Predicting spatial patterns of corn yield response to fertilizer nitrogen

by

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ABSTRACT

Soil testing for nitrate when corn plants are 15 to 30 cm tall is recognized as a valuable tool for estimating N fertilizer needs in humid portions of the United States. Although there is growing appreciation for the importance of spatial variability in soil nutrient levels, high-density sampling is not practical for the soil nitrate test. In this document we report initial studies to identify optimal sampling densities for non-fertilized corn after soybean in Iowa. Soil nitrate concentrations were measured in 24 cornfields in production agriculture during 1995, 1996, and 1997. The preceding crop on all fields was soybean, which did not receive fertilizer N. The mean spring soil nitrate concentration was 8.2 mg N kg^{-1}. Essentially all samples had concentrations below the critical value 25 mg N kg^{-1}, which is often used as the optimal level for corn production. An analysis of variance showed that a simple model, which included the variables Field, Test area within Field, and Sample, could explain 81% of the variation in soil nitrate concentrations. Linear regression analyses showed that much of the variation (78%) in soil nitrate concentrations within fields was explained by soil organic matter concentrations. Results show that soil nitrate concentrations can be predicted with reasonable accuracy even with extremely low-density sampling if soil organic matter concentrations are used to guide the sampling.

Nitrogen (N) fertilizer needs for corn usually are estimated by assuming that fertilizer needs are proportional to yields, but the validity of this assumption has been difficult to evaluate by using experimental data. We evaluated this assumption for corn grown after soybean in Iowa. Nitrogen fertilizer treatments were applied in replicated strips that crossed several soil types within each of 17 fields. The strips were harvested using combines equipped with yield monitors and global positioning system (GPS) receiver. A geographic information system (GIS) was used to calculate mean yields and yield responses to fertilizer N for fields and individual soil survey map units within fields. Analyses showed that neither observed yields nor published yield potentials provided a reasonable basis for predicting yield responses. However, yield responses showed significant relationships with soil survey map units and soil organic matter concentrations measured within soil map units (SMU). Soil organic matter concentrations were positively correlated with yields and negatively correlated with yield response to applied N. These observations suggest that increases in soil organic matter had dual effects, increasing yields and supplies of N. These observations also explain why N fertilizer needs should not be estimated from expected yield or attained yields under the conditions studied and suggest that soil organic matter deserves more attention when estimating N fertilizer needs.

CHAPTER 1: GENERAL INTRODUCTION

Introduction

Nitrogen is an important component of corn production. Soil testing for nitrate when corn plants are 15 to 30 cm tall has been used in many areas of the United States and has recently gained acceptance in the scientific community as a valuable tool for estimating N fertilizer needs in humid areas. Many studies have shown good relationships between soil nitrate concentrations and yield responses to fertilizer N in field trials (Carr et al., 1991; Fox et al., 1998; Francis and Schepers, 1997; Franzen and Peck, 1995; Magdoff et al., 1984; Meisinger et al., 1992). The test, however, has not gained widespread acceptance as a useful tool in production agriculture.

This lack of acceptance may be due to two primary issues. The first issue is related to poor results due to sampling design. The problem of determining the number of soil samples needed to represent the variability in a field has been debated since the 1920s (Lindsley and Bauer, 1929). Currently, there is growing appreciation for the importance of spatial variability when trying to determine a field's nutrient status (Carr et al., 1991; Franzen and Peck, 1992; Franzen and Peck, 1995). As a consequence, many producers currently are investing in high-density sampling, often a grid sampling, when soil testing for phosphorus, potassium, or acidity. High-density sampling, however, is not practical for the soil nitrate test, which requires that samples be collected from all fields within a few days each year. Most producers are reluctant to accept the results of relatively low-density sampling. This reluctance is reasonable because it has not been shown that low density sampling for soil nitrate testing is a reliable tool when estimating N fertilizer needs for fields (or management units) as defined by farmers. There is a need to identify optimal sampling densities for this test. In Chapter 2 we report initial studies to identify optimal sampling densities for non-fertilized corn after soybean in Iowa.

Nitrogen fertilizer needs for grain crops are commonly estimated by a mass balance approach (Stanford, 1973; Legg and Meisinger, 1982; Meisinger, 1984; Oberle and Keeney, 1990; Bock and Hergert, 1991). This approach considers the quantity of N expected to be contained in the final crop, the quantities of N that would be supplied by soils without addition of fertilizer N, and the fraction of fertilizer N that will be taken up by the crop. Because the last two factors are difficult to independently estimate on a site-specific basis, estimates of N fertilizer needs for individual fields often are based on the simplifying assumption that N fertilizer needs are proportional to yields expected or previously attained (Bray, 1963; Viets, 1965; Stanford, 1966; 1973; Miller, 1986; Peterson and Voss, 1984; Schepers et al., 1986; Rehm and Schmitt, 1989).

The validity of the assumption that N fertilizer needs for corn are proportional to yields attained has been recently questioned (Blackmer et al., 1992; Fox and Piekielek, 1995; Vanotti and Bundy, 1994; Blackmer et al., 1997; Blackmer, 2000), but this assumption has not been rigorously evaluated as a scientific hypothesis within a defined range of conditions. White and Blackmer (1996) described field techniques that seem to have great potential for testing the hypothesis that fertilizer needs tend to be proportional to yield levels. Fertilizer treatments (three rates of N) were applied in blocked and replicated strips that crossed several soil map units. Each strip was harvested as a single pass of a harvester equipped with a yield monitor, which recorded mean flows of grain in 1-second intervals. The harvester also had a global positioning system (GPS) receiver, which recorded the position of each flow measurement. With the use of a geographic information system (GIS), mean yields for each treatment were calculated for each strip or for portions of strips located within a soil map unit (or any other polygon considered a potential management unit). This method makes it possible to efficiently study observed relationships between yield levels and yield responses to fertilizer across controlled ranges of conditions. These observed relationships seem to provide a reasonable test for the hypothesis that N fertilizer needs are proportional to yield levels within certain defined ranges of conditions.

The objective of Chapter 3 is to use strip-plot trails, yield monitors, GPS receivers and GIS to test the hypothesis that N fertilizer needs tend to be proportional to yield levels within reasonably defined ranges of conditions. The range of conditions studied was for fertilizer N sidedressed for corn grown after soybean in Iowa fields that had not received recent applications of animal manure.

Thesis Organization

This dissertation is presented as four chapters, two of which are intended for publication. Chapter 1 is the General Introduction; chapter 2 will be submitted to the Soil Science Society of America Journal and chapter 3 will be submitted for publication in the Agronomy Journal. Chapter 4 is the General Conclusions.

References

Blackmer, A.M. 2000. Bioavailability of nitrogen. p. D-3 to D-18. *In* M.E. Sumner (ed.) Handbook of Soil Science. CRC Press, Boca Raton, FL.

Blackmer, A.M., R.D. Voss, and A.P. Mallarino. 1997. Nitrogen fertilizer recommendations for corn in Iowa. Iowa State Univ. Ext. Publ. Pm-1714.

Blackmer, A.M., T.F. Morris, and G.D. Binford. 1992. Predicting N fertilizer needs for corn in humid regions: Advances in Iowa. p. 57-72. *In* B.R. Bock and K.R. Kelley (ed.) Predicting N fertilizer needs for corn in humid regions. Natl. Fertilizer and Environ. Res. Cent., TVA, Muscle Shoals, AL.

Bock, B.R., and G.W. Hergert. 1991. Fertilizer nitrogen management. p. 130-164. *In* R. F. Follett et al. (ed.) Managing nitrogen for groundwater quality and farm profitability. SSSA, Madison, WI.

Bray, R.H. 1963. Confirmation of the nutrient mobility concept of soil-plant relationships. Soil Sci. 95:124-130.

Carr, P.M., G.R. Carlson, J.S. Jacobsen, G.A. Nielsen, and E.O. Skogley. 1991. Farming soils, not fields: A strategy for increasing fertilizer profitability. J. Prod. Agric. 4:57-61.

Fox, R.H., G.W. Roth, K.V. Iversen, and W.P. Piekielek. 1989. Soil and tissue nitrate tests compared for predicting soil nitrogen availability to corn. Agron. J. 81:971-974.

Francis, D.D. and J.S. Schepers. 1997. Selective soil sampling for site-specific nutrient management. Precision agriculture '97 papers presented at the first European Conference of Precision Agriculture:119-126.

Franzen, D.W. and T. Peck. 1992. Spatial variability of soil pH, phosphorus and potassium levels. p. 103-111. *In* R.G. Hoeft (ed.) 1992 Illinois Fertilizer Conf. Proc.

Franzen, D.W. and T.R. Peck. 1995. Field soil sampling density for variable rate fertilization. J. Prod. Agric. 8:568-574.

Legg, J.O., and J.J. Meisinger. 1982. Soil nitrogen budgets. p. 503-566. *In* F.J. Stevenson (ed.) Nitrogen in agricultural soils. Agron. Monogr. 22. ASA, CSSA, and SSSA, Madison, WI.

Lindsley, C.M. and F.C. Bauer. 1929. Test your soil for acidity. Univ. of Illinois. Agric. Exp. Stn. Circ. 346.

Magdoff, F.R., D. Ross, and J. Amadon. 1984. A soil test for nitrogen availability to corn. Soil Sci. Soc. Am. J. 48:1301-1304.

Meisinger, J.J., V.A. Bandel, J.S. Angle, B.E. O'Keefe, and C.M. Reynolds. 1992. Presidedress soil nitrate test evaluation in Maryland. Soil Sci. Soc. Am. J. 56:1527-1532.

Meisinger, J.J. 1984. Evaluating plant available nitrogen in soil-crop systems. p. 391-416. *In* R.D. Hauck et al. (ed.) Nitrogen in crop production. ASA, CSSA, SSSA, Madison, WI.

Miller, G.A. 1986. Establishing realistic yield goals. Iowa State Univ. Ext. Publ. Pm-1268.

Oberle, S.L., and D.R. Keeney. 1990. Factors influencing corn fertilizer requirements in the northern U.S. Corn Belt. J. Prod. Agric. 3:527-534.

Peterson, G.A., and R.D. Voss. 1984. Management of nitrogen in the west north central states. p. 721-733. *In* R.D. Hauck et al. (ed.) Nitrogen in crop production. ASA, CSSA, SSSA, Madison, WI.

Rehm, G., and M. Schmitt. 1989. Setting realistic crop yield goals. Univ. of Minnesota Ext. Publi. AG-FS-3873.

Schepers, J.S., K.D. Frank, and C. Bourg. 1986. Effect of yield goal and residual nitrogen concentrations on nitrogen fertilizer recommendations for irrigated maize in Nebraska. J. Fert. Issues 3:133-139.

Stanford, G. 1966. Nitrogen requirement of crops for maximum yield. *In* W. H. Vickar et al. (ed.) Agricultural anhydrous ammonia – technology and use. SSSA, Madison, WI.

Stanford, G. 1973. Rationale for optimum nitrogen fertilization for corn production. J. Environ. Qual. 2:159-166.

Stanford, G. and J.O. Legg. 1984. Nitrogen and yield potential. p. 263-272. *In* R.D. Hauck et al. (ed.) Nitrogen in crop production. ASA, CSSA, SSSA, Madison, WI.

Vanotti, M.B., and L.G. Bundy. 1994. An alternative rationale for corn nitrogen fertilizer recommendations. J. Prod. Agric. 7:243-249.

Viets, F.G., Jr. 1965. The plant's need for and use of nitrogen. *In* W.V. Bartholomew and F.E. Clark (ed.) Soil Nitrogen. Agron. Monogr. 10:503-549. SSSA, Madison, WI.

White, S.E., and A.M. Blackmer. 1996. Characterizing spatial patterns in response of corn to nitrogen fertilization. p. 257. *In* Agronomy abstracts. ASA, Madison, WI.

CHAPTER 2: VARIABILITY OF SOIL NITRATE CONCENTRATIONS IN NON-FERTILIZED FIELDS OF CORN AFTER SOYBEAN

A paper to be submitted to the Soil Science Society of America Journal

S.E. White and A.M. Blackmer

Abstract

Soil testing for nitrate when corn plants are 15 to 30 cm tall is recognized as a valuable tool for estimating N fertilizer needs in humid portions of the United States. Although there is growing appreciation for the importance of spatial variability in soil nutrient levels, high-density sampling is not practical for the soil nitrate test. In this paper we report initial studies to identify optimal sampling densities for non-fertilized corn after soybean in Iowa. Soil nitrate concentrations were measured in 24 cornfields in production agriculture during 1995, 1996, and 1997. The preceding crop on all fields was soybean, which did not receive fertilizer N. The mean soil nitrate concentration was 8.2 mg N kg^{-1}. Essentially all samples had concentrations below the critical value 25 mg N kg^{-1}, which is often used as the optimal level for corn production. An analysis of variance showed that 81% of the variation in soil nitrate concentrations could be explained by a simple model, which included the variables ***Field***, ***Test area within Field***, and ***Sample***. Linear regression analyses showed that much of the variation (78%) in soil nitrate concentrations within fields was explained by soil organic matter concentrations. Results show that soil nitrate

concentrations can be predicted with reasonable accuracy even with extremely low-density sampling if soil organic matter concentrations are used to guide the sampling.

Introduction

Soil testing for nitrate when corn plants are 15 to 30 cm tall has gained acceptance in the scientific community and is recognized as a valuable tool for estimating N fertilizer needs in humid portions of the United States. The rationale for the test, as well as observed relationships between soil nitrate concentrations and yield responses to fertilizer N in field trials, have been described in many scientific publications (Binford et al., 1992; Blackmer et al., 1989; Fox et al., 1998; Francis and Schepers, 1997; Franzen and Peck, 1995; Magdoff et al., 1984; Meisinger et al., 1992). The test, however, has not gained widespread acceptance as a useful tool in production agriculture.

This lack of acceptance is due primarily to two issues. The first issue is related to poor results due to sampling design. Many soil-testing programs are placed in jeopardy due to non-representative soil samples (Sabbe and Marx, 1987). When the entire field is the sampling unit, samples must be collected in a way that adequately represents the field average. Although it has been shown that as sampling density increases the variation between samples decreases (McIntyre, 1967), the economic success of soil sampling depends on the ability of the sampling to identify areas that will, and will not, respond to additions of fertilizer (Sawyer, 1994). This problem of determining the number of soil samples needed to represent the variability in a field has been debated since the 1920s (Lindsley and Bauer, 1929). There currently is growing appreciation for the importance of problems associated with spatial variability in soil nutrient levels within fields (Carr et al., 1991; Franzen and Peck, 1992; Franzen and Peck, 1995).

