So, in the case of nitrogen uptake, the deeper the soil was sampled, the higher the correlation was. Moreover, the depth of soil that should be sampled might vary considerably with soil texture and climatic conditions. On this account, it is difficult to conclude how deep the soil should be sampled. However, it is considered to be safe to conclude that sampling to the 0-48 inch depth should be sufficient for predicting nitrogen needs of cereals for the soils tested.

The relationships between the response of cereals to nitrogenous fertilizers and the nitrate nitrogen in each soil depth determined at seeding time for the two years are expressed in the following equations, where Y represents per cent yield and X accumulated nitrate nitrogen in pounds per acre.

(A) 0-6 inch depth
$Y = 41 \log X + 37$
When $Y = 100$ — $X = 34$
When $Y = 90$ — $X = 19$

(B) 0-12 inch depth
$Y = 41 \log X + 29$
When $Y = 100$ — $X = 53$
When $Y = 90$ — $X = 30$

(C) 0-24 inch depth
$Y = 38 \log X + 26$
When $Y = 100$ — $X = 86$
When $Y = 90$ — $X = 47$

(D) 0-36 inch depth
$Y = 36 \log X + 26$
When $Y = 100$ — $X = 118$
When $Y = 90$ — $X = 62$

(E) 0-48 inch depth
$Y = 34 \log X + 26$
When $Y = 100$ — $X = 154$
When $Y = 90$ — $X = 78$

The equations show that when the accumulated nitrate nitrogen of the 0-6, 0-12, 0-24, 0-36, and 0-48 inch depths was 34, 53, 86, 118, and 154 pounds per acre respectively, the per cent yield was 100, that is, there would be no response to nitrogen. When the accumulated nitrate nitrogen of the 0-6, 0-12, 0-24, 0-36 and 0-48 inch depths was 19, 30, 47, 62 and 78 pounds per acre, respectively, the per cent yield was 90. These values are higher than those obtained in the 1960 and the 1961 experiments and this is particularly true in the values which give 100 per cent yield, Insofar as the 0-48 inch depth is concerned, the amount of accumulated nitrate nitrogen which gave 90 per cent yield in the 1960 and the 1961 experiments was approximately 70 and 50 pounds per acre respectively. However, since the regression equation representing the long term experimental results should be used as a means of prediction, the regression equation representing the two years results has to be used for the time being. From the standpoint of economics, it is considered that if the accumulated nitrate nitrogen of the 0-48 inch depth is over 80 pounds per acre, nitrogen fertilization is not necessary for cereals in Manitoba.

Finally, it is suggested that further investigation is required, since two years results are not enough for this prediction purpose and the reliability of the results might be affected to a certain extent by seasonal factors, different culture practices, and different crops used in this investigation.

TABLE XIX Correlations of the Logarithm of Results Obtained by Various Methods of Estimating Available Soil Nitrogen with Per Cent Yield and Nitrogen Uptake in Grain, 1960-1961.

Method		Correlation Coefficient Per Cent Yield	Nitrogen Uptake in Grain
Organic Matter	(0-6 inch depth)	0.17	0.22
Permanganate oxidizable nitrogen	(0-6 inch depth)	0.32	0.26
PAN	(0-6 inch depth)	0.06	0.27
Nitrifying power	(0-6 inch depth)	0.33	0.32
Nitrate nitrogen	(0-48 inch depth)	0.67 **	0.67 **

