This is to certify that the

dissertation entitled

NITROGEN AVAILABILITY FOR SUGAR BEETS (Beta Vulgaris)
AS AFFECTED BY SOIL TYPE, CROPPING SYSTEM
AND NITROGEN RATE

presented by

MOHAMMAD BASHIR BUTT

has been accepted towards fulfillment
of the requirements for

Ph.D degree in CROP AND SOIL SCIENCE

Donald R. Christenson
Major professor

Date November 9, 1994

NITROGEN AVAILABILITY FOR SUGAR BEETS (*Beta Vulgaris*) AS AFFECTED BY SOIL TYPE, CROPPING SYSTEM AND NITROGEN RATE

By

Mohammad Bashir Butt

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Crop and Soil Science

1994

ABSTRACT

NITROGEN AVAILABILITY FOR SUGAR BEETS (*Beta Vulgaris*) AS AFFECTED BY SOIL TYPE, CROPPING SYSTEM AND N RATE

By

Mohammad Bashir Butt

Nitrogen supply for sugar beet production is important because of economic and environmental considerations. The objective of this research was to study the N availability for sugarbeet crop in Saginaw valley and Thumb region of Michigan. A series of experiments were conducted to study the effect of N fertilizer rate, cropping systems and soil type on sugar beet yield and quality. Effect of soil type, cropping system and sampling time on N mineralization potential (N_0) and associated rate constant (k) was evaluated in long term incubation experiments. The N_0 and k values were calculated using exponential and hyperbolic models by an iterative statistical procedure in a nonlinear regression program. The usefulness of several organic N availability indices for predicting N availability under various types of soils and cropping systems was evaluated by simple and multiple correlation and regression techniques.

In a 44 week incubation study, N_0 and k values varied both within and between soil series. This suggests that past management has a significant influence on mineralization potential. N_0 and k were affected by the amount of crop residue returned in the long term cropping systems study. Effect of sampling time on N mineralization was not clear due to the year to year variations of results. Both exponential and hyperbolic models were similar in predicting the reliable estimates of N_0 and k.

In fertilizer rate experiment yield response to applied N was significantly different for various types of soils and cropping systems. Percent sugar and juice purity showed a negative relationship with increasing amount of N.

Organic N measured by various procedures showed differences among the cropping systems and soils. However, the relationship between the organic N test and yield response did not allow for prediction of N fertilizer needs for sugar beet.

DEDICATED

To my mother, the most extraordinary blessing in my life

and

To the memories of my father who taught me the greatest values of life.

ACKNOWLEDGEMENTS

I am highly indebted to Almighty Allah, the most Merciful and Compassionate, the most Gracious and Beneficent, whose bounteous blessings enabled me to perceive and pursue higher ideals of life.

I wish to express my heart felt gratitude to my academic advisor, Dr. Donald R. Christenson Professor, Department of Crop and Soil Science for his valuable suggestions, inspiring and dexterous guidance, consistent encouragement and cooperation in completion of this manuscript. The financial and moral support he provided during the crisis with USAID is highly appreciated. I sincerely extend my thanks to Dr. Boyd Ellis, Dr. Darryl Warncke, Dr. James Crum and Dr. Irvin Widders for serving on my guidance committee, cooperation and critical evaluation of my work.

Sincere appreciation is extended to Calvin Bricker and Lee Siler for their help and cooperation in field and laboratory work. I would like to record my sincerest thanks to all my friends especially, Deliana Siregar , Gladis Zinati , Charles and Moacir for their help.

Appreciation is expressed to Michigan and Monitor Sugar Companies for their financial support. Gratitude is expressed to the Agronomic Staff of Sugar Companies for their assistance in conducting many of the field studies. The laboratory analysis conducted by the Companies is gratefully acknowledged.

I do not find words to offer my gratefulness to my loving mother, sister, brothers and in laws who stretched hands to achieve high goals of life.

Last, but not least my wife Faree and adorable daughter Nada deserve special thanks for their sacrifice and patience. Faree's help, encouragement and prayers enabled me to complete this manuscript.

TABLE OF CONTENTS

LIST OF TABLES.. vii

LIST OF FIGURES.. viii

CHAPTER I.
Introduction.. 1
List of References.. 5

CHAPTER II.
Review of Literature.. 7
List of References.. 27

CHAPTER III.
Nitrogen Mineralization As Affected By Cropping System .. 38
Material and Method.. 40
Results and Discussion.. 44
List of References.. 48

CHAPTER IV.
Nitrogen Mineralization Potential of Soils from Michigan's
Saginaw valley and Thumb Region.. 62
Materials and Methods.. 64
Results and Discussion.. 67
List of References.. 72

CHAPTER V.
Sugarbeet Yield And Quality As Affected By N Fertilizer,
Soil Type and Cropping System.. 87
Materials and Methods.. 89
Results and Discussion.. 91
List of References.. 97

CHAPTER VI.

Soil Analysis and Prediction of prediction of response to applied nitrogen 111
Materials and Methods........ 113
Results and Discussion........ 118
List of References........ 124

SUMMARY........ 132

LIST OF TABLES

CHAPTER III

Table 1. Total N and oxidizable C concentrations in soils from the cropping system study, 1992 and 1993 52

Table 2. Effect of cropping system and sampling date on N mineralization potential (N_0) rate constant (k) and active N fraction for exponential and hyperbolic models for samples taken in 1992 on Misteguay silty clay soil 53

Table 3. Effect of cropping system and sampling date on N mineralization potential (N_0) rate constant(k)and active N fraction for exponential and hyperbolic models for samples taken in 1993 on Misteguay silty clay soil 54

Table 4. Comparison of the instantaneous rate of reaction for the exponential and hyperbolic models at various incubation periods using linear regression on soil samples taken at two dates in 1992 from cropping systems study on a Misteguay silty clay soil 55

Table 5. Comparison of the instantaneous rate of reaction for the exponential and hyperbolic models at various incubation periods using linear regression on soil samples taken at two dates in 1993 from cropping systems study on a Misteguay silty clay soil 57

CHAPTER IV.

Table 1. Soil series, sub-order, total N, oxidizable C, particle size analysis and previous crop for soils used in the incubation study 75

Table 2. N mineralization potential (N_0), rate constant (k) and active N fraction for soils from the Saginaw Valley and Thumb region of Michigan 76

Table 3. Comparison of the instantaneous rate of reaction for the exponential and hyperbolic models at various incubation periods using linear regression on soil samples taken from N studies on 23 sites from 1991 through 1993 representing soil series in the Saginaw Valley and Thumb region of Michigan.. 77

CHAPTER V.

Table 1. Soil series, sub-order and cropping history of soils used in N fertilizer rate experiments.. 100

Table 2. Recoverable sugar as affected by N rate and cropping system for sugarbeet grown on Misteguay silty clay soil in 1992....... 101

Table 3. Recoverable sugar as affected by N rate and cropping system for sugarbeet grown on Misteguay silty clay soil in 1993....... 101

Table 4. Effect of N rate and cropping system on sugarbeet yield grown on a Misteguay silty clay soil in 1992.......................... 102

Table 5. Effect of N rate and cropping system on sugarbeet yield grown on a Misteguay silty clay soil in 1993.......................... 102

Table 6. Monthly rainfall and growing degree days at the Saginaw Valley Bean and Beet Research Farm for 1992 and 1993....... 103

Table 7. Percent sugar as affected by N rate and cropping system for sugarbeet grown on a Misteguay silty clay soil in 1992.......... 104

Table 8. Percent sugar as affected by N rate and cropping system for sugarbeet grown on a Misteguay silty clay soil in 1993.......... 104

Table 9. Clear juice purity as affected by N rate and cropping system for sugar beet grown on a Misteguay silty clay soil in 1992... 105

Table 10. Clear juice purity as affected by N rate and cropping system for sugar beet grown on a Misteguay silty clay soil in 1992... 105

Table 11. Effect of N rate on recoverable white sugar for sugarbeets grown at 13 locations from 1991-1993................................ 106

Table 12. Sugarbeet yield as affected by N rate grown at 13 locations from 1991-1993.. 107

Table 13. Effect of N rate on percent N in leaves for sugarbeets grown at 13 locations from 1991-1993 108

Table 14. Effect of N rate on percent sugar in sugarbeet grown at 13 locations from 1991-1993 109

Table 15. Effect of N rate on clear juice purity for sugarbeet grown at 13 locations from 1991-1993 110

CHAPTER VI

Table 1. Mineral N, organic N and Walkley Black carbon analysis for soil samples taken from the sugar beet cropping system on a Misteguay silty clay soil in 1992 and 1993 127

Table 2. Mineral N, organic N and Walkley Black carbon analysis for soil samples taken from various locations 128

Table 3. Linear correlation coefficients (r) among organic N analysis for samples noted in table 1 and 2 129

Table 4. Regression coefficient and associated coefficients of determination (R^2) for the Misteguay, Tappan, Parkhill and Kilmanagh series and for all soils combined relating response to applied N with mineral N and various organic N analysis... 130

LIST Of FIGURES

CHAPTER III.

Figure 1. Cumulative N mineralized for four cropping systems from a study on a Misteguay silty clay soil for samples taken May 1992.......... 58

Figure 2. Cumulative N mineralized for four cropping systems from a study on a Misteguay silty clay soil for samples taken August 1992.......... 59

Figure 3. Cumulative N mineralized for five cropping systems from a study on a Misteguay silty clay soil for samples taken May 1993 60

Figure 4. Cumulative N mineralized for five cropping systems from a study on a Misteguay silty clay soil for samples taken May 1993 samples.......... 61

CHAPTER IV.

Figure 1. Cumulative N mineralized for 5 Tappan soils.......... 79

Figure 2. Cumulative N mineralized for 3 Londo soils.......... 80

Figure 3. Cumulative N mineralized for 4 Kilmanagh.......... 81

Figure 4. Cumulative N mineralized for 2 Shebeon soils.......... 82

Figure 5. Cumulative N mineralized for a Grindstone.......... 83

Figure 6. Cumulative N mineralized for 3 Parkhill soils.......... 84

Figure 7. Cumulative N mineralized for 3 Capac soils.......................... 85

Figure 8. Cumulative N mineralized for a Zilwaukee and a Sloan soil... 86

CHAPTER I

INTRODUCTION

Nitrogen is a major plant nutrient that influences crop growth, but excessive use can lead to pollution of the environment by leaching, volatilization and erosion. Since it is a costly input in many parts of the world it can influence net return to the producer.

Nitrogen fertilizer management for sugar beet production requires more precise information than other crops (Carter et al., 1975). Inadequate N availability can limit plant growth and yield, but excess N may reduce both sucrose percentage and recoverable sucrose (Hills and Ulrich, 1971).

The concerns of an environmentally safe, economically feasible and biologically utilizable N supply requires accurate prediction of the fertilizer N requirement of the crop. Efficient utilization of fertilizer N in crop production requires an accurate assessment of native soil N availability and the optimum requirements of the crop itself. The crop fertilizer requirement is a function of many factors. Among these are residual and mineralizable soil N and those elements of crop and soil management that influence the fraction of total N that is in a readily mineralizable form (Stanford and Smith, 1972; 1976).

Nitrogen is derived predominantly from fertilizer, biologically fixed N_2, and mineralization of organic N from crop residues and soil organic matter.

Surface soils commonly contain between 0.08 and 0.4 percent total N, almost entirely in the organic form (Bremner, 1965a). The uptake of N is predominantly in NH_4 and NO_3 forms. Organic N is made available to plants by microbial oxidation of soil organic matter through the processes of mineralization and nitrification. The microbial decomposition of organic matter and release of N is an important process in rendering N available for plant growth.

Residues from the previous crop are very important because of their contribution of N to the successive crop. Crop rotation and the quantity of residue returned to the soil influences soil organic matter and hence net mineralization and available N are affected. Several long term studies have demonstrated the beneficial effects of crop rotation on soil organic matter content and crop production (Odell et al., 1984; Johnston, 1986). Mineralization rate is also affected by other soil physical, chemical and biotic properties. Texture is known to be a very important factor affecting soil organic-matter content. It has been reported that losses of organic matter, potentially mineralizable N and the N active fraction were greater in coarse textured compared to fine texture soils (Campbell and Souster, 1982; Herlihy, 1979). However, Bremner (1965b) reported that total N increased as texture became finer.

An accurate estimate of available N in soils requires a reliable method for assessing N supplying power of soil. Soil incubation methods for N mineralization are commonly used for characterizing the soil parameter which determines N mineralization.

The mineralization process may be expressed by the model utilizing the first order exponential equation as proposed by Stanford and Smith (1972):

$$N = N_o [1- \exp(-kt)]$$

From incubation experiments, one obtains results of the mineralized N as a function of time (t) with the objective of estimation of the mineralizeable N (N_o) and the rate coefficient (*k*) which characterizes the soil and enables prediction of its N supplying power (Talpaz et al., 1981).

The N mineralization potential (N_o) and associated rate constant (*k*), first represented by Stanford and Smith (1972), have been widely used as means of determining the effects of various agriculture practices, such as N fertilization, tillage, crop rotation etc. and soil properties on soil fertility (Herlihy, 1979; Doran, 1980; Campbell and Souster, 1982; Carter and Rennie 1982; Chae and Tabatabai, 1985; Bonde and Rosswell, 1987; Campbell et al., 1991; Gharous et al. 1990). The use of N_o as an estimate of active fraction of soil organic nitrogen under various climatic conditions and management practices still needs to be assessed by repeated experimentation.

In view of these concerns, this study examined the effects of cropping system and soil type in Lake bed area of Michigan, on N status of soil and the N availability to sugar beets. Specific objectives of the study were:

1. Measure differences in the N status of soil under various cropping systems after long term cropping practices by measuring different fractions of N in the soil.

2. Evaluate effects of cropping systems on N availability for sugar beet by various N availability indices.

3. Determine if one or more of the N availability indices correlate with the N supplying capacity of different soils and cropping systems.

4. Determine the effects of fertilizer N application on yield and quality of sugar beets in relation to N and organic matter status of soils under different soils and cropping systems.

5. Determine a quick soil analysis procedure that can be used to predict accurately, N requirements of sugar beet crop under various cropping systems.

LIST OF REFERENCES

Bonde, T.A. and T. Rosswall. 1987. Seasonal variation of potentially mineralizable nitrogen in four cropping systems. Soil Sci. Soc. Am. J. 51: 1508-1514.

Bremner, J.M. 1965a. Nitrogen availability indexes. *In* C.A. Black (ed.) Methods of soil analysis, part 2. Agronomy 9:1324-1345. Am. Soc. Agron., Madison, Wis.

Bremner, J.M. 1965b. Total nitrogen. *In* C.A. Black (ed.) Methods of soil analysis, part 2. Agronomy 9:1149-1378. Am. Soc. Agron., Madison, Wis.

Campbell, C.A. and W. Souster. 1982. Loss of organic matter and potentially mineralizable nitrogen from Saskatchewan soils due to cropping. Can. J. Soil Sci. 62:651-655.

Campbell, C.A., G.P. Lafond, A.J. Leyshon, R.P. Zentner, and H.H. Janzen. 1991. Effect of cropping practices on the initial potential rate of N mineralization in a thin Black Chernozem. Can. J. Soil Sci. 71: 43-53.

Carter J.N., D.T. Westermann, M.E. Jensen, and S.M. Bosma. 1975. Predicting N fertilizer needs for sugar beets from residual NO_3 and mineralizable nitrogen. J. Am. Soc. of Sugar Beet Tech. 18:232-244.

Carter, M.R. and D.A. Rennie. 1982. Changes in soil quality under zero tillage farming systems: Distribution of microbial biomass and mineralizable C and N potentials. Can. J. Soil Sci. 62:587-597.

Chae, Y.M. and M.A. Tabatabai. 1986. Mineralization of nitrogen in soils amended with organic wastes. J. Environ. Qual. 15:193-198.

Doran, J.W. 1980. Soil microbial and biochemical changes associated with reduced tillage. Soil Sci. Soc. Am. J. 44:765-771.

Gharous, R.L., R.L. Westerman, and P.N. Soltanpour. 1990. Nitrogen mineralization potential of arid and semiarid soils of Morocco. Soil Sci. Soc. Am. J. 54:438-443.

Herlihy, M. 1979. Nitrogen mineralization in soils of varying texture, moisture and organic matter. I. Potential and experimental values in fallow soils. Plant Soil 53:255-267.

Hills, F.J., and A. Ulrich. 1971. Nitrogen nutrition. pp.111-135. *In* R.T. Johnson et al. (eds.) Advances in sugar beet production: Principles and practices. The Iowa State University Press, Ames, Iowa.

Johnston, A.E. 1986. Soil organic matter effects on soils and crops. Soil Use Management. 2:97-105.

Odell, R.T., S.W. Melstead and W.M. Walker 1984. Changes of organic carbon and nitrogen of Morrow Plot soils under treatments, 1904-1973. Soil Sci. 137:160-171.

Stanford G. and S.J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. Proc. 36:465-472.

Stanford, G., and S.J. Smith. 1976. Estimating potentially mineralizable soil nitrogen from chemical index of soil nitrogen availability. Soil Sci 122: 71-76.

Talpaz, H., P. Fine, and B. Bar-Yasef. 1981. On the estimation of the N-mineralization parameters from incubation experiments. Soil Sci. Soc. Am. J. 45:993-996.

CHAPTER II

LITERATURE REVIEW

Nitrogen Availability Indices:

Nitrogen available for crops is derived from numerous sources; predominantly from fertilizer, biological N fixation and mineralization of organic N from wastes, crop residues and soil organic matter. Total N in the surface soils ranges from 0.08 TO 0.4% and if 1 to 3% of this N is mineralized in a growing season (Bremner, 1965a, 1965b) only 8 to 120 kg of N ha^{-1} may be available for crop utilization, which is not sufficient for most agronomic crops. Increasing needs of food by the growing world population led to extensive use of chemical fertilizers which may result in environmental contamination and at times low crop quality. Economic, environmental and crop quality problems associated with extensive fertilizer N use required a method that will provide a satisfactory index of soil-N availability and will permit reasonably accurate prediction of the fertilizer N requirements for crop production.

Many proposed biological and chemical methods have been considered in an effort to provide an index of soil N availability. In an extensive review, Bremner (1965b) discussed the advantages and disadvantages associated with these methods. Biological methods appear to be the most useful since N mineralization is biologically regulated. However, the methods are tedious, expensive and subject to variation due to sample pretreatment. Chemical methods are highly empirical, yet relatively inexpensive and less affected by sample pretreatment. The accuracy of any method is measured by the magnitude of the correlation coefficient between uptake of N in some vegetative test and laboratory results or correlation with previously established methods.

Biological Methods:

The most satisfactory methods currently available for assessing the potential ability of a soil to provide N for crop growth are those involving estimation of the mineral-N formed when soil is incubated under conditions which promote mineralization of soil-N. These methods are expected to give a fairly accurate index of the available N because in these methods micro-organisms are responsible for release of mineral N, just as they make organic soil-N available for crop growth during growing season. The validity of these methods have been confirmed by many researchers (Black et al., 1947; Pritchett et al., 1948; Allison and Sterling, 1949; White et al., 1949; Fitts et al., 1953; Andharia et al., 1953; Hanway and Dumenil, 1955; Munson and Stanford, 1955; Saunder et al., 1957; Cook et al., 1957; Eagle and Matthews, 1958; Pritchett et al., 1959; Synghal et al., 1959; Mackay et al., 1959, 1963; Olson et al., 1960; Clement and Williams, 1962; Gasser and Williams, 1963; Keeney and Bremner, 1967; Cornforth and Walmsley, 1971; Geist, 1977; Wilson et al., 1994a).

Two methods which showed the greatest potential for success are the aerobic method of Bremner (1965c) and the anaerobic method proposed by Waring and Bremner (1964). The anaerobic method consists of measuring the amount of NH_4-N mineralized after anaerobic incubation at 40 ^0C for 7 days. Keeney and Bremner (1966) established that N released by anaerobic incubation at 40 ^0C was better correlated with uptake of N by ryegrass than at 30 ^0C. Robinson (1967) modified the anaerobic method to allow for steam distillation of a filtered extract so as to prevent the alkaline hydrolysis of soil organic matter. Several investigators have since compared the correlation coefficients of these methods with uptake of N in the greenhouse and found correlation coefficient ranging from 0.57 to 0.93 (Hanway and Ozus, 1966; Kadirgamathoiyah and MacKenzie, 1970; Cornforth, 1968; Smith, 1966; Ryan et al., 1971; Gasser and Kalembasa, 1976; and Geist, 1977).

Smith and Stanford (1971) modified the method of Robinson (1967) by removing residual mineral N with 0.01 M $CaCl_2$ followed by incubation of the soil saturated with a minus N nutrient solution at 35 ^0C for 14 and 28 days. The NH_4 released was recovered by a series of centrifugation and washings. Correlation between results obtained after a 4 week incubation by the above method and the aerobic method was higher ($r = 0.93$) than the correlation obtained in 2 week incubations ($r = 0.86$). These results indicate that long term incubation is a better indication of potentially mineralizable N since results obtained in the first two weeks may be affected by the presence of recent crop residues of varying C/N ratio. Chickester et al. (1975) confirmed that the presence of crop residue with varying C/N ratios affect the degree of mineralization observed in short term incubation.

Anaerobic incubation has many advantages over aerobic incubation: i) only NH_4-N needs to be measured, ii) problems with water content are eliminated, iii) more N is measured in a given period and iv) a higher temperature can be used. This method has the disadvantage of requiring a considerable period of time and special incubation equipment and initial NO_3-N needs to be determined separately if this is to be utilized in fertilizer recommendations. Satisfactory correlation between N uptake and amount of N mineralized in an anaerobic incubation for 6 to 14 days at 30 to 40 °C has been shown in a large number of studies (Keeney and Bremner, 1966, 1967; Sims et al., 1967; Sims and Blackmon, 1967; Cornsforth and Walmsley, 1971; Ryan et al., 1971; Gasser and Kalembasa, 1976; Osborne and Storrier, 1976; Geist, 1977; Shumway and Atkinson, 1977;). Wilson et al. (1994b) compared anaerobic incubation for 7, 14 and 21 days with N uptake by rice crop in the greenhouse and found significant correlation. The 14 days incubation predicted total N uptake better (r^2 = 0.82) than 7 or 21 days incubation (r^2 = 0.71 and 0.65 respectively).

<u>Chemical Methods:</u>

A number of chemical methods have been used as indices of soil N availability and have been reviewed by Bremner (1965b), Jenkinson (1968), Dahnke and Vasey (1973), Campbell (1978) and Stanford (1982). The chemical indices have many advantages as well as disadvantages over biological methods. A major disadvantage of chemical methods is that they can not simulate microbial mineralization of N in the field. But, chemical methods are comparatively rapid, more convenient and generally more precise when compared to biological methods.

The use of chemical methods as N availability indices lies primarily in demonstrating a high degree of correlation with previously established methods or with uptake of N in the field or greenhouse. The chemical methods most commonly used includes measurement of total N, mineral N, organic matter or measuring the N released by extraction or treatment with various reagents.

One method which received major attention by researchers is hot-water or hot-salt extractable total N or NH_4-N. This test was first proposed by Livens (1959). A good correlation of this test with N uptake by ryegrass and with results of incubation procedures was reported by Keeney and Bremner (1966). Other investigators have also reported a strong correlation between hot water extractable N with other N indices or with greenhouse tests (Jenkinson, 1968; Robinson, 1968c; Verstraeten et al., 1970; Ryan et al., 1971; Lathwell et al., 1972; Gasser and Kalembasa, 1976; Osborne and Storrier 1976).

Stanford (1968) modified the hot water extraction method by extracting in 0.01 M $CaCl_2$ to provide a solution concentration similar to that occurring naturally in non-saline soils. The N released was determined either by the Kjeldahl method or by distillation with NaOH. Results obtained with both procedures were highly correlated. Stanford and co-workers further simplified this method by using the autoclave (Stanford and Demar, 1969) or the Conway microdiffusion technique (Smith and Stanford, 1971).

Stanford and Demar (1969) compared the autoclavable method with the anaerobic method of Waring and Bremner (1964) and obtained a correlation coefficient (r) of 0.94. Smith and Stanford (1971) reported that the correlation between NH_4 released upon autoclaving and N mineralized by the aerobic and anaerobic methods were different (r = 0.70 and 0.92, respectively). Smith et al. (1977) reported significant correlation of field estimates of N mineralization potential with autoclavable NH_4 (r = 0.86). Stanford and Smith (1976) evaluated the 16 hour autoclave-Conway microdiffusion method by comparing results of a large number of surface and subsurface samples with the N_0 value obtained by aerobic incubation. The chemical method was found highly related to N_0 (r = 0.92) on most soils except for a few highly calcareous soils. Fox and Piekielek (1978) also reported a significant relationship (r = 0.92) between autoclavable NH_4 and soil N supplying capacity.

Another method first proposed by Kresge and Merkle (1957) in which NH_4-N is released on distillation with alkaline $KMnO_4$ has also been used as a N availability index (Bremner, 1965b). Many researchers used this test and found a less satisfactory relationship of available N indices with this test when compared to other chemical tests (Jenkinson, 1968; Stanford and Legg, 1968; Cornforth and Walmsley, 1971; Osborne and Storrier, 1976; Stanford, 1978). Keeney and Bremner (1966) compared the NH_4-N released by alkaline $KMnO_4$ with N uptake by ryegrass and did not find a significant relationship. By contrast Stanford and Legg (1968) reported a relatively good correlation between this method and N uptake by oats grown in the green house.

Gianello and Bremner (1986), comparing the chemical methods of assessing potentially available organic N in soil, concluded that the alkaline $KMnO_4$ extraction was the least efficient of any of the 12 chemical methods they evaluated. The alkaline $KMnO_4$ extractable NH_4-N appears too variable and inconsistent to be a reliable indicator of seasonal N release from soil organic matter.

Stanford (1978) proposed an alternative to the alkaline $KMnO_4$ procedure by utilizing an acid environment. He concluded, the acidified $KMnO_4$ method was more precise than the alkaline $KMnO_4$ procedure. After comparing several combinations of $KMnO_4$ and H_2SO_4, Stanford and Smith (1978) proposed that a mixture of 0.05 M $KMnO_4$ and 0.5M H_2SO_4 provided the best indicator of potentially mineralizable N.

A comparison of NH_4 released with NaOH distillation was made with NH_4 released by the oxidant (measured as difference between NaOH and NaOH + $KMnO_4$) and it was found that the relationship of NH_4 to mineralizable N was similar with both procedures (Stanford 1978).

Sahrawat (1980) reported that acidified $K_2Cr_2O_7$-extractable NH_4-N was a good index of potentially available N based on correlations with N uptake by rice grown under greenhouse conditions. They also proposed a modification of the Walkley-Black procedure for determination of organic C (Walkley and Black, 1934) and potentially available N from the same sample (Sahrawat, 1982). In this procedure, the sample was analyzed for organic C as proposed by Walkley and Black except 0.5 M $FeSO_4 \cdot 7H_2O$ was used as the titrant. Afterwards, an aliquot was then distilled and the NH_4 liberated was used as an index of N availability.

Acid hydrolysis has also been used to estimate N availability by some researchers. Purvis and Leo (1961) used dilute H_2SO_4 to estimate potentially available N and obtained a good correlation (r = 0.97) when compared to N uptake by wheat, while several others have had little success (Keeney and Bremner, 1966; Prasad, 1965; Smith, 1966; Fox and Piekielek, 1978b).

Serna and Pomares (1992) evaluated four chemical methods (autoclave, 0.5 M $KMnO_4$, 6 M HCl and 0.01 M $NaHCO_3$) for the determination of N-availability indices and compared them with biological indices, i.e., plant N uptake and N mineralization during 16-week aerobic incubation. These results indicated that the autoclavable and HCl methods were more suitable for predicting N availability than the $KMnO_4$ and $NaHCO_3$ methods. They also concluded that prediction of soil N availability to plants improved if initial mineral N of soils and several chemical and biological methods were combined in a multiple regression analysis.

In Arkansas, studies were conducted recently to correlate chemical methods of estimating N mineralization with other laboratory indices (Wilson et al., 1994a) and with uptake in the greenhouse (Wilson et al., 1994b). Among the chemical methods tested, acidified $KMnO_4$ and acidified $K_2Cr_2O_7$ gave the best correlation with anaerobic incubation. A significant relationship between anaerobic incubation with HCl and oxalic acid extraction was also reported. In the second experiment, NH_4-N extracted with these four chemical methods was compared with the total N uptake by rice in the greenhouse. The best chemical index of N availability was oxidation with acidified $KMnO_4$ ($r^2 = 0.75$). Extraction with HCl and acidified $K_2Cr_2O_7$ were similar while oxalic acid extraction was least effective method.

N Mineralization Potential:

Environmental and economic concerns of N fertilization in agriculture production are the primary reasons that researchers look for a reliable method of estimating potentially mineralizable N in the soil. A number of soil availability indices have been proposed (discussed above) for determining the N-supplying abilities of soils. Most of these methods measure amounts of soil organic N mineralized in short term incubations or N extracted by various chemical reagents and provide estimates of relative rather than potential soil N supply (Harmsen and Kolenbrander, 1965; Spencer et al., 1966). These indices of soil organic N availability provide no measure of mineral N already present; e.g., residual N from previous fertilization or soil N actually mineralized between harvest and planting (Soper et al., 1971; Stanford and Legg, 1968).

In the 1970's, Stanford and co-workers (Stanford and Smith 1972, Stanford et al., 1973, Stanford and Smith, 1976, Stanford and Epstein, 1974) advanced the concept of potentially mineralizable N denoted as N_0 and a related mineralization rate constant (*k*) for use in characterizing soil available N.