Lindsley and Bauer (1929) originally recommended a sampling unit of 16 hectares that consisted of 23 sub samples (2.5 to 5 cm depth), five subsurface (30 cm depth), and five subsoil (51 cm depth) samples. In 1943 the recommended grid size was reduced to 11 subsurface samples per 16 hectares. Recently the grid size recommendation has been changed to 16 subsurface samples per 16 hectares (Peck, 1988) in response to increasing awareness of field variability and the growers' ability to respond to it. In addition to determining the number of samples to be collected to adequately represent a sampling unit, the issue of how to take those samples has been studied. The three primary designs are 1) random, 2) stratified random, and 3) systematic (grid) sampling.

These sampling designs have been studied both theoretically (Quenouille, 1949) and empirically (Rigney and Reed, 1946). Results show that systematic sampling leads to greater precision than random or stratified random if there are no linear trends across the field. Systematic sampling has been suggested by several researchers as the method best used to sample a field (Peck and Melsted, 1973; Sabbe and Marx, 1987).

Many producers currently are investing in high-density sampling, often grid sampling, when soil testing for phosphorus, potassium, or acidity. Such sampling is possible because time of sampling is not important and because fields do not need to be sampled each year. However, this leads to the second issue related to acceptance of the late spring soil nitrate test. Individual producers in the Corn Belt often grow hundreds of hectares of corn, and they are extremely busy with other field operations, such as cultivation, when corn plants are 15 to 30 cm tall. High-density sampling clearly is not possible for the soil nitrate test, which requires that samples be collected from all fields within a few days each year. Most producers are reluctant to accept the results of relatively low-density sampling, however, because soil tests for P, K and acidity show marked variability within their fields (Mallarino, 1996). This reluctance is reasonable because it has not been shown that low density sampling for soil nitrate testing is a reliable tool when estimating N fertilizer needs for fields (or management units) as defined by farmers. There is, therefore, an obvious need to identify optimal sampling densities for this test. Such sampling density should be expected to vary with climatic region and cultural practices.

In this paper we report initial studies to identify optimal sampling densities for non-fertilized corn after soybean in Iowa. Most of the corn in Iowa is grown after soybean, which usually is grown without application of fertilizer N. Non-fertilized corn after soybean, therefore, deserves special attention because problems associated with nonuniform applications or losses of fertilizer N are minimal. Moreover, recent studies suggest that there may be important advantages to delaying all applications of N until after this crop is 30 cm tall (Ellsworth, 2001).

Materials and Methods

Soil nitrate concentration distributions were studied in 24 cornfields in production agriculture during 1995, 1996, and 1997. Fields were chosen based on a relatively high level of variability in topography and soils. The fields were spread across 10 counties in Iowa (Fig. 1) and on several different soil associations (Table 1). Soil series, soil map symbol, and associated soil classification are given in Table 2. The preceding crop on all fields was soybean, which did not receive fertilizer N. Except for small amounts (20 to 30 kg N ha^{-1})

applied with phosphorous in the fall, fertilizer N was not applied for the corn crop before soils were sampled. All fields were managed by producers using their normal practices except for delaying application of N until the soils were sampled.

Each field was between 450 and 770 m long and 70 m wide. The geographic location of each field site was established using a global positioning system (GPS) receiver (Magellan ProMarkX, Magellan Systems Corp., San Dimas, CA) using unprojected latitude and longitude. Digital soil maps for each field were created using the command 'clip' in Arc/Info (version 7, ESRI) on Iowa's digital soil section maps (Iowa Cooperative Soils Survey, Iowa State University, Ames, IA).

Each field contained 12 to 16 strips that were six or eight rows wide (depending on the combine swath width) and ran the length of the field. Soil samples were collected along two transects parallel to the corn rows in each field. Each transect was selected to include the widest possible range in soil characteristics. Seven or eight test areas were placed along each transect to provide a total of 15 test areas per field. These test areas spanned approximately 12 m along the row and 16 m across rows. The test areas were positioned to capture the entire range in variability in soil characteristics within the field (particularly variability in topography and soil organic matter content). Therefore, some test areas represented only a small percentage of the field. The test areas were positioned so that soil within the test area appeared as uniform as possible with respect to landscape position, soil organic matter, and plant residue distribution. These test areas represent standard small plot areas. The location of each test area was established using a GPS receiver (Magellan ProMarkX, Magellan Systems Corp., San Dimas, CA). Test area map coverage's were projected to Universal

Transmercator (UTM) projection and the North American Datum of 1927 (NAD27) datum using Blue Marble Geographics, Geographic calculator 4.1.

Each test area was divided into three plots (12 m by 5.3 m). Two soil samples were collected from each plot when the corn was approximately 30 cm tall. Each soil sample consisted of a composite of eight cores (3.2 cm in diameter and 30 cm deep) collected along a diagonal line across the plots as illustrated in Figure 2. Individual cores in a sample were collected at prescribed distances from rows (in row, one-eighth the distance from one row to the next, one-quarter the distance from one row to the next, etc.) to minimize possible row effects on soil nitrate concentrations (Binford et al., 1992).

Soil samples were dried within 24 hours at 40°C and ground to pass a 2-mm screen. Sub-samples were analyzed for nitrate using the Lachat flow-injection procedure (Lachat Instruments, Milwaukee, WI; Method 12-107-4-1-B). Soil organic matter (SOM) concentrations were determined at the Iowa State University soil-testing lab (Walkley and Black, 1934) on composite samples from each test area.

The SAS command PROC GLM (v. 8.1, SAS Institute, Cary, NC) was used in all analysis of variance calculations. All data was checked for normality using the PROC UNIVARIATE command in SAS.

Results

When data from all field sites were pooled, soil nitrate concentrations had a mean of 8.2 mg N kg^{-1} with a standard deviation of 4 mg kg^{-1} (Fig. 3). Essentially all samples had concentrations below 25 mg N kg^{-1}, which is often considered optimal for corn production (Binford et al., 1992; Blackmer et al., 1989; Bundy and Andraski, 1995). The finding that mean concentrations of nitrate are only about one-third of optimal and that the standard deviation is only about one-quarter of optimal suggests that the value of information provided by the test may not justify the cost of relatively dense soil testing. The cost of relatively dense soil testing, for example, would not be recovered if the soil test reduced application of N by only a few kg N ha^{-1}.

Analysis of variance showed that 81% of the variability in soil nitrate concentrations was explained by a model that included the variables *Field*, *Test area within Field*, and *Sample* (Table 3). Moreover, the analyses showed that the variable *Sample* explained only a small portion of the variability. This model is important because it shows that soil nitrate concentrations were distributed in a way that was more orderly than random, and because it means that dense sampling may not be required in fields of non-fertilized corn after soybean.

The model in Table 3 has limited ability to predict soil nitrate concentrations in fields because the variable *Field* includes the effects of year (weather) as well as the effects of various soil characteristics (i.e., parent material, organic matter concentration, pH, texture, etc.) and cultural practices. All of these factors are confounded, so it is not possible to know which factors are important and how they interact.

Linear regression analyses showed that much of the variability in soil nitrate concentrations within fields was explained by soil organic matter (SOM) concentrations (Fig. 4). More than 50% of the variability was explained in 12 of the 24 fields, and the fields in which smaller percentages of variability were explained tended to have relatively little variability in soil organic matter concentrations.

Analysis of variance for pooled data from all fields (Table 4) showed that the variable *SOM within field* explained 78% of the variability in soil nitrate concentrations. Higher percentages of this variability were explained if soils were divided into two categories divided by an organic matter concentration of 40 g kg^{-1}. This categorization increased predictability because the overall relationships between mean soil nitrate concentrations and soil organic matter concentrations showed a discontinuity at a soil organic matter concentrations of 40 g kg^{-1}. We do not know the reason for this discontinuity, but we suspect it may be due to the tendency for the soils with more organic matter to occur in depressions that often accumulate water during rainfall events.

It is noteworthy that soil organic matter concentrations are confounded with landscape position in this study. This is not necessarily a problem because soil organic matter concentrations usually are confounded with landscape positions when many fields are studied within a small geographic area (i.e., within the same soil association). It is reasonable to assume, therefore, that ability to predict spatial patterns in soil nitrate concentrations on landscapes will increase as models are refined to include other soil characteristics found to have independent effects on soil nitrate concentrations.

The observation that soil nitrate concentrations tend to vary with soil organic matter concentrations is important because the distributions of organic matter are often known before samples are collected. These distributions can be estimated from landscape position, soil map units, or soil color. Blackmer and White (1998) reported that soil nitrate concentrations showed good relationships with soil color as measured by remote sensing. Dividing fields into appropriate categories based on approximate soil organic matter concentration makes it possible to sample each category separately and thereby greatly increase the percentage of variability in soil nitrate concentrations that can be predicted.

Analyses presented in Table 5 show that rainfall usually explained a much greater percentage of the variability in soil nitrate than did soil organic matter concentrations. These analyses are different from those presented in Table 3 because all fields are grouped into one of 5 different regions. Each region contains trials from different years, so the variable *May rainfall* primarily describes year-to-year variability in rainfall. The important information provided by this table is that variability in rainfall corresponds to variability in soil nitrate concentrations.

The effects of rainfall should not be expected to be important when establishing relationships between soil organic matter concentrations and soil nitrate concentrations in a single field in a single year. However, the analyses in Table 5 suggest that these effects are important when attempting to sample many fields across many different years. The relative importance of rainfall and soil organic matter should be expected to depend on the relative amounts of variability in rainfall and soil organic matter under the conditions studied. The value of soil testing for nitrate, therefore, depends on the ability to characterize year-to-year variability as well as spatial variability on the landscape within a given year.

Discussion

The results of this study show that the optimal sampling density for non-fertilized fields of corn after soybean depends on variability in soil organic matter concentrations. This is not a problem, however, because relationships between soil nitrate concentrations in the late spring and soil organic matter tend to share a similar relationship across groups of fields that are managed similarly and have similar rainfall. This common relationship means that soil nitrate concentrations can be predicted with reasonable accuracy even with extremely low-density sampling if soil organic matter concentrations are used to guide the sampling.

Iowa has about 8.5 million hectares in the corn-soybean cropping sequence. Under conditions of intensive corn production it is possible that a few dozen samples collected appropriately would provide reasonable assessments of soil nitrate concentrations across thousands of hectares.

The idea of collecting a group of samples to represent a specified range of soils is a marked departure from the customary assumption that a single sample represents only a specific small area of soil (Biggar, 1978; Cline, 1945). However, past sampling schemes have been designed to produce an acceptable average for a sample unit (frequently an entire field) with unknown variability or spatial pattern. Soil nitrate concentrations in this cropping system are closely tied to soil organic matter, which varies in a predictable way according to topography and drainage. Systematic sampling designs are not the most appropriate or efficient strategy in this system. And the idea of collecting a group of samples has merit because soil nitrate concentrations can be shown to follow somewhat predictable spatial patterns within years and the primary problem is characterizing the effects of weather and interactions of weather and landscape characteristics on distributions of nitrate concentrations in soils. The effects of such interactions may not be important when soil testing for P, K, or acidity, but these effects may be of critical importance when testing for soil nitrate in humid regions (Biggar, 1978; Jenny, 1941). Differences in the normal effects of rainfall on the soil nutrient being tested for require differences in sampling strategies (Cline, 1945).

The strategy of collecting a group of samples to characterize a range of soils should not be expected to work under all conditions. Studies in Iowa over the past decade indicate that spatial patterns in soil nitrate within cornfields recently treated with fertilizers are not as predictable as in soils studied here. Part of the problem is nonuniform applications of fertilizer as discussed by Blackmer and White (1998). Another part of the problem seems to be nonuniform losses of fertilizer N during the period between application and sampling (Bundy and Andraski, 1995). Spatial patterns in nitrate concentrations in fields of corn after corn may be dominated by variability in amounts of fertilizer N remaining from the previous year. Efficient sampling strategies for nitrate, therefore, require reasonable amounts of information concerning which fields on the landscape can be (or cannot be) grouped into predictable categories.

Soil nitrate concentrations were found to follow predictable patterns in this study because our sampling methods gave precise estimates of soil nitrate concentrations for small areas of soil that seemed to be reasonably homogenous when judged by similarity of cells of about a meter in size. Steps were taken to minimize possible effects of small-scale variability due to rows of plants. Numerous cores and several nitrate analyses were used to characterize nitrate concentrations in each test area. Calculations showed that nitrate concentrations were measured with a 95% confidence interval of plus or minus 0.5 mg N kg^{-1}.

The sampling methods used in this study may seem impractical for production agriculture. It should be noted, however, that collecting only one set of eight cores per test area would not have provided reasonable evidence that nitrate concentrations follow predictable patterns on the landscape. Under such conditions the study would not have revealed that it may be possible to characterize spatial patterns in nitrate concentrations within many fields by collecting a relatively few samples. More attention should be given to the possibility that higher per-sample costs may be small compared to reductions in numbers of samples that must be collected to obtain similar information.

Learning how to characterize spatial patterns of soils not recently fertilized seems to be an essential first step to the more complicated task of learning how to characterize spatial patterns in nitrate in soils that are recently fertilized. Research in Iowa suggests that soil nitrate concentrations in fertilized cornfields provide evidence for large losses of fertilizer N during the period between application and soil testing. Sampling methods that make it possible to characterize patterns in such losses could be extremely valuable when trying to identify practical ways to minimize these losses. For these reasons, soil testing for nitrate should be expected to provide valuable information on soils that are recently fertilized as well as soils that are not recently fertilized. It must be recognized, however, that the reasons for testing and the best methods of collecting samples may differ substantially between these categories of fields.

References

Biggar, J. W. 1978. Spatial variability of nitrogen in soils. Academic Press, New York, San Francisco, and London.

Binford, G.D., A.M. Blackmer, and M.E. Cerrato. 1992. Relationships between corn yields and soil nitrate in late spring. Agron. J. 84:53-59.