** Significant at the 1 per cent level

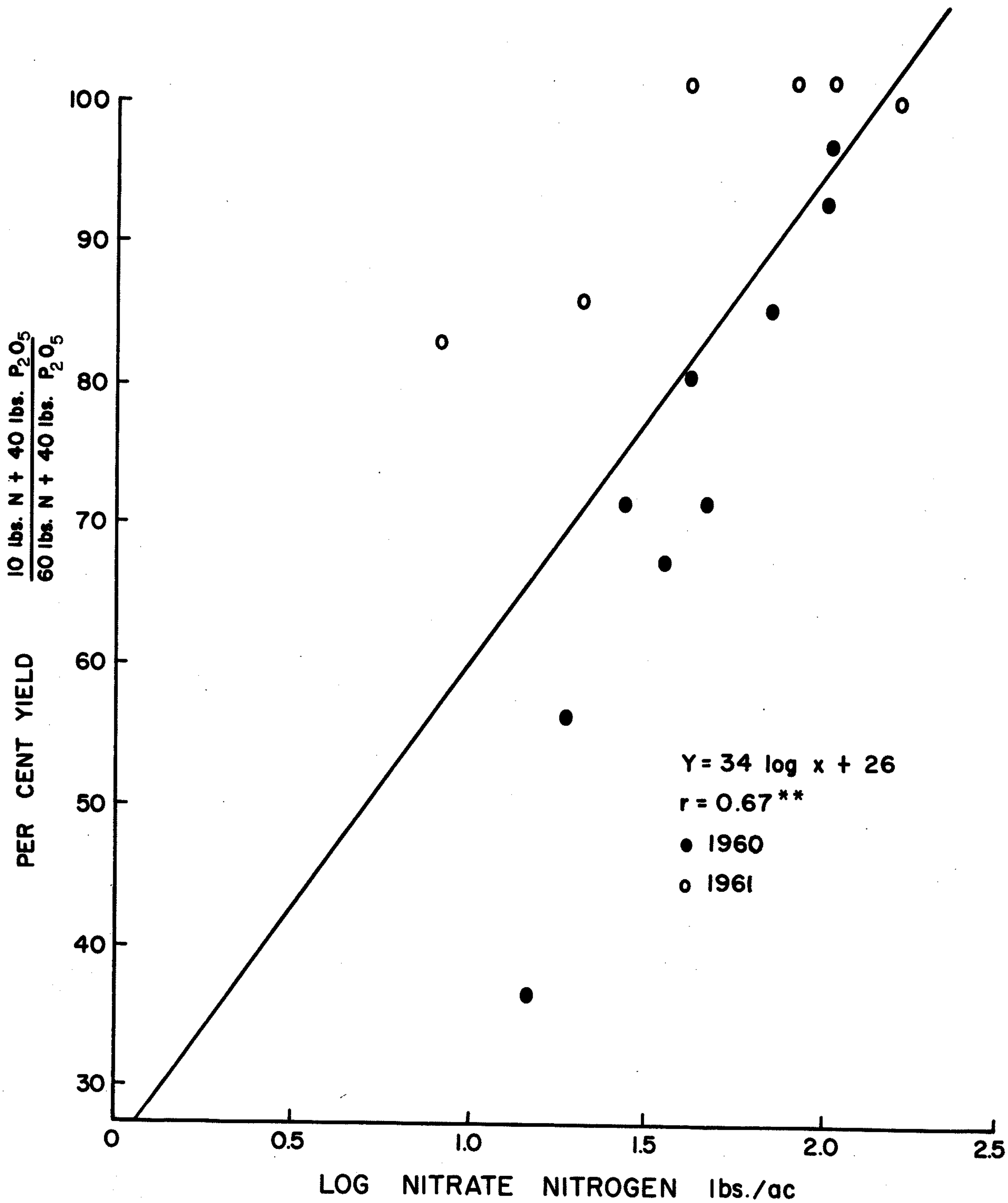

FIGURE XI Relationship between per cent yield and accumulated nitrate nitrogen in the 0-48 inch depth of fallowed soils and previously cropped soils.

SUMMARY AND CONCLUSIONS

This investigation was initiated to study the utility of the determination of the accumulated nitrate nitrogen in the soil profile to a depth of four feet at seeding time as a basis for predicting the nitrogen requirements of cereals in Manitoba. Other soil test methods that have been advocated and claimed to be promising were also investigated. The results were obtained from soils of varying profile type, texture, PH, lime and organic matter content.

In 1960, nine fertilizer trials on stubble land were laid out using barley as the test crop. In 1961, thirteen fertilizer trials on stubble and fallow land were laid out using oats and wheat as the test crops, however, seven plots were lost and the experimental results were adversely affected due to the unusual severe drought conditions prevailing during the growing season. A greenhouse experiment was carried out early in 1961 using oats as the test crop.

