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

A THESIS

Submitted to the Faculty of Graduate Studies and Research

of the University of Manitoba

by

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In Partial Fulfillment of the Requirements for

the degree of

MASTER OF SCIENCE

July, 1962

ACKNOWLEDGEMENT

The writer wishes to express his indebtedness to Dr. R.J. Soper of the Department of Soil Science, The University of Manitoba, who suggested the problem and under whose supervision the investigation was conducted.

Acknowledgement is also made to Dr. R.A. Hedlin for helpful suggestion and criticism of the manuscript; to Dr. M.A. Zwarich, Mr. L.E. Pratt, Mr. G.J. Racz and Mr. G.S. Emmond for valuable advice and technical assistance.

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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 $10^{o}C$ 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 ½ 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