Blackmer, A.M. and S.E. White. 1998. Using precision farming technologies to improve management of soil and fertiliser nitrogen. Aust. J. Agric. Res. 49:555-564.

Blackmer, A.M., D. Pottker, M.E. Cerrato, and J. Webb. 1989. Correlations between soil nitrate concentrations in late spring and corn yields in Iowa. J. Prod. Agric. 2: 103-109.

Blue Marble. 1999. Geographic calculator. Version 4.1. Gardiner, Maine.

Bundy, L.G. and T.W. Andraski. 1995. Soil yield potential effects on performance of soil nitrate tests. J. Prod. Agric. 8:561-568.

Carr, P.M., G.R. Carlson, J.S. Jacobsen, G.A. Nielsen, and E.O. Skogley. 1991. Farming soils, not fields: A strategy for increasing fertilizer profitability. J. Prod. Agric. 4:57-61.

Cline, M.G. 1945. Principles of soil sampling. Soil Sci. 58: 275-288.

Ellsworth, J.W. 2001. Dividing cornfields into soil management units for nitrogen fertilization. Iowa State Univ., Ames, IA.

Entz, T. and C. Chang. 1991. Evaluation of soil sampling schemes for geostatistical analyses: a case study for soil bulk density. Can. J. Soil Sci. 71:165-176.

Fox, R.H., G.W. Roth, K.V. Iversen, and W.P. Piekielek. 1989. Soil and tissue nitrate tests compared for predicting soil nitrogen availability to corn. Agron. J. 81:971-974.

Francis, D.D. and J.S. Schepers. 1997. Selective soil sampling for site-specific nutrient management. Precision agriculture '97 papers presented at the First European Conference of Precision Agriculture.

Franzen, D.W. and T. Peck. 1992. Spatial variability of soil pH, phosphorus and potassium levels. p. 103-111. *In* R.G. Hoeft (ed.) 1992 Illinois Fertilizer Conf. Proc.

Franzen, D.W. and T.R. Peck. 1995. Field soil sampling density for variable rate fertilization. J. Prod. Agric. 8:568-574.

Jenny, H. 1941. Factors of soil formation. McGraw-Hill Book Company, New York and London.

Lindsley, C.M. and F.C. Bauer. 1929. Test your soil for acidity. Univ. of Illinois. Agric. Exp. Stn. Circ. 346.

Magdoff, F.R., D. Ross, and J. Amadon. 1984. A soil test for nitrogen availability to corn. Soil Sci. Soc. Am. J. 48:1301-1304.

Mallarino, A.P. 1996. Spatial variability patterns of phosphorus and potassium in no-tilled soils for two sampling scales. Soil Sci. Soc. Am. J. 60:1473-1481.

McIntrye, G.A. 1967. Soil sampling for soil testing. J. Aust. Inst. Agric. Sci. 18: 309-318.

Meisinger, J.J., V.A. Bandel, J.S. Angle, B.E. O'Keefe, and C.M. Reynolds. 1992. Presidedress soil nitrate test evaluation in Maryland. Soil Sci. Soc. Am. J. 56:1527-1532.

Peck, T.R. and S.W. Melsted. 1973. Field sampling for soil testing. Soil testing and plant analysis. p. 67-75.

Peck, T.R. 1988. Soil testing-making it work. 1988 Illinois Fertilizer Conf., Proc. Peoria, IL. p. 26-27.

Quenouille, M.H. 1949. Problems in plane sampling. Ann. Math. Statist. 20:355-375.

Reed, J.F. and J.A. Rigney. 1947. Soil sampling from fields of uniform and nonuniform appearance and soil types. J. Am. Soc. Agron. 39:26-40.

Rigney, J.A. and J.F. Reed. 1946. Some factors affecting the accuracy of soil sampling. Soil Sci. Soc. Am. Proc. 10: 257-259.

Sabbe, W.E. and D.B. Marx. 1987. Soil sampling: spatial and temporal variability. ASA Spec. Publ. 21: 1-14.

SAS Institute. 1988. SAS User's Guide: Statistics. 5th ed. SAS inst., Cary, NC.

Sawyer, J.E. 1994. Concepts of variable rate technology with considerations for fertilizer applications. J. Prod. Agric. 7:195-201.

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

Welch, L.F., D.L. Mulvaney, M.G. Oldham, L.V. Boone, and J.W. Pendleton. 1971. Corn yields with fall, spring, and sidedress nitrogen. Agron. J. 63(119-123).

Table 1. Description of field study sites including county, soil association, soil map symbol (SMS), and series name.

Field	County	Association	SMS	Series
1	Delaware	Kenyon-Clyde-Floyd	175B	Dickinson
			226	Lawler
			241B	Burkhardt
			391B	Clyde-Floyd
			399	Readlyn
			83B	Kenyon
			84	Clyde
2	Greene	Canisteo-Webster-Nicollet	107	Webster
			138B2	Clarion
			507	Canisteo
			55	Nicollet
			6	Okoboji
			878B	Ocheyedan
			878B2	Ocheyedan
			878C2	Ocheyedan
			879	Fostoria
3	Greene	Canisteo-Webster-Nicollet	138B2	Clarion
			4	Knoke
			507	Canisteo
			55	Nicollet
			638C2	Clarion-Storden
4	Boone	Canisteo-Clarion-Nicollet	107	Webster
			138B	Clarion
			138C2	Clarion
			507	Canisteo
			55	Nicollet
			6	Okoboji
			95	Harps
5	Boone	Canisteo-Clarion-Nicollet	107	Webster
			138B	Clarion
			507	Canisteo
			6	Okoboji

Table 1. (continued)

Field	County	Association	SMS	Series
6	Buchanan	Kenyon-Clyde-Floyd	391B	Clyde
			83B	Kenyon
7	Blackhawk	Tama-Muscatine-Garwin	119B	Muscatine
			11B	Colo-Ely
			120B	Tama
			377B	Dinsdale
			377C2	Dinsdale
			83C	Kenyon
			83C2	Kenyon
8	Blackhawk	Dinsdale-Klinger-Maxfield	377B	Dinsdale
			391B	Clyde
			782B	Donnan
			83B	Kenyon
9	Boone	Canisteo-Clarion-Nicollet	138B	Clarion
			138C2	Clarion
			507	Canisteo
			55	Nicollet
10	Blackhawk	Marshan-Sawmill-Bremer	11B	Colo-Ely
			133	Colo
			377B	Dinsdale
			426B	Aredale
			426C2	Aredale
			83B	Kenyon
11	Greene	Lester-Fluvaquents-Wadena	108	Wadena
			202	Cylinder
			203	Cylinder
			259	Biscay
			308	Wadena
			485	Spillville
			639C2	Salida-Storden
			639D2	Salida-Storden

Table 1. (continued)

Field	County	Association	SMS	Series
12	Boone	Canisteo-Clarion-Nicollet	107	Webster
			138B	Clarion
			507	Canisteo
			55	Nicollet
			6	Okoboji
			95	Harps
13	Boone	Canisteo-Clarion-Nicollet	507	Canisteo
			62C2	Storden
			655	Crippin
			90	Okoboji
			95	Harps
14	Blackhawk	Dinsdale-Klinger-Maxfield	118	Garwin
			119B	Muscatine
			11B	Colo-Ely
			377B	Dinsdale
			377C2	Dinsdale
15	Blackhawk	Dinsdale-Klinger-Maxfield	118	Garwin
			119B	Muscatine
			11B	Colo-Ely
			377B	Dinsdale
			377C2	Dinsdale
16	Calhoun	Webster-Nicollet-Clarion	107	Webster
			507	Canisteo
			55	Nicollet
17	Buchanan	Kenyon-Clyde-Floyd	391B	Clyde-Floyd
			83B	Kenyon
18	Greene	Canisteo-Webster-Nicollet	107	Webster
			138B	Clarion
			55	Nicollet
19	Delaware	Kenyon-Clyde-Floyd	391B	Clyde-Floyd
			83B	Kenyon

Table 1. (continued)

Field	County	Association	SMS	Series
20	Blackhawk	Tama-Muscatine-Garwin	118	Garwin
			119	Muscatine
			120B	Tama
			377B	Dinsdale
			377C2	Dinsdale
21	Carroll	Clarion-Nicollet-Webster	138B	Clarion
			138B2	Clarion
			55	Nicollet
22	Calhoun	Webster-Nicollet-Clarion	107	Webster
			507	Canisteo
			55	Nicollet
23	Linn	Kenyon-Dinsdale	377B	Dinsdale
			381B	Klinger-Maxfield
24	Calhoun	Webster-Nicollet-Clarion	107	Webster
			507	Canisteo
			55	Nicollet

Table 2. Soil series, soil map symbol (SMS), and corresponding classification of soils found at 17 field sites.

Series	SMS	Classification
Webster	107	Fine-loamy, mixed, superactive, mesic Typic Endoaquolls
Wadena	108	Fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Hapludolls
Garwin	118	Fine-silty, mixed, superactive, mesic Typic Endoaquolls
Muscatine	119	Fine-silty, mixed, superactive, mesic, Aquic Hapludolls
Muscatine	119B	Fine-silty, mixed, superactive, mesic, Aquic Hapludolls
Colo-Ely	11B	Fine-silty, mixed, superactive, mesic Aquic Cumulic Hapludolls
Tama	120B	Fine-silty, mixed, superactive, mesic Typic Argiudolls
Colo	133	Fine-silty, mixed, superactive, mesic Cumulic Endoaquolls
Clarion	138B	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Clarion	138B2	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Clarion	138C2	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Dickinson	175B	Coarse-loamy, mixed, superactive, mesic Typic Hapludolls
Cylinder	202	Fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Aquic Hapludolls
Cylinder	203	Fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Aquic Hapludolls
Lawler	226	Fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Aquic Hapludolls
Burkhardt	241B	Sandy, mixed, mesic Typic Hapludolls
Biscay	259	Fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Endoaquolls
Wadena	308	Fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Hapludolls
Dinsdale	377B	Fine-silty, mixed, superactive, mesic Typic Argiudolls
Dinsdale	377C2	Fine-silty, mixed, superactive, mesic Typic Argiudolls
Klinger-Maxfield	381B	Fine-silty, mixed, superactive, mesic Aquic Hapludolls
Clyde-Floyd	391B	Fine-loamy, mixed, superactive, mesic Aquic Hapludolls
Readlyn	399	Fine-loamy, mixed, superactive, mesic Aquic Hapludolls
Knoke	4	Fine, smectitic, calcareous, mesic Cumulic Vertic Endoaquolls
Aredale	426B	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Aredale	426C2	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Spillville	485	Fine-loamy, mixed, superactive, mesic Cumulic Hapludolls
Canisteo	507	Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls

Table 2. (continued)

Series	SMS	Classification
Nicollet	55	Fine-loamy, mixed, superactive, mesic Aquic Hapludolls
Okoboji	6	Fine, smectitic, mesic Cumulic Vertic Endoaquolls
Storden	62C2	Fine-loamy, mixed, superactive, Typic Eutrudepts
Clarion-Storden	638C2	Fine-loamy, mixed, superactive, mesic Typic Hapludolls

Table 3. Analysis of variance of soil nitrate concentrations.

Source of variation	df	Model sum of squares	Significance levels (P)
		-------% -------	
Field	24	61	<0.0001
Test area (Field)	340	19	<0.0001
Sample (Test area)	76	1	0.6135

Table 4. Analysis of variance for within field variability in soil nitrate concentrations.

Source of variation	df	Model sums of squares
		------- % -------
SOM(Field)	25	78
SOM <= 40 mg kg^{-1}	23	88
SOM > 40 mg kg^{-1}	24	85

Table 5. Analysis of variance of soil nitrate by region.

Region	R-Squared value for model	Percentage of variability explained by model variables		
		May rainfall	SOM	May rain * SOM
	---- % -----	---- % -----	---- % -----	---- % -----
A	50	40	0	10
B	65	62	1	2
C	40	28	9	3
D	33	2	27	3
E	83	65	18	0
F	22	-	22	-

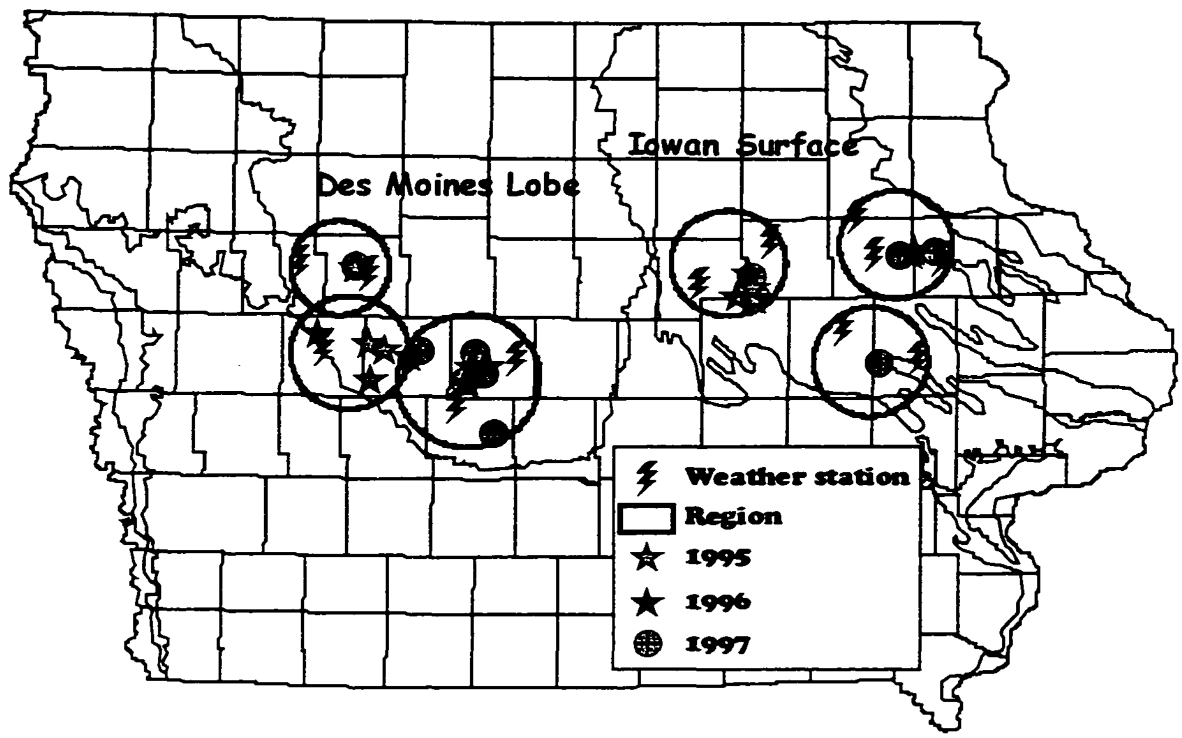

Fig. 1. Locations of fields, weather stations, and regions in study.