The conclusions are:

(1) The accumulated nitrate nitrogen in the soil profile to a depth of four feet at seeding time varied extremely from soil to soil and seemed to be as available as the nitrogen added as fertilizer at seeding time.

(2) The determinations of accumulated nitrate nitrogen in the soil profile, PAN and nitrifying power appeared to be promising for predicting nitrogen needs of cereals for the soils tested in each of the two years. This was particularly true of the determination of accumulated nitrate nitrogen in the 0-48 inch depth.

(3) The determination of permanganate oxidizable nitrogen did not appear to be as promising as the determinations of accumulated nitrate

nitrogen, PAN and nitrifying power for predicting nitrogen needs of cereals for the soils tested in each of the two years; while the determination of organic matter was of little value insofar as the soils tested are concerned.

(4) When the results of the two years were put together, only the determination of accumulated nitrate nitrogen in the profile at seeding time appeared to have any real value for predicting nitrogen needs of cereals for the soils tested in Manitoba. The utility of the other methods was of questionable value.

(5) It is considered that nitrogen fertilization is not necessary for cereals, if the accumulated nitrate nitrogen of the 0-48 inch depth at seeding time is over 80 pounds per acre.

(6) Both the mineralization of nitrogen during the growing season in the fields and that during one-month growing period in the greenhouse seemed tobbe considerable.

(7) The loss of accumulated nitrate nitrogen due to leaching during the growing season seemed to be small.

(8) The accumulated nitrate nitrogen in the soil profile as well as nitrogenous fertilizers applied at seeding time appeared to have a bearing on nitrogen taken up and per cent protein in grain.

(9) There was evidence that the cereals employed in the 1960 investigation removed accumulated nitrate nitrogen and moisture from the depth of 36-48 inch.

(10) In the 1960 experiment, it was found that there was not much difference between heading stage and harvest time insofar as the accumulated nitrate nitrogen and the available moisture in the 0-48 inch depth are concerned.

(11) In the 1960 experiment, it was shown that the protein content in grain of Canadian 6-Row barley in the 10-40 treatment did not exceed the upper limit of protein content for brewing purposes, when the total amount of the accumulated nitrate nitrogen in the 0-48 inch depth of the soils tested plus 10 pounds of nitrogen added as fertilizer at seeding time was below 70 pounds per acre.

(12) PAN and nitrifying power of the soils tested were similar in magnitude and highly correlated with each other.

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APPENDIX I The Amount of Nitrate Nitrogen in the Soil Profile at Seeding Time, 1960.

Soil Depth Inches	Nitrate Nitrogen lb./ac. McDonald	Dicks	Campbell	Barg	Yuill	Kroeker	Ferris	Stanger	Anderson	Average
0-6	5	7	10	9	8	11	12	9	17	10
6-12	2	5	6	7	7	9	8	9	10	7
12-24	3	4	14	7	13	10	14	18	14	11
24-36	3	1	4	3	12	8	20	29	27	12
36-48	2	2	4	3	8	5	18	37	36	13
Total	15	19	38	29	48	43	72	102	104	52

APPENDIX II The Amount of Nitrate Nitrogen in the Soil Profile at Heading Stage, 1960.

Soil Depth	Nitrate Nitrogen lb./ac.									
Inches	McDonald	Dicks	Campbell	Barg	Yuill	Kroeker	Ferris	Stanger	Anderson	Average
0-6	1	6	4	1	6	3	3	3	1	3
6-12	1	2	3	2	3	2	2	3	0	2
12-24	2	1	10	2	3	4	4	10	2	4
24-36	2	3	1	1	3	4	8	13	14	5
36-48	2	2	0	1	4	2	13	20	36	9
Total	8	14	18	7	19	15	30	49	53	23

APPENDIX III The Amount of Nitrate Nitrogen in the Soil Profile at Harvest Time, 1960.