Stanford and Smith (1972) suggested that the potentially mineralizable N (N_0) of a soil and its rate constant could be estimated by incubating the soil at optimum conditions and measuring the N mineralized and time of incubation. Nitrogen mineralization potential is defined as the amount of soil N that is susceptible to mineralization according to first order kinetics. N_0 is calculated from the first order equation:

$$-dn/dt = kN$$

Integrate from time 0 to t:

$$\ln N_t - \ln N_0 = -kt$$

Taking antilogarithms:

$$N_t = N_0 \exp(-kt)$$

The amount of inorganic N mineralized (N_{min}) is defined as the difference between the amount of mineralizable organic N at time 0 and at time t:

$$N_{min} = N_0 - N_t$$

or

$$N_{min} = N_0 - N_0 \exp(-kt) = N_0[1-\exp(-kt)]$$

The amount of mineralized N accumulated after various time periods are measured directly in laboratory incubation, and statistical techniques are used to estimate N_0 and k from the analytical data.

Since Stanford and Smith (1972) presented the concept of N_0 and k it has been used, modified and discussed in great detail by numerous researchers (Stanford et al., 1974, 1975, 1977; Smith et al., 1977; 1980; Oyanedel and Rodriguez, 1977; Campbell et al., 1981; Marion et al., 1981; Mackay and Carefoot 1981; Campbell and Souster, 1982; Griffin and Lain, 1983; Olness, 1983; Juma et al., 1984; Deans et al., 1986; Ellert and Bettany, 1988; Boyle and Paul 1989; Gharous et al., 1990; Soudi et al., 1990).

Stanford and Epstein (1974) studied the relationship between soil water and soil N mineralization. Results from nine soils with differing chemical and physical properties showed highest N mineralization rates between matric potential of -0.01 to -0.033 MPa. Water content higher or lower than this range decreased the N mineralization. Myers et al. (1982) studied the quantitative relationship between net N mineralization and moisture content of soils. Soil samples from 0-15 and 15-30 cm depths of five cultivated Queensland soils and 32 virgin and cultivated western Canadian soils were incubated at a range of moisture contents at 35 °C. Results showed that in most soils net N mineralization was linearly related to moisture content in the available range (-0.03 to -4.0 MPa). Optimum moisture for net N mineralization corresponded to a soil pore water potential of between -0.01 and -0.03 MPa, while that at which no net mineralization occurred was close to -4.0 MPa.

The procedure for estimating net N mineralization proposed by Stanford and co-workers was used to estimate the N_0 and *k* values for 5 Queensland semi arid soils, each incubated at 5 different temperatures (Campbell et al., 1981). Results presented showed N_0 ranged from 97 ug N g^{-1} of soil for subsoils to 250 for cultivated clayey surface soils. N_0 values were also found to be directly proportional to the total soil carbon while the active N fraction (portion of organic matter that supplies a major portion of plant available N) was found to be directly proportional to CEC. The rate constant value was directly proportional to total C and increased with temperature to 40 °C. In another study, Campbell et al. (1984) determined the Arrhenius relationship between rate constant and absolute temperature for 33 virgin and cultivated Western Canadian prairies soils. Results showed no significant differences in Arrhenius relationships between soils within each soil zone. Thus, a single Arrhenius equation was calculated for different soils in each zone.

Some efforts have also been made to relate the N mineralization to soil texture and interesting results have been reported. Campbell and Souster (1982) studied twelve prairie surface soils representing paired virgin and cultivated coarse, medium and fine textured soils to determine the losses of potentially mineralizable N and total organic matter due to cultivation and related these losses to soil texture. Results showed that cropping caused large losses of organic C and N. N_0 values for virgin soils were much greater than cultivated soils. Medium textured soils generally had the highest organic matter content and potentially mineralizable N. El-Haris et al. (1983) studied the effects of tillage, cropping, and fertilizer management on soil N mineralization potential in a long term crop rotation experiment. Results indicated that N_0 values for fall samples were unaffected by tillage or crop rotation but for spring samples it was significantly higher for either chisel plow or no till than for moldboard plow. Also peas-alfalfa-green manure followed by alternate spring wheat-winter wheat had a significantly higher N_0 than both continuous winter wheat and winter wheat-pea rotation. Nitrogen mineralization potential increased linearly with increasing N rate.

Soudi et al. (1990) studied N mineralization in semiarid soils of Morocco and determined the rate constant variations with soil depth. The data presented in this study have demonstrated the variability of N mineralization among the soils and the decrease of mineralization rate with depth, which is attributed to decreased biodegradability of organic compounds with depth.

N mineralization and Mathematical Models:

Accurate prediction of N mineralization in soils requires reliable parameters which are determined in incubation experiments. The estimated values of the potentially mineralizable organic N and the mineralization rate constant also depend on the mathematical analysis of the incubation results. Considerable effort has been made comparing mathematical models for calculating reliable estimates of N_0 and k. Smith et al. (1980) incubated soils of varying properties and made comparisons between the nonlinear least square equation (NLLS) and the more traditional least square fit of a straight line to log transformed data, for estimating N_0 and k values. The NLLS equation gave a more precise fit to the data and hence, more accurate estimates of both the N mineralization potential and the mineralization rate constant for each soil. Talpaz et al. (1981) tried to estimate the N_0 and k values for the data from published experimental results by Stanford and Smith (1972) by using linear and nonlinear models. Both models gave different values for N_0 and k. They showed that non-linear regression is better than the linear technique.

The procedure outlined by Stanford and Smith (1972) assumes that N mineralization follows first order kinetics and N_0 and k are estimated with the assumption that there is only one active fraction of soil organic matter, or that the one estimated is the major active N pool. However, our knowledge shows there is more than one pool and several researchers have attempted to define and quantify two or three pools.

Juma et al. (1984) conducted experiments to determine the most suitable mathematical equation and the most appropriate method for calculating the values of the parameters of the equation describing the net N mineralization in soil. The cumulative net N mineralized in two treatments of ^{15}N labelled soil and five unlabelled Saskatchewan soils showed curvilinear trends that could be fitted to either hyperbolic or first order equations.

Deans et al. (1986) used single and double exponential equations to compare the mineralization potential and rate constant values obtained from the data of several published and unpublished studies. It was reported that a double exponential model more closely fits N mineralization data obtained from laboratory incubation studies. The single exponential equation gave a systematic under estimation of N_0 and over estimation of *k*. The double exponential equation was more consistent in estimating rate constant and showed smaller mean square error values. Beauchamp et al. (1986) conducted a laboratory study to determine how soil pretreatment and cropping history affects the kinetics of N mineralization. Results showed that net N mineralization followed first order kinetics regardless of pretreatment. However, air drying enhanced the N mineralization during the first 7 days of incubation. They suggested an amendment to the traditional first order model by including easily mineralized N fraction mostly released during the first 7 days. This amended model gave a better fit to the data. Bonde and Rosswell (1987) used three different models (1st order, two component and a simplified special case of the two-component model) to describe the data from an incubation study of soils from four different cropping systems. The results showed that in all cases the special case of the two component model offered the best description of the curves of accumulated mineral N.

Ellert and Bettany (1988) incubated several forested and cultivated soils for 37 weeks with intermittent leaching and evaluated several kinetic models for the ability to accommodate, continuously decreasing rates, a large initial flush of mineralization, a mineralization lag phase or a constant rate of release near the end of incubation. They found that commonly used kinetic models were incapable of describing a mineralization pattern in all soils. Mineralization in the forest E horizon was best described by a modified 1st order model. Soils from a field cultivated since 1905, a recently cleared field and the organic layer from native forest had fluctuating mineralization rates which appeared as lags in the cumulative amounts of inorganic N released over time. The lagged mineralization pattern was best described by consecutive reaction or Gompertz models. Fitting nonlinear kinetic models to incremental data from each incubation interval was superior to conventional approaches which use cumulative data obtained by summing the incremental observations.

Use of N_0 and k in N studies:

The concept of N_0 and k has been and still is being used widely to observe the mineralization trend in soils with varying properties and under varying cultural and management conditions. Chae and Tabatabai (1986) compared the mineralization of N in soils amended with various sewage sludges, animal manures and plant materials. The soils were incubated for 26 weeks with leaching every two weeks. The results showed that total N mineralized from the organic waste material varied considerably, depending on the type of soil and organic waste material.

Bonde and Rosswell (1987) incubated soils samples from four different cropping system, collected at four different occasions during the growing season 13 weeks to measure the potentially mineralizable N. A steady decline of mineralized N in all systems from spring to harvest and a subsequent increase from harvest to autumn was reported. The fact that the amount of mineralizable N decreases during the growing season and increases in autumn as a result of organic matter input provides evidence for the existence of an active fraction of soil organic matter. Large differences of N_0 and k values were found among cropping systems and sampling times.

Campbell et al. (1984) developed a N mineralization model by combining N_0 with functions representing the effects of temperature and moisture on k. This model performed well in predicting the amount of N mineralized during a growing season when soil was incubated in plastic bags placed in an incubator or buried in the field. A similar model was used to estimate the net N mineralized in situ from soil under 1) summer fallow 2) cropped-dryland and 3) cropped irrigated conditions (Campbell et al., 1988). The results obtained from the model were compared to the in situ measured N mineralized during a growing season. The model showed reasonably good agreement to the measured values.

Campbell (1991a) studied the effects of cropping practices on N mineralization. The objective of this study was to determine whether the potentially mineralizable N concept (Stanford and Smith, 1972) would provide a more sensitive parameter than total soil or hydrolyzable amino-N for identifying and quantifying changes in the soil organic matter quality resulting from commonly used cultural and management practices. The effectiveness of the potentially mineralizable N concept for this purpose was examined using data from a 30 year crop rotation study carried out on a Rego thin Black Chernozem soil. In this study a parameter termed initial potential rate of N mineralization (N_0k) proved useful as an index for delineating the relative effects of cultural and management practices on soil organic matter quality.

Cropping System Effects on Organic C, N and Crop Yields:

Crop rotations have been used as a management practice for decades. The beneficial affects of crop rotation on soil properties and crop yields have been reported by many researchers (Robinson, 1966; Adams et al., 1970; Cooper, 1971; Brawand and Hossner, 1976; Baldock et al., 1981; Odell et al., 1984; Johnston, 1986; Zielke and Christenson, 1986; Hesterman et al., 1987; Peterson and Varvel, 1989; Havlin et al., 1990; Varvel and Peterson, 1990; Campbell et al., 1991a, 1991b). The benefits of crop rotation over continuous cropping are generally related to addition of legumes in crop rotation or inclusion of crops with large amounts of residue.

Fertilizer N recommendations require an estimate of N available from the previous crop to avoid over or under fertilization. Different crop sequences contribute different amounts of N to the succeeding crop. Hence, the amount of fertilizer required for a certain crop will vary with the cropping system. Many researchers studied the effects of crop rotation in combination with N fertilizer rates on crop yields. Studies (Welch, 1979; Heichel and Barnes, 1984; and Nafziger and Mulvaney, 1984) reported that the optimum rate of N applied for cereal crop production is lower when following soybean than following other crops. Janzen (1987) studied the effects of long term cropping affects on soil organic matter characteristics in a spring wheat rotation. They found that distribution of organic N and C among labile and stable pools was strongly affected by crop rotation. Levels of mineralizable N and C in a continuous wheat treatment were approximately twice those in the fallow-wheat rotation. Also N mineralization in the forage legume rotation was less than in the continuous wheat treatment.

In a series of experiments Peterson and Varvel (1989) studied the effects of crop rotation and fertilizer N on (i) soybean, (ii) sorghum and (iii) corn, yields grown on a Sharpsburg silty clay loam in Nebraska. In one of these experiments, soybean grown in monoculture was compared with soybean grown in rotation with corn, sorghum or sorghum + clover. The rotation in which soybean followed sorghum produced a higher yield than soybean following corn. In a second experiment, grain sorghum in rotation gave higher yields than when grown in continuous system. Continuous sorghum showed a greater response to applied N than sorghum in rotation. Also in the same series of experiments, corn grown following soybean produced maximum grain with only 90 kg N ha^{-1} while continuous corn required at least 180 kg N ha^{-1} for maximum yield.

Campbell et al. (1991a) compared the effects of legume rotation on quantity and quality of soil organic C with continuous cropping and fertilizer N. A 6-year rotation including 1 year of fallow, 2 years of spring wheat and 3 years of bromegrass and alfalfa had a greater quantity of soil organic N relative to that of unfertilized continuous wheat, but they were equivalent to that of fertilized continuous wheat. Campbell et al. (1991b) also studied the effects of long term crop rotation on total soil N and the amount and quality of hydrolyzable amino compounds. Results showed that a fallow monoculture wheat rotation and unfertilized continuous wheat failed to maintain soil N. A 3-year legume green manure-wheat-wheat system maintained soil N while a 6-year fallow-cereal-hay and fertilized continuous wheat system increased soil N.

In another study (Bagayoko et al., 1992), continuous soybean and sorghum were compared with soybean-sorghum rotation. Results indicated that soybean in crop rotation can contribute soil NO_3-N and consequently increase yield. Plots with soybean as the previous crop had 44 to 50 kg ha^{-1} more NO_3-N in the soil profile than did plots with continuous sorghum. The grain sorghum yield in rotation plots was also significantly higher than continuous cropping system plots. Bundy et al. (1993) studied the corn response to applied N in several crop sequences involving corn and soybean. Results indicated that corn yields and N uptake were higher in rotation than continuous cropping, which indicated the need to adjust N fertilizer recommendations for corn in soybean-corn system to avoid over use of fertilizer.

Mohammed and Clegg (1993) studied the effects of pearl millet-soybean rotation on millet productivity. Millet grain yield increased when grown after soybean and the yield increase was equivalent to that obtained with 45 kg ha^{-1} of applied N. Percent N in various plant parts and N uptake by millet also increased when grown after soybean crop. Residual NO_3-N in the soil profile was also higher in the rotation treatment.

In addition to legumes in the rotation, the quality and quantity of residues added to the soil from the previous crop are another beneficial effect of crop rotations on soil properties and succeeding crop yield. Crop residue management influences the availability of N. When crop residues low in N are incorporated, immobilization of residual mineral N remaining in the soil after harvest occurs. After maximum immobilization, mineralization of the immobilized N occurs resulting in a net release of N (Allison and Klein, 1962).

Crops like corn leaving larger quantities of residue are more beneficial in the rotation than the crops which leave smaller amounts of residue. Several studies reported the direct relationship between crop residues added and C and N of soil. Larson et al. (1972) reported that soil organic C was linearly related to the quantity of residues added and that 5 Mg ha^{-1} of corn or alfalfa residues were needed to maintain initial organic C content. Rasmussen et al. (1980) also reported a similar response in Nebraska.

Havlin et al. (1990) studied the crop rotation and tillage effects on soil organic C and N. Results of these studies showed increased organic C and N with sorghum rotation compared to continuous beans and this increase was directly related to the amount of residues added. Collins et al. (1992) also measured changes in C and N status of soil due to long term crop rotation. Treatments include wheat straw incorporated, wheat-fallow, wheat straw + barnyard manure. Total soil C and N contents were significantly greater in annual crop compared to wheat-fallow rotations.

LIST OF REFERENCES

Adams, W.E., H.D. Morris, and R.N. Dawson. 1970. Effects of cropping systems and nitrogen levels on corn (Zea mays L.) in the southern Piedmont Region. Agron. J. 62:655-659.

Allison F.E., and L.D. Sterling. 1949. Nitrate formation from soil organic matter in relation total nitrogen and cropping practices. Soil Sci. 67:239-252.

Allison, F.E., and C.J. Klein. 1962. Rates of immobilization and release of nitrogen following additions of carbonaceous materials and nitrogen to soils. Soil Sci. 93:383-386.

Andharia. R.M., G. Stanford, and F.W. Schaller. 1953. Nitrogen status of Marshall silt loam as influenced by different crop rotations. Soil Sci. Soc. Am. Proc. 17:247-251.

Bagayoko, M., S.C. Mason, and R.J. Sabata. 1992. Effects of previous cropping system on soil nitrogen and grain sorghum yield. Agron. J. 84:862-868.

Baldock, J.O., and R.L. Higgs, W.H. Paulson, J.A. Jackobs and W.D. Shrader. 1981. Legume and mineral nitrogen effects on crop yields in several crop sequences in the Upper Mississippi Valley. Agron. J. 73:885-890.

Beauchamp E.G., W.D. Reynolds, D. Brasche-Villeneuve, and K. Kirby. 1986. Nitrogen mineralization kinetics with different soil pretreatment and cropping histories. Soil. Sci. Soc. Am. J. 50:1478-1483.

Black, C.A., L.B. Nelson, and W.L. Pritchett. 1947. Nitrogen utilization by wheat as affected by rate of fertilization. Soil Sci. Soc. Am. Proc. 11:393-396.

Bonde, T.A., and T. Rosswall. 1987. Seasonal variation of potentially mineralizable nitrogen in four cropping systems. Soil. Sci. Soc. Am. J. 51:1508-1514.

Boyle, M., and E.A. Paul, 1989. Carbon and nitrogen mineralization kinetics in soil previously amended with sewage sludge. Soil. Sci. Soc. Am. J. 53:99-103.

Brawand, H., and L.P. Hossner. 1976. Nutrient content of sorghum leaves and grain as influenced by long-term crop rotation and fertilizer treatment. Agron. J. 68:277-280.

Bremner, J.M. 1965a. Total nitrogen. *In* C. A. Black et al. (ed.) Methods of soil analysis, Part 2. Agronomy 9:1149-1178. Am. Soc. Agron., Madison, Wis.

Bremner, J.M. 1965b. Nitrogen availability indexes. *In* C. A. Black et al. (ed.) Methods of soil analysis, Part 2. Agronomy 9:1324-1345. Am. Soc. Agron., Madison, Wis.

Bremner, J.M. 1965c. Organic nitrogen in soils. *In* W. V. Bartholomew and F. E. Clark (ed.) Soil nitrogen. Agronomy 10:93-149. Am. Soc. Agron., Inc., Madison, Wis.

Bundy, L.G., and T.W. Andraski. 1993. Soil and plant nitrogen availability tests for corn following alfalfa. J. Prod. Agric. 6:200-206.

Campbell, C.A. 1978. Soil organic carbon, nitrogen and fertility. p. 173-172. *In* M. Schnitzer and S.U. Khan, Eds. Soil organic matter. Developments in Soil Science. V. 8. Elsevier. Amsterdam.

Campbell, C.A., R.J.K. Myers, and K.L. Weier. 1981. Potentially mineralizable nitrogen, decomposition rates and their relationship to temperature for five Queensland soils. Aust. J. Soil Res. 19:323-332.

Campbell, C.A., and W. Souster. 1982. Loss of organic matter and potentially mineralizeable nitrogen from Saskatchewan soils due to croppping. Can. J. Soil Sci. 62:651-655.

Campbell,C.A., Y.W. Jame and G.E. Winkleman. 1984. Mineralization constants and their use for estimating nitrogen mineralization in some Canadian prairie soils. Can. J. Soil Sci. 64:333-343.

Campbell, C.A., Y.W. Jame, and R. De Jong. 1988. Predicting net nitrogen mineralization over a growing season: Model verification. Can. J. Soil. 68:537-552.

Campbell, C.A., M. Schnitzer, G.P. Lafond, R.P. Zentner, and J.E. Knipfel. 1991a. Thirty year crop rotations and management practices effects on soil and amino-N. Soil Sci. Soc. Am. J. 55:739-745.

Campbell, C.A., G.P. Lafond, A.J. Leyshon, R.P. Zentner, and H.H. Janzen. 1991b. Effect of cropping practices on the initial potential rate of N mineralization in a thin Black Chernozem. Can. J. Soil Sci. 71: 43-53.

Chae, Y.M., and M.A. Tabatabai. 1986. Mineralization of nitrogen in soils amended with organic wastes. J. Environ. Qual. 15:193-198.

Chickester, F.W., J.O. Legg, and G. Stanford, 1975. Relative mineralization rates of indigenous and recently incorporated ^{15}N-Labeled nitrogen. Soil Sci. 120:133-138.

Clement, C.R., and T.E. Williams. 1962. An incubation technique for assessing the nitrogen status of soils newly ploughed from leys. J. Soil Sci. 13: 82-91.

Collins, H.P., P.E. Rasmussen, and C.L. Douglas, Jr. 1992. Crop rotation and residue management effects on soil carbon and microbial dynamics. Soil. Sci. Soc. Am. J. 56:783-788.

Cook, F.D., F.G. Warder, and J.L. Doughty, J.L. 1957. Relationship of nitrate accumulation to yield response of wheat in some Saskatchewan soils. Can. J. Soil Sci. 37:84-88.

Cooper, R.L. 1971. Influence of soybean production practices on lodging and seed yield in highly productive environments. Agron. J. 63:490-493.

Cornforth, I.S., and D. Walmsley. 1971. Methods of measuring available nutrients in west indian soils. 1. Nitrogen. Plant Soil 35:389-399.

Cornforth, I.S. 1968. The potential availability of organic nitrogen fractions in some West Indian soils. Exp. Agric. 4:193-201.

Dahnke, W.C., and E.H. Vasey. 1973. Testing soils for nitrogen. p. 97-114. *In* L. M. Walsh and J. D. Beaton (ed.). Soil testing and plant analysis. Soil Sci. Soc. Am., Madison, Wis.

Deans, J.R., J.A.E. Molina, and C.E. Clapp. 1986. Models for predicting potentially mineralizable nitrogen and decomposition rate constants. Soil Sci. Soc. Am. J. 50:323-326.

Eagle, D.J., and B.C. Matthews. 1958. Measurement of nitrate-supplying power of soils by an incubation method and correlation with crop yield response. Can. J. Soil Sci. 38: 161-170.

El-Haris, M.K., V.L. Cochran, L.F. Elliot, and D.F. Bezdicek. 1983. Effect of tillage, cropping and fertilizer management on soil nitrogen mineralization potential. Soil Sci. Soc. Am. J. 47:1157-1161.

Ellert B.H. and J.R. Bettany. 1988. Comparison of kinetic models for describing net sulfur and nitrogen mineralization. Soil. Sci. Soc. Am. J. 52:1692-1702.

Fitts, J.W., W.V. Bartholomew, and H. Heidel. 1953. Correlation between nitrifiable nitrogen and yield response of corn to nitrogen fertilization on Iowa soils. Soil Sci. Soc. Am. Proc. 17: 119-122.

Fox R.H., and W.P. Piekielek. 1978. A rapid method for estimating the nitrogen supplying capability of a soil. Soil Sci. Soc. Am. J. 42:751-753.

Fox R.H., and W.P. Piekielek. 1978. Field testing of several N availability indexes. Soil Sci. Soc. Am. J. 42:747-750.

Fyles, J.W., and W.B. McGill. 1987. Nitrogen mineralization in forest soil profiles from central Alberta. Can. J. For. Res. 17:242-249.

Gasser, J.K.R., and R.J.B. Williams. 1963. Soil nitrogen. VII. Correlations between measurements of nitrogen status of soils and nitrogen % and nitrogen content of crops. J. Sci. Food Agr. 14:269-277.

Gasser, J.K.R., and S.J. Kalembasa. 1976. The effects of leys and organic manures on the available-N in clay and sandy soils. J. Soil Sci. 27:237-249.

Geist, J.M. 1977. Nitrogen response relationships of some volcanic ash soils. Soil Sci. Soc. Am. J. 41:996-1000.

Gharous, R.L., R.L. Westerman, and P.N. Soltanpour. 1990. Nitrogen mineralization potential of arid and semiarid soils of Morocco. Soil Sci. Soc. Am. J. 54:438-443.

Gianello, C., and J.M. Bremner. 1986. Comparison of chemical methods of assessing potentially available nitrogen in soil. Commun. Soil Sci. Plant Anal. 17:195-214.

Gianello, C., and J.M. Bremner. 1988. A rapid distillation method of assessing potentially available organic nitrogen in soil. Commun. Soil Sci. Plant Anal. 19:1551-1568.

Griffin, G.F. and A.F. Laine. 1983. Nitrogen mineralization in soils previously amended with organic wastes. Agron. J. 75:124-129.

Hanway, J., and L. Dumenil. 1955. Predicting nitrogen fertilizer needs of Iowa soils: III. Use of nitrate production together with other information as a basis for making nitrogen fertilizer recommendations for corn in Iowa. Soil Sci. Soc. Am. Proc. 19: 77-80.

Hanway, J.J., and T. Ozus. 1966. Comparisons of laboratory and greenhouse indexes of nutrient availability in soils. Iowa Res. Bull. 544.

Harmsen. G.w., and G.J. Kolenbrander. 1965. Soil inorganic nitrogen. *In* W.V. Bartholomew and F.E. Clark (ed.), Soil nitrogen. Agronomy 10:43-92. Am. Soc. Agron., Madison, WI.

Havlin J.L., D.E. Kissel, L.D. Moaddux, M.M. Claassen, and J.H. Long. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Sci. Soc. Am. J. 54:448-452.

Heichel, G.H., and D.K. Barnes. 1984. Opportunities for lowering crop nitrogen needs from symbiotic nitrogen fixation. p.49-59. *In* D.F. Bezdicek, J.F. Power, D.R. Keeney, and M.J.Weig (ed.) Organic farming current technology and its role in a sustainable agriculture. Spec. Publ. 46. ASA. CSSA. and SSSA. Madison, WI.

Herlihy, M. 1979. Nitrogen mineralization in soils of varying texture, moisture and organic matter. I. Potential and experimental values in fallow soils. Plant Soil 53:255-267.

Hesterman, O.B., M.P. Russelle, C.C. Sheaffer, and G.H. Heichel. 1987. Nitrogen utilization from fertilizer and legume residues in legume-corn rotations. Agron. J. 79:726-731.

Janzen, H.H. 1987. Soil organic matter characteristics after long-term cropping to various spring wheat rotations. Can. J. Soil Sci. 67:845-855.

Jenkinson, D.S. 1968. Chemical tests for potentially available nitrogen in soil. J. Sci. Food Agric. 19:160-168.

Johnston, A.E. 1986. Soil organic matter effects on soils and crops. Soil Use Management. 2:97-105.

Juma, N.G., E.A. Paul, and B. Mary. 1984. Kinetic analysis of net nitrogen mineralization in soil. Soil Sci. Soc. Am. J. 48:753-757.

Kadirgamathoiyah, S., and A.F. Mackenzie. 1970. A study of soil nitrogen organic fractions and correlation with yield response of sudan-sorghum hybrid grass on Quebec soils. Plant Soil. 33:120-128.

Keeney, D.R., and J.M. Bremner. 1966. Comparison and evaluation of laboratory methods of obtaining an index of soil nitrogen availability. Agron. J. 58:498-503.

Keeney, D.R., and J.M. Bremner. 1967. Determination of isotope-ratio analysis of different forms of nitrogen in soils: VI. Mineralizable nitrogen. Soil Sci. Soc. Am. Proc. 31:34-39.

Kresge, C.B., and I.G. Merkle. 1957. A study of the validity of laboratory techniques in appraising the available nitrogen producing capacity of soils. Soil Sci. Soc. Am. Proc. 21:516-521.

Larson, W.E., C.E. Clapp, W.H. Pierre, and Y.B. Morachan. 1972. Effect of increasing amounts of organic residues on continuous corn. II. Organic carbon, nitrogen, phosphorous, and sulfur. Agron. J. 64:204-208.

Lathwell, D.J., H.D. Dubey, and R.H. Fox. 1972. Nitrogen-supplying power of some tropical soils of Puerto Rico and methods of its evaluation. Agron. J. 64:763-766.

Livens, J. 1959. Contribution a l'etude de l'azote mineralisable du sol. Agricultura Louvain 7:27-44.

MacKay, D.C., C.R. MacEachern, and R.F. Bishop. 1959. The relation of soil test values to fertilizer response by the potato. I. Nitrate production and crop yield. Can. J. Soil Sci. 39: 144-150.

MacKay, D.C., C.R. MacEachern, and R.F. Bishop. 1963. The relation of soil test values to fertilizer response by the potato. II. Nitrate production and nitrogenous fertilizer requirements. Can. J. Soil Sci. 43: 242-249.

MacKay, D.C., and J.M. Carefoot. 1981. Control of water content in laboratory determination of mineralizable nitrogen in soils. Soil Sci. Soc. Am. J. 45:444-446.

Marion, G.M., J. Kummerow, and P.C. Miller. 1981. Predicting nitrogen mineralization in Chaparral soils. Soil Sci. Soc. Am. J. 44:956-961.

Mohammed, M.S., and M.D. Clegg. 1993. Pearl millet-soybean rotation and nitrogen fertilizer effects on millet productivity. Agron. J. 85:1009-1013.

Molina, J.A.E., C.E. Clapp, and W.E. Larson. 1980. Potentially mineralizable nitrogen in soil: The simple exponential model does not apply for the first 12 weeks of incubation. Soil Sci. Soc. Am. J. 44:442-443.

Munson, R.D., and G. Stanford. 1955. Predicting nitrogen fertilizer needs of Iowa soils: IV. Evaluation of nitrate production as a criterion of nitrogen availability. Soil Sci. Soc. Am. Proc. 19:464-468.

Myers, R.J.K., C.A. Campbell and K.L. Weier. 1982. Quantitative relationship between net nitrogen mineralization and moisture content of soils. Can. J. Soil Sci. 62:111-124.

Nafziger, E.D., R.L. Mulvaney, D.L. Mulvaney, and L.E. Paul. 1984. Effect of previous crop on the response of corn to fertilizer nitrogen. J. Fert. Issues 1:136-138.

Odell, R.T., S.W. Melstead, and W.M. Walker 1984. Changes of organic carbon and nitrogen of Morrow Plot soils under treatments, 1904-1973. Soil Sci. 137:160-171.

Olness, A. 1983. Nitrogen mineralization potentials, N_0, and correlations with maize response. Agron. J. 76:171-172.

Olson, R.A., M.W. Meyer, W.E. Lamke, A.D. Woltemath, and R.E. Weiss. 1960. Nitrate production rate as a soil test for estimating fertilizer nitrogen requirements of cereal crops. Trans. Intern. Congr. Soil Sci. 7th Madison. 1960. 2: 463-470.