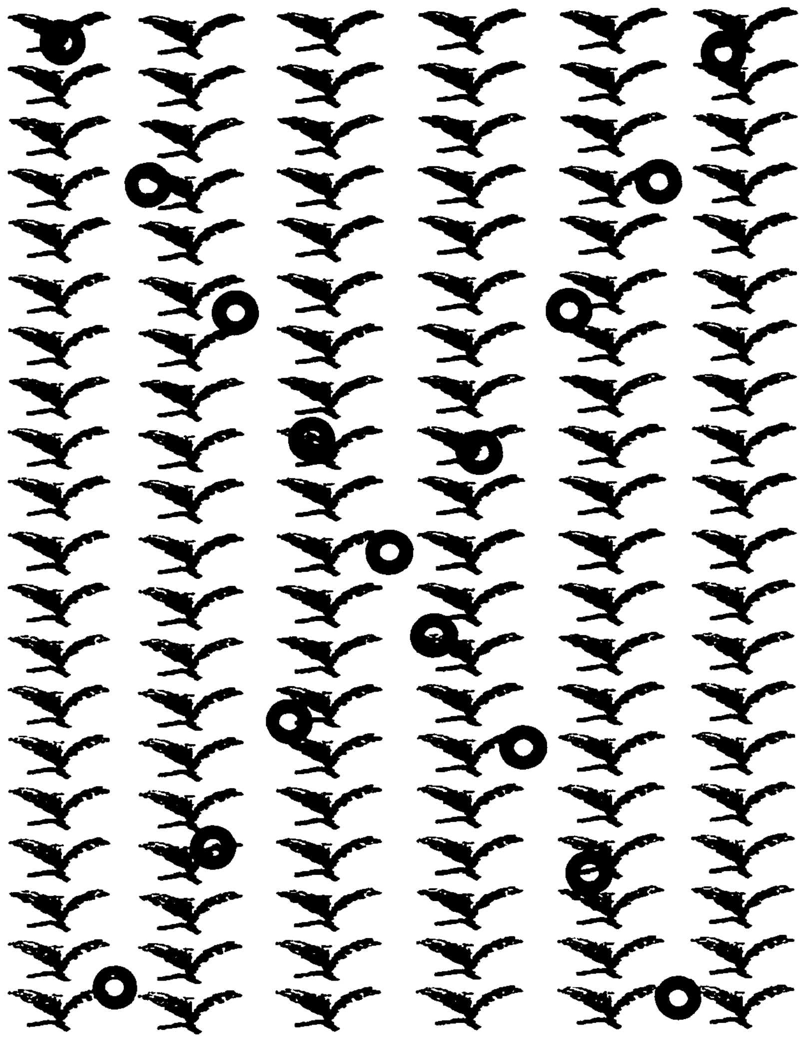

Fig. 2. Schematic illustration of soil sampling points (indicated by dark circles) relative to corn rows within a plot.

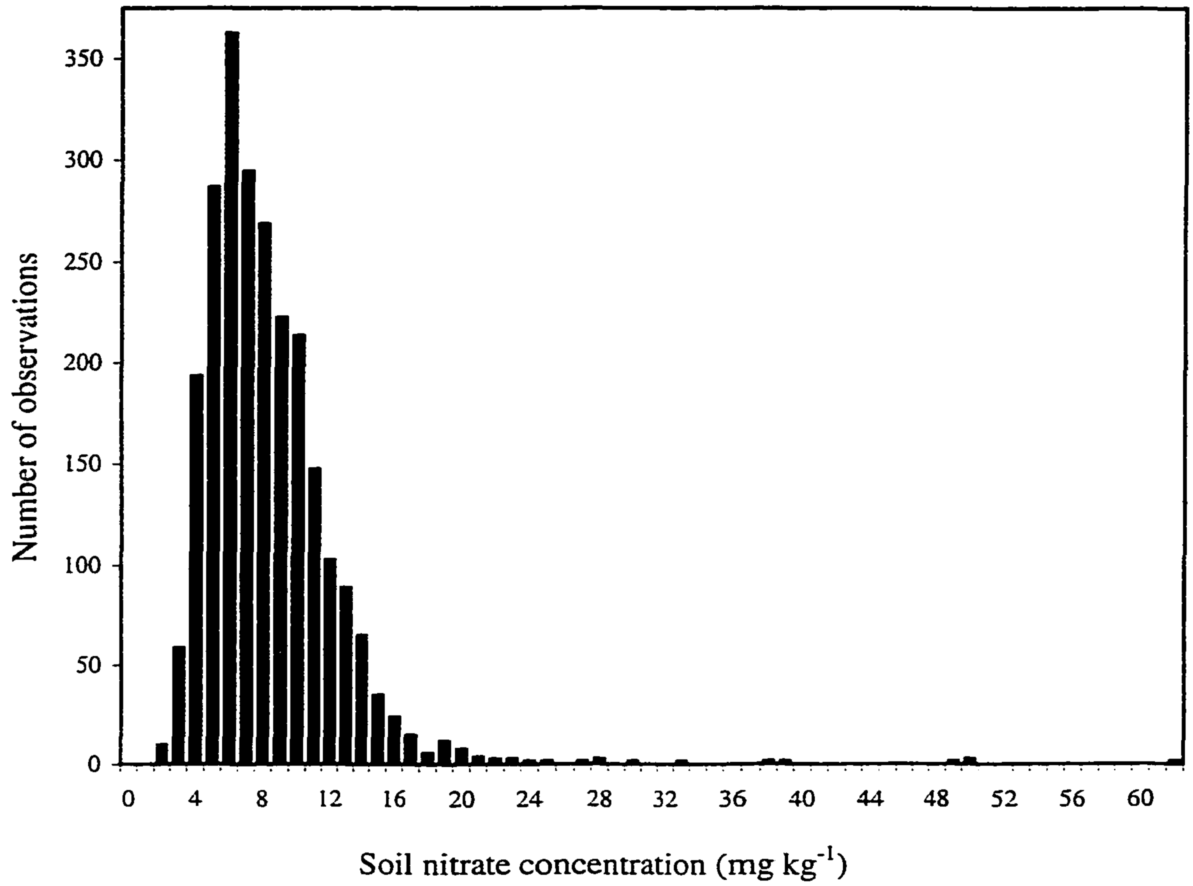

Fig. 3. Frequency distribution of soil nitrate concentrations observed at all test areas.

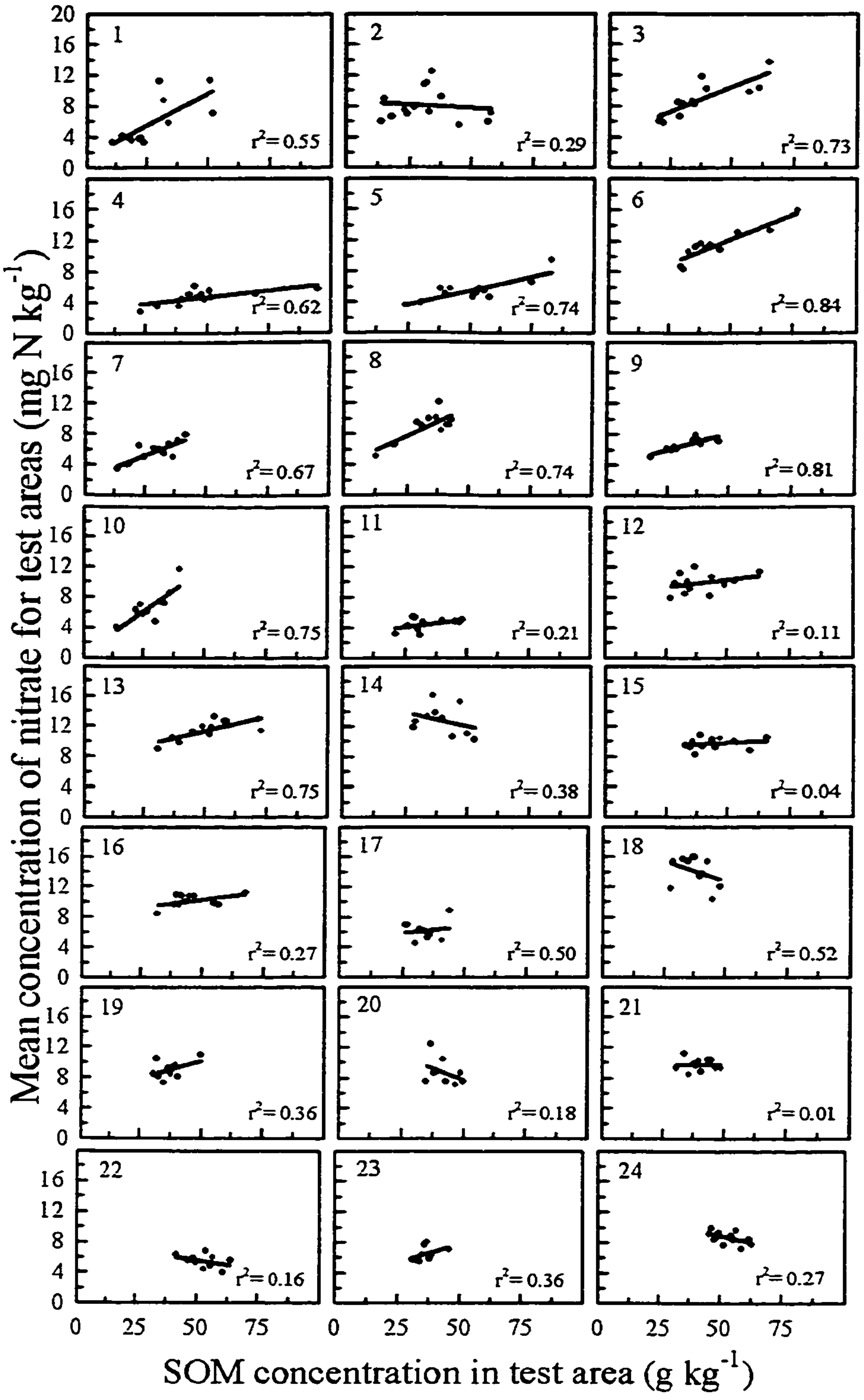

Fig. 4. Relationships between soil organic matter and soil nitrate concentrations within each field.

CHAPTER 3: RELATIONSHIPS BETWEEN YIELD LEVELS AND YIELD RESPONSE TO NITROGEN FERTILIZATION IN IOWA CORNFIELDS

A paper to be submitted to the Agronomy Journal

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Abstract

Nitrogen (N) fertilizer needs for corn usually are estimated by assuming that fertilizer needs are proportional to yields, but the validity of this assumption has been difficult to evaluate by using experimental data. We evaluated the validity of this assumption for corn grown after soybean in Iowa. Nitrogen fertilizer treatments were applied in replicated strips that crossed several soil types within each of 17 fields. The strips were harvested using combines equipped with yield monitors and global positioning system (GPS) receiver. A geographic information system (GIS) was used to calculate mean yields and yield responses to fertilizer N for fields and individual soil survey map units within fields. Analyses showed that neither observed yields nor published yield potentials provided a reasonable basis for predicting yield responses. However, yield responses showed significant relationships with soil survey map units and soil organic matter concentrations measured within soil map units (SMU). Soil organic matter concentrations were positively correlated with yields and negatively correlated with yield response to applied N. These observations suggest that increases in soil organic matter had dual effects, increasing yields and supplies of N. These

observations also explain why N fertilizer needs should not be estimated from expected yield or attained yields under the conditions studied and suggest that soil organic matter deserves more attention when estimating N fertilizer needs.

Introduction

Nitrogen fertilizer needs for grain crops are commonly estimated by a mass balance approach (Stanford, 1973; Legg and Meisinger, 1982; Meisinger, 1984; Oberle and Keeney, 1990; Bock and Hergert, 1991). This approach considers the quantity of N expected to be contained in the final crop, the quantities of N that would be supplied by soils without addition of fertilizer N, and the fraction of fertilizer N that will be taken up by the crop. Because the last two factors are difficult to independently estimate on a site-specific basis, estimates of N fertilizer needs for individual fields often are based on the simplifying assumption that N fertilizer needs are proportional to yields expected or previously attained (Bray, 1963; Viets, 1965; Stanford, 1966; 1973; Miller, 1986; Peterson and Voss, 1984; Schepers et al., 1986; Rehm and Schmitt, 1989). The tendency of producers to use unrealistic estimates of attainable yields when calculating N fertilizer needs is commonly identified as a major barrier to improving N management during crop production (Keeney, 1982; National Research Council, 1993).

The validity of the assumption that N fertilizer needs for corn are proportional to yields attained has been recently questioned (Blackmer et al., 1992; Fox and Piekielek, 1995; Vanotti and Bundy, 1994; Blackmer et al., 1997; Blackmer, 2000), but this assumption has not been rigorously evaluated as a scientific hypothesis within a defined range of conditions. A major reason is that large amounts of experimental data are required. In addition, experimental methods for direct measurement of N fertilizer needs are based on measurements of yield response to N in field studies. Data from many different plots are needed to obtain a single estimate of N fertilizer needs. Numerous estimates of fertilizer needs are needed to evaluate the assumption within each combination of cropping system and soil association within a region. It has not been practical to conduct enough response trials to reasonably test the hypothesis across the range of conditions where fertilizer needs are assumed to be proportional to yields attained.

White and Blackmer (1996) described field techniques that seem to have great potential for testing the hypothesis that fertilizer needs tend to be proportional to yield levels. Fertilizer treatments (three rates of N) were applied in blocked and replicated strips that crossed several soil map units. Each strip was harvested as a single pass of a harvester equipped with a yield monitor, which recorded mean flows of grain in 1-second internals. The harvester also had a GPS receiver, which recorded the position of each flow measurement. With the use of GIS, mean yields for each treatment were calculated for each strip or for portions of strips located within a soil map unit (or any other polygon considered a potential management unit). This method makes it possible to efficiently study observed relationships between yield levels and yield responses to fertilizer across controlled ranges of conditions. These observed relationships seem to provide a reasonable test for the hypothesis that N fertilizer needs are proportional to yield levels with certain defined ranges of conditions.