Soil Depth	Nitrate Nitrogen lb./ac.									
Inches	McDonald	Dicks	Campbell	Barg	Yuill	Kroeker	Ferris	Stanger,	Anderson	Average
0-6	1	2	1	1	2	2	1	1	3	2
6-12	1	2	2	1	1	2	1	4	2	2
12-24	1	2	2	2	1	2	5	18	6	4
24-36	1	1	2	2	2	2	3	24	8	5
36-48	1	1	2	2	2	2	3	25	32	8
Total	5	8	9	8	8	10	13	72	51	21

APPENDIX IV The Amount of Available Moisture in the Soil Profile at Seeding Time, 1960.

Soil Depth	Available Moisture Inches									
Inches	McDonald	Dicks	Campbell	Barg	Yuill	Kroeker	Ferris	Stanger	Anderson	Average
0-6	0.99	1.13	0.68	0.67	1.47	1.00	1.43	1.01	0.85	1.03
6-12	1.06	0.92	0.72	0.62	1.77	1.21	1.72	1.13	0.71	1.09
12-24	1.81	2.15	1.71	0.83	2.47	1.68	2.79	2.17	1.19	1.87
24-36	2.24	1.73	1.21	1.12	3.30	1.65	2.85	3.01	1.02	2.01
36-48	2.62	1.79	1.31	1.73	2.77	1.39	2.11	3.14	1.13	2.00
Total	8.72	7.72	5.63	4.97	11.78	6.93	10.90	10.46	4.90	8.00

APPENDIX V The Amount of Available Moisture in the Soil Profile at Heading Stage, 1960.

Soil Depth	Available Moisture Inches									
Inches	McDonald	Dicks	Campbell	Barg	Yuill	Kroeker	Ferris	Stanger	Anderson	Average
0-6	0.38	0.45	0.16	-0.28	0.33	0.20	0.48	0.28	-0.24	0.20
6-12	0.48	0.20	0.43	-0.22	0.32	0.24	0.28	0.42	-0.33	0.20
12-24	1.06	1.78	1.07	-0.38	0.40	0.75	0.69	0.94	-0.48	0.65
24-36	1.60	1.89	1.04	0.07	1.07	0.35	1.36	0.98	0.16	0.95
36-48	2.33	2.11	1.20	1.33	1.64	0.95	1.92	1.42	0.53	1.50
Total	5.85	6.43	3.90	1.92	3.76	2.49	4.73	4.04	-0.36	3.50

APPENDIX VI The Amount of Available Moisture in the Soil Profile at Harvest Time, 1960.

Soil Depth Inches	Available Moisture Inches									
	McDonald	Dicks	Campbell	Barg	Yuill	Kroeker	Ferris	Stanger	Anderson	Average
0-6	1.05	0.78	0.67	0.49	0.15	0.90	0.35	-0.27	0.48	0.51
6-12	1.18	0.80	0.93	0.45	0.17	0.93	0.23	0.07	0.34	0.55
12-24	1.74	1.74	1.20	0.80	0.34	0.75	1.43	0.59	-0.40	0.91
24-36	1.98	1.50	0.70	0.72	0.46	0.94	1.44	0.96	-0.14	0.95
36-48	2.50	1.88	0.99	1.30	1.32	0.56	2.53	1.16	0.30	1.39
Total	8.45	6.70	4.49	3.76	2.44	3.88	5.98	2.51	0.58	4.31

APPENDIX VII The Amount of Nitrate Nitrogen and Available Moisture in the Soil Profile of the Summer Fallow Area at Harvest Time, 1960.

Soil Depth	Nitrate Nitrogen lb./ac.				Available Moisture Inches			
Inches	Anderson	McDonald	Barg	Average	Anderson	McDonald	Barg	Average
0-6	23	6	15	15	0.60	1.07	0.76	0.81
6-12	27	8	13	16	0.48	1.12	0.92	0.77
12-24	22	15	20	19	0.75	1.92	1.37	1.35
24-36	18	11	12	14	0.86	2.26	1.19	1.44
36-48	32	3	7	14	0.83	2.44	1.98	1.75
Total	1122	43	67	78	3.52	8.81	6.02	6.12

APPENDIX VIII The Amount of Nitrate Nitrogen and Available Moisture in the Soil Profile at Seeding Time.