Osborne, G.F., and R. R. Storrier. 1976. Influence of different sources of nitrogen fertilizer on the value of soil nitrogen tests. Aust. J. Exp. Agric. Anim. Husb. 16:881-885.

Oyanedel, C., and J. Rodriguez. 1977. Estimation of N mineralization in soils. Cienc. Invest. Agraria. 4:33-44.

Peterson, T.A., and G.E. Varvel. 1989a. Crop yields as effected by rotation and nitrogen rate. 1. Soybean. Agron. J. 81:728-731.

Peterson T.A., and G.E. Varvel. 1989b. Crop yields as effected by rotation and nitrogen rate. 2. Grain Sorghum. Agron. J. 81:731-735.

Peterson T.A., and G.E. Varvel. 1989c. Crop yields as effected by rotation and nitrogen rate. 3. Corn. Agron. J. 81:735-738.

Prasad, R. 1965. Determination of potentially available nitrogen in soils - A rapid procedure. Plant Soil 2:261-264.

Pritchett, W.L., C.A. Black and L.B. Nelson. 1948. Mineralizable nitrogen in soils in relation to the response of oats to nitrogen fertilization. Soil Sci. Soc. Am. Proc. 12:327-331.

Pritchett, W.L., C.F. Eno, and M.W. Malik. 1959. The nitrogen status of the mineral soils of Florida. Soil Sci. Soc. Am. Proc. 23: 127-130.

Purvis, E.R. and M.W.M. Leo. 1961. Rapid procedure for estimating potentially available soil nitrogen under greenhouse conditions. J. Agric. Food Chem. 9:15-17.

Rasmussen, P.E., R.R. Allmaras, R.C. Rhode, and N.C. Roager, Jr. 1980. Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. Soil Sci. Soc. Am. J. 44:596-600.

Robinson, R.G. 1966. Sunflower-soybean and grain sorghum-corn rotations versus monoculture. Agron.J. 58:475-477.

Robinson, J.B.D. 1967. Anaerobic incubation of soil and the production of ammonium. Nature. 214:534.

Robinson, J.B.D. 1968a. A simple available soil nitrogen index. 1. Laboratory and greenhouse studies. J. Soil Sci. 269-279.

Robinson, J.B.D. 1968b. A simple available soil nitrogen index. II. Field crop evaluation. J. Soil Sci. 19:280-299.

Robinson, J.B.D. 1968c. Chemical index for available soil nitrogen. East Africa Agric. For. J. 33:299-301.

Ryan, J.A., J.L. Sims, and D.E. Peaslee. 1971. Laboratory methods for estimating plant available nitrogen in soil. Agron. J. 63:48-51.

Sahrawat, K.L. 1980. Nitrogen supplying ability of some Philippine rice soils. Plant Soil 55:181-187.

Sahrawat, K.L. 1982. Simple modification of the Walkley-Black method for simultaneous determination of organic carbon and potentially mineralizable nitrogen in tropical rice soils. Plant and Soil. 69:73-77.

Saunder, D.H., B.S. Ellis, and A. Hall. 1957. Estimation of available nitrogen for advisory purposes in Southern Rhodesia. J. Soil Sci. 8:301-312.

Schmitt, M.A., and G.W. Randall. 1994. Developing a soil nitrogen test for improved recommendations for corn. J. Prod. Agric. 7:328-334.

Serna, M.D., and F. Pomares. 1992. Evaluation of chemical indices of soil organic nitrogen availability in calcareous soils. Soil Sci. Soc. Am. J. 56:1486-1491.

Shumway, J.S., and W.A. Atkinson. 1977. Measuring and predicting growth response in unthinned stands of Douglas-fir by paired tree analysis and soil testing. DNR Note no. 15, State of Washington, Dep. of Natural resources, Olympia, Washington.

Sims J.L., and B.G. Blackmon. 1967. Predicting nitrogen availability to rice. II. Assessing available nitrogen in silt loams with different previous year crop history. Soil Sci. Soc. Am. Proc. 31:676-680.

Sims, J.L., J.P. Wells, and D.L. Tackett. 1967. Predicting nitrogen availability to rice: I. Comparison of methods for determining available nitrogen to rice from field and reservoir soils. Soil Sci Soc. Am. Proc. 31:672-680.

Smith, J.A. 1966. An evaluation of nitrogen soil test methods for Ontario soils. Can. J. Soil Sci. 48:185-194.

Smith. J.L., R.R. Schnabel, B.L. McNeal, and G.S. Campbell. 1980. Potential errors in the first-order model for estimating soil nitrogen mineralization potentials. Soil Sci. Soc. Am. J. 44:996-100.

Smith S.J., and G. Stanford. 1971. Evaluation of a chemical index of soil nitrogen availability. Soil Sci. 3:228-232.

Smith, S.J., L.B. Young, and G.E. Miller. 1977. Evaluation of soil nitrogen mineralization potentials under modified field conditions. Soil Sci. Soc. Am. J. 41:74-76.

Soper, R.J., G.J. Racz, and P.I. Fehr. 1971. Nitrate nitrogen in the soil as a means of predicting the fertilizer nitrogen requirements of barley. Can. J. Soil Sci. 51:45-49.

Soudi, B., A. Sbai, and C.N. Chiang. 1990. Nitrogen mineralization in semiarid soils of Morocco: Rate constant variation with depth. Soil Sci. Soc. Am. J. 54:756-761.

Spencer, W.F., A.J. Mackenzie, and F.G. Viets, Jr. 1966. The relationships between soil tests for available nitrogen uptake by various irrigated crops in the western states. Soil Sci. Soc. Am. Proc. 30:480-485.

Stanford, G. 1968. Extractable organic nitrogen and nitrogen mineralization in soils. Soil Sci. 106:345-351.

Stanford, G., and J.O. Legg. 1968. Correlation of soil N availability indexes with N uptake by plants. Soil Sci. 105:320-326.

Stanford, G., and W.H. DeMar. 1969. Extraction of soil organic nitrogen by autoclaving in water. 1. The NaOH-distillable fraction as an index of soil nitrogen availability. Soil Sci. 107:203-205.

Stanford G., and S.J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. Proc. 36:465-472.

Stanford, G., J.O Legg, and S.J. smith. 1973. Soil N availability evaluations based on nitrogen mineralization potentials of soils and uptake of labeled and unlabeled N by plants. Plant Soil 39:113-124.

Stanford, G., and E. Epstein. 1974. Nitrogen mineralization-water relations in soils. Soil Sci. Soc. Am. Proc. 38:103-108.

Stanford, G., N.J. Carter, and S.J. Smith. 1974. Estimates of potentially mineralizable soil nitrogen based on short-term incubation. Soil Sci. Soc. Am. Proc. 38: 99-102.

Stanford, G.., M.H. Frere, and R.A. Van der Pol. 1975. Effect of fluctuating temperatures on soil nitrogen mineralization. Soil Sci 119:22-226.

Stanford, G., and S.J. Smith. 1976. Estimating potentially mineralizable soil nitrogen from chemical index of soil nitrogen availability. Soil Sci. 122: 71-76.

Stanford, G., J.N. Carter, D.T. Westermann, and J.J. Meisinger. 1977. Residual nitrate and mineralizable soil nitrogen in relation to nitrogen uptake by irrigated sugarbeets. Agron. J. 69:303-308.

Stanford, G., 1978. Evaluation of ammonium release by alkaline permanganate as an index of soil nitrogen availability Soil Sci. 126:244-253.

Stanford, G., and S.J. Smith. 1978. Oxidative release of potentially mineralizable soil nitrogen by acid permanganate extraction. Soil Sci.126:210-218.

Stanford, G., 1982. Assessment of soil nitrogen availability. *In* F.J. Stevenson (ed.) Nitrogen in agricultural soils. Agron. 22:651-688. Am. Soc. Agron. Madison. Wisconsin.

Synghal, K.N., J.A. Toogood, and C.F. Bentley. 1959. Assessing nitrogen requirements of some Alberta soils. Can. J. Soil Sci. 39: 120-128.

Talpaz, H., P. Fine, and B. Bar-Yasef. 1981. On the estimation of the N-mineralization parameters from incubation experiments. Soil Sci. Soc. Am. J. 45:993-996.

Varvel G.E., and T.A. Peterson. 1990. Residual soil nitrogen as affected by continuous, two-year and four-year crop rotation systems. Agron. J. 82:958-962.

Verstraeten, L.M. J., K. Vlassek, and J. Livens. 1970. Factors affecting the determination of available soil nitrogen by chemical methods. 1. Comparison of extractable with mineralized nitrogen. Soil Sci. 110:299-305.

Walkley, A., and I.A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a modification of the chromic acid titration method. Soil Sci. 37:29-38.

Waring, S.A., and J.M. Bremner. 1964. Ammonium production in soil under waterlogged conditions as an index of nitrogen availability. Nature 201: 951-952.

Welch. L.F. 1979. Nitrogen use and behavior in crop production. Univ. of Illinois, Agric. Exp. Stn. Bull. 261.

White, J.W., F.J. Holben, C.D. Jeffries, and A.C. Richer. 1949. Correlation of microbiological and chemical soil data with crop yields on the Jordan Soil Fertility Plots. Soil Sci. 67:279-285.

Wilson, C.E.Jr., R.J. Norman, B.R. Wells, and M.D. Correll. 1994a. Chemical estimation of nitrogen mineralization in paddy rice soils: I. Comparison to laboratory indices. Commun. Soil Sci. Plant Anal. 25:573-590.

Wilson, C.E. Jr., R.J. Norman, B.R. Wells, and M.D. Correll. 1994b. Chemical estimation of nitrogen mineralization in paddy rice soils: II. Comparison to green house availability indices. Commun. Soil Sci. Plant Anal. 25:591-604.

Zielke R.C., and D.R. Christenson. 1986. Organic carbon and nitrogen changes in soil under selected cropping systems. Soil Sci. Soc. Am. J. 50:363-367.

CHAPTER III

Nitrogen Mineralization Potential As Affected By Cropping System

Increased agriculture production as well as maintenance and protection of our natural resources like soil and water is a concern of agricultural scientists. But need for food for a rapidly increasing world population along with growing concern about environmental quality and long term productivity of agroecosystems has emphasized the need to develop and implement management strategies for soil and agriculture systems.

Nitrogen availability for crop production is dependent on management practices. Organic matter and chemical fertilizers are the main sources of N for crop production. The maintenance of the quality and quantity of organic matter through residue management and efficient use of fertilizer N improves the economy of production and reduces the risk of pollution.

Management practices like tillage, crop rotation and quantity of residue returned influences the soil organic matter levels. Larson et al. (1972) reported that soil organic carbon was linearly related to the quantity of residues added and that 5 Mg ha^{-1} of corn or alfalfa residues were needed to maintain the initial organic C content. Rasmussen et al.

(1980) also reported similar estimates.

Several long term studies have evaluated the beneficial effects of crop rotation, especially inclusion of legume crops in the rotation, on soil organic matter content and on crop productivity (Odell et al., 1984; Johnston, 1986; Zielke and Christenson, 1986; Havline et al., 1990). Nitrogen released during the microbial decomposition of organic matter is the key process in rendering N available for plant growth (Rosswall, 1976; Ellenberg, 1977; Lee and Stewart, 1978).

The crop fertilizer N requirement is a function of many factors. Among these are residual and mineralizable soil N and those elements of crop and soil management that influence the fraction of total N that is in a readily mineralizable form (Stanford and Smith, 1972; 1976).

Efficient use of fertilizer N requires an estimate of the exact amount needed for a crop. This estimate can only be obtained if we know the amount of N needed by the crop and the amount supplied by the soil from residual N and through microbial decomposition of the organic residues.

Stanford and coworkers (Stanford and Smith, 1972; Stanford et al., 1973; Stanford and Epstein, 1974) proposed a method for predicting N mineralized from soil organic matter. In this method soils are incubated in the laboratory under optimal conditions of moisture and temperature and net N mineralized is measured. The mineralization process is usually expressed by the first order rate equation and N mineralization potential (N_0) and rate constant of mineralization (k) are estimated by an iterative statistics.

Nitrogen mineralization potential has been widely used as a means to determine the effects of various agricultural practices on soil fertility, such as N fertilization, tillage, crop rotation and manure additions (Doran, 1980; Campbell and Souster, 1982; Carter and Rennie, 1982; El-Haris et al., 1983; Griffin and Laine, 1983; Beauchamp et al., 1986; Bonde and Rosswall, 1987; Janzen, 1987; Havlin et al., 1990; Varvel and Peterson, 1990; Aulakh et al., 1991; Collins et al., 1992).

Most authors have considered N_0 to be characteristic for a certain cropping system and soil and have not investigated possible seasonal patterns. If N_0 is considered to measure an equivalent of active fraction of soil organic matter, then seasonal fluctuations should occur. Some workers in this regard have shown seasonal fluctuation of N_0 values. Bonde and Rosswall (1987) found that differences of N_0 values due to sampling time were as high as differences between cropping systems. El-Haris et al. (1983) found N_0 values to be twice as high when soils were sampled in mid-September as when sampled in mid-March. The spring k values were a factor three greater than those from autumn. Stanford et al. (1977) also found a 20% reduction in N_0 values for a number of soils when April sampling was compared with September.

The objectives of this study were to: (i) compare the relative effects of several cropping systems including sugarbeet in various combinations with corn, dry beans and foragelegumes on mineralized N, nitrogen mineralization potential and rate constant of mineralization and (ii) compare the effects of sampling time on N mineralization.

MATERIALS AND METHODS

Study Area:

This experiment was a part of the long term cropping system study conducted on a Misteguay silty clay soil (Aeric Haplaquepts). A detailed description of the study is given by Christenson et al. (1991). The cropping systems selected for this study were corn-corn-sugarbeets (CCB), corn-navy beans-sugarbeets (CBeB), navy beans-navy beans-sugarbeets (BeBeB), oats-navy beans-sugar beets (OBeB) from the 1992 study while one more system, oats alfalfa-navy beans-sugar beets (OABeB) was also included for 1993. The experiment in the field was arranged as a randomized complete block design with four replications. Each plot was subdivided into subplots for four N fertilizer treatments (0, 45, 90, 135 kg N ha^{-1}).

Soil Sampling:

Soil samples from the zero N plots were collected twice during the growing season. The first samples were collected at the time of planting and second in August. All samples were collected to a depth of 20 cm and each consisted of 20 probes per plot. Samples were air dried, ground, sieved through a 2-mm screen and stored in air tight glass bottles for latter analyses.

Laboratory Incubation Study:

A modified aerobic incubation procedure, based on the principles and methods outlined by Stanford and Smith (1972) and Campbell et al., (1992) was used to measure mineralizable N and the mineralization rate constant. Ten g of air dried soil mixed with 20 g of acid washed quartz sand was incubated in small plastic tubes at 30 °C temperature and 100% relative humidity. Soil moisture content was established at approximately -0.03 MPa by adding 5 ml of water to each tube and the moisture level was maintained by adding water to bring the tubes to predetermined weights.

Soil in separate tubes was used for each incubation period of 0, 1, 2, 4, 8, 16, 24, 32, and 40 weeks. The tubes containing soils were arranged in the incubator in a randomized complete block design with four replications corresponding to replications in the field study.

At the end of each incubation period soil NO_3 and NH_4 were extracted by shaking soil in the tubes with 100 ml of M KCl (Bremner, 1965a) for one hour and filtering through rinsed Whatman no. 40 filter paper. The filterate was analyzed for NO_2 plus NO_3 and NH_4 by using a flow-through injection system (Am. Public Health Assoc., 1981).

Organic Carbon Determination:

Organic C was determined by Walkley and Black wet combustion with chromic acid (Walkley and Black, 1934; Walkley, 1935, 1947). Ten ml of N $K_2Cr_2O_7$ was added to 1.5 g of soil in a 500 ml Erlenmeyer flask followed by addition of 20 ml concentrated H_2SO_4. The sample was allowed to digest and cool for 30 minutes. Then 170 ml distilled water and 3 drops of ferrion (1,10-orthphenanthroline ferrous sulfate) were added and the sample was titrated to a maroon end point using 0.5 N $Fe(NH_4)_2(SO_4)_2$. Results of duplicate determinations were calculated as % organic C in air dry soil.

Total Nitrogen:

Total N in the soil samples was determined by the micro-Kjeldahl method described by Bremner (1965b). One gram of soil ground to pass through 0.25-mm sieve was digested for 5 hours in 3 ml of concentrated H_2SO_4 containing 1.5g K_2SO_4 + 15 mg Se. After cooling, each sample received 20 ml of water. Ammonia was released by alkaline distillation, collected in H_3BO_3 and titrated with standard sulfuric acid using methyl purple as the end point indicator.

Calculations:

Two models were used to describe the data of this study. The first model utilized was the first-order exponential equation describing net N mineralization proposed by Stanford and Smith (1972):

$$N = N_0[1 - \exp(-kt)]$$

where N is mineralized N in time t, and N_0 and k are the N-mineralization potential and rate constant values.

The second model used was the hyperbolic equation proposed by Juma et al. (1984):

$$N = N_0 t/(T_c + t)$$

In this equation T_c is the half time for mineralization and is related to the rate constant k by the following:

$$T_c = \ln 2/k$$

All other terms are as described above.

A Systat nonlinear least-squares regression program was used to evaluate N_0 and k

in both models (Wilkinson, 1986).

RESULTS AND DISCUSSION

Total N and Oxidizable Carbon:

Total N and oxidizable C for soils from various cropping systems are given in Table 1. Results indicated that the cropping system and sampling time interaction was not significant. However, significant differences in total N (1992 samples only) and organic C (1992 and 1993 samples) were found among cropping systems. Time of sampling did not show significant differences. The total N values ranged from 1.45 to 1.65 g kg^{-1} with the lowest for BeBeB system and highest for CCB during both years. The organic C values ranged from 9.94 to 12.6 g kg^{-1}. The concentration was highest for CCB and lowest for BeBeB.

Nitrogen Mineralization:

Cumulative N mineralized during a period of 40 weeks for soil samples taken during 1992 and 1993 is shown graphically in Figures 1-4. The general trend for cumulative N mineralized was similar for all cropping systems at both sampling dates and for both years. The rate of mineralization was rapid in the beginning of the incubation and declined with time. The range of mineralized N was from 74 to 111 mg kg^{-1} of soil. The lowest quantity was observed in soils from BeBeB system for both years and highest in CBeB during 1992 and OABeB during 1993. Sampling time had no significant effect on cumulative mineralized N, which is contrary to the findings of Bonde and Rosswall (1987). The possible reasons for differences might be due to differences in soil type, different cropping sequences, duration of incubation or climatic conditions.

The statistical analysis for the N_0 values showed an insignificant interaction between cropping systems and sampling date in both 1992 or 1993 (Tables 2 and 3). However, there were significant differences among cropping systems in both years. N_0 values obtained by the exponential model ranged from 72 to 101 mg kg^{-1} and from 87 to 137 mg kg^{-1} by the hyperbolic model. The highest values of N_0 were obtained in the CCB system while the lowest values occured in the BeBeB system. The values for both sampling dates were not significantly different, which is contrary to the findings of other researchers (El-Haris et al. 1983; Stanford et al. 1977; Bonde and Rosswall, 1987). It is clear from the results that nitrogen mineralization potential was higher in the cropping system where larger amounts of residues were added back to the soil. The cropping systems studied in this experiment can be arranged as CCB = OABeB > CBeB = OBeB = BeBeB based on the N_0 values.

The rate constant of mineralization (*k*) estimated by the exponential model ranged from 0.069 to 0.159 $week^{-1}$, while it ranged from 0.044 to 0.081 $week^{-1}$ when calculated with hyperbolic model (Table 2 and 3). The *k* values did not show any consistent change due to cropping system, but it is apparent from the results that N_0 and *k* values have a reciprocal relationship. The higher N_0 value corresponds to lower *k* values and visa-versa.

Exponential vs Hyperbolic:

The N_0 and *k* values in this study were estimated by both exponential and hyperbolic models. Data in Tables 2 and 3 indicate that N_0 values estimated by exponential model were lower than those estimated with hyperbolic model, while this relationship was opposite for *k* value.

The comparison between two models can best be made using the instantaneous rate of reactions (the slope of the line) for each model. The instantaneous rate of reaction for exponential model was computed by the equation:

$$dN/dt = N_0 * k \exp(-kt)$$

while for hyperbolic model it was computed as:

$$dN/dt + N_0 * T_C/(T_C+t)^2$$

The rate of reaction computed by the two equations for each soil are highly correlated for each period of incubation with r^2 values ranging from 0.86 to 1.00 (Table 4 and 5) which supports the previous research that both models can be successfully used to estimate reliable N_0 and *k* values (Juma et al., 1984; Gharous et al., 1990).

An important aspect is that although N_0 values calculated by the two models were different, the rate of change was similar with both models. The order of ranking for cropping systems based on N_0 values remained similar with both models.

The Active Nitrogen Fraction:

The active N fraction is considered the portion of organic matter that supplies a major part of the plant available N for crop growth. It is represented by N_0/N_t where N_t is total N concentration of soil. The values for active N fraction (Table 2 and 3) ranged from 5 to 7% for the exponential model and 5 to 9% for the hyperbolic model. Again, the highest values for the active N fraction were found for the cropping systems where higher amounts of crop residues were returned to the soil. Number one in rank was CCB followed by OABeB, CBeB, OBeB and BeBeB. However, these differences in active N fraction values among cropping system were not significant statistically.

CONCLUSION

Results of this study proves that differences of N_0 and active N fraction do exist among the cropping systems. Therefore, it is important to study soils for N mineralization trend periodically for making accurate prediction of the fertilizer N requirement. The assumption that sampling time might be effecting the N mineralization trend could not be proven in this study. A very high correlation between the exponential and the hyperbolic model for N_0 and k values was observed in this study. This supported earlier reports that a single exponential model as well as a hyperbolic model can be used to describe N mineralized, mineralization potential, and active N fraction in soil. (Juma et al., 1984: Gharous et al., 1990).

LIST OF REFERENCES

American Public Health association. 1981. Standard methods for examination of water and waste water, 1981. 15th ed Am. Public Health Assoc., Washington, DC.

Aulakh, M.S., J.W. Doran, D.T. Walters, A.R. Mosier, and D.D. Francis. 1991. Crop residue type and placement effects on denitrification and mineralization. Soil Sci. Soc. Am. J. 55:1020-1025.

Beauchamp E.G., W.D. Reynolds, D. Brasche-Villeneuve, and K. Kirby. 1986. Nitrogen mineralization kinetics with different soil pretreatment and cropping histories. Soil. Sci. Soc. Am. J. 50:1478-1483.

Bonde, T.A., and T. Rosswall. 1987. Seasonal variation of potentially mineralizable nitrogen in four cropping systems. Soil. Sci. Soc. Am. J. 51:1508-1514.

Bremner, J. M. 1965a. Inorganic forms of nitrogen. *In* C. A. Black et al. (ed.) Methods of soil analysis, Part 2. Agronomy 9:1179-1237. Am. Soc. Agron., Madison, Wis.

Bremner, J. M. 1965b. Nitrogen availability indexes. *In* C. A. Black et al. (ed.) Methods of soil analysis, Part 2. Agronomy 9:1324-1345. Am. Soc. Agron., Madison, Wis.

Campbell, C.A., and W. Souster. 1982. Loss of organic matter and potentially mineralizeable nitrogen from Saskatchewan soils due to cropping. Can. J. Soil Sci. 62:651-655.

Campbell, C.A., B.H. Ellert, and Y.W. Jame. 1992. Nitrogen mineralization potential in soils. *In.* Soil sampling and methods of analysis. M.R. Carter (ed.) Can. Soc. Soil Sci. 341-349.

Carter, M.R., and D.A. Rennie. 1982. Changes in soil quality under zero tillage farming systems: Distribution of microbial biomass and mineralizable C and N potentials. Can. J. Soil Sci. 62:587-597.

Christenson, D.R., C.E. Bricker, and R.S. Gallagher. 1991. Crop yields as affected by cropping system and rotation. Michigan State Univ. Agric. Exp. Sta. Res. Rep. 516.

Collins, H.P., P.E. Rasmussen, and C.L. Douglas, Jr. 1992. Crop rotation and residue management effects on soil carbon and microbial dynamics. Soil. Sci. Soc. Am. J. 56:783-788.

Doran, J.W. 1980. Microbial changes associated with residue management with reduced tillage. Soil Sci. Soc. Am. J. 44:518-524.

Ellenberg, V.H. 1977. Stickstoff als Standortsfaktor, inber sonder fur mitteleuropaische Pflanzengesellschaften. Plant soil. 12:1-22.

El-Haris, M.K., V.L. Cochran, L.F. Elliot, and D.F. Bezdicek. 1983. Effect of tillage, cropping and fertilizer management on soil nitrogen mineralization potential. Soil Sci. Soc. Am. J. 47:1157-1161.

Griffin, G.F., and A.F. Laine. 1983. Nitrogen mineralization in soils previously amended with organic wastes. Agron. J. 75:124-129.

Havlin J.L., D.E. Kissel, L.D. Moaddux, M.M. Claassen, and J.H. Long. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Sci. Soc. Am. J. 54:448-452.

Janzen, H.H. 1987. Soil organic matter characteristics after long-term cropping to various spring wheat rotations. Can. J. Soil Sci. 67:845-855.

Johnston, A.E. 1986. Soil organic matter effects on soils and crops. Soil Use Management. 2:97-105.

Juma, N.G., E.A. Paul, and B. Mary. 1984. Kinetic analysis of net nitrogen mineralization in soil. Soil Sci. Soc. Am. J. 48:753-757.

Larson, W.E., C.E. Clapp, W.H. Pierre, and Y.B. Morachan. 1972. Effect of increasing amounts of organic residues on continuous corn. II. Organic carbon, nitrogen, phosphorous, and sulfur. Agron. J. 64:204-208.

Lee, J.A., and G.R. Stewart. 1978. Ecological aspects of nitrogen assimilation. Adv. Bot. Res. 6:1-43.

Odell, R.T., S.W. Melstead, and W.M. Walker 1984. Changes of organic carbon and nitrogen of Morrow Plot soils under treatments, 1904-1973. Soil Sci. 137:160-171.

Rasmussen, P.E., R.R. Allmaras, R.C. Rhode, and N.C. Roager, Jr. 1980. Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. Soil Sci. Soc. Am. J. 44:596-600.

Roswall, T. 1976. The internal nitrogen cycle between microorganisms, vegetation and soil. Ecol. Bull. 22:157-167.

Stanford G., and S.J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. Proc. 36:465-472.

Stanford, G., J.O Legg, and S.J. Smith. 1973. Soil N availability evaluations based on nitrogen mineralization potentials of soils and uptake of labeled and unlabeled N by plants. Plant Soil 39:113-124.

Stanford, G., and E. Epstein. 1974. Nitrogen mineralization-water relations in soils. Soil Sci. Soc. Am. Proc. 38:103-108.

Stanford, G., and S.J. Smith. 1976. Estimating potentially mineralizable soil nitrogen from chemical index of soil nitrogen availability. Soil Sci. 122: 71-76.

Stanford,G., J.N. Carter, D.T. Westermann, and J.J. Meisinger. 1977. Residual nitrate and mineralizable soil nitrogen in relation to nitrogen uptake by irrigated sugarbeets. Agron. J. 69:303-308.

Varvel G.E., and T.A. Peterson. 1990. Residual soil nitrogen as affected by continuous, two-year and four-year crop rotation systems. Agron. J. 82:958-962.

Walkley, A., and I.A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a modification of the chromic acid titration method. Soil Sci. 37:29-38.

Walkley, A., 1935. An estimation of methods for determining organic carbon and nitrogen in soils. J. Agric. Sci. 25:588-609.

Walkley, A. 1947. A critical examination of a rapid method for determining organic carbon in soils-effect of variation in digestion condition and of inorganic soil constituents. Soil Sci. 63:251-264.

Wilkinson, L.S. 1986. The system for statistics. Systat, Inc., Evanston, IL.

Zielke R.C., and D.R. Christenson. 1986. Organic carbon and nitrogen changes in soil under selected cropping systems. Soil Sci. Soc. Am. J. 50:363-367.

Table 1. Total N and oxidizable C concentration in soils from the cropping system study, 1992 and 1993.

Cropping System	Sample Date	Total N 1992	Total N 1993	Oxidizable C 1992	Oxidizable C 1993
		--------------	g kg^{-1}	--------------	
CCB	May	1.64	1.54	12.4	10.9
CBeB	May	1.58	1.48	11.9	10.3
BeBeB	May	1.45	1.47	10.7	10.1
OBeB	May	1.52	1.48	11.6	10.1
OABeB	May	-	1.53	-	10.8
CCB	Aug	1.65	1.57	12.8	10.8
CBeB	Aug	1.58	1.47	11.8	9.81
BeBeB	Aug	1.46	1.46	11.1	9.94
OBeB	Aug	1.51	1.47	11.6	10.1
OABeB	Aug	-	1.57	-	10.6
LSD (0.05)†		N.S.	N.S.	N.S.	N.S.
		Simple Effects			
Cropping System					
CCB		1.65	1.55	12.6	10.9
CBeB		1.58	1.48	11.9	10.0
BeBeB		1.45	1.47	10.9	9.94
OBeB		1.52	1.48	11.6	10.0
OABeB		-	1.55	-	10.7
LSD (0.05)		0.107	N.S.	0.946	0.59
Sample Date					
May		1.55	1.51	11.6	10.4
Aug		1.55	1.51	11.8	10.2
LSD (0.05)		N.S.	N.S.	N.S.	N.S.

† Comparison of two cropping systems within on sampling date.

Table 2.

Table 2. Effect of cropping system and sampling date on N mineralization potential (N_0), rate constant (k) and active N fraction for exponential and hyperbolic models for samples taken in 1992 on Misteguay silty clay soil.