The objective of this report is to use strip-plot trials, yield monitors, GPS receivers and GIS to test the hypothesis that N fertilizer needs tend to be proportional to yield levels within reasonably defined ranges of conditions. The range of conditions studied is when fertilizer N is sidedressed for corn grown after soybean in Iowa fields that have not received recent applications of animal manure.

Corn grown after soybean covers about 4.2 million ha in Iowa, and accounts for most of the fertilizer N applied in this state. Fertilizer N is not applied for soybean crops, so studies of yield responses to fertilizer N are not complicated by large variability in carryover of fertilizer N applied for previous crops. Studies focusing on side dressed N avoid the problem that yield responses often are influenced by early season losses of fertilizer when fertilizers are applied in the fall or early spring. An accompanying study (White and Blackmer, 2001) showed that concentrations of soil nitrate at the time this crop begins rapid growth were highly predictable in the system studied.

Materials and Methods

Corn yield relationships to soil map units and soil samples were studied in 17 cornfields in production agriculture during 1995, 1996, and 1997. Fields were chosen based on a relatively high level of variability in topography and soils. The fields were spread across 10 counties in Iowa (Fig. 1) and on several different soil associations (Table 1). Soil series, soil map symbols, and associated soil classification are given in Table 2. The preceding crop on all fields was soybean, which did not receive fertilizer N. Except for small amounts (20 to 30 kg N ha^{-1}) applied with phosphorous in the fall, fertilizer N was not applied for the corn crop before soils were sampled. All fields were managed by producers using their normal practices except for delaying application of N until after the soils were sampled.

Each field was between 450 and 770 m long and 70 m wide. The geographic location of each field site was established using a GPS receiver (Magellan ProMarkX, Magellan Systems Corp., San Dimas, CA) using unprojected latitude and longitude. All fields included several soil map units. Digital soil maps for each field were created using the command 'clip' in Arc/Info (version 7, ESRI) on Iowa's digital soil section maps (Iowa Cooperative Soils Survey, Iowa State University, Ames, IA). The published yield potentials from the Iowa Soil Property and Interpretations Database (ISPAID version 6.1) for each soil map unit were joined to the soils coverage for each field site using the ArcView command 'join'. The published yield potentials were designed to represent yields attainable as a 5-year average with the technology available in 1971 and average weather conditions (Fenton et al., 1971). Yield potentials were estimated in two stages. First, benchmark soils, which included large acreages with large databases from corn yield studies and fertilizer and rotation studies by Iowa State University, and the Iowa corn yield tests, were used. Yield information from successful farmers was also used in the calculation. In the second stage yields from soils with limited data and yield information were estimated by using associated benchmark soils, a knowledge of soil characteristics and their effects on yield potential, and available data provided the yield estimates. The authors of the published yield potentials believe they have taken into account many factors affecting yields, such as soil type, slope, erosion, drainage, cropping pattern, fertilizer, crop variety, plant population, timeliness, and weather in their estimate of yield potential.

Each field contained 12 to 16 strips that were six or eight rows wide (depending on the combine swath width) and ran the length of the field. Soil samples were collected along two transects parallel to the corn rows in each field. Each transect was selected to include the widest possible range in soil characteristics. Seven or eight test areas were placed along each transect to provide a total of 15 test areas. These test areas spanned approximately 12 m along the row and 16 m across rows. The test areas were positioned to capture the entire range in variability in soil characteristics within the field (i.e. some test areas represented insignificant proportions of the field). However, the test areas were also positioned so that soil within the test area appeared as uniform as possible with respect to landscape position, soil organic matter, and plant residue distribution. The location of each test area was established using a GPS receiver (Magellan ProMarkX, Magellan Systems Corp., San Dimas, CA). Test area map coverage's were projected to Universal Transmercator (UTM) projection and the North American Datum of 1927 (NAD27) datum using Blue Marble Geographics, Geographic calculator 4.1.

Each test area was divided into three plots (12 m by 5.3 m). Two soil samples were collected from each plot when the corn was approximately 30 cm tall. Each soil sample consisted of a composite of eight cores (3.2 cm in diameter and 30 cm deep) collected along a diagonal line across the plots (as illustrated in Figure 2). Individual cores in a sample were collected at prescribed distances from rows (in row, one eighth the distance from one row to the next, one quarter the distance from one row to the next, etc.) to minimize possible row effects on soil nitrate concentrations. Soil samples were dried within 24 hours at 40 °C and ground to pass a 2 mm sieve. Sub-samples were analyzed for nitrate using the Lachat flow-injection procedure (Lachat Instruments, Milwaukee, WI; Method 12-107-4-1-B). Soil organic matter (SOM) concentrations were determined at the Iowa State University soil-testing lab (Walkley and Black, 1934) on composite samples from each test area.

The farmers using their combine equipped with yield monitors and GPS receivers harvested the fields. Yield data was recorded at 1-s intervals. The exported yield data was imported into PC ArcView (ESRI, Redlands CA) for post processing and analysis. The yield data was processed in two ways. Whole field averages for each soil map unit and N fertilizer treatment were calculated by dividing the yield data into three data sets; one for each N treatment. These coverage's were then analyzed using the Spatial Analyst Extension 'Summarize by zone'. The zones used were those of the soil map units. Summary data from this analysis can be found in Table 3. All other yield data presented in this paper were calculated by averaging the yield for each N treatment from an area 61 m in length centered on each test area at a field site. It is believed that yield monitor data taken from at least 61 m represents the actual yield value well (personal communication with Dr. T.S. Colvin). All yield response data was calculated by subtracting yields at the lower N rate from those of the next higher N rate for each test area within a field site.

The SAS command PROC GLM (v. 8.1, SAS Institute, Cary, NC) was used in all analysis of variance calculations. All data was checked for normality using the PROC UNIVARIATE command in SAS.

Results and Discussion

Yields and Yield Responses

Mean yields of grain observed across all field sites were 8.4 Mg ha^{-1} with 56 kg N ha^{-1}, 9.2 Mg ha^{-1} with 112 kg N ha^{-1} applied and 9.0 Mg ha^{-1} with 156 kg N ha^{-1} applied. When data from all field sites are considered together, the first increase in N rate was profitable because it usually takes about 0.25 Mg of grain to pay for the 56 kg of fertilizer N. The second increase in N rate was not profitable, however, because this increase resulted in a net decrease in yields. The reason for the decrease in yields is not known.

Within individual field sites, mean yields of grain showed statistically significant ($P < 0.05$) positive responses to the first 56 kg N ha^{-1} increase in rate of fertilization at 12 field sites (Table 4). The second 56 kg N ha^{-1} increase in N rate had statistically significant effects on yields at 6 field sites; three were increases in yield and three were yield decreases.

Within the 61 soil map units among individual field sites, mean yields of grain showed statistically significant ($P < 0.05$) responses to the first 56 kg N ha^{-1} increase in fertilization at 20 field-SMU, and each of these were yield increases. The second 56 kg N ha^{-1} increase had statistically significant effects on yields in only 5 of the field-SUM; three had yield increases and two had yield decreases.

Observed Yields Versus Yield Potentials

When data from all field sites were pooled, no statistically significant relationships were observed between mean yields observed within soil map units and published yield potentials for the soil map units (Fig. 3). Good relationships should not necessarily be expected, however, because yields observed at a given field site should be expected to vary greatly with weather and cultural practices. Observed yields, therefore, should not be confused with the published yield potential, which does not vary with weather and cultural practices. In situations where yield potentials and the methods for calculating yield potential are not explicitly defined, it is impossible to use observed yields to evaluate the accuracy of published yield potentials. Nevertheless, it is valid to conclude that published yield potentials were essentially unrelated to observed yields.

Published yield potentials usually were not significantly correlated with mean yields observed for soil map units within fields (Table 5). Because weather and cultural practices were constant within fields, significant correlations might be expected within fields even in situations where variability in weather and cultural practices obscured expected relationships across different fields. The finding that observed correlation coefficients were negative almost as often as they were positive indicates that published yield potentials usually were not even correlated with observed yields in situations where weather and cultural practices are held constant.

An underlying problem in relating published yield potentials to observed yields is the relatively small variability in published yield potential. The published yield potentials for the soil map units in this study, for example, had a mean of 7.1 Mg ha^{-1} and a standard deviation of only 1.0 Mg ha^{-1}. The effects of such small differences should be hard to detect amid the normally expected variability due to weather and cultural practices.

The finding that published yield potentials did not explain much of the variability in yields does not necessarily indicate that published yield potentials were not useful for estimating N fertilizer needs. Estimates of fertilizer needs, for example, often are based on measurements of yield response to applied N and economic analyses (Heady et al., 1955; Nelson et al., 1985; Black, 1993; Colwell, 1994) rather than on a balance approach that considers absolute levels of yields expected or attained.

Yield Responses Versus Published Yield Potential

When data from all field sites were pooled, no statistically significant relationships were observed between mean yield responses to N observed within soil map units and published yield potentials for the soil map units (Fig. 4). Good relationships should not necessarily be expected, however, because yield responses observed at a given field site will vary greatly with weather and cultural practices.

Published yield potentials were not significantly correlated with mean yield responses observed for soil map units within fields (Table 6). This observation presents compelling evidence that published yield potentials did not provide a reasonable basis for estimating N fertilizer needs in this study.

Yields Versus Yield Responses

When data from all field sites were pooled, no statistically significant relationship was observed between mean yield responses to the second 56 kg N ha^{-1} N observed within soil map units and mean yields attained for the soil map units (Fig. 5). Good relationships should not necessarily be expected, however, because the relationship between yields and yield responses observed at a given field site should be expected to vary greatly with interactions of weather and cultural practices (i.e., corn hybrid, planting density, etc.).

Mean yields observed at the lower N rate were not usually significantly correlated with mean yield responses observed for soil map units within fields (Table 7). This observation presents a compelling reason to question the validity of the N-balance approach for estimating N fertilizer needs under the conditions encountered in this study. The need to question the validity of this approach is further supported by an analysis of variance indicating that published yield potential had no significant correlation to observed yield or yield responses to added N (Tables 8, 9, and 10).

Analysis of variance revealed that soil map units explained much of the variability in observed yields (Table 11) and observed yield responses to N fertilization (Tables 12 and 13). This observation indicates that one or more of the factors included in the concept of soil map unit did offer a valid basis for estimating N fertilizer needs, even if published yield potentials do not always do so. The basic problem, however, is that soil map units are divided by a variety of soil characteristics simultaneously.

Soil Organic Matter Concentrations

Analysis of variance showed that much of the variability in observed yields and yield response to N was explained when soil map units were represented by soil organic matter concentrations measured within the soil map units (Tables 14 and 15, respectively). Regression analyses showed that mean observed yields for the map units tend to increase with the soil organic matter concentrations (Fig. 6). These analyses reveal that yields were increased by organic matter concentrations or some factor(s) usually correlated with soil organic matter concentrations (i.e., N mineralization rate, water holding capacity, etc.). The pattern of rainfall in Iowa is such that soil water holding capacity often is a major factor affecting yields, especially in situations where nutrient deficiencies are minimized by fertilization. It seems likely, therefore, that at least part of the effect of soil organic matter concentrations on yields was related to availability of water for plant growth.

Regression analyses showed that mean yield responses to the first increase in rate of fertilization tended to be inversely correlated with soil organic matter concentrations for the map units (Fig. 7). This finding can be explained by recognizing that amounts of N mineralization during the growing season should be proportional to soil organic matter concentrations under the conditions of this study, where all fields had similar cropping history. Increases in amounts of N mineralization should be expected to decrease N fertilizer needs if yield levels do not vary.

The results of this study suggest that soil organic matter increased yield potential and increased supplies of N for corn. Increases in organic matter seemed to have greater effects on supplies of N for crop growth than on yield potential. This apparent two-fold effect explains why yield responses to added N decreased with organic matter content with the first increase in rate of N fertilization and why yield responses were not observed at higher rates of fertilization. This two-fold effect also explains why N fertilizer needs showed no simple relationships with yield levels of the corn.

Conclusions

The results of this study raise several important questions about the practice of estimating N fertilizer needs based on the concept of N balance. The first question relates to the lack of clarity concerning what is denoted by published yield potentials. This term is essentially undefined because it is not linked to specific weather and cultural practices, including sufficiency of N for crop growth. The tendency for mean yield of grain for a soil map unit to gradually increase over time with improvements in management practices and plant genetics presents a special problem.

Another major question relates to the assumption that N fertilizer needs should be expected to be proportional to yields of corn. Although it is obvious that the amount of nutrients needed by plants tend to increase with yields, it does not necessarily follow that N fertilizer needs also increase with plant yields. Under some conditions, it seems that the amounts of N available for plant growth tend to be correlated with factors that also determine plant yields by mechanisms unrelated to N availability. Under conditions found when producing corn after soybean in Iowa, the independent effects of organic matter on supplies of water and N for growth seem to obscure any relationship between N fertilizer needs and yields. Such relationships should not necessarily be expected, however, in other cropping sequences or in regions having lower concentrations of soil organic matter or different rainfall patterns.

The results of this study clearly suggest that soil organic matter concentrations deserve attention when making N fertilizer recommendations for corn after soybean in Iowa. The assumption that soil organic matter is not an important factor when estimating N fertilizer needs in Iowa seems to originate from a period when farming systems were different than today (Fitts et al., 1953; Hanway and Dumenil, 1955). The earlier farming systems included great variability in cropping systems and previous crop had great effects on the amounts of N mineralized in the soil during the growth of corn. Fields were relatively small and often divided for reasons (landscape position, drainage, etc) that correlated with soil organic matter concentrations. Corn tended to be grown on soils best suited for corn, which imposed some restraints on the range in organic matter concentrations on which this crop was grown. Assumptions that were valid with such farming systems should not be expected to apply where corn is planted after soybeans in large fields that include essentially all soils found on the landscape.