STUBBLE PLOTS, 1961

Soil Depth	Nitrate Nitrogen lb./ac.				Available Moisture Inches			
Inches	Campbell	Skinner	Cook	Average	Campbell	Skinner	Cook	Average
0-6	27	14	3	15	0.82	0.82	0.92	0.79
6-12	20	4	1	8	1.65	0.53	0.71	0.96
12-24	32	4	1	12	2.42	1.64	1.99	2.02
24-36	21	0	1	7	1.25	1.94	2.74	1.98
36-48	6	1	2	3	1.31	2.00	3.13	2.15
Total	106	23	8	45	7.45	6.93	9.29	7.90

APPENDIX IX The Amount of Nitrate Nitrogen and Available Moisture in the Soil Profile at Harvest Time.

STUBBLE PLOTS, 1961

Soil Depth	Nitrate Nitrogen lb./ac.				Available Moisture Inches			
Inches	Campbell	Skinner	Cook	Average	Campbell	Skinner	Cook	Average
0-6	5	1	1	2	-0.07	0.10	0.16	0.06
6-12	10	0	0	3	0.38	-0.21	-0.03	0.06
12-24	16	0	0	5	0.75	0.25	0.91	0.64
24-36	18	0	0	6	0.39	1.30	2.01	1.23
36-48	8	0	0	3	0.54	1.71	2.48	1.58
Total	57	1	1	19	1.99	3.15	5.53	3.57

APPENDIX X The Amount of Nitrate Nitrogen and Available Moisture in the Soil Profile of the Summer Fallow Strip at Harvest Time.

Summer Fallow Area in Stubble Plots, 1961.

Soil Depth	Nitrate Nitrogen lb./ac.				Available Moisture Inches			
Inches	Campbell	Skinner	Cook	Average	Campbell	Skinner	Cook	Average
0-6	43	22	19	28	0.48	0.72	0.53	0.58
6-12	27	17	12	19	0.97	0.42	0.17	0.52
12-24	28	6	5	13	1.46	1.69	1.44	1.53
24-36	28	1	0	10	1.11	2.10	2.40	1.87
36-48	14	1	0	5	0.96	1.90	2.71	1.86
Total	140	47	36	75	4.98	6.83	7.25	6.36

APPENDIX XI The Amount of Nitrate Nitrogen and Available Moisture in the Soil Profile at Seeding Time.

FALLOW PLOTS, 1961.

Soil Depth	Nitrate Nitrogen lb./ac.				Available Moisture Inches			
Inches	Last	Catellier	Goulet	Average	Last	Catellier	Goulet	Average
0-6	29	57	24	37	0.95	0.49	0.72	0.72
6-12	15	14	6	12	1.20	1.22	0.70	1.04
12-24	30	10	7	16	2.06	2.31	1.83	2.07
24-36	41	5	4	17	1.96	2.51	1.85	2.11
36-48	54	4	3	20	1.67	2.25	1.92	1.95
Total	169	90	44	102	7.84	8.75	7.02	7.89

APPENDIX XII The Amount of Nitrate Nitrogen and Available Moisture in the Soil Profile at Harvest Time.

FALLOW PLOTS, 1961.

Soil Depth	Nitrate Nitrogen lb./ac.				Available Moisture Inches			
Inches	Last	Catellier	Goulet	Average	Last	Catellier	Goulet	Average
0-6	33	5	6	15	-0.28	-0.15	0.03	-0.13
6-12	20	5	4	7	0.06	0.29	0.06	0.14
12-24	38	8	4	17	0.23	0.66	0.95	0.61
24-36	48	4	4	19	0.79	0.72	0.93	0.81
36-48	54	6	3	21	1.15	1.15	1.58	1.29
Total	193	28	21	79	1.95	2.67	3.55	2.72