Cropping System	Sample Date	Exponential Model N_0	Exponential Model k	Hyperbolic Model N_0	Hyperbolic Model k	Active N Fraction Exp.	Active N Fraction Hyp.
		mg kg^{-1}	wk^{-1}	mg kg^{-1}	wk^{-1}	%	%
CCB	May	94.3	0.075	120	0.054	5.76	7.33
CBeB	May	84.0	0.114	102	0.089	5.33	6.44
BeBeB	May	71.7	0.103	88.1	0.078	4.94	6.06
OBeB	May	82.8	0.107	102	0.083	5.43	6.68
CCB	Aug	85.8	0.109	105	0.082	5.19	6.35
CBeB	Aug	85.5	0.093	108	0.065	5.43	6.84
BeBeB	Aug	69.7	0.113	85.1	0.088	4.80	5.87
OBeB	Aug	82.3	0.091	101	0.069	5.44	6.71
LSD (0.05)†		N.S.	N.S.	N.S	N.S.	N.S	N.S.
Simple Effects							
Cropping System							
CCB		94.3	0.0861	122	0.0631	5.74	7.41
CBeB		84.8	0.104	105	0.0772	5.38	6.64
BeBeB		70.7	0.108	86.6	0.0831	4.87	5.97
OBeB		82.5	0.0991	102	0.0761	5.44	6.69
LSD (0.05)		11.9	N.S.	21.2	N.S.	N.S.	N.S.
Sampling Date							
May		85.3	0.0971	108	0.0745	5.49	6.91
Aug		80.8	0.102	99.8	0.0765	5.21	6.44
LSD (0.05)		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

† Comparison of two cropping systems within a sampling date.

Table 3. Effect of cropping system and sampling date on N mineralization potential (N_0), rate constant (k) and active N fraction for exponential and hyperbolic models for samples taken in 1993 on a Misteguay silty clay soil.

Cropping System	Sample Date	Exponential Model N_0	Exponential Model k	Hyperbolic Model N_0	Hyperbolic Model k	Active N Fraction Exp.	Active N Fraction Hyp.
		mg kg^{-1}	wk^{-1}	mg kg^{-1}	wk^{-1}	---------%---------	
CCB	May	109	0.077	141	0.057	7.11	9.18
CBeB	May	89.1	0.116	106	0.096	6.01	7.16
BeBeB	May	74.4	0.157	88.0	0.130	5.05	5.99
OBeB	May	82.8	0.150	97.5	0.126	5.62	6.62
OABeB	May	105	0.096	130	0.074	6.84	8.48
CCB	Aug	109	0.068	146	0.044	6.99	9.33
CBeB	Aug	93.4	0.078	118	0.057	6.39	8.06
BeBeB	Aug	89.1	0.074	114	0.051	6.09	7.82
OBeB	Aug	90.6	0.086	114	0.063	6.16	7.75
OABeB	Aug	106	0.068	137	0.047	6.77	8.74
LSD (0.05)†		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Simple Effects							
Cropping System							
CCB		109	0.0728	144	0.0504	7.05	9.26
CBeB		91.3	0.0968	112	0.0764	6.20	7.61
BeBeB		81.7	0.115	101	0.0903	5.57	6.91
OBeB		86.7	0.118	106	0.0943	5.89	7.19
OABeB		105	0.0821	133	0.0608	6.81	8.61
LSD (0.05)		9.82	0.0344	16.1	0.0344	0.71	1.13
Sample date							
May		91.9	0.119	112	0.0964	6.13	7.49
August		97.7	0.0748	126	0.0524	6.48	8.34
LSD (0.05)		*	*	*	*	*	*

† Comparison of two cropping systems within one sampling date.

Table 4. Comparison of the instantaneous rate of reaction for the exponential and hyperbolic models at various incubation periods using linear regression on soil samples taken at two dates in 1992 from cropping systems study on a Misteguay silty clay soil.

Cropping System	Sample Date	Weeks 1 Exp.	Weeks 1 Hyp.	Weeks 2 Exp.	Weeks 2 Hyp.	Weeks 4 Exp.	Weeks 4 Hyp.	Weeks 8 Exp.	Weeks 8 Hyp.
		mg N kg^{-1} wk^{-1}							
CCB	May	6.53	8.03	6.06	6.98	5.22	5.42	3.87	3.54
CBeB	May	8.56	10.3	7.64	8.26	6.08	5.69	3.85	3.17
BeBeB	May	6.65	8.01	6.00	6.61	4.88	4.71	3.24	2.75
OBeB	May	7.92	9.72	7.12	7.93	5.76	5.57	3.76	3.18
CCB	Aug	8.40	9.89	7.53	8.09	6.05	5.71	3.91	3.28
CBeB	Aug	7.25	8.47	6.60	7.18	5.48	5.35	3.78	3.30
BeBeB	Aug	7.05	8.47	6.29	6.85	5.02	4.74	3.19	2.66
OBeB	Aug	6.85	8.32	6.26	7.00	5.21	5.15	3.62	3.13
r^2		0.98		0.98		0.92		0.92	

Table 4 (continued).

Cropping System	Sample Date	Weeks 16 Exp.	16 Hyp.	24 Exp.	24 Hyp.	32 Exp.	32 Hyp.	40 Exp.	40 Hyp.
		---mg N kg^{-1} wk^{-1}---							
CCB	May	2.13	1.85	1.17	1.13	0.647	0.765	0.356	0.551
CBeB	May	1.54	1.39	0.619	0.783	0.248	0.599	0.100	0.346
BeBeB	May	1.42	1.26	0.625	0.724	0.275	0.468	0.121	0.328
OBeB	May	1.60	1.43	0.684	0.812	0.292	0.522	0.125	0.364
CCB	Aug	1.63	1.49	0.681	0.855	0.284	0.544	0.119	0.379
CBeB	Aug	1.80	1.61	0.854	0.955	0.406	0.631	0.193	0.457
BeBeB	Aug	1.29	1.18	0.521	0.662	0.211	0.423	0.0851	0.294
OBeB	Aug	1.74	1.50	0.841	0.879	0.405	0.577	0.195	0.410
r^2		0.98		0.98		0.96		0.96	

Table 5. Comparison of the instantaneous rate of reaction for the exponential and hyperbolic models at various incubation periods using linear regression on soil samples taken at two sampling dates in 1993 from cropping systems study conducted on a Mistequay silty clay soil.

Cropping system	Sample Date	Weeks 1 Exp.	Weeks 1 Hyp.	Weeks 2 Exp.	Weeks 2 Hyp.	Weeks 4 Exp.	Weeks 4 Hyp.	Weeks 8 Exp.	Weeks 8 Hyp.
		----------mg N kg^{-1} wk^{-1}----------							
CCB	May	7.80	9.82	7.22	8.49	6.19	6.53	4.54	4.21
CBeB	May	9.17	11.3	8.17	9.00	6.48	6.08	4.09	3.31
BeBeB	May	9.98	11.7	8.53	8.73	6.23	5.39	3.32	2.64
OBeB	May	10.7	12.7	9.21	9.52	6.82	5.94	3.74	2.94
OABeB	May	9.15	11.3	8.31	9.41	6.85	6.80	4.66	4.03
CCB	Aug	6.98	8.24	6.52	7.34	5.69	5.92	4.33	4.09
CBeB	Aug	6.74	8.26	6.23	7.14	5.33	5.48	3.90	3.52
BeBeB	Aug	6.08	7.27	5.65	6.37	4.88	5.01	3.64	3.33
OBeB	Aug	7.17	8.67	6.57	7.39	5.53	5.56	3.92	3.47
OABeB	Aug	6.70	8.16	6.26	7.21	5.47	5.75	4.17	3.90
r^2		0.98		0.98		0.86		0.98	

Table 5. (Continued)

Table 5. (Continued)

Cropping system	Sample Date	Weeks: 16		24		32		40	
		Exp.	Hyp.	Exp.	Hyp.	Exp.	Hyp.	Exp.	Hyp.
		mg N kg^{-1} wk^{-1}							
CCB	May	2.45	2.16	1.32	1.31	0.711	0.882	0.383	0.633
CBeB	May	1.62	1.42	0.644	0.787	0.255	0.488	0.101	0.344
BeBeB	May	0.947	1.03	0.269	0.546	0.0769	0.337	0.0219	0.228
OBeB	May	1.12	1.16	0.337	0.617	0.1015	0.382	0.0305	0.259
OABeB	May	2.16	1.88	0.999	1.094	0.463	0.708	0.219	0.497
CCB	Aug	2.51	2.28	1.45	1.45	0.842	1.01	0.488	0.739
CBeB	Aug	2.09	1.804	1.12	1.09	0.601	0.734	0.322	0.526
BeBeB	Aug	2.02	1.78	1.12	1.102	0.623	0.749	0.346	0.543
OBeB	Aug	1.97	1.72	0.985	1.024	0.495	0.679	0.248	0.483
OABeB	Aug	2.43	2.13	1.41	1.34	0.8203	0.919	0.477	0.670
r^2		1.00		1.00		1.00		1.00	

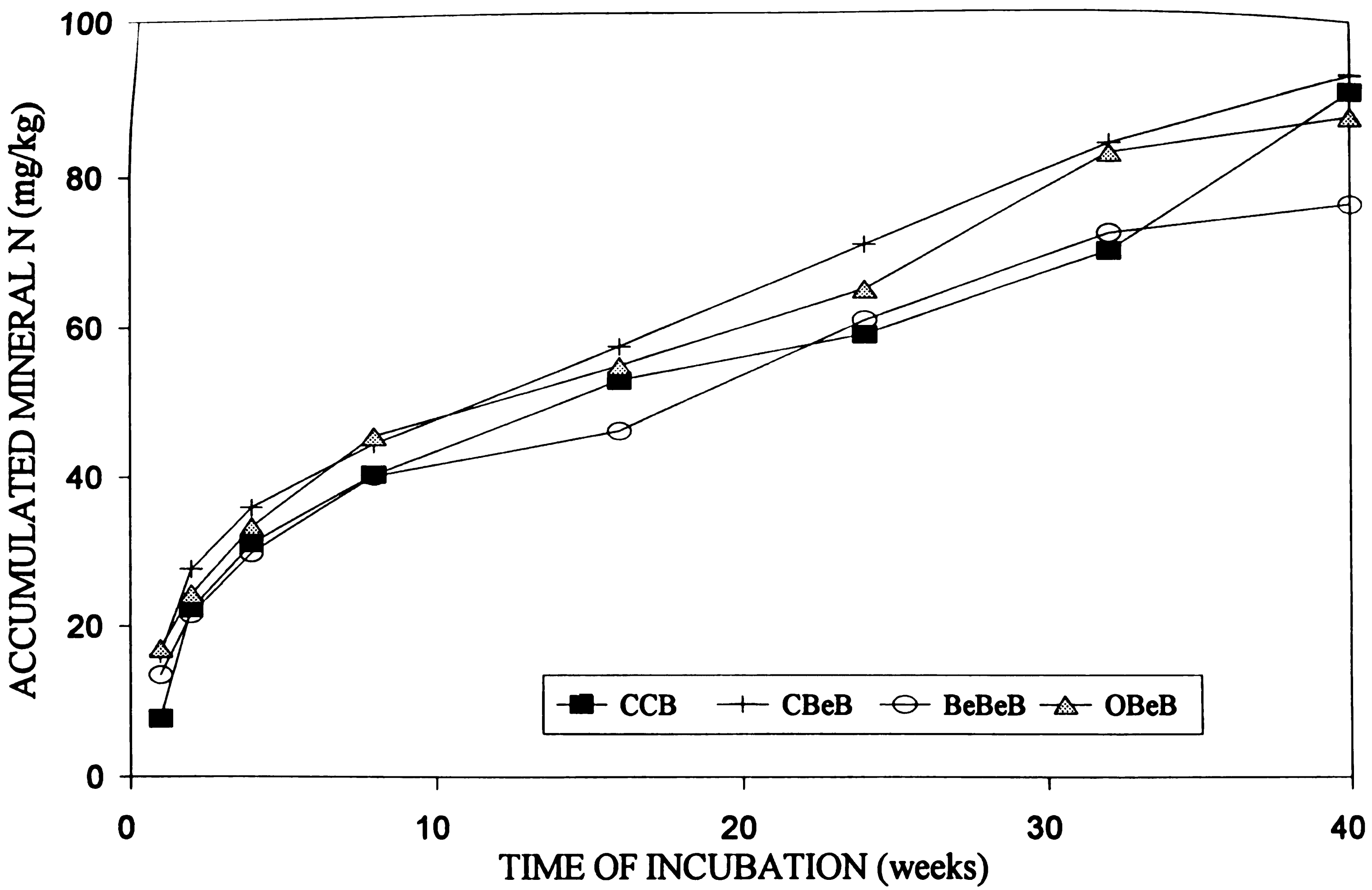

Figure 1. Cumulative N mineralized for four cropping systems from a study on a Misteguay silty clay soil for samples taken May 1992.

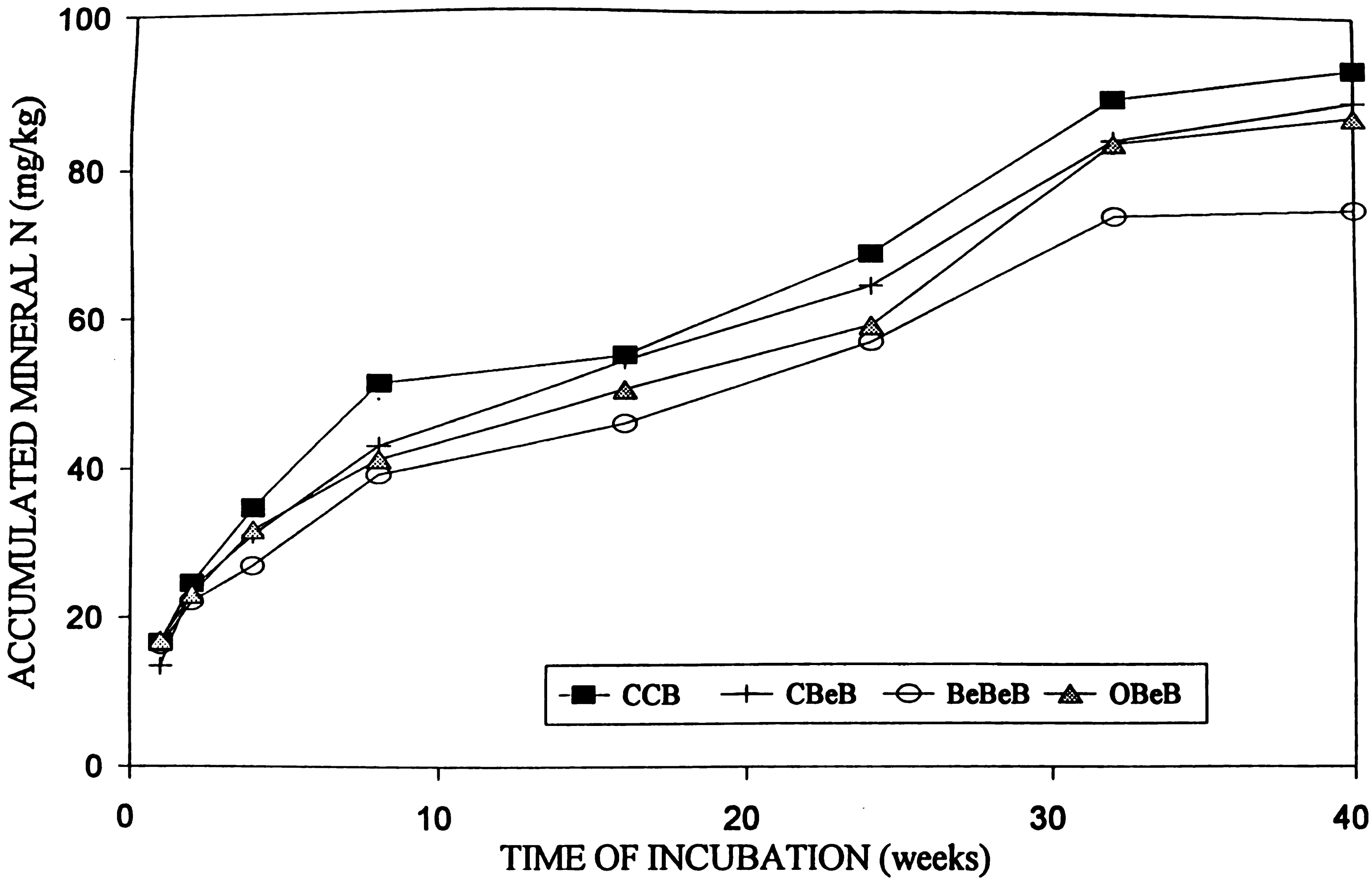

Figure 2. Cumulative N mineralized for four cropping systems from a study on a Misteguay silty clay soil for samples taken August 1992.

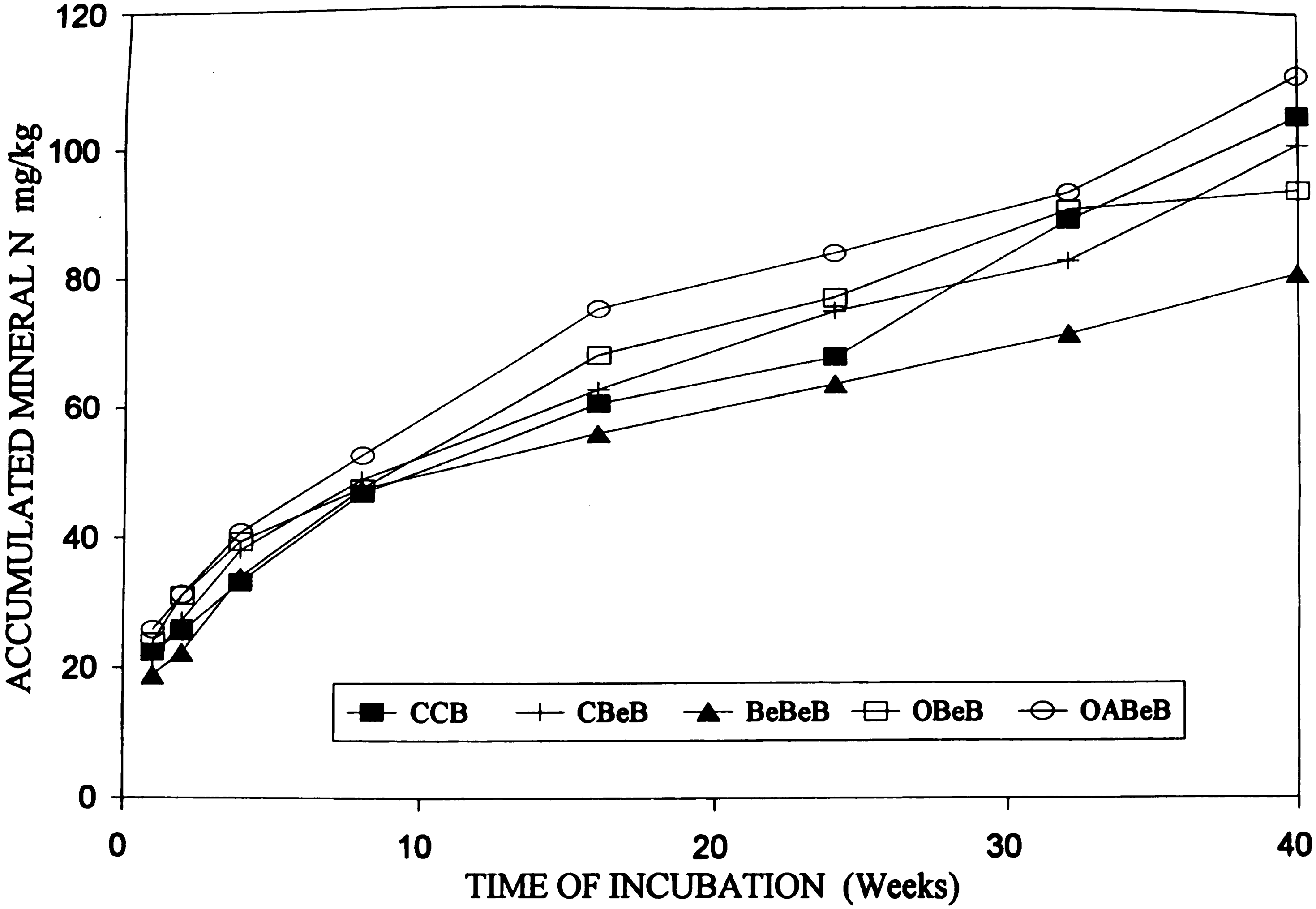

Figure 3. Cumulative N mineralized for five cropping systems from a study on a Misteguay silty clay soil for samples taken May 1993.

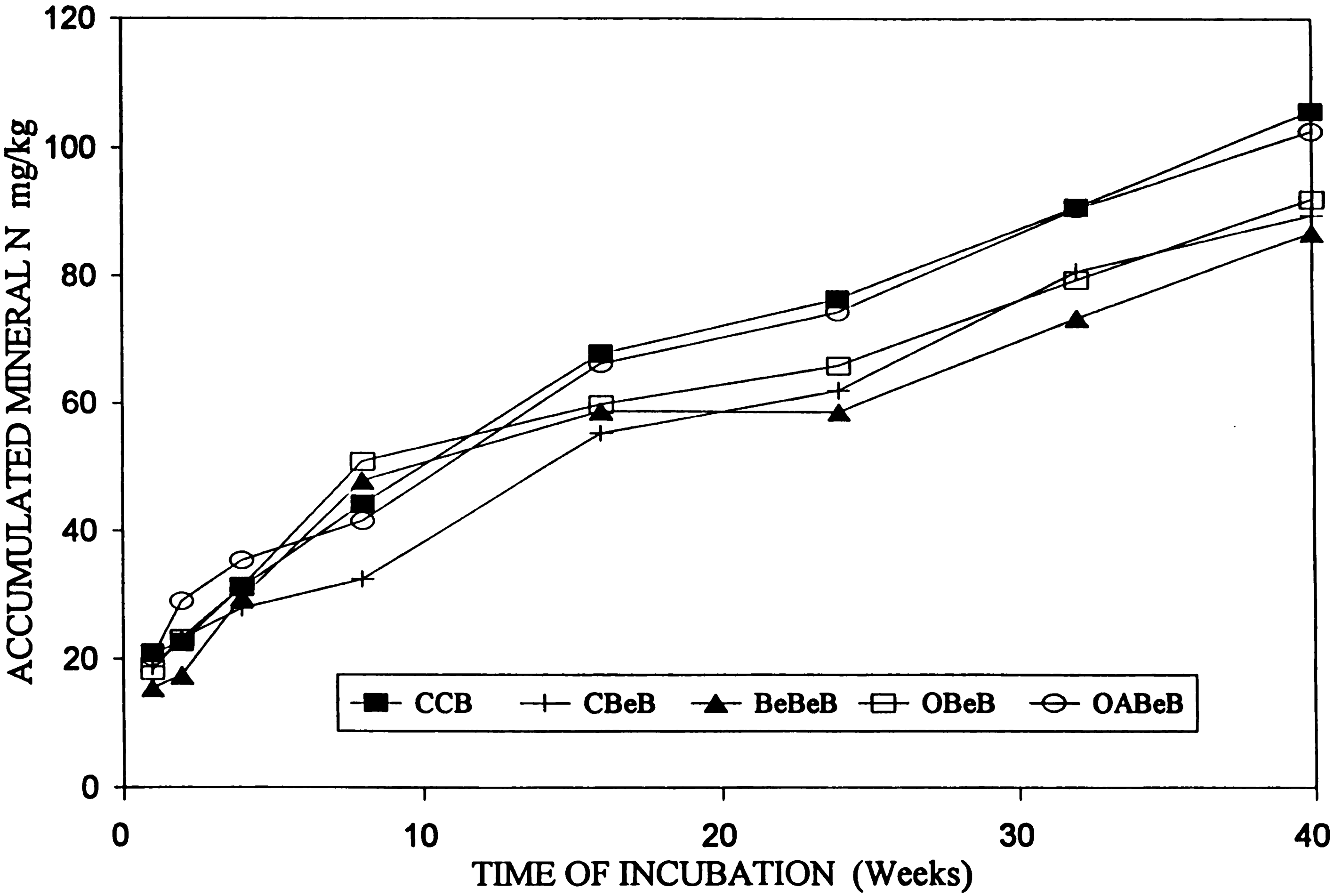

Figure 4. Cumulative N mineralized for five cropping systems from a study on a Misteguay silty clay soil for samples taken August 1993.

CHAPTER IV

Nitrogen Mineralization Potential of Soils from Michigan's Saginaw Valley and Thumb Region.

Nitrogen, an essential component of any crop production system, is under criticism for its potential hazard to our environment and secondly, for economic reasons due to increasing cost of fertilizer in many developing countries of the world. Efficient use of N fertilizer for crop production improves the economic returns to the producers and decreases the potential risk of polluting the environment especially water resources.

The most important aspect in efficient fertilizer use is the estimation of the amount of N fertilizer needed for the crop under a particular soil and environmental conditions. For an accurate estimate of the amount of fertilizer needed by the crop, one must know the amount of N supplied by the soil. The amount of N derived from the soil depends on the initial residual N present in the soil at planting and the mineralization of soil organic N through microbial decomposition of organic residues during crop growth (Cassman and Munns, 1980). Residual N can easily be measured as extractable NO_3-N and NH_4-N in soil, but N mineralized during the growing season, is difficult to estimate (Cabrera and Kissel, 1988; and Cassman and Munns, 1980).

One method which provides an estimate of N supplying power of soils was proposed by Stanford and co-workers (Stanford and Smith, 1972; Stanford et al. 1973; Stanford and Epstein, 1974) and has been used by many others (Smith et al., 1977; Herlihy, 1979; Stanford et al., 1977; Oyanedel and Rodriguez, 1977; Campbell and Souster, 1982; Griffin and Laine, 1983; Chae and Tabatabai, 1985; Bonde and Rosswall, 1987; Gharous et al., 1990; Campbell et al. 1991).

Stanford and Smith (1972) incubated soils under optimal conditions to determine the N mineralization potential (N_0) and rate constant (k) of soils. The N_0 values in this method are calculated based on the hypothesis that the rate of N mineralization is proportional to the quantity of N comprising the mineralizable substrate. It is estimated by an iterative statistical method from a first order rate equation. Nitrogen mineralization rate was correlated to the quantity of mineralizable N and the square root of time (Lindemann and Cardenas, 1984). However, N_0 values are affected by many complex interactions of soil biological, chemical and physical properties and environmental variables such as texture, organic matter, temperature and moisture (Campbell et al., 1981; Herlihy, 1979).

The effect of moisture on N-mineralization has been studied by many researchers and varying results have been reported. Miller and Johnson (1964) reported optimum moisture level to vary from -0.015 to -0.05 MPa while Stanford and Epstein (1974) found -0.01 to -0.033 MPa to be optimal. In other experiments, Cassman and Munns (1980), Chiang et al.(1983) and Myers et al. (1982) reported a moisture tension of 0.03 MPa for maximum mineralization rate.

Temperatures within the range that are normally encountered under field conditions have also been found to profoundly affect soil N mineralization. Cassman and Munns (1980) found the optimum temperature for N mineralization to be from 30 to 35 ^{0}C. In an other experiment, Stanford et al. (1973) found similar mineralization rates in different soils for each temperature studied in the range of 5 to 35 °C.

Soil texture has also been reported to affect the soil organic matter content and hence mineralizable and total N are subject to change too. Bremner (1965) reported that total N increased as texture became finer. Campbell and Souster (1982) and Herlihy (1979) also reported lower organic matter, potentially mineralizable N and the active N fraction in coarse textured soils.

The objective of this study was to determine the N mineralization potential, rate constant and instantaneous rate of reaction for a number of soils from Saginaw Valley and Thumb region of Michigan. Also exponential and hyperbolic models were compared to calculate N_0 and k values for each soil.

MATERIALS AND METHODS

Soils under Study

Michigan's Saginaw Valley and Thumb area consists of soils formed from glacial till parent material with pockets of lacustrine material and consists of soils with a range of physical, chemical and biological properties. The texture of soils range from very fine to medium and coarse material. Some physical and biological properties of these soils may have been affected by the kind and intensity of management including length of time under cultivation.

In this study 23 soils were selected representing 9 different soil series. The classification and selected physico-chemical properties of soils are given in Table 1.

Soil Sampling:

The soils used in this study were from the fields that were under fertilizer rate experiments during the years of 1989 to 1992. Soil samples were collected from the 0 to 20 cm depth in the control plot at planting time in spring. The samples were air dried, sieved through a 2-mm sieve and stored in air tight glass bottles.

Laboratory Incubation Study:

A modified aerobic incubation procedure based on the principles and methods outlined by Stanford and Smith (1972) and Campbell et al. (1992) was used to measure mineralizable N and mineralization rate constant. Ten g of air dried soil mixed with 20 g of acid washed quartz sand was incubated in small centrifuge tubes at 30 °C and 100% relative humidity. Moisture content was established at approximately -0.03 MPa by adding 5 ml of water to each tube. Moisture content was maintained by adding water to bring the tubes to the predetermined weights.

Soil in separate tubes was used for each incubation period of 0, 1, 2, 4, 8, 12, 20, 28, and 44 weeks. The tubes containing soils were arranged in the incubator in a randomized complete block design with four replications. Replications in the laboratory correspond to the respective replications from the field studies.

At the end of each incubation period the mineral N was extracted by shaking the soil in the tubes with 100 ml of M KCl (Bremner, 1965) for one hour on a mechanical shaker and filtering through rinsed Whatman no. 40 filter paper. The filtrate was analyzed for NO_2 plus NO_3 and NH_4 by using a flow-through injection system (Am. Public Health Assoc., 1981).

Total Nitrogen:

Total N in the soil was determined by the micro-Kjeldahl method described by Bremner (1965). One g of soil, ground to pass through a 0.25-mm sieve, was digested for 5 hours in 3 ml of concentrated H_2SO_4 containing 1.5 g K_2SO_4 + 15 mg Se. After cooling, each sample received 20 ml of water. Ammonia was released by alkaline distillation, collected in H_3BO_3 and titrated with standard sulfuric acid using methyl purple as the endpoint indicator.