It seems that Kellogg (1938, p. 879-880) correctly identified the limitations of the balance-sheet approach to making fertilizer recommendations when he noted that this method considers the soil to be essentially a static storage bin for plant nutrients. He noted that the system fails because it ignores the dynamic nature of the relationship between soils and plants. A noteworthy point illustrated by the work in this study is that new precision farming technologies offer great potential for studying the dynamic nature of relationships between soils and plants. Yield monitors with GPS make it possible to characterize yields and yield responses as continuous variables across the landscape. GIS makes it possible to relate observed yields and yield responses to measurable soil characteristics, and these relationships provide a sound basis for estimating fertilizer needs. The value of these new tools may be greatest in systems where crops are planted in large fields that include essentially all soil types found on the landscape.

References

Black, C.A. 1993. Soil fertility evaluation and control. CRC Press, Boca Raton, FL.

Blackmer, A.M. 2000. Bioavailability of nitrogen. p. D-3 to D-18. *In* M.E. Sumner (ed.) Handbook of Soil Science. CRC Press, Boca Raton, FL.

Blackmer, A.M., T.F. Morris, and G.D. Binford. 1992. Predicting N fertilizer needs for corn in humid regions: Advances in Iowa. p. 57-72. *In* B.R. Bock and K.R. Kelley (ed.) Natl. Fertilizer and Environ. Res. Cent. TVA, Muscle Shoals, AL.

Blackmer, A.M., R.D. Voss, and A.P. Mallarino. 1997. Nitrogen fertilizer recommendations for corn in Iowa. Iowa State Univ. Ext. Publ. Pm-1714.

Blackmer, A.M. and S.E. White. 1998. Using precision farming technologies to improve management of soil and fertiliser nitrogen. Aust. J. Agric. Res. 49:555-564.

Bock, B.R., and G.W. Hergert. 1991. Fertilizer nitrogen management. p. 130-164. *In* R. F. Follett et al. (ed.) Managing nitrogen for groundwater quality and farm profitability. SSSA, Madison, WI.

Bray, R.H. 1963. Confirmation of the nutrient mobility concept of soil-plant relationships. Soil Sci. 95:124-130.

Blue Marble. 1999. Geographic calculator. Version 4.1. Gardiner, Maine.

Colwell, J.D. 1994. Estimating fertilizer requirements. A quantitative approach. CAB International, Wallingford, UK.

Fenton, T.E., E.R. Duncan, W.D. Shrader, and L.C. Dumenil. 1971. Productivity levels of some Iowa soils. Iowa State Univ. Ext. Publ. Pm-66.

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

Fox, R.H., and W.P. Piekielek. 1995. The relationship between corn grain yield potential and economic optimum nitrogen fertilizer rates. Agronomy Series Number 136. Agronomy Department, The Pennsylvania State University.

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. Amer. Proc. 19:77-80.

Heady, E.O., J.T. Pesek, and W.G. Brown. 1955. Crop response surfaces and economic optima in fertilizer use. Iowa Agric. Exp. Stn. Bull. 424.

Iowa Soil Properties and Interpretations Database. 1996. Iowa Agriculture and Home Economics Experiment Station, University Extension Service, Iowa State University.

Keeney, D.R. 1982. Nitrogen management for maximum efficiency and minimum pollution. p. 605-649. *In* F.G. Stevenson (ed.) Nitrogen in agricultural soils. Agron. Monogr. 22. ASA, CSSA, SSSA, Madison, WI.

Kellogg, C.E. 1938. Soils and society. p. 863-886. *In* Soils and men. Yearbook of Agriculture. U.S. Printing Office, Washington, D.C.

Legg, J.O., and J.J. Meisinger. 1982. Soil nitrogen budgets. p. 503-566. *In* F.J. Stevenson (ed.) Nitrogen in agricultural soils. Agron. Monogr. 22. ASA, CSSA, and SSSA, Madison, WI.

Meisinger, J.J. 1984. Evaluating plant available nitrogen in soil-crop systems. p. 391-416. *In* R.D. Hauck et al. (ed.) Nitrogen in crop production. ASA, CSSA, SSSA, Madison, WI.

Miller, G.A. 1986. Establishing realistic yield goals. Iowa State Univ. Ext. Publ. Pm-1268.

National Research Council. 1993. Soil and water quality: and agenda for agriculture. p. 266-281. National Academy Press, Washington, D.C.

Nelson, L.A., R.D. Voss, and J. Pesek. 1985. Agronomic and statistical evaluation of fertilizer response. p. 53-90. *In* O.P. Engelstad (ed.) Fertilizer technology and use. SSSA, Madison, WI.

Oberle, S.L., and D.R. Keeney. 1990. Factors influencing corn fertilizer requirements in the northern U.S. Corn Belt. J. Prod. Agric. 3:527-534.

Peterson, G. A., and R. D. Voss. 1984. Management of nitrogen in the west north central states. p. 721-733. *In* R.D. Hauck et al. (ed.) Nitrogen in crop production. ASA, CSSA, SSSA, Madison, WI.

Rehm, G., and M. Schmitt. 1989. Setting realistic crop yield goals. Univ. of Minnesota Ext. Publi. AG-FS-3873.

SAS Institute. 1988. SAS User's Guide: Statistics. 5th ed. SAS inst., Cary, NC.

Schepers, J.S., K.D. Frank, and C. Bourg. 1986. Effect of yield goal and residual nitrogen concentrations on nitrogen fertilizer recommendations for irrigated maize in Nebraska. J. Fert. Issues 3:133-139.

Stanford, G. 1966. Nitrogen requirement of crops for maximum yield. *In* W. H. Vickar et al. (ed.) Agricultural anhydrous ammonia – technology and use. SSSA, Madison, WI.

Stanford, G. 1973. Rationale for optimum nitrogen fertilization for corn production. J. Environ. Qual. 2:159-166.

Stanford, G. and J.O. Legg. 1984. Nitrogen and yield potential. p. 263-272. *In* R.D. Hauck et al. (ed.) Nitrogen in crop production. ASA, CSSA, SSSA, Madison, WI.

Vanotti, M.B., and L.G. Bundy. 1994. An alternative rationale for corn nitrogen fertilizer recommendations. J. Prod. Agric. 7:243-249.

Viets, F.G., Jr. 1965. The plant's need for and use of nitrogen. *In* W.V. Bartholomew and F.E. Clark (ed.) Soil Nitrogen. Agron. Monogr. 10:503-549. SSSA, Madison, WI.

White, S.E., and A.M. Blackmer. 1996. Characterizing spatial patterns in response of corn to nitrogen fertilization. p. 257. *In* Agronomy abstracts. ASA, Madison, WI.

Table 1. Description of field study sites including county, soil association, soil map symbol (SMS), and series name

Field	County	Association	SMS	Series
1	Blackhawk	Dinsdale-Klinger-Maxfield	118	Garwin
			119B	Muscatine
			11B	Colo-Ely
			377B	Dinsdale
			377C2	Dinsdale
2	Greene	Canisteo-Webster-Nicollet	4	Knoke
			55	Nicollet
			507	Canisteo
			138B2	Clarion
			638C2	Clarion-Storden
3	Blackhawk	Tama-Muscatine-Garwin	119B	Muscatine
			11B	Colo-Ely
			120B	Tama
			377B	Dinsdale
			377C2	Dinsdale
			83C	Kenyon
			83C2	Kenyon
4	Greene	Clarion-Nicollet-Webster	6	Okoboji
			55	Nicollet
			107	Webster
			138B	Clarion
			138B2	Clarion
			638C2	Clarion-Storden
5	Greene	Canisteo-Webster-Nicollet	55	Nicollet
			107	Webster
			138B	Clarion
6	Carroll	Clarion-Nicollet-Webster	55	Nicollet
			138B	Clarion
			138B2	Clarion

Table 1. (continued)

Field	County	Association	SMS	Series
7	Blackhawk	Tama-Muscatine-Garwin	118	Garwin
			119	Muscatine
			120B	Tama
			377B	Dinsdale
			377C2	Dinsdale
8	Blackhawk	Dinsdale-Klinger-Maxfield	377B	Dinsdale
			391B	Clyde
			782B	Donnan
			83B	Kenyon
9	Buchanan	Kenyon-Clyde-Floyd	391B	Clyde-Floyd
			83B	Kenyon
10	Greene	Canisteo-Webster-Nicollet	6	Okoboji
			55	Nicollet
			107	Webster
			507	Canisteo
			879	Fostoria
			138B2	Clarion
			878B	Ocheyedan
			878B2	Ocheyedan
			878C2	Ocheyedan
11	Blackhawk	Dinsdale-Klinger-Maxfield	118	Garwin
			119B	Muscatine
			11B	Colo-Ely
			377B	Dinsdale
			377C2	Dinsdale
12	Boone	Canisteo-Clarion-Nicollet	507	Canisteo
			62C2	Storden
			655	Crippin
			90	Okoboji
			95	Harps

Table 1. (continued)

Field	County	Association	SMS	Series
13	Blackhawk	Marshan-Sawmill-Bremer	133	Colo
			11B	Colo-Ely
			377B	Dinsdale
			426B	Aredale
			426C2	Aredale
			83B	Kenyon
14	Linn	Kenyon-Dinsdale	377B	Dinsdale
			381B	Klinger-Maxfield
15	Buchanan	Kenyon-Clyde-Floyd	391B	Clyde
			83B	Kenyon
16	Delaware	Kenyon-Clyde-Floyd	391B	Clyde-Floyd
			83B	Kenyon
17	Calhoun	Webster-Nicollet-Clarion	55	Nicollet
			107	Webster
			507	Canisteo

Table 2. Soil series, soil map symbol (SMS), and corresponding classification of soils found at 17 field sites.

Series	SMS	Classification
Webster	107	Fine-loamy, mixed, superactive, mesic Typic Endoaquolls
Garwin	118	Fine-silty, mixed, superactive, mesic Typic Endoaquolls
Muscatine	119	Fine-silty, mixed, superactive, mesic, Aquic Hapludolls
Muscatine	119B	Fine-silty, mixed, superactive, mesic, Aquic Hapludolls
Colo-Ely	11B	Fine-silty, mixed, superactive, mesic Aquic Cumulic Hapludolls
Tama	120B	Fine-silty, mixed, superactive, mesic Typic Argiudolls
Colo	133	Fine-silty, mixed, superactive, mesic Cumulic Endoaquolls
Clarion	138B	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Clarion	138B2	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Dinsdale	377B	Fine-silty, mixed, superactive, mesic Typic Argiudolls
Dinsdale	377C2	Fine-silty, mixed, superactive, mesic Typic Argiudolls
Klinger-Maxfield	381B	Fine-silty, mixed, superactive, mesic Aquic Hapludolls
Clyde-Floyd	391B	Fine-loamy, mixed, superactive, mesic Aquic Hapludolls
Knoke	4	Fine, smectitic, calcareous, mesic Cumulic Vertic Endoaquolls
Aredale	426B	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Aredale	426C2	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Canisteo	507	Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls
Nicollet	55	Fine-loamy, mixed, superactive, mesic Aquic Hapludolls
Okoboji	6	Fine, smectitic, mesic Cumulic Vertic Endoaquolls
Storden	62C2	Fine-loamy, mixed, superactive, Typic Eutrudepts
Clarion-Storden	638C2	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Crippin	655	Fine-loamy, mixed, superactive, mesic, Aquic Hapludolls
Donnan	782B	Fine-loamy over clayey, mixed, superactive, mesic Aquollic Hapludalfs
Kenyon	83B	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Kenyon	83C	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Kenyon	83C2	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Ocheyedan	878B	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Ocheyedan	878B2	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Ocheyedan	878C2	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
Fostoria	879	Fine-loamy, mixed, superactive, mesic Aquic Hapludolls
Okoboji	90	Fine, smectitic, mesic Cumulic Vertic Endoaquolls
Harps	95	Fine-loamy, mixed, superactive, mesic Typic Calciaquolls

Table 3. Yields observed at 3 rates of N fertilization within each field and soil map area.

				Mean yield of grain		
Field	SMS	Published yield potential	Map unit area	56 kg N ha^{-1}	112 kg N ha^{-1}	168 kg N ha^{-1}
		-- Mg ha^{-1} --	---- ha ----		---------- Mg ha^{-1} ----------	
1	118	7.8	1.5	9.7	9.8	9.8
1	119B	8.2	1.2	9.7	9.7	10.1
1	11B	6.6	1.4	10.0	10.2	10.5
1	377B	7.5	5.5	9.0	9.1	9.3
1	377C2	7.0	1.4	8.5	8.2	8.6
2	4	5.1	0.2	9.5	9.5	9.9
2	55	7.1	1.3	7.8	9.9	9.6
2	507	6.6	1.3	9.4	10.8	10.2
2	138B2	6.7	1.6	7.5	8.9	8.6
2	638C2	5.5	0.5	8.9	10.9	10.4
3	11B	6.6	1.4	7.7	8.6	8.3
3	120B	7.8	0.5	9.5	10.0	9.9
3	377B	7.5	1.3	9.3	9.8	9.7
3	83C	6.8	0.3	8.1	8.7	9.0
3	83C2	6.6	0.5	8.8	9.4	9.1
4	6	5.3	0.1	9.9	9.4	9.7
4	55	7.1	0.6	8.4	9.4	8.2
4	107	6.9	0.7	9.6	9.5	9.8
4	138B	6.9	0.6	8.3	8.4	8.2
4	638C2	5.5	3.4	8.3	8.2	8.0
5	55	7.1	2.8	8.5	9.1	9.0
5	107	6.9	3.6	8.2	9.2	8.7
6	55	7.5	1.5	7.9	7.8	8.1
6	138B	6.9	1.5	8.4	8.2	8.4
6	138B2	6.7	1.6	8.7	8.8	8.6
7	118	7.8	3.4	9.7	10.1	10.2
7	119	8.2	2.4	9.7	10.2	9.8
7	120B	7.8	1.5	9.7	9.6	10.1
7	377C2	7.1	1.0	10.2	10.7	10.5
8	377B	7.5	0.4	8.5	8.8	7.0
8	391B	6.3	0.2	9.6	9.4	9.1
8	782B	4.4	0.5	8.8	8.7	8.4
8	83B	7.1	1.6	9.1	9.1	8.8

Table 3. (continued)

Field	Label	Published yield potential	Map unit area	Mean yield of grain 56 kg N ha^{-1}	112 kg N ha^{-1}	168 kg N ha^{-1}
		-- Mg ha^{-1} --	---- ha ----	---------- Mg ha^{-1} ----------		
9	391B	6.5	0.1	9.6	10.7	10.7
9	83B	7.1	3.1	9.1	10.5	10.3
10	6	5.3	0.7	5.8	7.0	7.9
10	55	7.1	1.1	8.1	8.6	8.7
10	107	6.9	3.4	7.5	8.4	8.7
10	507	6.6	1.7	6.7	8.0	8.0
10	138B2	6.7	0.7	7.0	7.3	7.6
10	878B	5.3	1.0	7.5	8.3	8.0
10	878C2	4.8	0.8	7.1	7.5	7.5
11	118	7.8	0.6	8.6	8.9	8.8
11	119B	8.2	1.0	8.6	9.3	9.2
11	11B	6.6	0.3	7.6	9.5	9.6
11	377B	7.5	3.6	8.7	9.2	9.2
11	377C2	7.0	1.1	7.9	9.2	9.3
12	90	5.4	0.6	11.0	11.2	.
12	95	5.6	1.0	10.9	9.0	.
12	507	6.7	3.5	10.2	10.4	.
12	655	6.7	1.8	8.9	10.3	.
12	62C2	6.1	0.3	10.2	11.0	.
13	11B	6.6	1.0	9.3	10.1	9.7
13	426C2	6.6	2.6	7.6	9.7	9.7
14	377B	7.5	2.9	7.5	10.1	11.2
14	381B	7.2	1.4	7.3	10.0	11.2
15	83B	9.7	2.6	7.2	9.5	.
16	391B	6.5	3.0	7.3	8.5	8.0
16	391B	8.9	1.9	7.9	9.9	.
17	55	7.5	4.3	9.0	9.1	9.3
17	107	6.9	2.2	9.2	9.4	9.7

Table 4. Yield response to first and second 56 kg ha^{-1} of fertilizer N for each site.

Field	Observed yield response at lower N rate to	
	First 56 kg ha^{-1} of N	Second 56 kg ha^{-1} of N
	Mg ha^{-1}	
1	0.05	0.20 *
2	1.54 *	-0.32 *
3	0.67 *	-0.15
4	-0.01	-0.17
5	0.80 *	-0.30
6	-0.05	0.05
7	0.39 *	-0.08
8	-0.05	-0.48 *
9	1.36 *	-0.17
10	0.84 *	0.09
11	0.69 *	0.03
12	0.58 *	Na
13	1.81 *	-0.05
14	2.62 *	1.12 *
15	1.22 *	-0.59 *
16	2.20 *	na
17	0.13	0.25 *

* Statistically different than zero at alpha 0.05.

Table 5. Correlation coefficients for published yield potentials and mean observed yields within field and soil map unit.

Field	Published yield potential versus observed yield at		
	56 kg N ha^{-1}	112 kg N ha^{-1}	168 kg N ha^{-1}
1	-0.06	-0.05	-0.14
2	-0.37	-0.14	-0.27
3	0.62 *	0.62 *	0.57 *
4	0.08	0.21	0.16
5	0.22	-0.01	0.20
6	-0.55 *	-0.53 *	-0.73 *
7	-0.31	-0.23	-0.46
8	0.04	0.14	-0.06
9	-0.25	-0.06	-0.22
10	0.27	0.46	0.65 *
11	0.47	-0.04	-0.36
12	-0.53 *	-0.14	na
14	0.14	0.11	0.01
17	-0.25	-0.39	-040

* Statistically significant at alpha < 0.05.

Table 6. Correlation coefficient between published yield potential and mean yield response within each soil map area and field.

	Published yield potential	
Field	Response to first 56 kg ha^{-1} of N	Response to second 56 kg ha^{-1} of N
1	0.02	-0.28
2	0.39	-0.25
3	-0.32	0.21
4	0.22	-0.11
5	-0.26	0.14
6	-0.14	0.29
7	0.06	-0.21
8	0.29	-0.25
9	0.18	-0.16
10	0.09	0.29
11	-0.43	-0.49
12	0.45	na
14	-0.05	-0.12
17	-0.05	-0.16

* Statistically significant at alpha 0.05.

Table 7. Correlation coefficient between observed yield at lowest N rate and mean yield response within each soil map area and field.

Field	Mean observed yield correlated with: Response to first 56 kg ha^{-1} of N	Response to second 56 kg ha^{-1} of N
1	0.08	-0.35
2	-0.72*	-0.31
3	-0.67*	0.55
4	-0.44	-0.21
5	-0.40	-0.76*
6	0.08	-0.92*
7	-0.26	-0.55*
8	0.29	-0.09
9	-0.32	-0.59*
10	-0.70*	-0.33
11	-0.90*	-0.52*
12	-0.84*	na
13	-0.93*	-0.36
14	-0.80*	-0.22
15	-0.38	na
16	-0.56	-0.16
17	-068*	-0.06

* Statistically significant at alpha 0.05.

Table 8. Analysis of variance for observed yields.

Source of variation	df	Model sum of squares	Significance levels (P)
		--------% --------	
Field	16	30	< 0.0001
Published yield potential	1	0	0.8011
N rate	1	7	< 0.0001
N rate * yield potential	1	1	0.0006
Error	692	62	

Table 9. Analysis of variance for response to the first 56 kg N ha^{-1} increase in fertilizer.

Source of variation	df	Model sum of squares	Significance levels (P)
		--------% --------	
Field	16	59	< 0.0001
Published yield potential	1	0	0.0077
Error	723	41	

Table 10. Analysis of variance for response to the second 56 kg N ha^{-1} increase in fertilizer.

Source of variation	df	Model sum of squares	Significance levels (P)
		--------% --------	
Field	16	33	< 0.0001
Published yield potential	1	0	0.0803
Error	723	67	

Table 11. Analysis of variance for observed yields over entire field site.

Source of variation	df	Model sum of squares	Significance levels (P)
		--------% --------	
Field	16	53	< 0.0001
Soil map unit	16	16	0.0010
N rate	1	9	< 0.0001
N rate * soil map unit	19	5	0.6348
Error	54	17	

Table 12. Analysis of variance for mean yield response to the first 56 kg ha^{-1} of N.

Source of variation	df	Model sum of squares	Significance levels (P)
		--------% --------	
Field	16	59	< 0.0001
Soil map unit	26	8	0.0171
Field* Soil map unit	18	3	0.6424
Error	186	30	

Table 13. Analysis of variance for mean yield response to the second 56 kg ha^{-1} of N.

Source of variation	df	Model sum of squares	Significance levels (P)
		--------% --------	
Field	14	32	< 0.0001
Soil map unit	22	9	0.2824
Field* Soil map unit	17	3	0.9481
Error	164	56	

Table 14. Analysis of variance of mean observed yield and soil organic matter (SOM).

Independent variable	Source of variation	df	Model sum of squares	Significance levels (P)
			--------% --------	
Yield at 56 kg N ha^{-1}	SOM (field)	17	50	< 0.0001
Yield at 112 kg N ha^{-1}	SOM (field)	17	50	< 0.0001
Yield at 168 kg N ha^{-1}	SOM (field)	15	60	< 0.0001

Table 15. Analysis of variance of yield response and soil organic matter (SOM).

Independent variable	Source of variation	df	Model sum of squares	Significance levels (P)
			--------% --------	
Yield response 1[a]	SOM (field)	17	55	< 0.0001
Yield response 2[b]	SOM (field)	15	32	< 0.0001

a-Yield response to the first 56 kg N ha^{-1} fertilizer N.
b-Yield response to the second 56 kg N ha^{-1} fertilizer N.

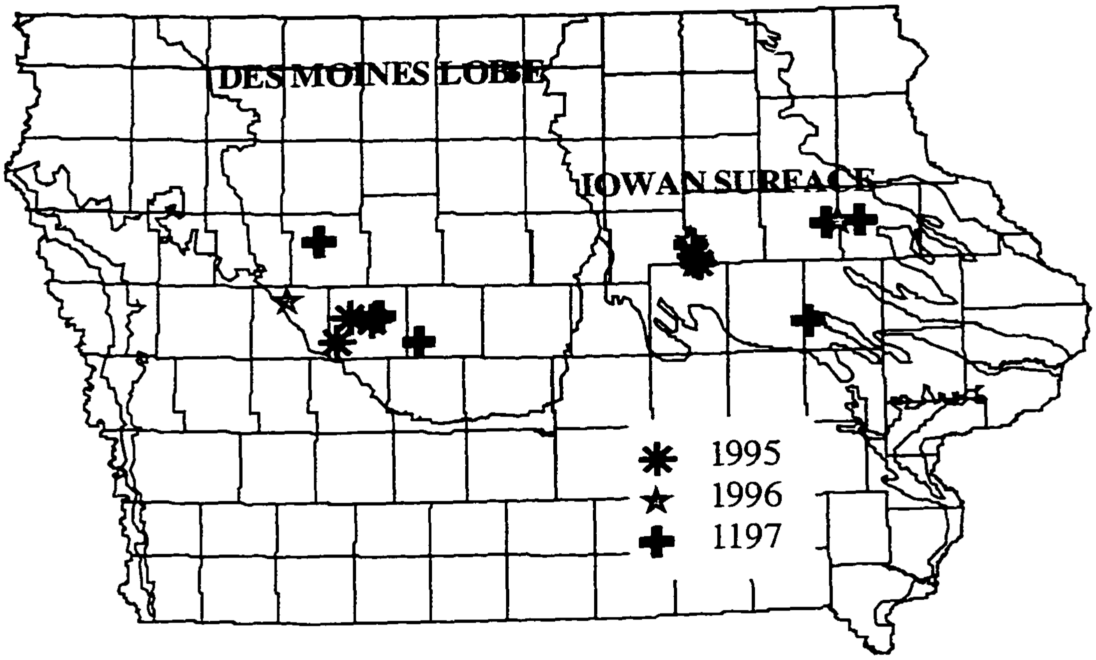

Fig. 1. Location of field sites.

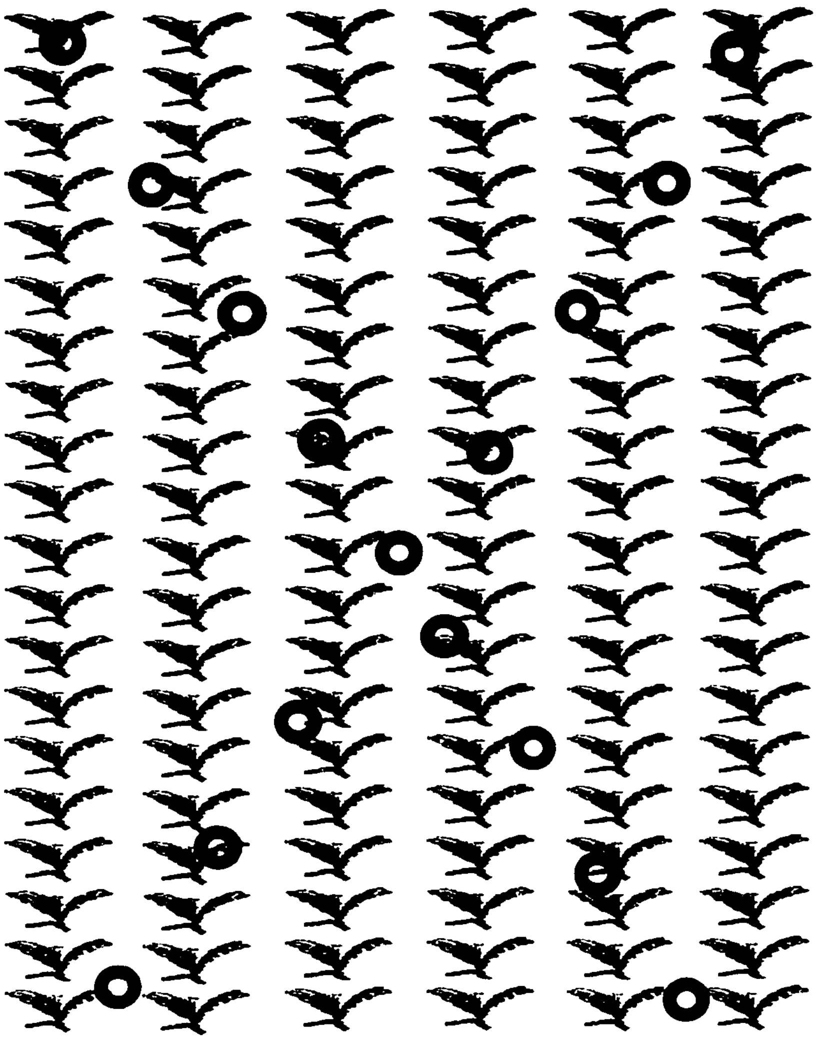

Fig. 2. Schematic illustration of soil sampling points (indicated by dark circles) relative to corn rows within a plot.