Organic Carbon Determination:

Organic C was determined by Walkley-Black wet digestion with chromic acid method (Walkley and Black, 1934; Walkley, 1935, 1947). Ten ml of M $K_2Cr_2O_7$ were added to 1.5 g soil in a 500 ml Erlenmeyer flask followed by addition of 20 ml concentrated H_2SO_4. The sample was allowed to digest and cool for 30 minutes. Then 170 ml distilled water and 3 drops of ferrion (1,10-orthphenanthroline ferrous sulfate) were added and the sample was titrated to a maroon end point using 0.5 N $Fe(NH_4)_2(SO_4)_2$. Results of duplicate determinations were calculated as % organic C in air dry soil.

Calculations:

Two models were used to describe the data of this study. The first model utilized was the first-order exponential equation describing net N mineralization proposed by Stanford and Smith (1972):

$$N = N_0[1 - \exp(-kt)]$$

where N is mineralized N in time t, and N_0 and k are the N-mineralization potential and rate constant values.

The second model used was the hyperbolic equation proposed by Juma et al. (1984):

$$N = N_0 * t/(T_c + t)$$

In this equation T_c is the half time for mineralization and is related to the rate constant k by the following:

$$T_c = \ln 2/k$$

All other terms are as described above.

A Systat nonlinear least-squares regression program was used to evaluate N_0 and k in both models (Wilkinson, 1986).

RESULTS AND DISCUSSION

Table 1 contains total N and oxidizable C values for various soils used in this study. Kjeldahl N and oxidizable C values ranged from 0.9 to 5.2 and 7.10 to 58.1 g kg^{-1} respectively. Soils within the same series showed variation in total N and oxidizable C values, probably reflecting past soil and crop of these soils.

Nitrogen Mineralization

Cumulative N mineralized during a period of 44 weeks for various soils is shown graphically in Figures 1 - 8. The same general trend for cumulative mineralized N is shown for all soils. The rate of mineralization was rapid at first, then declined with the length of the incubation period. The quantity of mineral N produced during 44 weeks of incubation ranged from 59 to 161 mg kg^{-1} of soil. The lowest quantity was observed in Kilmanagh 1, while the greatest amount of mineral N produced was found in the Zilwaukee series.

The N_0 values (Table 2) obtained by the exponential model ranged from 68 to 167 mg kg^{-1} and from 90 to 212 mg kg^{-1} by the hyperbolic model. These values are equal to or slightly less than those obtained by Gharous et al., (1990) for 13 different soils from arid and semi-arid region of Morocco and the recalculated data of Stanford and Smith (1972) reported by Talpaz et al. (1981) for 39 different soils from the U.S. The highest value of 167 mg kg^{-1} and lowest value of 68 mg kg^{-1} were obtained in Zilwaukee and Kilmanagh 1 soils, respectively.

The differences in N_0 values were found not only among different soil series, but within the same series. N_0 ranged from 70 to 98 for the Tappan series and from 68 to 128 for the Kilmanagh series. These results ruled out the possibility of using single N_0 and k values for predicting N availability for all soils within one series.

The rate constant (k) value estimated by the exponential model ranged from 0.053 to 0.103 $week^{-1}$ while they ranged from 0.031 to 0.077 $week^{-1}$ when estimated with the hyperbolic model. The k values were not consistent within a soil series. The k values obtained using exponential model in this study are generally higher than those reported by

Stanford and Smith (1972). However, they are similar to those reported by Smith et al. (1980) and the recalculated data of Stanford and Smith (1972) reported by Talpaz et al. (1981), but are lower than those reported by Beauchamp et al. (1986). The reasons for these differences are not clear, but it might be the result of different types of soils and the duration of incubation period.

The *k* values obtained by hyperbolic model are within the same range as reported by Stanford and Smith (1972) and are much lower than those reported in Smith et al. (1980), Beauchamp et al. (1986) and recalculated values by Talpaz (1981). Based on the information available the reasons for these differences are not clear.

Exponential vs Hyperbolic Model

In this study, N_0 and *k* values were estimated by both exponential and hyperbolic model and were compared to see the differences between the two models. The N_0 values estimated by the hyperbolic model were higher in all cases than those estimated by the exponential model. Contrary to this, the *k* values estimated by the hyperbolic model were lower than those estimated by the exponential model.

The comparison between the two models can best be made using the instantaneous rate of reaction computed for each model. The instantaneous rate of reaction for exponential model was computed by the equation:

$$dN/dt = N_0\, k \exp(-kt)$$

while for hyperbolic model it was computed as:

$$dN/dt = N_0\, T_c/(T_c + t)^2$$

The instantaneous rates of reaction computed by the two equations for each soil are highly correlated for each period of incubation with linear coefficients of determination (r^2) ranging from 0.86 to 0.99 (Table 3). These high r^2 values are evidence that both models can be used in laboratory incubation studies to estimate N_0 and k values of the soils. Similar results were obtained by Gharous et al. (1990) when they used both models and compared instantaneous rates of reaction. Our results supported the earlier reports that both exponential and hyperbolic models can be used to estimate reliable N_0 and k values in soils if a nonlinear least squares fitting technique is used.

The Active Nitrogen Fraction

The active N fraction is considered the portion of organic matter that supplies a major part of the plant available nitrogen for crop growth. It is represented by N_0/N_t where, N_t is total N concentration of soil. In this study the active N fraction values ranged from 3 to 11 % and from 4 to 14 % for exponential and hyperbolic models respectively (Table 2). The highest value was observed for the Capac 3 soil and lowest for Zilwaukee soil.

The data indicated that, even though different types of soils showed differences in the active N fraction, soils in the same series were generally similar. This is opposed to the N_0 values which were significantly different from each other for different soils belonging to the same series.

CONCLUSIONS

N availability index for plants is not as simple as developing the plant available P index from soil testing. The C/N ratio has been used to predict N availability, and it has generally been reported that C/N ratio of the decomposing materials should be below 20 to 25 to obtain appreciable net mineralization (Harmsen and Kolenbrander, 1965). There is one weakness in this assumption that stable organic fractions are relatively resistant to decomposition and the general rule that net mineralization of organic N depends primarily on N content of the substrate holds true only for readily mineralizable part of the decaying materials.

Since C/N ratio and total N content of soil have certain limitations, to be successful indices for available N, N_0 and *k* values would be a better index for providing estimates of the N supplying power of soils. But N_0 and k values also have certain disadvantages for successful use in soil management and crop production system. One major limitation is the time required is so great that it can not be used in a routine soils analyses program. Another limitation is that laboratory incubation does not account for environmental effects. Variation in temperature and moisture under field conditions are not duplicated in the laboratory. For more successful use of incubation procedures, it is important to include field calibration of the estimates of N_0 values. However, the laboratory incubation procedure does provide information concerning the mineralization characteristics of each soil/management system. Further studies are needed for the field calibration of laboratory generated N_0 estimates.

LIST OF REFERENCES

American Public Health association. 1980. Standard methods for examination of water and waste water, 1981. 15th ed. Am. Public Health Assoc., Washington, DC.

Beauchamp E.G., W.D. Reynolds, D. Brasche-Villeneuve, and K. Kirby. 1986. Nitrogen mineralization kinetics with different soil pretreatment and cropping histories. Soil. Sci. Soc. Am. J. 50:1478-1483.

Bonde, T.A., and T. Rosswall. 1987. Seasonal variation of potentially mineralizable nitrogen in four cropping systems. Soil. Sci. Soc. Am. J. 51:1508-1514.

Bremner, J.M. 1965a. Organic nitrogen in soils. *In* W. V. Bartholomew and F. E. Clark (ed.) Soil nitrogen. Agronomy 10:93-149. Am. Soc. Agron., Inc., Madison, Wis.

Bremner, J.M. 1965b. Nitrogen availability indexes. *In* C. A. Black et al. (ed.) Methods of soil analysis, Part 2. Agronomy 9:1324-1345. Am. Soc. Agron., Madison, Wis.

Bremner, J.M. 1965b. Total nitrogen. *In* C. A. Black et al. (ed.) Methods of soil analysis, Part 2. Agronomy 9:1149-1176. Am. Soc. Agron., Madison, Wis.

Cabrera, M.L. and D.E. Kissel. 1988. Evaluation of a method to predict nitrogen mineralization from soil organic matter under field conditions. Soil Sci. Soc. Am. J. 52:1027-1031.

Campbell, C.A., and W. Souster. 1982. Loss of organic matter and potentially mineralizeable nitrogen from Saskatchewan soils due to cropping. Can. J. Soil Sci. 62:651-655.

Campbell, C.A., R.J.K. Myers, and K.L. Weier. 1981. Potentially mineralizable nitrogen, decomposition rates and their relationship to temperature for five Queensland soils. Aust. J. Soil Res. 19:323-332.

Campbell, C.A., G.P. Lafond, A.J. Leyshon, R.P. Zentner, and H.H. Janzen. 1991. Effect of cropping practices on the initial potential rate of N mineralization in a thin Black Chernozem. Can. J. Soil Sci. 71: 43-53.

Campbell, C.A., B.H. Ellert, and Y.W. Jame. 1992. Nitrogen mineralization potential in soils. *In* Soil sampling and methods of analysis. M.R. Carter (ed.) Can. Soc. Soil Sci. 341-349.

Cassman, K.G., and D.N. Munns. 1980. Nitrogen mineralization as affected by soil moisture and depth. Soil. Sci. Soc. Am. J. 44:1233-1237.

Chae, Y.M., and M.A. Tabatabai. 1986. Mineralization of nitrogen in soils amended with organic wastes. J. Environ. Qual. 15:193-198.

Chiang, C., B. Soudi, and A. Moreno. 1983. Soil nitrogen mineralization and nitrification under Moroccan conditions. *In* Nutrient balance and the need for fertilizers in semiarid and arid regions. Proc. Colloq. Int. Potash Inst., 17:77-87.

Gharous, R.L., R.L. Westerman, and P.N. Soltanpour. 1990. Nitrogen mineralization potential of arid and semiarid soils of Morocco. Soil Sci. Soc. Am. J. 54:438-443.

Griffin, G.F., and A.F. Laine. 1983. Nitrogen mineralization in soils previously amended with organic wastes. Agron. J. 75:124-129.

Harmsen. G.w., and G.J. Kolenbrander. 1965. Soil inorganic nitrogen. *In* W.V. Bartholomew and F.E. Clark (ed.), Soil nitrogen. Agronomy 10:43-92. Am. Soc. Agron. Madison, WI.

Herlihy, M. 1979. Nitrogen mineralization in soils of varying texture, moisture and organic matter. I. Potential and experimental values in fallow soils. Plant Soil 53:255-267.

Juma, N.G., E.A. Paul, and B. Mary. 1984. Kinetic analysis of net nitrogen mineralization in soil. Soil Sci. Soc. Am. J. 48:753-757.

Lindemann, W.C., and M. Cardenas. 1984. Nitrogen mineralization potential and nitrogen transformations of sludge-amended soils. Soil Sci. Soc. Am. J. 48:1072-1077.

Miller, R.D., and D.D. Johnson. 1964. The effects of soil moisture tension on carbon dioxide evolution, nitrification, and nitrogen mineralization. Soil Sci. Soc. Am. Proc. 28:644-647.

Myers, R.J.K., C.A. Campbell and K.L. Weier. 1982. Quantitative relationship between net nitrogen mineralization and moisture content of soils. Can.J. Soil Sci. 62:111-124.

Smith J.A., L.B. Young, and G.E. Miller. 1977. Evaluation of soil nitrogen mineralization potential under modified field conditions. Soil Sci Soc. Am. J. 41:74-76.

Smith. J.L., R.R. Schnabel, B.L. McNeal, and G.S. Campbell. 1980. Potential errors in the first-order model for estimating soil nitrogen mineralization potentials. Soil Sci. Soc. Am. J. 44:996-1000.

Stanford, G., J.N. Carter, D.T. Westermann, and J.J. Meisinger. 1977. Residual nitrate and mineralizable soil nitrogen in relation to nitrogen uptake by irrigated sugarbeets. Agron. J. 69:303-308.

Stanford, G., and E. Epstein. 1974. Nitrogen mineralization-water relations in soils. Soil Sci. Soc. Am. Proc. 38:103-108.

Stanford, G., N.J. Carter, and S.J. Smith. 1974. Estimates of potentially mineralizable soil nitrogen based on short-term incubation. Soil Sci. Soc. Am. Proc. 38: 99-102.

Stanford G., and S.J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. Proc. 36:465-472.

Stanford, G., and S.J. Smith. 1976. Estimating potentially mineralizable soil nitrogen from chemical index of soil nitrogen availability. Soil Sci. 122: 71-76.

Stanford, G., J.O. Legg, and S.J. Smith. 1973. Soil N availability evaluations based on nitrogen mineralization potentials of soils and uptake of labeled and unlabeled N by plants. Plant Soil 39:113-124.

Talpaz, H., P. Fine, and B. Bar-Yasef. 1981. On the estimation of the N-mineralization parameters from incubation experiments. Soil Sci. Soc. Am. J. 45:993-996.

Walkley, A., and I.A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a modification of the chromic acid titration method. Soil Sci. 37:29-38.

Walkley, A., 1935. An estimation of methods for determining organic carbon and nitrogen in soils. J. Agric. Sci. 25:588-609.

Walkley, A. 1947. A critical examination of a rapid method for determining organic carbon in soils-effect of variation in digestion condition and of inorganic soil constituents. Soil Sci. 63:251-264.

Wilkinson, L.S. 1986. The system for statistics. Systat, Inc., Evanston, IL.

Table 1 Soil series, sub-order, total N, oxidizable C, particle size analysis and previous crop for soils used in the incubation study.

Soil Series	Sub order	Previous Crop	Total N	Oxid. C	Sand	Clay
			----------g kg^{-1}			--------
Tappan 1	Typic Haplaquolls	-	1.3	9.95	490	260
Tappan 2		drybean	1.3	12.0	580	160
Tappan 3		navybean	1.2	11.1	600	190
Tappan 4		corn	1.4	11.8	460	260
Tappan 5		corn	0.9	8.96	620	180
Londo 1	Aeric glossaqualfs	-	1.3	9.99	460	240
Londo 2		-	1.2	10.1	440	300
Londo 3		-	1.5	13.6	490	220
Kilmanagh 1	Aeric Haplaquepts	drybean	0.7	5.47	720	130
Kilmanagh 2		drybean	1.3	10.3	600	150
Kilmanagh 3		drybean	1.6	13.7	470	240
Kilmanagh 4		navybean	1.1	8.52	610	170
Shebeon 1	Aeric Ochraqualfs	-	0.9	7.10	590	200
Shebeon 2		-	1.5	13.2	470	220
Grindstone	Glossaquic Hapludalfs	-	0.9	7.40	500	230
Parkhill 1	Mollic Haplaquepts	wheat	1.2	11.0	540	170
Parkhill 2		soybean	1.5	12.5	500	220
Parkhill 3		wheat	1.4	14.7	430	220
Capac 1	Aeric Ochraqualfs	-	2.4	18.9	300	380
Capac 2		-	1.1	8.70	480	190
Capac 3		-	1.1	8.86	570	160
Zilwaukee	Typic Haplaquolls	-	5.2	58.1	240	340
Sloan	Fluvaquentic Haplaquolls	soybean	1.7	11.1	280	210

Table 2. N mineralization potential (N_0), rate constant (*k*) and active N fraction for soils from the Saginaw Valley and Thumb region of Michigan.

Soil	Exponential Model		Hyperbolic Model		Active N fraction	
Series	N_0	*k*	N_0	*k*	Exp.	Hyp.
	mg k^{-1}	week^{-1}	mg kg^{-1}	week^{-1}	--------%-------	
Tappan 1	87.1	0.075	110	0.054	6.70	8.45
Tappan 2	97.7	0.064	130	0.040	7.51	10.0
Tappan 3	81.2	0.058	111	0.034	6.77	9.29
Tappan 4	98.9	0.055	134	0.034	7.07	9.53
Tappan 5	70.7	0.053	99.5	0.031	7.86	11.1
Londo 1	96.8	0.078	125	0.052	7.45	9.61
Londo 2	82.4	0.082	105	0.058	6.86	8.74
Londo 3	88.4	0.074	114	0.050	5.89	7.62
Kilmanagh 1	68.1	0.058	97.0	0.032	9.72	13.9
Kilmanagh 2	111	0.079	142	0.054	8.54	10.9
Kilmanagh 3	128	0.059	173	0.038	8.02	10.8
Kilmanagh 4	90.3	0.069	123	0.043	8.21	11.2
Shebeo 1	70.6	0.088	89.8	0.061	7.84	9.98
Shebeon 2	98.4	0.070	128	0.046	6.56	8.50
Grindstone	87.2	0.075	111	0.052	9.69	12.3
Parkhill 1	83.5	0.064	111	0.039	6.96	9.27
Parkhill 2	110	0.074	145	0.045	7.31	9.69
Parkhill 3	115	0.068	140	0.051	8.20	9.98
Capac 1	111	0.101	136	0.076	4.61	5.66
Capac 2	104	0.086	130	0.062	9.47	11.9
Capac 3	119	0.074	154	0.049	10.8	14.0
Zilwaukee	167	0.079	213	0.057	3.23	4.11
Sloan	105	0.103	128	0.077	6.15	7.50
LSD (0.05)	16.7	N.S.	26.5	0.024	-	-

Table 3. Comparison of the instantaneous rate of reaction for the exponential and hyperbolic models at various incubation periods using linear regression on soil samples taken from N studies on 23 sites from 1991 through 1993 representing soil series in the Saginaw Valley and Thumb region of Michigan.

Soil	1		2		4		8	
Series	Exp.	Hyp.	Exp.	Hyp	Exp.	Hyp.	Exp.	Hyp.
	mg N kg^{-1} wk^{-1}							
Tappan 1	6.04	7.36	5.61	6.40	4.83	4.97	3.58	3.25
Tappan 2	5.86	6.67	5.50	6.00	4.84	4.93	3.75	3.50
Tappan 3	4.43	4.90	4.18	4.48	3.72	3.78	2.95	2.80
Tappan 4	5.15	5.87	4.87	5.36	4.37	4.53	3.50	3.35
Tappan 5	3.55	4.08	3.37	3.75	3.03	3.20	2.45	2.41
Londo 1	6.99	8.14	6.46	7.11	5.53	5.56	4.05	3.67
Londo 2	6.19	7.42	5.70	6.40	4.85	4.91	3.50	3.14
Londo 3	6.06	7.11	5.63	6.25	4.85	4.94	3.61	3.30
Kilmanagh 1	3.71	4.12	3.50	3.78	3.12	3.21	2.48	2.40
Kilmanagh 2	8.13	9.44	7.51	8.22	6.41	6.40	4.67	4.19
Kilmanagh 3	7.11	8.51	6.70	7.69	5.96	6.37	4.71	4.57
Kilmanagh 4	5.78	6.71	5.40	6.00	4.71	4.88	3.58	3.40
Shebeon 1	5.70	6.63	5.22	5.68	4.38	4.31	3.07	2.72
Shebeon 2	6.42	7.48	5.99	6.62	5.21	5.30	3.93	3.62
Grindstone	6.03	7.14	5.60	6.25	4.82	4.89	3.58	3.23
Parkhill 1	4.98	5.58	4.67	5.03	4.11	4.15	3.19	2.97
Parkhill 2	7.56	8.36	7.02	7.42	6.05	5.96	4.50	4.09
Parkhill 3	7.27	8.84	6.79	7.75	5.93	6.10	4.52	4.06
Capac 1	10.1	12.1	9.09	10.0	7.44	7.21	4.98	4.23
Capac 2	8.20	9.82	7.53	8.39	6.34	6.32	4.50	3.96
Capac 3	8.19	9.55	7.61	8.40	6.56	6.64	4.88	4.45
Zilwaukee	12.1	15.0	11.2	12.9	9.59	9.92	7.00	6.37
Sloan	9.66	11.5	8.72	9.51	7.11	6.80	4.72	3.97
r^2	0.98		0.98		0.98		0.96	

Table 3. (continued)

Soil series	12		20		28		44	
	Exp.	Hyp.	Exp.	Hyp	Exp.	Hyp.	Exp.	Hyp.
	----------	----------	----------	-------mg N kg^{-1} wk^{-1}	----------	----------	----------	----------
Tappan 1	2.66	2.28	1.46	1.31	0.80	0.85	0.24	0.44
Tappan 2	2.90	2.62	1.74	1.62	1.04	1.10	0.37	0.60
Tappan 3	2.35	2.16	1.48	1.39	0.93	0.97	0.37	0.55
Tappan 4	2.81	2.58	1.81	1.67	1.17	1.16	0.48	0.66
Tappan 5	1.98	1.88	1.30	1.24	0.85	0.88	0.36	0.51
Londo 1	2.96	2.60	1.59	1.50	0.85	0.97	0.24	0.51
Londo 2	2.52	2.18	1.32	1.23	0.69	0.79	0.19	0.40
Londo 3	2.69	2.37	1.49	1.38	0.83	0.91	0.25	0.48
Kilmanagh 1	1.97	1.86	1.24	1.21	0.78	0.85	0.31	0.49
Kilmanagh 2	3.40	2.95	1.80	1.69	0.96	1.10	0.27	0.57
Kilmanagh 3	3.73	3.44	2.33	2.15	1.46	1.47	0.57	0.81
Kilmanagh 4	2.72	2.51	1.57	1.53	0.91	1.02	0.30	0.55
Shebeon 1	2.16	1.87	1.07	1.04	0.53	0.66	0.13	0.33
Shebeon 2	2.97	2.62	1.70	1.56	0.97	1.03	0.32	0.55
Grindstone	2.66	2.30	1.46	1.33	0.81	0.86	0.24	0.45
Parkhill 1	2.47	2.23	1.49	1.39	0.90	0.94	0.32	0.52
Parkhill 2	3.34	2.98	1.85	1.78	1.02	1.19	0.31	0.63
Parkhill 3	3.45	2.90	2.01	1.69	1.17	1.10	0.39	0.58
Capac 1	3.33	2.78	1.49	1.46	0.67	0.90	0.13	0.44
Capac 2	3.19	2.71	1.61	1.50	0.81	0.95	0.21	0.48
Capac 3	3.63	3.19	2.01	1.87	1.11	1.23	0.34	0.64
Zilwaukee	5.12	4.43	2.73	2.50	1.46	1.60	0.42	0.82
Sloan	3.13	2.60	1.38	1.36	0.61	0.84	0.12	0.41
r^2	0.96		0.96		0.90		0.74	

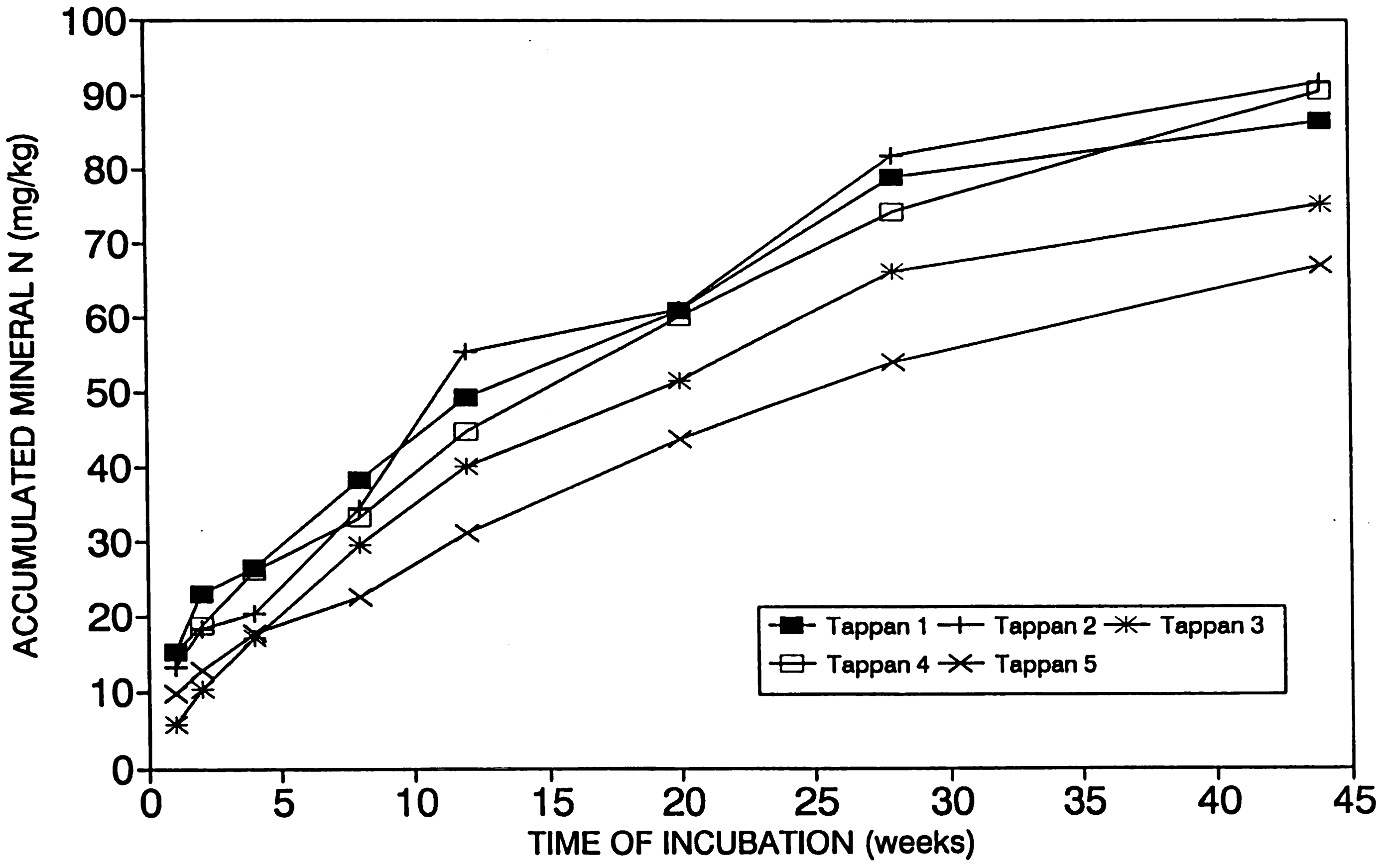

Figure 1. Cumultive N mineralized for 5 Tappan soils.

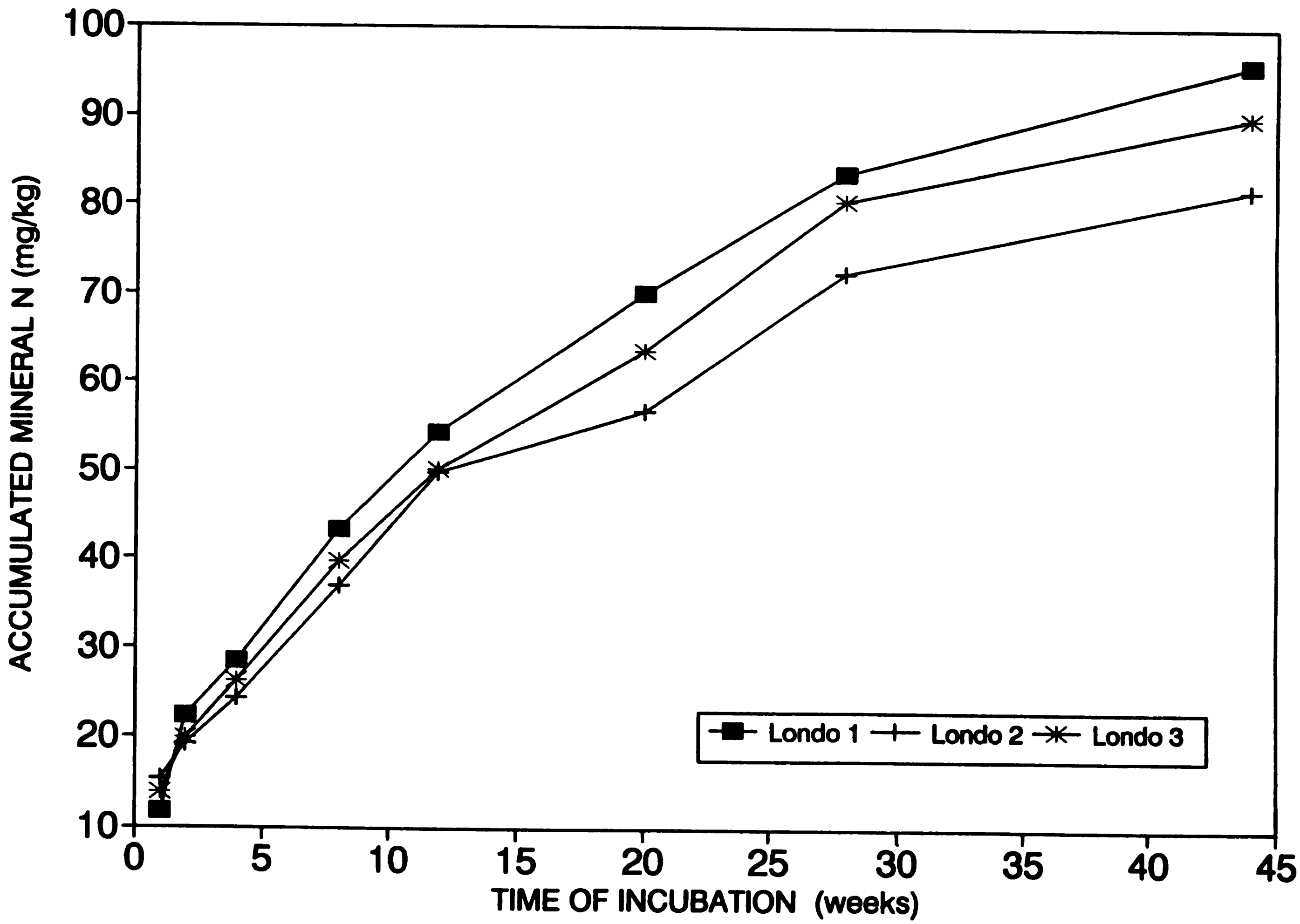

Figure 2. Cumulative N mineralized for 4 Londo soils.

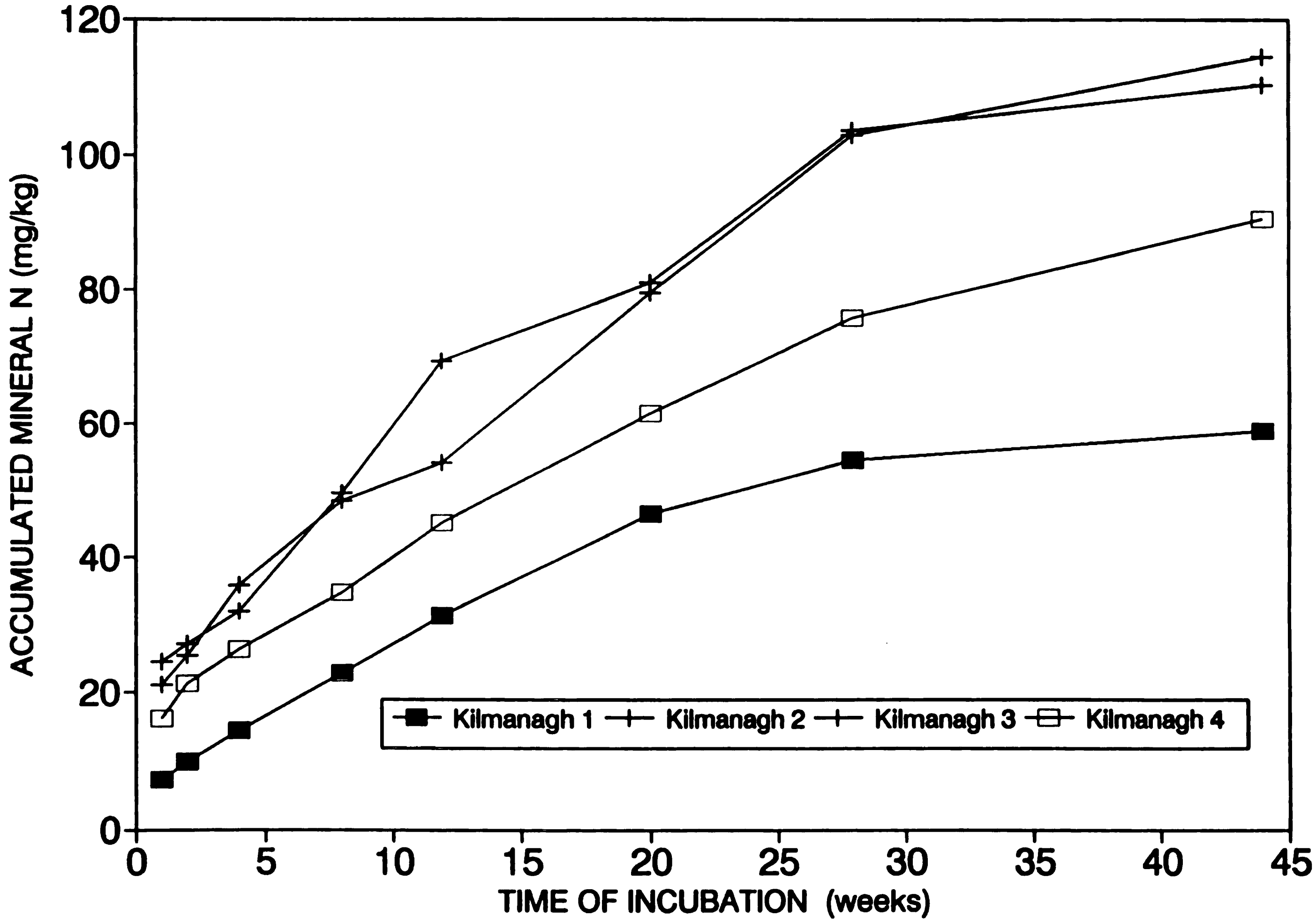

Figure 3. Cumulative N mineralized for 4 Kilmanagh soils.

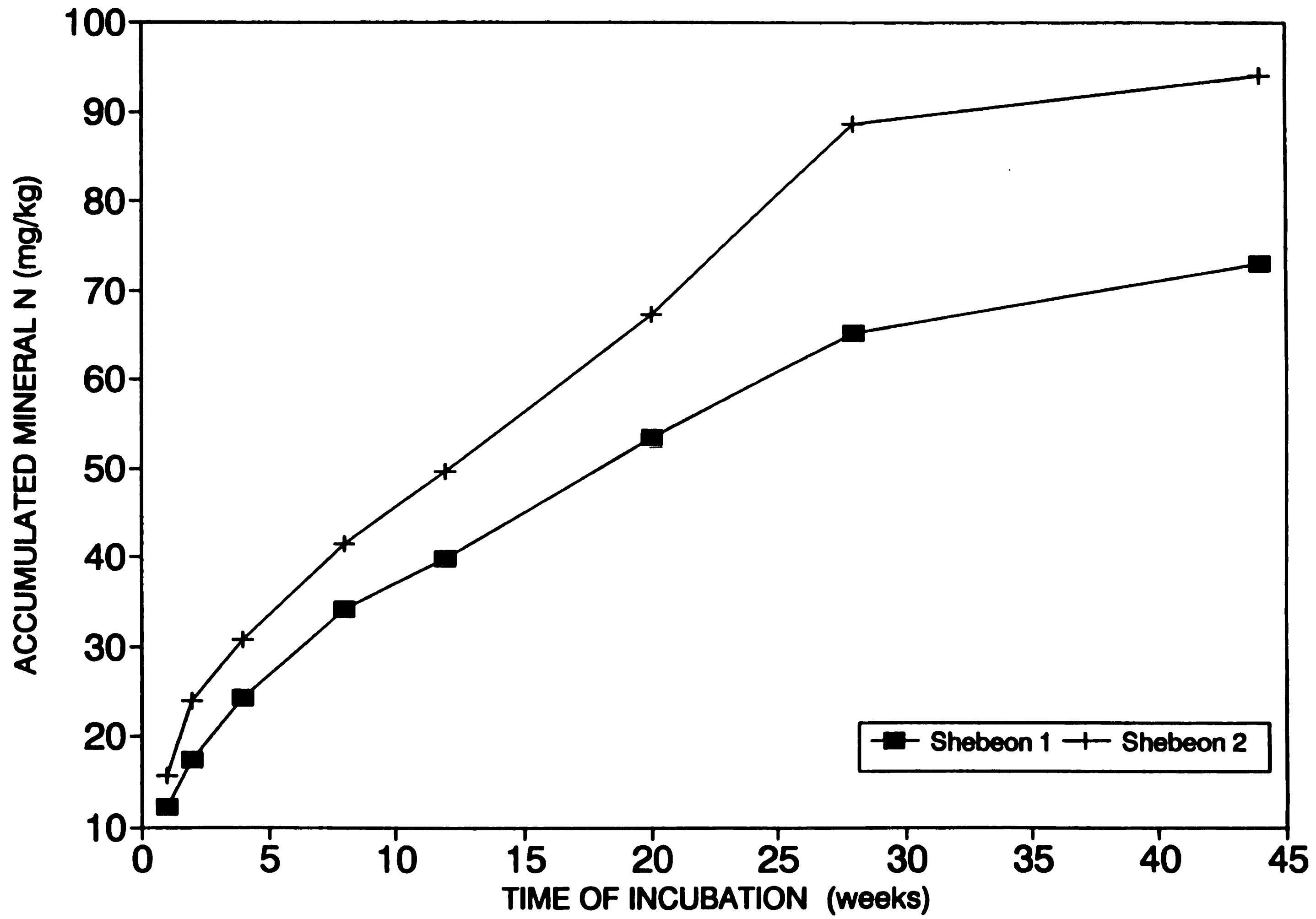

Figure 4. Cumulative N mineralized for 2 Shebeon soils.

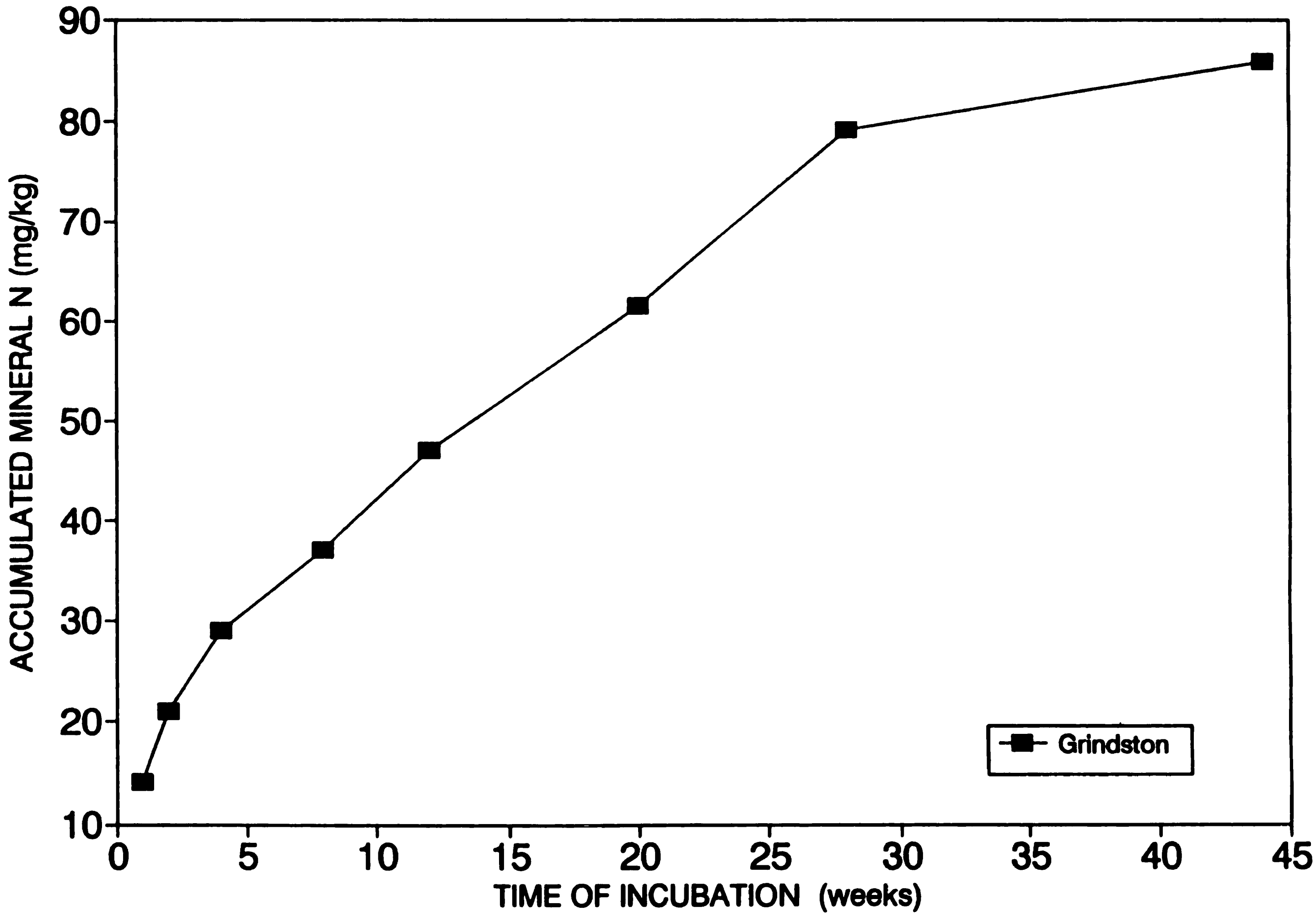

Figure 5. Cumulative N mineralized for a Grindston soil.

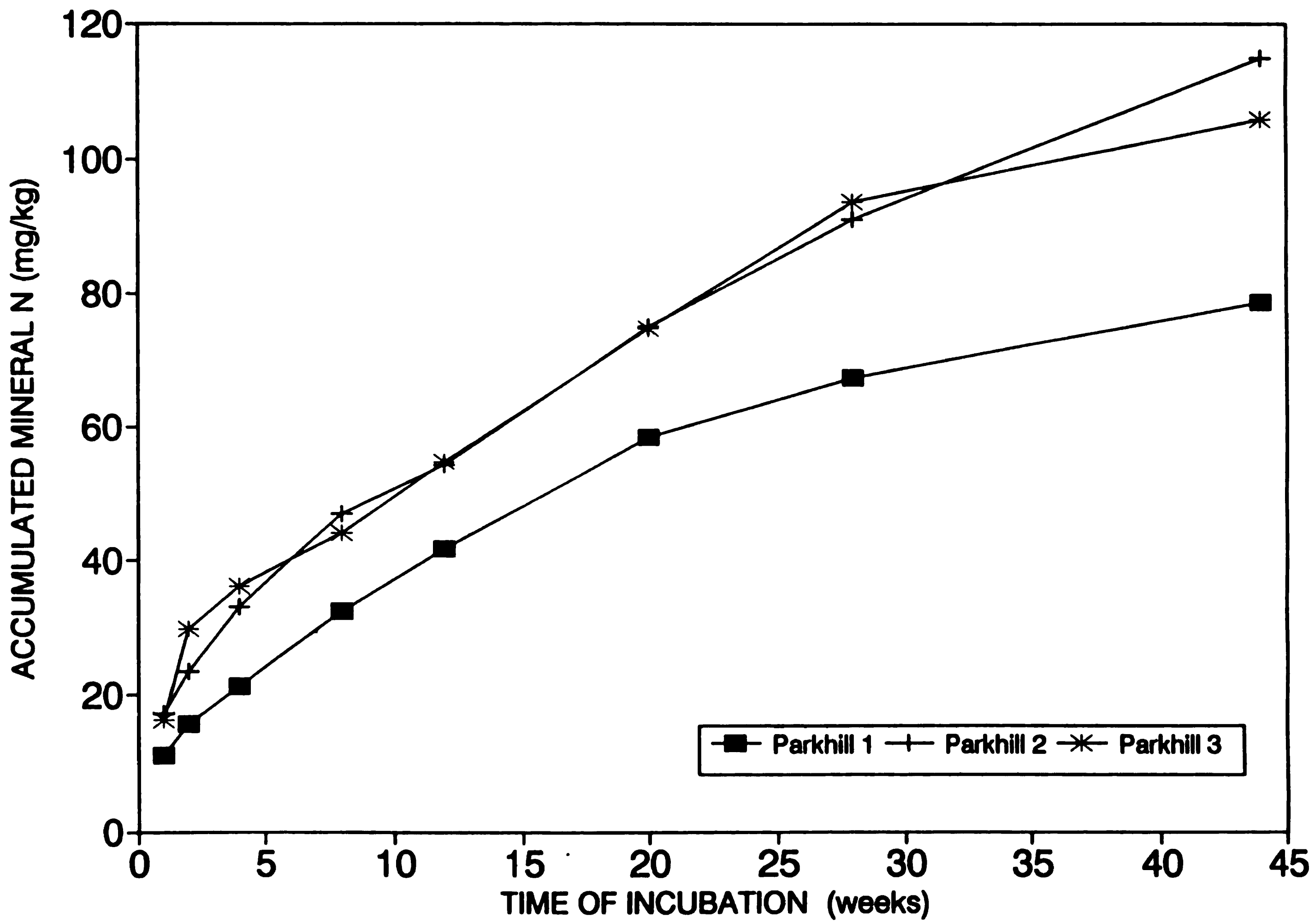

Figure 6. Cumulative N mineralized in 3 Parkhill soils.

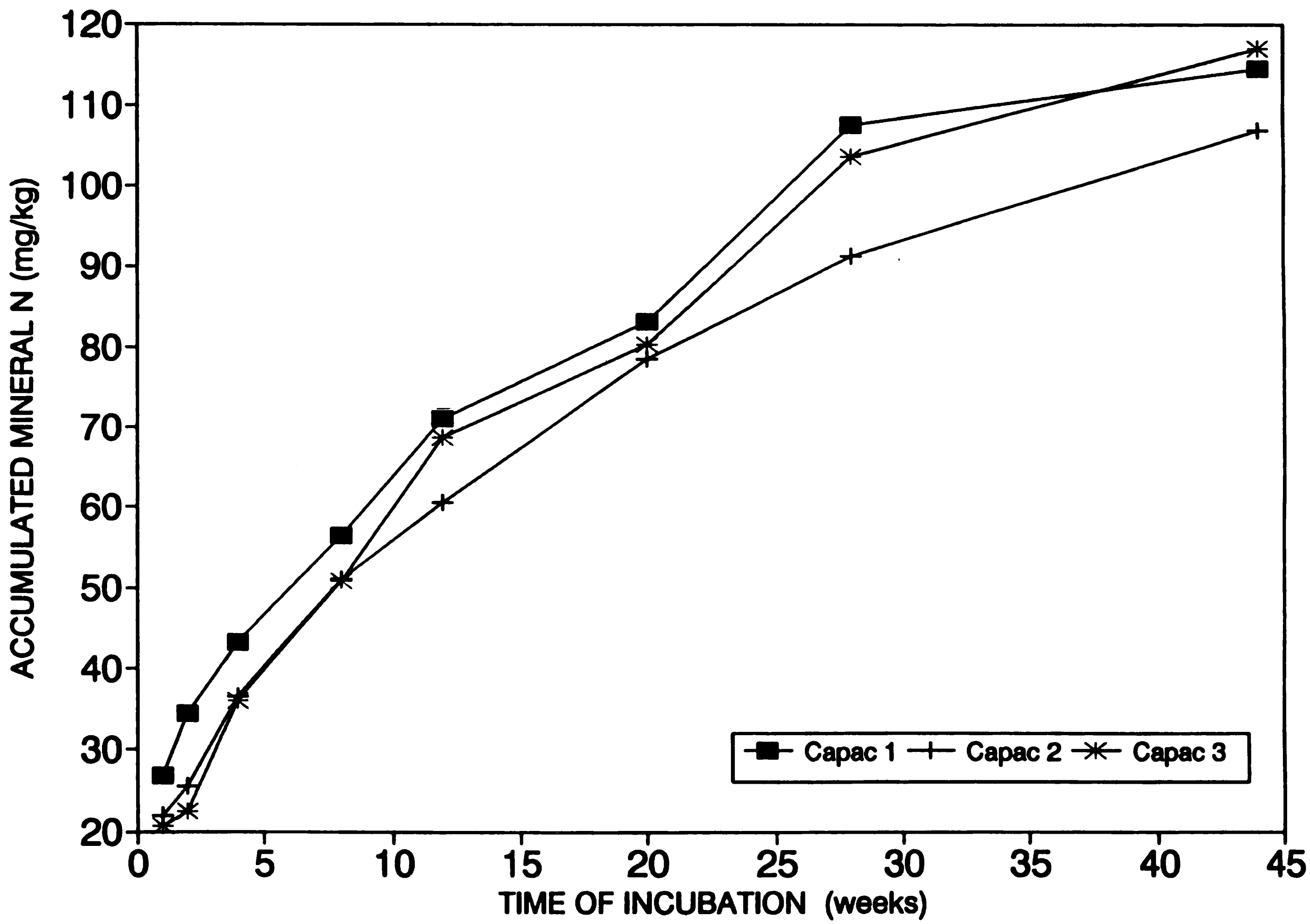

Figure 7. Cumulative N mineralized in 3 Capac soils.

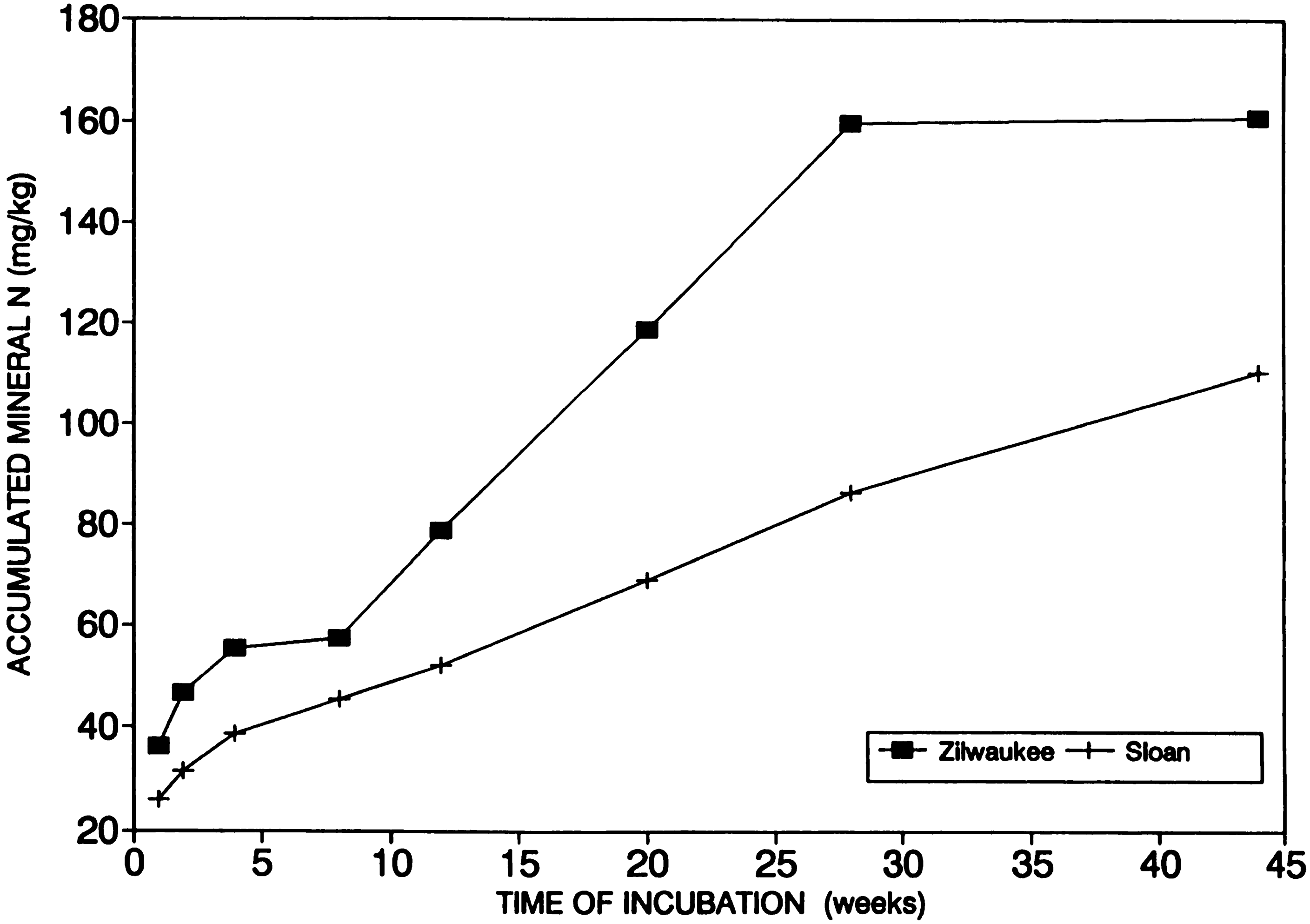

Figure 8. Cumulative N mineralized in a Zilwaukee and a Sloan soil.

CHAPTER V

Sugarbeet Yield and Quality as Affected by N Fertilizer, Soil Type and Cropping System.

Farmers and researchers have always shown an interest in crop rotations as a management tool. In the past this interest had resulted because of a lack of or increased cost of inorganic N fertilizer and reduced yield in monoculture (Varvel and Peterson, 1990). In many industrialized countries inorganic nitrogen fertilizers are not expensive, but increased concerns of environment and water pollution have increased the interest in crop rotation as an attractive means to reduced use of chemical fertilizer (Keeney, 1982).

Although the beneficial effects of crop rotation have been well documented, the increased need for food and every day changing economics of crop production requires a continuous evaluation of the contribution of crop rotation and adaptation of other management strategies for optimum crop production. One of these management practices is the use of fertilizer N along with crop rotation to fulfill the gap between crop fertilizer N requirements and amount of N available from the previous crop in the sequence.

Optimum and economic crop production without polluting the environment requires an accurate estimate of the fertilizer N required. It is especially true for the crops like sugarbeet which requires more precise information for N fertilizer management (Carter et al., 1975). Inadequate N availability limits plant growth and root yield, but over fertilization of sugarbeet with N reduces both sucrose percentage and recoverable sucrose (Hills and Ulrich, 1971). Also, excess N may stimulate more leaf growth than necessary, could be lost by leaching into ground water on sandy soils, or be lost through denitrification.

The beneficial effects of crop rotation over monoculture are mainly related to inclusion of legumes or high residue producing crops in the sequence. Rotation plays an important role in the maintenance of soil fertility (Gakale and Clegg, 1987; Clegg, 1982; Zielke and Christenson, 1986; Roder et al., 1988), improvement of soil physical properties (Fahad et al., 1982), reduction of pathogens (Cook, 1984) and control of soil erosion (Mannering et al., 1968). Large increases in yield of various crops due to rotations have been reported by many researchers (Clegg, 1982; Gakale and Clegg, 1987; Johnson, 1987; Peterson and Varvel, 1989; Roder et al., 1989; Bundy et al., 1993). In Michigan, researchers also reported increased sugarbeet yield due to rotation especially when legumes were included in the sequence (Cook et al., 1946; Robertson et al., 1967 and 1977; Christenson, 1989; Christenson et al., 1991).

In the sugarbeet growing area of Michigan, there is a wide diversity of soils and farm management practices. The latter includes growing legumes in rotation, returning varying amounts of crop residues due to the length of rotation and mix of crops, and application of animal manure. In view of this diversity it is necessary to know the N fertilizer response under varying soil and crop management conditions.

The objective of this experiment was to study the effects of N fertilizer, cropping system and soil type on sugarbeet yield and quality.

MATERIALS AND METHODS

Field Study

Two series of field studies were conducted to evaluate the effect of N rate on yield and quality of sugarbeet. The first study was conducted on a Misteguay silty clay soil (Aeric Haplaquept) in 1992 and 1993 to evaluate various cropping systems with respect to response to applied N for sugarbeet. This study compares five selected systems from a long term experiment that was initiated in 1972 and arranged as randomized complete block design with four replications. The five systems considered as treatments are as follows: Corn-corn-sugar beet (CCB), corn-navy bean-sugar beet (CBeB), navy bean-navy bean-sugar beet (BeBeB), oat-navy bean-sugar beet (OBeB) and oat-alfalfa-navy bean-sugar beet (OABeB). All crops were grown every year using the recommended cultural practices. Details of this long term rotation study are described by Christenson et al. (1991).

Each treatment plot was divided into four sub-plots and N fertilizer was broadcasted at planting at rates of 0, 45, 90 and 135 kg N ha^{-1}. Sugarbeets were planted in a 71 cm row spacing in the last week of April and were thinned to 20 cm between plants approximately five weeks after planting. In the last week of October the sugar beets were defoliated with a beater/topper and mechanically harvested. Yields were estimated by weighing the beets harvested from a two-10 meter rows. Twenty average size beet roots were selected from each plot. These beets were sliced and the juice extracted from the resulting pulp was immediately frozen. The analysis of variance was calculated utilizing a split plot design with cropping system as the main plot and nitrogen rate as the sub-plot.

The second study consisted of a series of fertilizer N trials at 13 different locations in the Saginaw Valley and Thumb area of Michigan. The details of the soil type and classification are given in Table 1. Sugarbeet was planted at these locations during the years of 1991, 1992 and 1993. Nitrogen was broadcasted at planting at the rate of 0, 45, 78, 112, and 146 kg N ha^{-1}. Beets were harvested mid- to late-October determining yield and quality in a manner similar to the cropping system experiment. Each experiment was replicated four times. A combined analysis of variance was calculated, treating locations as the main plot and N rate as sub-plot.

Plant Tissue Collection:

Twenty leaf blades (youngest mature leaves) were collected approximately 12 weeks after planting. The samples were dried, ground and saved for analysis.

Laboratory Analysis:

1. Total Nitrogen in Leaves

Total N of the plant was determined by the micro-Kjeldahl method described by. Two hundred mg of ground plant tissue, was digested for 5 hours in 3 ml of concentrated H_2SO_4 containing 1.5g K_2SO_4 + 15mg Se. After cooling each sample received 20 ml of distilled water. Ammonia was released by alkaline distillation, collected in H_3BO_3 and titrated with standard sulfuric acid using methyl purple as the endpoint indicator.

2. Sugarbeet Quality Analysis

The frozen juice collected from beet roots was analyzed by the Michigan Sugar Company Agriculture Research Laboratory for clear juice purity and sucrose content according to the methods described by Dexter et al. (1967), and Caruthers and Oldfield (1961), respectively.

RESULTS AND DISCUSSION

Effect of Cropping System and N Fertilizer Rate on Sugarbeet Yield and Quality.

The effect of cropping systems and N fertilizer rates on sugar beet yield parameters were studied in this experiment. Recoverable white sugar per hectare (RWSH) is one parameter used to estimate the yield of sugarbeet crop. Tables 2 and 3 show the effects of cropping system and N rate on RWSH in 1992 and 1993. The cropping system by N rate interaction was not significant in either year. Significant effects of cropping system and N rate were found in both years. Among the cropping systems OABeB gave the highest RWSH in both years, while CCB and CBeB during 1992 and 1993, respectively, were the lowest. In 1993 N rate greater than 90 kg N ha^{-1} did not show any response. However, in 1992 a yield response was observed up to 135 kg N ha^{-1} even though there was not significant a difference between 90 and 135 kg N ha^{-1}.

The yield of beet roots is given in Tables 4 and 5 for 1992 and 1993 crops. The cropping system by N rate interaction was not significant in either year. However, significant differences for simple effects of cropping system and nitrogen rate were found in both years. Among the cropping systems the highest yield (64.7 Mg ha^{-1}) was observed for OABeB system, while the lowest yield (45.1 Mg ha^{-1}) was obtained in CBeB system. The systems that produced the highest and the lowest yields of beets were same for both years. The cropping systems can be ranked as follows with respect to significant differences of yield: OABeB = CCB > BeBeB = OBeB = CBeB for 1992 and OABeB > OBeB = BeBeB = CCB > CBeB for 1993.

The simple effects of N rate on beet yield showed that crop responded to applied N significantly up to the highest rate (135 kg ha^{-1}) during 1992 and up to 90 kg N ha^{-1} during 1993. There was more rainfall in 1993 than in 1992 during May and June (Table 6). The fertilizer was applied in mid-May both years, so the difference in response is not related to differences in rainfall immediately after application. Greater denitrification would be expected in 1993 than in 1992 with potentially wetter soils. The accumulation in growing degree days is similar both years. The greater response to applied nitrogen in 1992 could be explained if nitrate nitrogen were present in the soil in July. There could possibly be more denitrification this year than in 1993 because of the greater rainfall. Unpublished data show there can be large concentrations of nitrate present in early July.

The other parameters measured were percent sugar and clear juice purity (CJP). The interaction of cropping system and fertilizer rate was significant for percent sugar for both years (Table 7 and 8). Increasing N rate did not significantly affect percent sugar for the CCB, CBeB or the BeBeB system in 1992. Sugar accumulation was suppressed by increasing

N for the OBeB and OABeB system. Results in 1993 were dissimilar to those obtained in 1992. Percent sugar was not significantly affected by N rate for CBeB or BeBeB while it caused decline with the other systems. Highest percent sugar in the beets was found in OBeB cropping system with 45 kg N ha^{-1} and the lowest percentage was observed in OABeB system with 135 kg N ha^{-1}.

It was interesting to note that the lowest percent sugar was observed in the same treatment (OABeB system) where highest amount of RWS and highest root yield were observed. This might be due to higher sugarbeet yield decreasing sugar concentration in the beet. It is apparent that greater yields of the OABeB system compensated for the reduction in sugar concentration at the higher rates. It is desirable to produce high yields with high sucrose concentration to get maximum benefits from applied N.

Clear juice purity declined with increasing nitrogen rates in both years, but the effect was significant only in 1992 (Table 9 and 10). The highest CJP was obtained in the treatments where no fertilizer was applied and the lowest percent was obtained where highest amount of fertilizer N (135 kg N ha^{-1}) was applied. Among the cropping systems, CCB gave the highest CJP during 1993 cropping season, but during 1992 CBeB was at the top. These differences were too small to be statistically significant and suggest there is little effect of cropping system on CJP.

Effect of N Fertilizer Rate on Sugarbeet Yield and Quality at Various Locations.

N fertilizer rate experiments were carried out at 13 different locations in Michigan to evaluate the effect of N rate on sugarbeet yield and quality across a number of soil types.

Table 11 contains the RWS yield data, which shows a significant interaction between location and N rates. The significant interaction indicates the need for developing N fertilizer recommendation based on soil type in sugarbeet growing area of Michigan. The most RWS was obtained at the Weiss farm in 1991 with 146 kg N ha^{-1}, while lowest amount was observed in Knochel farm in 1992 from the control treatment. When the N fertilizer rate treatment effects on RWS were observed at individual locations, it was found that 5 sites (Ryers 91, Roggenbuck 91, Russell 92, Sutto 92 and Russell 93) did not show any response to applied N. Three other sites (Maust 92, Maust 93, Swartz 92) respond up to 45 kg N ha^{-1}, while only 2 (Fogg 91, Weiss 91), 1 (Siler 91) and 2 (Fisher 91, Knochel 92) sites respond to N rate 78, 112 and 146 kg N ha^{-1}, respectively.

As shown with RWS, root yield response to applied N was highly variable among various locations as shown by the significant interaction of N rate and location (Table 12). Highest root yield was observed at the Weiss farm in 1991 while lowest on the Knochel farm in 1992.

The data for N concentration in leaf blades might be helpful to understand the differences of yield response to applied N (Table 13). Similar to the results of RWS and root yield, N content of leaf blade in sugarbeet grown at various locations showed variable response to applied N. Results of N rate effects on RWS were compared with the percent N in the leaves and no relation between the two was found. It is interesting to note that at all locations percent N in the leaves (Table 13) was below the intermediate levels of N for optimum yields (3.6 - 4.0%) given by Chapman (1967). In view of the very low N concentrations in the leaves, it is difficult to explain the lack of response to applied N.

A significant interaction was found for percent sugar in the beets (Table 14). Percent sugar ranged from 16.9 to 21.4. The highest percent sugar was found at Ryers farm in 1991 in the treatment where no N was applied. Examining the simple effects of N rate, it is clear that increasing the amount of N fertilizer decreased the sugar concentration in beets. Although, percent sucrose in the beets did not show any response to applied N, but beet root yield and ultimately RWS did increase with increased N at several locations. The need for searching optimum fertilizer N rate for maximum root yield and highest percentage of sucrose still exists.

The location and N rate individually affected CJP significantly (Table 15). The amount of N fertilizer and the CJP data showed a reciprocal relationship. The highest CJP (94.6%) was obtained where no fertilizer was applied and lowest (93.6%) in the treatment where highest amount of N fertilizer (146 kg N ha^{-1}) was applied. Among the locations, Weiss farm gave the highest CJP while Roggenbuck was lowest. The decline in juice purity with increasing N reduced the recoverable sugar. The increased beet root yield with increased fertilizer did compensate for reduced sucrose percentage and juice purity at some locations. But, the ultimate goal for sugarbeet production is maximum RWS which can only be obtained with higher yields and maximum juice purity. The locations where yield did not respond to increased N rate needs more attention in terms of increasing the juice purity. Our results are in line with previous findings of Baldwin and Stevenson (1969) and Hills and Ulrich (1971). These researchers reported a decreased percent sucrose and juice purity with increasing N.

CONCLUSION

Sugarbeet yield and quality parameters measured in this study were found highly affected by cropping system, soil type and location and fertilizer rate. Percent sugar in the roots and clear juice purity were highly affected by N rate, declining with increasing rate. The sugarbeet yield response to applied N was highly variable from location to location and from one crop sequence to another. The differences of yield response to applied N under different cropping systems and at various locations indicate that crop N needs are dependent on soil type and crop management practices. Therefore, better N fertilizer recommendations for sugar beet can only be made if these factors are taken into consideration.

LIST OF REFERENCES

Baldwin, C.S. and J.F. Stevenson. 1969. The effect of nitrogen on yield, percent sucrose, and clear juice purity of sugarbeets. J. Am. Soc. Sugar Beet Tech. 15:522-527.

Bundy, L.G., and T.W. Andraski. 1993. Soil and Plant nitrogen availability tests for corn following alfalfa. J. Prod. Agric. 6:200-206.

Carruthers, A., and J.F.T. Oldfield. 1961. Methods for assessment of beet quality. Intern. Sugar J. 63:72-74.

Carter J.N., D.T. Westermann, M.E. Jensen, and S.M. Bosma. 1975. Predicting N fertilizer needs for sugar beets from residual NO_3 and mineralizable nitrogen. J. Am. Soc. of Sugar Beet Tech. 18:232-244.

Clegg, M.D. 1982. Effect of soybean and nitrogen response of subsequent sorghum crops in Eastern Nebraska. Field Crop Res. 5233-239.

Chapman, H.D. 1967. Plant analysis values suggestive of nutrient status of selected crops. *In* Soil testing and plant analysis part II. Soil Sci. Soc. Am. Spec. Pub. 2.

Christenson, D.R. 1989. Sugar beet yield trends as affected by cropping system. J. Sugar Beet Res. 26:A5.

Christenson D.R. C.E. Bricker, and R.S. Gallagher. 1991. Crop yields as affected by cropping system and rotation. Michigan State Univ. Agric. Exp. Sta. Res Rep. 516.

Cook, R.L., C.E. Miller, and L.S. Robertson. 1946. Sugar beets in seven Michigan system of crop rotation. Proc. Am. Soc. Sugarbeet tech. 4:73-87.

Cook, R.J., 1984. Root health: importance and relationship to farming practices. *In* D.F. Bezdicek, J.F. Power, and D.R. Keeney, M.J. Wright (ed.). Organic Farming: current technology and its role in a sustainable agriculture. Spec. Publ. 46:111-127. ASA, CSSA, SSSA. madison, WI.

Dexter, S. T. , M. G. Frakes, and F.W. Snyder. 1967. A rapid and practical method for determining extractable white sugar as may be applied to the evaluation of agronomic practices and grower deliveries in the sugarbeet industry. J. Am. Soc. Sugar Beet Tech. 14:433-454.

Fahad, A.A., L.N. Mielke, A.D. Flowerday, and D. Swartzendruber. 1982. Soil physical properties as affected by soybean and other cropping sequences. Soil Sci Soc. Am. J. 46:377-381.

Gakale, L.P., and M.D. Clegg. 1987. Nitrogen from soybean for dryland sorghum. Agron. J. 79:1057-1061.

Hills, F.J., and A. Ulrich. 1971. Nitrogen nutrition. pp.111-135. *In* R.T. Johnson et al. (eds.) Advances in sugar beet production: Principles and practices. The Iowa State University Press, Ames, Iowa.

Johnson, R.R. 1987. Crop management. *In* J,R. Wilcox (ed.). Soybean: Improvement production, and uses, 2nd ed. Agron. Monogr. 16:355-390. ASA, CSSA, and SSSA, Madison WI.

Keeney, D.R. 1982. Nitrogen management for maximum efficiency and minimum pollution. *In* F.G. Stevenson (ed.). Nitrogen in agricultural soils. Agron. Monogr. 2:605-649. ASA, CSSA, and SSSA, Madison WI.

Mannering, J.V., L.D. Meyer, and C.B. Johnson, 1968. Effect of cropping intensity on erosion and infiltration. Agron. J. 60:206-209.

Moore, S., and W.H. Stein. 1954. A modified ninhydrin reagent for the photometric determination of amino acids and related compounds. J. Biol. Chem. 211:907.

Peterson T.A., and G.E. Varvel. 1989. Crop yields as effected by rotation and nitrogen rate. I: Soybean. Agron. J. 81:727-731.

Peterson T.A., and G.E. Varvel. 1989. Crop yields as effected by rotation and nitrogen rate. II: Grain Sorghum. Agron. J. 81:731-734.

Peterson T.A., and G.E. Varvel. 1989. Crop yields as effected by rotation and nitrogen rate. III: Corn. Agron. J. 81:735-738.

Robertson, L.S., R.L. Cook, C.D. Piper, R.H. Dowdy, and J.F. Davis. 1965. Sugarbeet production in Michigan as affected by crop sequence and fertility levels. J. Am. Soc. Sugarbeet Tech. 13:304-313.

Robertson, L.S., R.L. Cook, and J.F. Davis. 1977. The Ferden Farm report. IV: Soil management for navy beans. Michigan Agric. Exp. Sta. Res. Rep. 350.

Roder, W., S.C. Mason, M.D. Clegg, J.W. Doran, and K.R. Kniep. 1988. Plant and microbial response to sorghum-soybean cropping systems and fertility management. Soil Sci. Soc. Am. J. 52:1337-1342.

Varvel G.E., and T.A. Peterson. 1990. Residual soil nitrogen as affected by continuous, two-year and four-year crop rotation systems. Agron. J. 82:958-962.

Zielke, R.C., and D.R. Christenson. 1986. Organic carbon and nitrogen changes in soil under selected cropping systems. Soil Sci. Soc. Am. J. 50:363-367.

Table 1. Soil series, sub-order, oxidizable C and cropping history for soils used in N fertilizer rate experiments.

Location	Year	Soil Series	Sub order	Oxidiz. C	Previous Crop
				g kg^{-1}	
Ryers	1991	Tappan	Typic Haplaquolls	9.73	soybean
Weiss	1991	Tappan		13.7	drybean
Russell	1992	Tappan		10.2	corn
Russell	1993	Tappan		12.5	drybean
Knochel	1992	Tappan		12.3	drybean
Roggenbuck	1991	Kilmanagh	Aeric Haplaquepts	12.2	wheat
Maust	1992	Kilmanagh		50.8	soybean
Maust	1993	Kilmanagh		9.06	drybeans
Fisher	1991	Parkhill	Mollic Haplaquepts	6.82	drybeans
Siler	1991	Parkhill		10.4	drybean
Fogg	1991	Zilwaukee	Typic Haplaquolls	54.5	corn
Sutto	1991	Sloan	Fluvaquentic Haplaquolls	10.8	soybean
Swartz	1991	mixed	-	27.2	-

Table 2. Recoverable white sugar as affected by N rate and cropping system for sugarbeet grown on Misteguay silty clay soil in 1992.

Cropping system	Nitrogen rate kg ha^{-1} 0	45	90	135	Ave.
	-------------------kg ha^{-1}-------------------				
CCB	5470	7050	7250	7420	6810
CBeB	5770	6730	6870	8000	6840
BeBeB	5280	7180	7320	8060	6960
OBeB	8170	8170	8370	8810	8380
OaBeB	7810	8420	9040	8950	8560
Average	6500	7510	7770	8250	
LSD (0.05)†		N.S.			
LSD (0.05) N rate		0.482			
LSD (0.05) Cropping system		0.687			

† Comparing two N rate means within a cropping system.

Table 3. Recoverable white sugar as affectd by N rate and cropping system for sugarbeet grown on Misteguay silty clay soil in 1993.

Cropping system	Nitrogen rate kg ha^{-1} 0	45	90	135	
	-------------------kg ha^{-1}-------------------				
CCB	6390	6980	8110	7810	7320
CBeB	4700	5710	7300	7290	6250
BeBeB	5540	7010	7330	8190	7020
OBeB	6120	6850	7300	7830	7020
OABeB	7220	7530	8930	7650	7830
Average	5990	6820	7790	7760	
LSD (0.05)†		N.S.			
LSD (0.05) N rate		603			
LSD (0,05) Cropping system		500			

† Comparing two N rate means within a cropping system.

Table 4. Effect of N rate and cropping system on yield of sugarbeet grown on a Misteguay silty clay in 1992.

Cropping system	Nitrogen rate kg ha^{-1}				
	0	45	90	135	Ave.
	Mg ha^{-1}				
CCB	41.1	52.4	53.9	55.8	50.8
CBeB	43.5	50.3	51.1	59.4	51.1
BeBeB	39.5	53.1	54.5	61.2	52.1
OBeB	60.0	59.6	64.0	67.1	62.6
OaBeB	58.0	62.7	68.2	69.7	64.7
Average	48.4	55.6	58.3	62.6	
LSD (0.05)[†]			N.S.		
LSD (0.05) cropping system			5.19		
LSD (0.05) N rate			3.68		

[†] Comparing two N rate within a cropping system.

Table 5. Effect of N rate and cropping system on yield of sugarbeet grown on a Misteguay silty clay in 1993.

Cropping system	Nitrogen rate kg ha^{-1}				
	0	45	78	135	Ave.
	Mg ha^{-1}				
CCB	47.4	52.3	63.7	59.9	50.8
CBeB	37.1	43.2	55.0	55.8	47.7
BeBeB	42.5	53.1	55.1	63.2	53.5
OBeB	45.0	51.9	55.8	61.5	53.5
OABeB	53.6	56.7	68.5	60.9	59.8
Average	45.1	51.4	59.6	60.3	
LSD (0.05)			N.S.		
LSD (0.05) cropping system			4.86		
LSD (0.05) N rate			3.87		

[†] Comparing two N rate within a cropping system.

Table 6. Monthly rainfall and growing degree days at the Saginaw Valley Bean and Beet Research Farm for 1992 and 1993.

Month	Rainfall		Growing Degree Days †	
	1992	1993	1992	1993
	- - - mm - - -		- - - - °C - - -	
April	116	104	25	0.00
May	28.3	70.0	128	97.8
June	53.3	77.0	240	221
July	110	62.0	328	339
August	74.2	117	275	323
September	104	102	155	84.0
Total	486	532	1151	1060

† Growing degree days = Cumulative daily [{(Max+Min)/2}-10]

Table 7. Percent sugar as affected by N rate and cropping system for sugarbeet grown on a Misteguay silty clay soil in 1992.

Cropping system	Nitrogen rate kg ha^{-1} 0	45	90	135	Ave.
	%				
CCB	17.9	18.2	18.2	18.0	18.1
CBeB	17.8	17.9	18.1	18.2	18.0
BeBeB	17.9	18.1	18.1	18.0	18.0
OBeB	18.2	18.4	17.8	17.9	18.1
OABeB	18.1	18.2	17.9	17.7	18.0
Average	18.0	18.2	18.0	17.9	
LSD (0.05)†		0.319			

† comparing two N rate within a cropping system.

Table 8. Percent sugar as affectd by N rate and cropping system for sugarbeet grown on a Misteguay silty clay soil in 1993.

Cropping system	Nitrogen rate kg ha^{-1} 0	45	90	135	Ave.
	%				
CCB	18.2	18.3	17.8	17.6	18.0
CBeB	17.9	18.0	18.2	18.0	18.0
BeBeB	18.0	18.1	18.2	17.9	18.1
OBeB	18.4	18.1	18.1	17.7	18.1
OABeB	18.3	18.3	17.9	17.5	18.0
Average	18.2	18.2	18.0	17.7	
1LSD (0.05)†		0.346			

† comparing two N rate within a cropping system.

Table 9. Clear Juice purity (CJP) as affectd by N rate and cropping system for sugarbeet grown on a Misteguay silty clay soil in 1992.

Cropping system	Nitrogen rate kg ha^{-1} 0	45	90	135	Ave.
	%				
CCB	95.3	94.9	95.2	95.0	95.1
CBeB	95.3	95.5	95.3	95.1	95.3
BeBeB	95.4	95.4	95.3	94.7	95.2
OBeB	95.5	95.3	94.8	94.8	95.1
OaBeB	95.3	94.8	95.1	94.3	94.9
Average	95.4	95.2	95.1	94.8	
LSD (0.05)†			N.S.		
LSD (0.05) cropping system			N.S.		
LSD (0.05) N rate			0.275		

† comparing two N rate within a cropping system.

Table 10. Clear Juice purity (CJP) as affectd by N rate and cropping system for sugarbeet grown on a Misteguay silty clay soil in 1993.

Cropping system	Nitrogen rate kg ha^{-1} 0	45	90	135	Ave.
	%				
CCB	95.4	94.4	93.6	95.3	94.7
CBeB	93.3	94.8	94.5	94.1	94.2
BeBeB	94.0	94.2	94.3	94.2	94.2
OBeB	94.9	94.2	94.1	93.7	94.2
OABeB	94.7	94.1	94.3	93.7	94.2
Average	94.5	94.3	94.2	94.2	
LSD (0.05)†			N.S.		
LSD (0.05) cropping system			N.S.		
LSD (0.05) N rate			N.S.		

† comparing two N rate within a cropping system.

Table 11. Effect of nitrogen rate on recoverable white sugar (RWS) for sugarbeets grown at 13 locations in Michigan from 1991-1993.

		Nitrogen rate (kg ha^{-1})					
Location	Year	0	49	78	112	146	Ave.
		kg ha^{-1}					
Ryers	1991	<u>7760</u>	7690	7900	7390	7220	7590
Weiss	1991	13200	1380	<u>1430</u>	1440	1480	1410
Russell	1992	<u>6240</u>	6460	6680	6460	6390	6450
Russell	1993	<u>4890</u>	5240	5440	4790	5220	5110
Knochel	1992	3990	4920	5740	6010	<u>6670</u>	5470
Roggenbuck	1992	<u>4740</u>	5770	5760	5120	5280	5330
Maust	1992	6800	<u>7900</u>	7790	7840	7860	7630
Maust	1993	6570	<u>7220</u>	6820	7400	6350	6870
Fisher	1991	5430	6610	6790	7540	<u>7840</u>	6840
Siler	1991	6170	6860	7060	<u>7820</u>	7630	7100
Fogg	1991	7250	8050	<u>8570</u> †	8520	7660	8010
Sutto	1992	<u>5600</u>	5780	6160	5940	5930	5880
Swartz	1992	5630	<u>6310</u>	5990	6260	6660	6170
Average		6480	7120	7310	7340	7350	
LSD (0.05)‡				824			

† Optimum value is underlined.

‡ Comparison of nitrogen rates within a location.

Table 12. Sugarbeet root yield as effected by N rate for beets grown at 13 locations in Michigan, from 1991-1993.

Location	Year	Nitrogen rate (kg ha^{-1}) 0	45	78	112	146	Ave.
		MG ha^{-1}					
Ryers	1991	49.3	48.9	51.2	48.4	49.3	49.4
Weiss	1991	62.7	65.1	67.3	69.2	73.9	67.7
Russell	1992	44.9	47.9	48.5	47.3	47.6	47.3
Russell	1993	33.6	37.5	38.8	36.3	40.8	37.4
Knochel	1992	27.3	33.5	38.5	41.1	45.2	37.1
Roggenbuck	1991	33.0	39.1	40.0	36.9	40.2	37.8
Maust	1992	45.8	53.4	52.0	53.4	53.2	51.6
Maust	1993	49.8	54.1	52.7	56.2	51.8	52.9
Fisher	1991	35.1	42.2	44.3	48.8	51.2	44.3
Siler	1991	43.9	48.4	50.3	57.2	57.6	51.5
Fogg	1991	48.7	55.1	59.9	58.7	55.6	55.6
Sutto	1992	44.2	46.3	47.8	48.8	48.5	47.1
Swartz	1992	39.4	43.2	42.0	45.5	49.4	43.9
Average		42.9	47.3	48.7	49.8	51.1	
LSD (0.05)†				4.19			

† Comparison of nitrogen rate within a location.

Table 12. Effect of nitrogen rate on percent N in leaves for sugarbeet grown at 13 locations from 1991-1993.

Location	Year	Nitrogen rate (kg ha^{-1})					
		0	49	78	112	146	Ave.
		%					
Ryers	1991	2.37	2.37	2.37	2.83	2.82	2.55
Weiss	1991	1.77	1.69	1.90	1.96	2.36	2.94
Russell	1992	2.52	2.54	2.46	2.44	2.87	2.57
Russell	1993	2.73	2.63	2.95	3.16	3.23	2.94
Knochel	1992	1.88	1.86	1.62	1.94	2.21	1.90
Roggenbuck	1991	1.97	1.94	2.11	2.30	2.39	2.14
Maust	1992	2.34	2.46	2.74	2.70	2.70	2.59
Maust	1993	2.09	2.16	2.51	2.81	2.83	2.48
Fisher	1991	1.95	2.08	2.13	2.32	2.63	2.22
Siler	1991	2.11	2.06	2.06	2.07	2.42	2.14
Fogg	1991	2.37	2.48	2.31	2.21	2.32	2.34
Sutto	1992	1.80	2.13	2.16	2.27	2.37	2.15
Swartz	1992	2.13	2.12	2.72	2.62	3.14	2.54
Average		2.16	2.19	2.31	2.43	2.64	
LSD (0.05)†				0.293			

† comparison of N rate within a location.

Table 14. **Effect of nitrogen rate on percent sugar in sugarbeet grown at 13 locations in Michigan from 1991-1993.**

Location	year	nitrogen rate (kg ha^{-1}) 0	45	78	112	146	Ave.
		------------ % ------------					
Ryers	1991	21.4	21.2	21.0	21.0	20.6	21.1
Weiss	1991	20.8	21.0	21.0	21.0	20.5	20.6
Russell	1992	18.7	18.5	19.9	18.6	18.5	18.6
Russell	1993	20.0	19.7	19.6	18.7	18.5	19.3
Knochel	1992	19.7	19.9	20.0	19.8	20.0	19.9
Roggenbuck	1992	20.1	20.4	20.1	29.7	19.1	19.9
Maust	1992	19.9	19.9	20.0	20.0	20.0	20.0
Maust	1993	18.3	19.6	18.1	18.3	17.3	18.1
Fisher	1991	20.5	21.0	20.7	21.0	20.5	20.5
Siler	1991	19.4	20.0	19.2	19.0	19.0	19.1
Fogg	1991	20.3	20.0	20.0	20.0	19.1	19.8
Sutto	1992	17.5	17.2	17.7	16.9	17.1	17.3
Swartz	1992	19.2	19.6	19.4	18.8	18.7	19.1
Average		19.7	19.7	19.6	19.4	19.1	
LSD (0.05)†				0.649			

† Comparison of nitrogen rates within a location.

Table 15. Effect of nitrogen rate on clear juice purity (CJP) for sugarbeet grown at 13 locations in Michigan from 1991-1993.

Location	year	nitrogen rate (kg ha^{-1})					Aver.
		0	49	78	112	146	
		%					
Ryers	1991	94.3	94.1	93.8	94.0	92.7	93.8
Weiss	1991	95.9	95.6	95.5	95.1	95.0	95.4
Russell	1992	95.1	94.5	94.2	94.6	94.1	94.5
Russell	1993	94.0	92.8	93.3	92.9	91.9	94.8
Knochell	1992	94.9	94.8	94.9	94.7	94.5	92.9
Roggenbuck	1992	93.1	93.7	93.2	92.4	91.6	92.8
Maust	1992	95.1	94.8	95.2	94.5	94.6	94.8
Maust	1993	93.7	93.6	93.5	93.6	93.1	94.5
Fisher	1991	95.6	95.6	95.3	95.5	95.1	95.4
Siler	1991	93.8	93.9	94.3	93.6	93.2	93.8
Fogg	1991	94.4	94.1	93.8	93.9	93.7	93.9
Sutto	1992	94.2	94.2	94.4	94.0	93.8	94.1
Swartz	1992	95.0	94.8	94.5	94.4	93.7	93.5
Average		94.6	94.3	94.3	94.1	93.6	
LSD (0.05)†				N.S.			
LSD (0.05) N rate				0.262			
LSD (0.05) cropping system				0.438			

† Comparison of nitrogen rate within a location.

CHAPTER VI

Soil Analysis and Prediction of Response to Applied Nitrogen

Optimum and economic crop production without polluting the environment requires an accurate estimate of fertilizer N required. It is especially true for the crops like sugarbeet which requires more precise information of N fertilizer management (Carter et al., 1975). Inadequate N availability limits plant growth and root yield, but over fertilization of sugarbeet with N reduces the quality by decreasing both sucrose percentage and recoverable sucrose (Hills and Ulrich, 1971). Also excess N may stimulate more leaf growth than necessary or could be lost by leaching, creating water pollution.

Soil and plant tissue tests can provide essential information for decision making for efficient and economical use of N fertilizer. A number of such procedures have been proposed and discussed (Bremner, 1965a: Dahnke and Vasey, 1973; Robinson, 1968). Soil N analysis using various procedures and correlating them with crop uptake in the field and in the greenhouse are commonly used to get information about soil available N. The success of such a procedure depends upon its correlation with N uptake by the plants in the greenhouse or field and yield data (Keeney, 1982).

The search for a consistent and reliable soil N test that can predict N availability for a crop and can be used in a routine soil testing laboratory has lasted over half a century (Keeney, 1982; Stanford, 1982). Among the methods, developed biological indices such as aerobic and anaerobic incubation have gained popularity. However, these methods are not useful for routine laboratory analysis because of time constraints (Wilson et al., 1994). Alternatively, chemical methods of soil analysis might be more attractive because they are rapid and more precise (Serna and Pomares, 1992). However, use of chemical method is open to the criticism because no chemical treatment of soil is likely to simulate the microbial processes responsible for mineralization of soil N.

A number of soil chemical treatments such as oxidation and acid hydrolysis have been utilized in the development of chemical indices of N availability. Among the chemical methods, alkaline $KMnO_4$ (Kresge and Merkle, 1957), $K_2Cr_2O_7$ extraction (Sahrawat, 1982), Walkley-Black procedure for organic carbon (Walkley and Black, 1934), dilute H_2SO_4 hydrolysis (Purvis and Leo, 1961), $CaCl_2$ autoclaving (Stanford and Demar, 1969) and phosphate-borate steam distillation (Gianello and Bremner, 1988) have been used. Many researchers have used these methods and correlated them with crop N uptake in the greenhouse or field. The results reported with each of these methods vary with the circumstances. Success of any of these methods depends upon the circumstances under which it is used.

In the sugarbeet growing area of Michigan, there is a wide diversity of soils and farm management practices including crop rotations centered on small grains, dry beans, corn, soybeans, forages and sugarbeets. Residues from these crops along with animal manure are returned to the soil. In view of this diversity it is necessary to know the N supplying capability of a soil if reasonably accurate recommendations for fertilizer N needs are to be made. At present there is not enough research data to make a reliable prediction of N supply. The main concern in this regard is to determine a procedure that is quick, efficient and economically feasible for routine use and have a high correlation with uptake and yield data.

In view of these concerns, the objective of this experiment was to evaluate various laboratory methods for obtaining a suitable index of soil N availability and correlate them with N uptake and yield parameters of sugarbeet crop under varying soils and cropping systems.

MATERIALS AND METHODS

Field Study

Two series of field studies were used to evaluate various cropping systems and soils with respect to N availability to sugar beet crop at several N fertilizer rates. The first study was conducted on a Misteguay silty clay soil (Aeric Haplaquept) in 1992 and 1993 to compare five cropping systems from a long term experiment that was initiated in 1972 and arranged as randomized complete block design with four replications. The five systems considered as treatments are as follows: corn-corn-sugar beet (CCB), corn-navy bean-sugar beet (CBeB), navy bean-navy bean-sugar beet (BeBeB), oat-navy bean-sugar beet (OBeB) and oat-alfalfa-navy bean-sugar beet (OABeB). All crops were grown every year utilizing recommended cultural practices. Details of the procedure followed and yield results are given by Christenson et al. (1991).

Each treatment plot was divided into four sub-plots and N fertilizer was broadcasted at the rates of 0, 45, 90 and 135 kg N ha^{-1}. Sugarbeets were planted in a 71 cm row spacing in the last week of April and were thinned to 20 cm between plants approximately five weeks after planting. In the last week of October the sugarbeets were defoliated and mechanically harvested. Yields were estimated by weighing the beets harvested from a two-10 meter rows. Twenty average size beets were selected from each plot. These beets were sliced and the juice extracted from the resulting pulp was immediately frozen. The analysis of variance was calculated utilizing a split plot design with cropping system the main plots and N rate the subplot.

The second experiment consisted of fertilizer N trials at 13 different locations in the Saginaw Valley and Thumb region of Michigan. The details of the soil type and classification are given in Table 1 (Chapter 3). Sugarbeets were planted at these locations during the years of 1991, 1992 or 1993. Nitrogen was broadcasted at planting at the rate of 0, 45, 78, 112, and 146 kg N ha^{-1}. Beets were harvested mid- to late- October determining yield and quality in a manner similar to the cropping system experiment. Each experiment was replicated four times. A combined analysis of variance was calculated, treating locations as main plot and N rate as sub-plot.

Soil Sample Collection:

In both series of studies, soil samples were taken from the control plot at planting time. All samples were taken to a depth of 0-20 cm. Each sample consisted of 20 probes per plot. Samples collected were air dried, ground, sieved through 2 mm screen and stored in air tight bottles for laboratory analysis.

Laboratory Analysis:

1. Organic carbon determination

Oxidizable organic carbon was determined by the Walkley-Black wet digestion with chromic acid (Walkley and Black, 1934; Walkley, 1935, 1947). Ten ml of M $K_2Cr_2O_7$ was added to 1.5 g soil in a 500 ml Erlenmeyer flask followed by addition of 20 ml concentrated H_2SO_4. The sample was allowed to digest and cool for 30 minutes. Then 170 ml distilled water and 3 drops of ferrion (1,10-orthophenanthroline ferrous sulfate) were added, and the sample was titrated to a maroon end point using 0.5 N $Fe(NH_4)_2(SO_4)_2$. Results of duplicate determination were used to calculate % oxidizable C in air dry soil.

2. Total Nitrogen

Total N of the soil was determined by the micro-Kjeldahl method described by Bremner, (1965b). One gram of soil ground to pass a 0.25 mm sieve, was digested for 5 hours in 3 ml of concentrated H_2SO_4 containing 1.5 g K_2SO_4 + 15 mg Se. After cooling, each sample received 20 ml of distilled water. Ammonia was released by alkaline distillation, collected in H_3BO_3 and titrated with standard sulfuric acid using methyl purple as the end point indicator.

3. Nitrate and Ammonium

Nitrate and ammonium were extracted by shaking 10 g soil with 100 ml of M KCl followed by filtering (Bremner, 1965c). The filtrate was analyzed for NO_3 plus NO_2 and NH4 by using a flow through injection system (American Public Health Association., 1981).

4. Phosphate-Borate steam distillation

Potentially available organic N in soil was measured by the method of Gianello and Bremner (1988). This method involves the determination of NH_4-N produced by steam distillation of soil sample with phosphate-borate buffer solution. The buffer solution is prepared by dissolving $Na_3PO_4.12H_2O$ and $Na_2B_4O_7.10H_2O$ in the ratio of 4:1 in water. Four g of soil ground to pass through 0.25 mm screen was distilled with 40 ml of phosphate-borate buffer solution adjusted to a pH of 11.2. NH_3 released was collected in 5 ml of Boric acid and titrated with standard H_2SO_4.

5. Autoclavable N

Ammonium N released on autoclaving in dilute $CaCl_2$ solution was measured as described by Stanford and DeMar (1969) and modified by Smith and Stanford (1971) and Stanford and Smith (1976). A 10 g soil sample mixed with 25 ml of 0.01 M $CaCl_2$ was autoclaved at 121 °C for 16 hours and the NH_4-N was measured by steam distillation.

6. Anaerobic Incubation

Ammonium N produced under water logged conditions was measured (Waring and Bremner, 1964). Five g of soil with 12.5 ml of water was incubated in closed tube at 40 °C for one week. At the end of incubation period 0.2 to 0.3 g of MgO was added followed by steam distillation to release NH_3 which was trapped in H_3BO_3 and titrated using a standard acid. The amount of NH_4-N present in the soil before incubation was determined by KCl extraction and mineralizable N was calculated from the difference of the two analyses.

7. Alkaline Permanganate

The NH_4-N was recovered by steam distilling soil during extraction with alkaline permanganate. One gram of soil with 10 ml of extracting solution (5 g $KMnO_4$ dissolved per liter of 10N NaOH) was distilled for 4 minutes into 5 ml of boric acid-indicator solution and titrated against 0.005 N H_2SO_4 (Subbiah and Asija, 1956). The soils were also distilled with NaOH extractant alone to determine NH_4-N released by hydrolysis. Oxidative NH_4-N released was estimated as the difference between total NH_4-N produced during alkaline permanganate extraction and that derived by NaOH distillation.

8. Sugarbeet quality analysis

The frozen juice that was collected from beet roots was analyzed by the Michigan sugar company Agriculture Research Laboratory for clear juice purity and sucrose content according to the methods described by Dexter et al. (1967) and Carruthers and Oldfield (1961), respectively.

Statistical Models for Evaluating response to Soil N

Simple correlation and multiple regression were employed to evaluate various soil test procedures to sugarbeet response. Among various statistical models evaluated the following one gave the best results, so others are not reported.

$$\text{Response} = B_o + B_1N_1 + B_2N_2 + B_{11}N_1^2 + B_{22}N_2^2$$

where: N_1 is nitrate nitrogen and N_2 is the organic N test and B_x is the regression coefficient. The response to applied N was calculated by dividing the RWS yield for the optimum N rate by the RWS of the control. Optimum N rate was evaluated using the LSD (5%) to separate treatment means. When there was no response to applied N, the response was recorded as 1.00. Recoverable white sugar sugar values were taken from Tables 3 and 11 in Chapter 3.

RESULTS AND DISCUSSION

Soil Nitrogen

Soil organic and inorganic N was measured by various procedures for soil samples taken from the cropping system study and N fertilizer rate studies at various locations.

Data in Table 1 contains the soil N test data for the samples taken during 1992 and 1993 from the cropping system study. Each procedure is expected to measure a different fraction of soil N resulting in a different range of values. This was the case for all procedures. The phosphate-borate, anaerobic mineralization and $KMnO_4$ extractions were able to differentiate between cropping systems, while the other procedures did not.

The phosphate-borate method differentiated among cropping systems which contained corn in 1992, but did not in 1993. Even though CCB had the highest extractable N in 1993, the BeBeB system had a similar amount to the CCB system. There was a fairly large range in amount of N extracted with phosphate-borate in 1993, but the differences among the cropping systems were not significant statistically. The relatively high N values for soils under the CCB system reflect corn residues returned in these systems.

Anaerobic mineralization gave significantly different results for the various cropping systems in both years. However, the results were not consistent among cropping systems for two years. In 1992, the test was greater for the CCB system than for BeBeB and the OBeB systems. In 1993 the test did not differentiate between systems which had larger amount of residues from those with low amount of residues. For example, the amount of N mineralized from the OBeB system was greater than that for the CCB system. It is not unreasonable to expect that the OABeB system would have greater mineralization than the BeBeB system. However, the amount mineralized here is similar to the OBeB system. The reasons for low N values with the anaerobic procedure during 1992 compared to 1993 are not clear.

The N extracted by $KMnO_4$ was inconsistent from year to year. While the differences were significant in 1992, this test did not reflect the amount of crop residues returned to the soil. In 1993, the differences between systems were not significantly different. The effect of corn residues on the Walkley-Black C is shown in both years for the CCB and the CBeB cropping systems.

The results presented in Table 2 for 13 locations indicated that N measured with all of these procedures showed significant differences among the various locations. This was not surprising because each location was expected to have soils under different management conditions giving different N supplying characteristics.

The highest values of N were found in the Zilwaukee series on the Fogg 91 farm for all procedures except $KMnO_4$. This would be expected based on the carbon concentration in this soil. The Tappan soil from the Ryers 91 location also had a high carbon concentration and the associated tests were also high. The lowest N values were observed in Knochel farm.

The differences of long term management may account for such differences in N values among soils as well as differences between soils caused during soil formation.

One thing interesting is that although soils at various locations were found significantly different with regard to $KMnO_4$ extracted N, the range in values was not as large as with other procedures.

Soils at different locations within the same series also showed significant differences of N with all procedures. Phosphate-borate N in the Tappan series ranged from 9.5 mg kg^{-1} on Knochel 91 site to 69.5 on Ryers 91 site. With the same procedure on the Kilmanagh series values ranged from 17.5 to 30.6 mg kg^{-1} for Maust 91 and Roggenbuck 91 sites, respectively.

Other procedures also showed similar results. Anaerobic mineralized N values ranged from 6.1 on Knochel 92 site to 46.7 mg kg^{-1} at Ryers 91 site on Tappan series. With the same procedure mineralized N values ranged 16.5 to 32.9 mg kg^{-1} on Kilmanagh soil series. Similarly, Walkley Black oxidizable carbon ranged from 0.973 to 1.22% at two different locations in Parkhill series and it ranged from 0.682 to 5.08% for soils at different locations in the Tappan series. These differences in N at various locations within the same series may be the result of previous management or could have existed from soil formation. The only data available is the previous year's crop which is not enough to suggest any management impact.

The goal in selecting procedures used in this study was to extract different fractions of organic N. The autoclaving procedure was used because it is a rigorous extraction of the hydrolyzable fraction, while the phosphate-borate extraction is a less rigorous extraction of the same fraction. $KMnO_4$ is an oxidative procedure. The anaerobic and aerobic incubation methods release N through biological activity.

While comparing different procedures for organic N determination it was observed that autoclaving gave the highest numbers followed by $KMnO_4$ and phosphate-borate. This indicates that N from more resistant organic substances is released by autoclaving. Phosphate-borate seems to be moderate extractant compared to $KMnO_4$ extraction, which might be releasing some comparatively resistant material during oxidation. Anaerobic mineralization released N is similar quantities to phosphate-borate, while aerobic mineralization (mineralization potential, N_o) released larger quantities. Mineralization potential is the result of a long term aerobic incubation and may be expected to release more N that some other procedures.

Relationship among Sugarbeet Yield Parameters and Soil N tests

Data in Table 3 shows the relationship between various N indices and sugarbeet yield parameters. There was a significant correlation among all organic N procedures. However, most showed a weak relationship accounting for less than 25% of the variability between the methods. The procedures that related well were phosphate-borate with autoclavable N, and Walkley-Black with autoclavable N. These methods evidently extract similar fractions of organic N. Among all these procedures anaerobic incubation gave the lowest relationship with other procedures. The relationship of $KMnO_4$ with all other procedures was negative, which is difficult to explain.

Simple correlation coefficients of sugarbeet yield and quality parameters and selected soil organic N analyses are also given in Table 3. There were not any relationships which accounted for a significant amount of the variability in the data. The negative values between some of the analyses and quality parameters reflect the negative effect of nitrogen on beet quality.

There were some significant linear relationships between yield parameters themselves. Yield was positively related to RWS and percent sugar and CJP were significantly related to RWS. These relationships are similar to the findings of previous studies (Hills and Ulrich, 1971; Hills et al, 1978; and Carter and Traveler, 1981).

Correlation Between Yield Response and N Availability Indices.

Multiple regression techniques were used to describe relationships between the sugar beet yield parameter, as the dependent variable, and soil mineral and organic N tests as independent variables. Linear and squared terms were included for each independent variable. Response of RWS to applied N was used as the yield parameter. Regression coefficients and associated coefficients of determination (R^2) for various soil series are given in Table 4. The results indicated that in all soil series except Misteguay, phosphate-borate gave a significant relation to yield response. When the regression was calculated using all soils together, the anaerobic mineralized N, autoclavable and $KMnO_4$ procedures were found significantly related to yield response. However, none of the R^2 values indicated sufficient precision for the test to be used for predicting N fertilizer needs for sugar beet production.

CONCLUSION

The goal of this work was to develop a soil N test to predict N availability for sugar beet. The work on the cropping systems study did not show a good relationship between any of the tests and yield response in part because there were not large differences between the various systems. Secondly, the relative ranking of extractable N concentrations were not consistent between years.

Another goal was to determine if a soil test might work on individual soil series. While the results indicate that there may be some success for individual series, the results do not suggest that this approach would be workable. Some soil series like Tappan, Kilmanagh, and Parkhill showed a significant correlation with phosphate-borate procedure but the value of the correlation was not high enough and same regression model did not give significant correlation when soils were combined together. Differences of N value among the soils within the same series were as large as between the series which suggests that long term management might be more influential on N availability than the soil series characteristics.

These results are similar to that of Varsa (1970) in that the chemical and biological tests are not useful in predicting the availability of N from the organic fraction for making N recommendations for sugar beet production.

LIST OF REFERENCES

American Public Health Association. 1980. Standard methods for examination of water and waste water, 1981. 15th ed Am. Public Health Assoc., Washington, DC.

Bremner, J.M. 1965a. Nitrogen availability indexes. *In* C. A. Black et al. (ed.) Methods of soil analysis, Part 2. Agronomy 9:1324-1345. Am. Soc. Agron., Madison, Wis.

Bremner, J.M. 1965b. Total nitrogen. *In* C. A. Black et al. (ed.) Methods of soil analysis, Part 2. Agronomy 9:1149-1178. Am. Soc. Agron., Madison, Wis.

Bremner, J.M. 1965c. Inorganic forms of nitrogen. *In* C. A. Black et al. (ed.) Methods of soil analysis, Part 2. Agronomy 9:1179-1237. Am. Soc. Agron., Madison, Wis.

Carruthers, A., and J.F.T. Oldfield. 1961. Methods for assessment of beet quality. Intern. Sugar J. 63:72-74.

Carter J.N., D.T. Westermann, M.E. Jensen, and S.M. Bosma. 1975. Predicting N fertilizer needs for sugar beets from residual NO_3 and mineralizable nitrogen. J. Am. Soc. of Sugar Beet Tech. 18:232-244.

Carter, J.N., and D.J. Traveller. 1981. Effect of time and amount of nitrogen uptake on sugarbeet growth and yield. Agron. J. 73:665-671.

Christenson, D.R., C.E. Bricker, and R.S. Gallagher. 1991. Crop yields as affected by cropping system and rotation. Michigan State Univ. Agric. Exp. Sta. Res Rep. 516.

Dahnke, W.C., and E.H. Vasey. 1973. Testing soils for nitrogen. p. 97-114. *In* L. M. Walsh and J. D. Beaton (ed.). Soil testing and plant analysis. Soil Sci. Soc. Am., Madison, Wis.

Dexter, S.T. , M.G. Frakes, and F.W. Snyder. 1967. A rapid and practical method for determining extractable white sugar as may be applied to the evaluation of agronomic practices and grower deliveries in the sugarbeet industry. J. Am. Soc. Sugar Beet Tech. 14:433-454.

Gianello, C., and J.M. Bremner. 1986. Comparison of chemical methods of assessing potentially available nitrogen in soil. Commun. Soil Sci. Plant Anal. 17:195-214.

Gianello, C., and J.M. Bremner. 1988. A rapid steam distillation method of assessing potentially available organic nitrogen in soil. Commun. Soil Sci. Plant Anal. 19:1551-1568.

Hills, F.J., and A. Ulrich. 1971. Nitrogen nutrition. pp.111-135. *In* R.T. Johnson et al. (ed.) Advances in sugar beet production: Principles and practices. The Iowa State University Press, Ames, Iowa.

Hills, F.J., F.E Broadbent, and M Fried. 1978. Timing and rate of fertilizer nitrogen for sugarbeet related to nitrogen uptake and pollution potential. J. Environ. Qual. 7:368-372.

Keeney, D.R. 1982. Nitrogen management for maximum efficiency and minimum pollution. *In* F.G. Stevenson (ed.). Nitrogen in agricultural soils. Agronomy. Monogr. 2:605-649. ASA, CSSA, and SSSA, Madison WI.

Kresge, C.B., and I.G. Merkle. 1957. A study of the validity of laboratory techniques in appraising the available nitrogen producing capacity of soils. Soil Sci.Soc. Am. Proc. 21:516-521.

Purvis, E.R., and M.W.M. Leo. 1961. Rapid procedure for estimating potentially available soil nitrogen under greenhouse conditions. J. Agric. Food Chem.9:15-17.

Robinson, J.B.D. 1968a. A simple available soil nitrogen index. 1. Laboratory and greenhouse studies. J. Soil Sci. 269-279.

Robinson, J.B.D. 1968b. A simple available soil nitrogen index. II. Field crop evaluation. J. Soil Sci. 19:280-299.

Robinson, J.B.D. 1968c. Chemical index for available soil nitrogen. East Africa Agric. For. J. 33:299-301.

Sahrawat, K.L. 1982. Simple modification of the Walkley-Black method for simultaneous determination of organic carbon and potentially mineralizable nitrogen in tropical rice soils. Plant and Soil. 69:73-77.

Serna, M.D., and F. Pomares. 1992. Evaluation of chemical indices of soil organic nitrogen availability in calcareous soils. Soil Sci. Soc. Am. J. 56:1486-1491.

Smith S.J., and G. Stanford. 1971. Evaluation of a chemical index of soil nitrogen availability. Soil Sci. 3:228-232.

Stanford, G., and W.H. DeMar. 1969. Extraction of soil organic nitrogen by autoclaving in water. 1. The NaOH-distillable fraction as an index of soil nitrogen availability. Soil Sci. 107:203-205.

Stanford, G., and S.J. Smith. 1976. Estimating potentially mineralizable soil nitrogen from chemical index of soil nitrogen availability. Soil Sci. 122: 71-76.

Stanford, G., 1982. Assessment of soil nitrogen availability. *In* F.J. Stevenson (ed.) Nitrogen in agricultural soils. Agronomy. 22:651-688. Am. Soc. Agron. Madison. Wisconsin.

Subbiah, B.V., and G.L. Asija. 1956. A rapid procedure for the estimation of available nitrogen in soils. Current Sci. 25:259-260.

Varsa, E.C. 1970. The use of soil and petiole tests for detecting residual nitrogen and for predicting responses of sugar beets (Beta vulgaris) to nitrogen fertilization. PH.D Dissertation. Michigan State Univ. East Lansing.

Walkley, A., and I.A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a modification of the chromic acid titration method. Soil Sci. 37:29-38.

Walkley, A., 1935. An estimation of methods for determining organic carbon and nitrogen in soils. J. Agric. Sci. 25:588-609.

Walkley, A. 1947. A critical examination of a rapid method for determining organic carbon in soils-effect of variation in digestion condition and of inorganic soil constituents. Soil Sci. 63:251-264.

Waring, S.A., and J.M. Bremner. 1964. Ammonium production in soil under waterlogged conditions as an index of nitrogen availability. Nature 201: 951-952.

Wilson, C.E.Jr., R.J. Norman, B.R. Wells, and M.D. Correll. 1994a. Chemical estimation of nitrogen mineralization in paddy rice soils: Comparison to laboratory indices. Commun. Soil Sci. Plant Anal. 25:573-590.

Table 1. Mineral N, organic N and Walkley Black carbon analysis for soil samples taken from the sugarbeet cropping system on a Misteguay silty clay soil in 1992 and 1993.

Cropping System	NO_3	NH_4	Phos. Borate	Anaer. Miner.	Miner. Poten.	Autoc.	$KMnO_4$ -NaOH	Oxid. C
	------------	------------	------------	mg kg^{-1}	------------	------------	------------	%
1992								
CCB	3.79	6.06	23.2	22.6	103	48.3	70.2	1.24
CBeB	4.15	7.74	20.5	15.3	84.0	44.9	66.3	1.19
BeBeB	3.48	6.30	16.8	10.7	71.7	40.9	70.3	1.07
OBeB	3.82	7.04	16.9	11.0	82.8	64.5	64.5	1.16
LSD (0.05)	N.S.	N.S.	4.47	9.21	N.S.	N.S.	5.91	0.113
1993								
CCB	2.38	2.63	26.9	31.9	109	44.8	72.6	1.09
CBeB	3.69	3.20	23.3	34.4	89.1	42.2	71.6	1.03
BeBeB	3.84	2.01	25.1	30.2	74.4	43.0	70.3	1.00
OBeB	3.82	1.79	21.1	36.0	82.7	43.7	75.3	1.00
OABeB	4.24	1.86	19.6	36.4	104	45.1	75.4	1.08
LSD (0.05)	0.280	N.S.	N.S.	4.21	N.S.	N.S.	N.S.	0.069

Table 2. Mineral N, organic N and Walkley Black carbon analysis for soil samples taken from various locations.

Location	Yr	Soil Series	Previous Crop	NO_3	NH_4	Phos. Bor.	Anaer. Miner.	Auto.	$KMnO_4$ -NaOH	Oxid. C
				mg kg^{-1}						%
Ryers	91	Tappan	soybeans	6.26	0.01	69.5	46.7	133	38.5	5.08
Weiss	91	Tappan	drybeans	2.83	1.43	20.0	7.61	37.3	52.5	0.906
Russell	92	Tappan	corn	5.14	7.70	14.6	8.40	41.4	50.4	1.08
Russell	93	Tappan	drybeans	5.43	0.91	29.5	38.0	57.9	62.6	1.23
Knochel	92	Tappan	drybeans	2.80	4.51	9.50	6.10	33.8	45.0	0.682
Fisher	91	Parkhill	wheat	1.85	5.30	25.7	15.6	45.6	52.0	0.973
Siler	91	Parkhill	soybeans	1.19	4.23	35.6	17.1	58.9	55.9	1.22
Roggenb	91	Kilmanagh	drybeans	3.08	3.84	30.6	32.9	63.8	51.1	1.37
Maust	92	Kilmanagh	drybeans†	4.86	5.77	17.5	16.5	50.8	50.3	1.02
Maust	93	Kilmanagh	drybeans	5.39	0.84	22.7	32.3	50.7	62.6	1.04
Fogg	91	Zilwaukee	corn	2.93	8.00	80.2	56.9	156	31.8	5.45
Sutto	92	Sloan	soybeans	8.22	6.12	23.6	30.7	58.1	58.1	1.25
Swartz	92	Mixed	-	1.55	7.29	35.7	24.4	106	44.9	2.72
LSD (0.05)				2.32	1.97	8.94	10.2	21.3	7.55	0.595

† Animal manure applied in 1989.

Table 3. Linear correlation coefficients (r) among organic N analysis for samples noted in Table 1 and 2.

Parameter	Phos-Borate	Anaer. Miner.	Autoc.	$KMnO_4$ +NaOH	$KMnO_4$ -NaOH	WBC	YLD	RWS	%S	CJP
Phos-Borate	1.00									
Anaerobic	0.815*	1.00								
Autoclave	0.599*	0.373*	1.00							
$KMnO_4$+NaOH	0.481*	0.354*	0.544*	1.00						
$KMnO_4$	-0.558*	-0.402*	-0.637*	-0.259*	1.00					
WBC	0.599*	0.365*	0.963*	0.572*	-0.639*	1.00				
Yield	0.028	-0.096	-0.061	-0.193	-0.001	-0.057	1.00			
RWS	-0.021	-0.143	-0.061	-0.115	-0.080	-0.085*	0.884*	1.00		
% S	0.242*	0.187	-0.085	-0.071	-0.293*	-0.091	0.035	0.343*	1.00	
CJP	-0.236	-0.468*	-0.136	-0.129	0.200	-0.154	0.236	0.358*	0.001	1.00

Table 4. Regression coefficients and associated multiple coefficients of determination (R^2) for the Misteguay, Tappan, Parkhill and Kilmanagh series and for all soils combined relating response to applied N with mineral N and various organic N analysis.

Organic Nitrogen	B_o	B_1	B_2	B_{11}	B_{22}	R^2
Misteguay Soil						
Phos-Borate	0.0148	0.369	-0.0459	0.0124	-0.000453	0.111
Mineralized	0.0450	0.362	-0.0462	0.00984	-0.000309	0.102
Autoclave	-2.07	0.205	-0.0282	0.115	-0.00131	0.162
$KMnO_4$+NaOH	9.99	0.313	-0.0404	-0.221	0.00124	0.267
$KMnO_4$	4.77	0.410	-0.0483	-0.133	0.000911	0.244
Walkley Black	-4.24	0.163	-0.0250	8.18	-3.49	0.194
Tappan Soil						
Phos-Borate	0.454	0.0681	-0.00478	0.0169	-0.000173	0.464*
Mineralized	0.603	0.050	-0.0010	0.0123	-0.000208	0.370
Autoclave	1.27	0.0550	0.00384	-0.0601	0.000605	0.193
$KMnO_4$+NaOH	0.392	-0.0311	0.00194	-0.00311	-0.0000087	0.192
$KMnO_4$	0.0928	-0.0110	0.000460	0.00915	-0.000183	0.297
Walkley Black	1.88	0.0251	-0.00121	-3.62	1.62	0.192
Parkhill Soil						
Phos-Borate	3.40	-0.199	0.0385	-0.175	0.00298	0.937*
Mineralized	-2.03	-0.503	0.222	0.373	-0.011	0.825*
Autoclave	1.44	-0.673	0.176	0.00370	0.0000212	0.594
$KMnO_4$+NaOH	-15.5	-0.540	0.0194	0.0356	-0.00190	0.726
$KMnO_4$	2.26	-0.787	0.209	-0.0360	0.000363	0.633
Walkley Black	1.35	-0.667	0.175	-0.0601	0.0108	0.581

Table 4. Continued.

Organic Nitrogen	B_o	B_1	B_2	B_{11}	B_{22}	R^2
<u>Kilmanagh Soil</u>						
Phos-Borate	0.886	0.034	-0.00355	-0.017	0.000633	0.698*
Mineralized	0.812	-0.0185	0.00062	-0.0106	0.000147	0.357
Autoclave	1.44	-0.0564	0.00398	0.0196	0.000242	0.373
$KMnO_4$+NaOH	0.842	-0.00587	0.000741	-0.0000433	0.0000138	0.631
$KMnO_4$	1.03	-0.0373	0.00241	-0.00193	0.0000342	0.240
Walkley Black	0.953	-0.0346	0.00204	-0.0130	0.0951	0.386
<u>Combined on all Soils</u>						
Phos-Borate	0.388	-0.149	-0.0140	0.0239	-0.000227	0.151
Mineralized	0.470	-0.197	0.0168	0.0368	-0.000501	0.263*
Autoclave	2.05	-0.247	0.0239	-0.0298	0.000164	0.294*
$KMnO_4$+NaOH	0.692	-0.189	0.0189	-0.00276	0.0000492	0.174
$KMnO_4$	1.76	-0.164	0.0163	-0.0220	0.0000688	0.190*
Walkley Black	1.18	-0.1941	0.0189	-0.380	0.0706	0.175

Response = $B_o + B_1N_1 + B_2N_2 + B_{11}N_1^2 + B_{22}N_2^2$.
where N_1 = Soil nitrate
N_2 = organic N test.

SUMMARY

The main goal of this study was to investigate the N availability for sugarbeet crop under various soil types, cropping systems and N fertilizer rates in the lake bed region of Michigan. Sugar beet yield and quality parameters along with soil N status with several procedures were measured. Long term incubation studies were carried out to investigate the effect of soil type, cropping system and sampling time on N mineralization. Simple correlation and regression techniques were employed to investigate the relationship between response to applied N fertilizer and soil test values.

The results of the experiments can be summarized as following:

1. Long term aerobic incubation showed that general trend for cumulative N mineralized was same for all cropping systems and soils. The rate of mineralization was rapid in the beginning of the incubation and gradually declined with time.
2. Nitrogen mineralization potential did not show any interaction of cropping system and sampling time. However, cropping systems showed significant differences. N_0 values were higher for corn-corn-sugarbeet than for other systems reflecting the amount of residues returned to the soil in the 20 years

of cropping previous to this study. Sampling time did not show any difference of N mineralization potential during 1992 while, significant differences were found during 1993.

3. Soil samples from various locations showed wide differences of N mineralization potential. Due to large differences of N_0 values for soils within the same series, soils could not be grouped based on series characteristics.

4. Generally higher N_0 values and lower K values were obtained with hyperbolic model compared to exponential model. However, instantaneous rate of reaction calculated with both exponential and hyperbolic model gave a very high correlation, which means that both models can be used to describe N mineralization potential of soils.

5. Active N fraction gave a reciprocal relationship with soil organic carbon. Soils with highest oxidizable carbon content gave lowest active N fraction value.

6. Differences in recoverable white sugar (RWS), root yield, percent sugar and clear juice purity were observed among the cropping systems and different types of soils. RWS and beet yield was found to be lower in the systems where higher amounts of corn residues were added.

7. Response to fertilizer N was variable among different locations. At some locations no response to applied N was observed, while at some other locations response was observed even at the highest N rate (146 kg N ha^{-1}). Percent sugar and clear juice purity gave a reciprocal relationship with N rate

in both experiments. However, recoverable sugar generally increased with increasing N rate, indicating that increased yield compensated for the decline in sugar concentration.

8. N concentration in leaf blades was less than the critical level in all treatments, so it is not possible to draw any relationship with yield response.

9. Among several soil tests for N, phosphate-borate, anaerobic mineralization and $KMnO_4$ extraction were able to differentiate among the cropping systems. Relatively high N values in CCB system by these procedures reflected the addition of corn residues.

10. Soils at various locations showed significant differences in N concentration with all procedures. This might be the result of differences in long term management practices, but due to limited information concerning past management this inference could not be verified.

11. Soils at different locations belonging to the same series also showed significant differences with regard to N values with various procedures. This indicated that soils can not be grouped on the basis of series characteristics for fertility evaluation or fertilizer recommendations.

12. None of the tests showed a good relationship with yield response. Although, significant correlation between phosphate-borate test and yield response was observed in some soil series, the relationship is not strong enough to suggest the use of this test for N availability prediction.