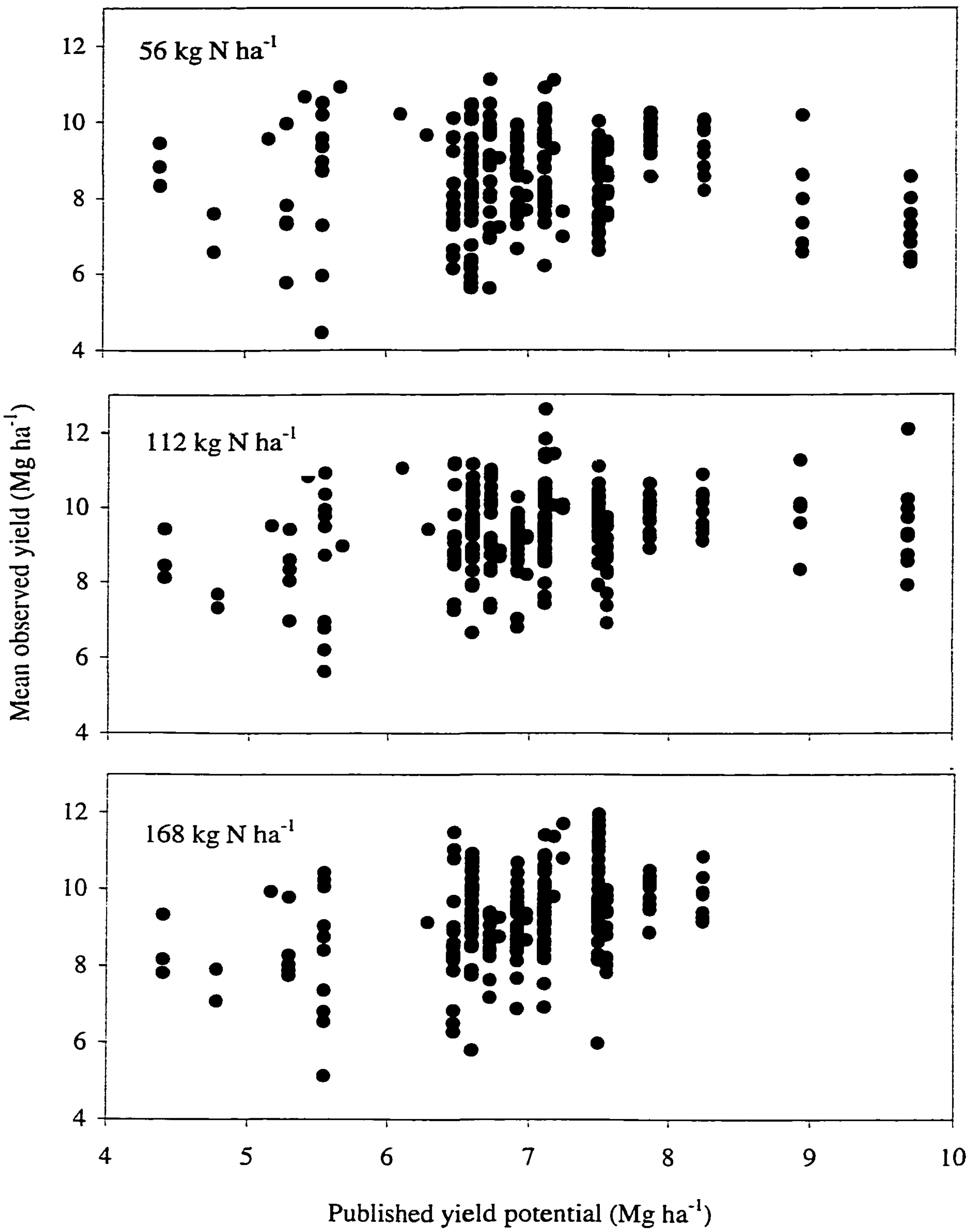
56 kg N ha-1
112 kg N ha-1
168 kg N ha-1
Mean observed yield (Mg ha-1)
Published yield potential (Mg ha-1)
12
10
8
6
4
4
5
6
7
8
9
10

Fig. 3. Relationship between published yield potential and mean observed yield within each soil map unit

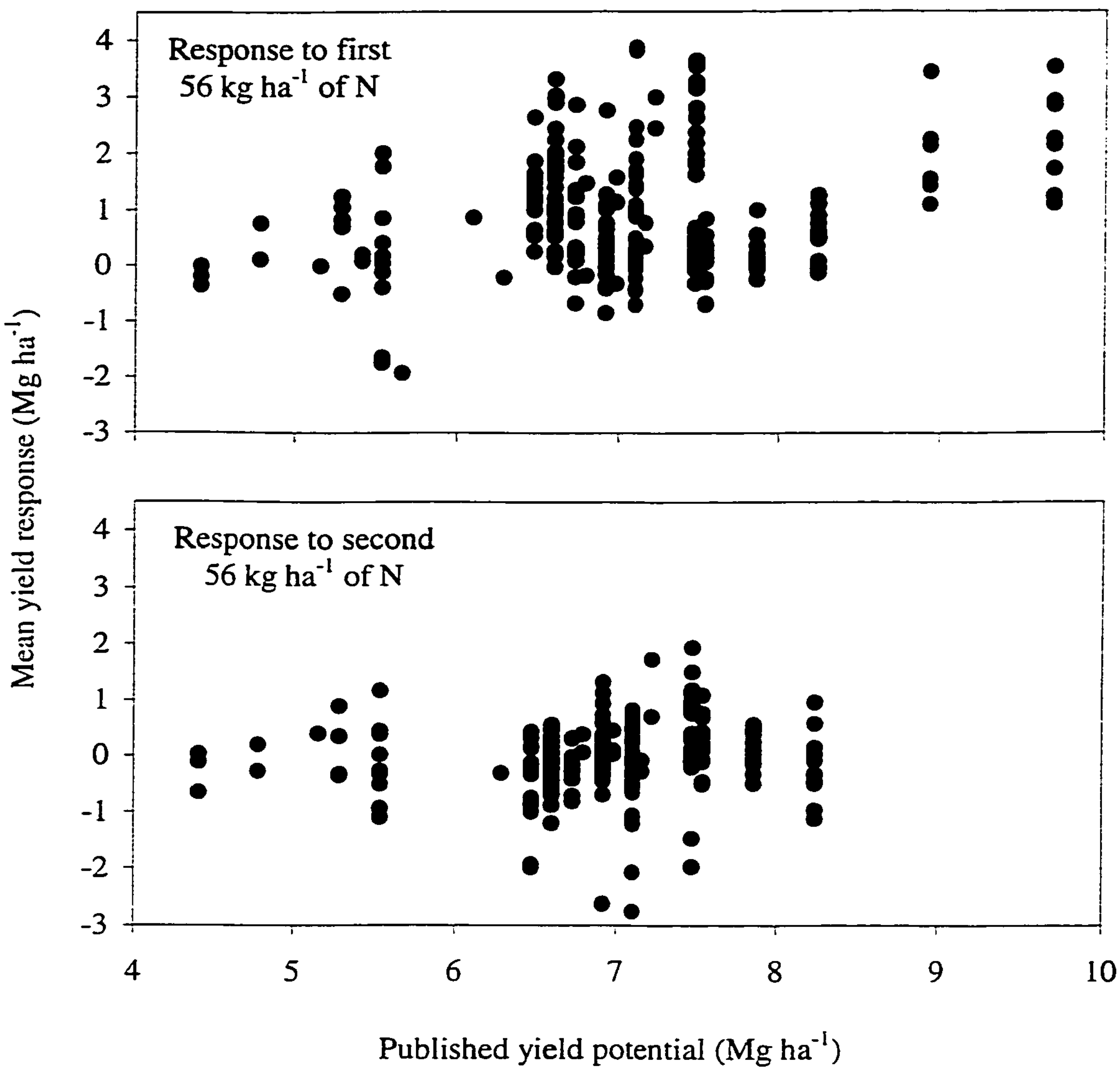

Fig. 4. Relationships between published yield potential and mean yield response to N fertilization within each soil map unit.

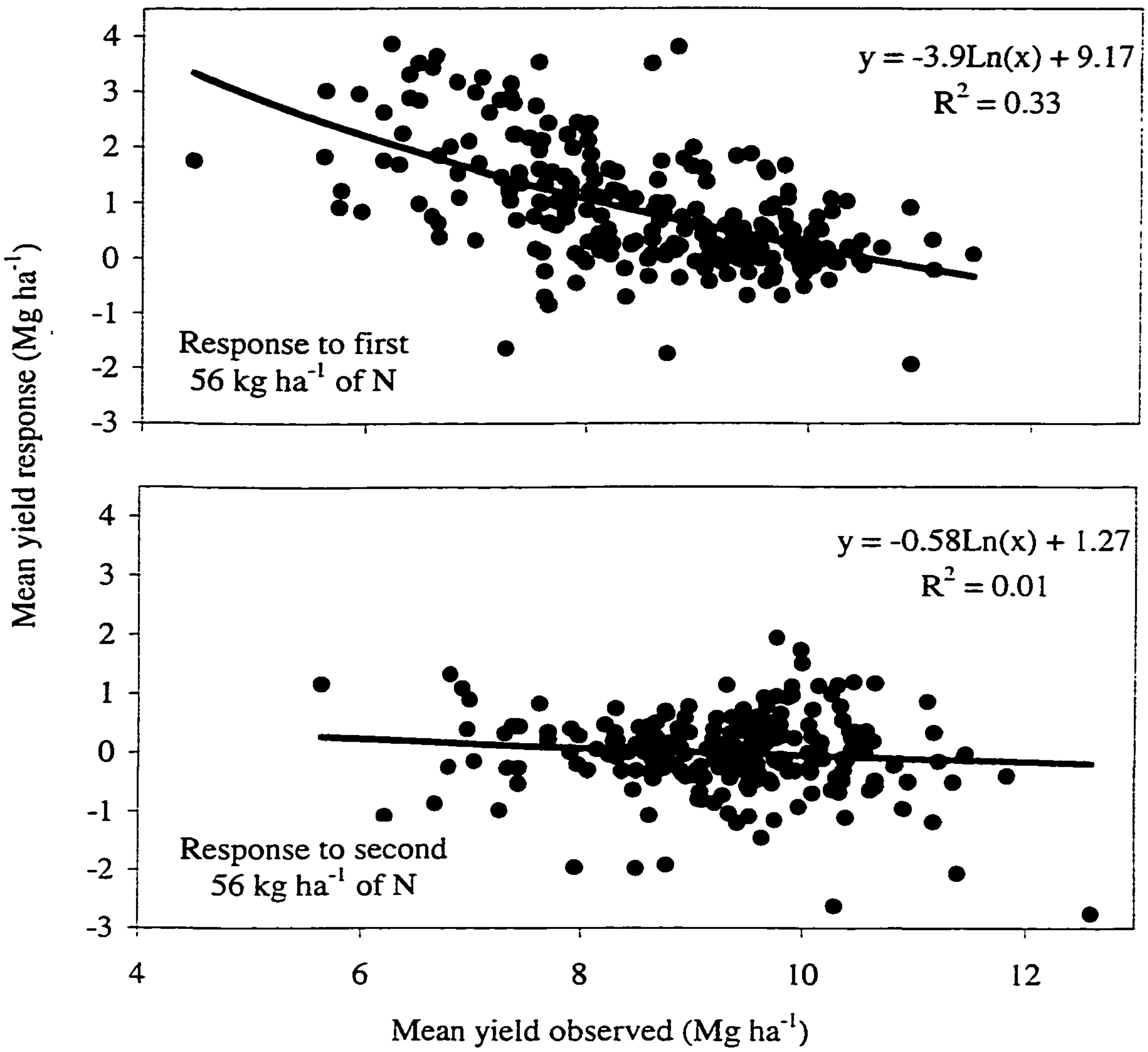

Fig. 5. Relationships between mean yield response and mean yield attained at lowest N rate within soil map units.

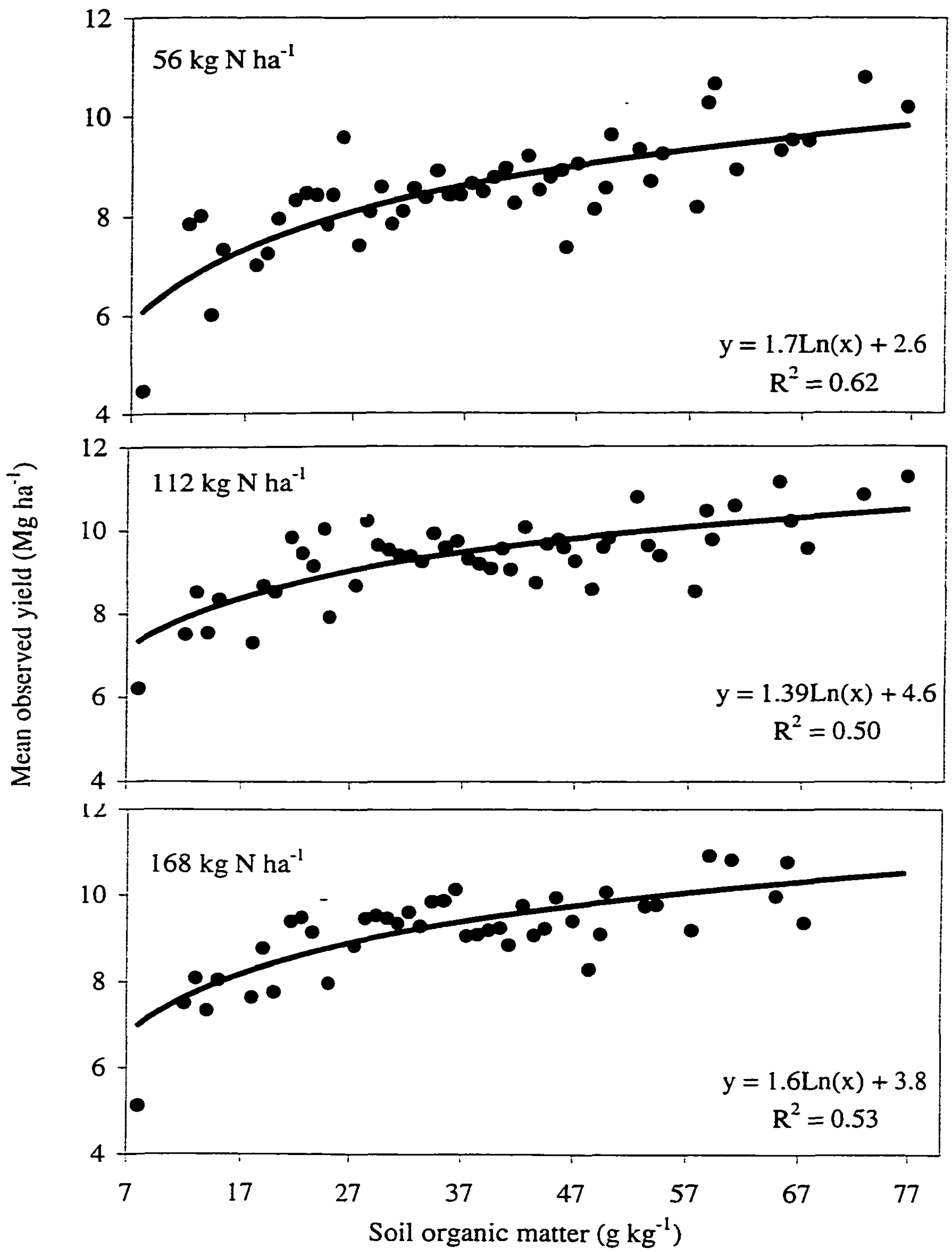

Fig. 6. Relationship between mean observed yield and soil organic matter within soil map unit.

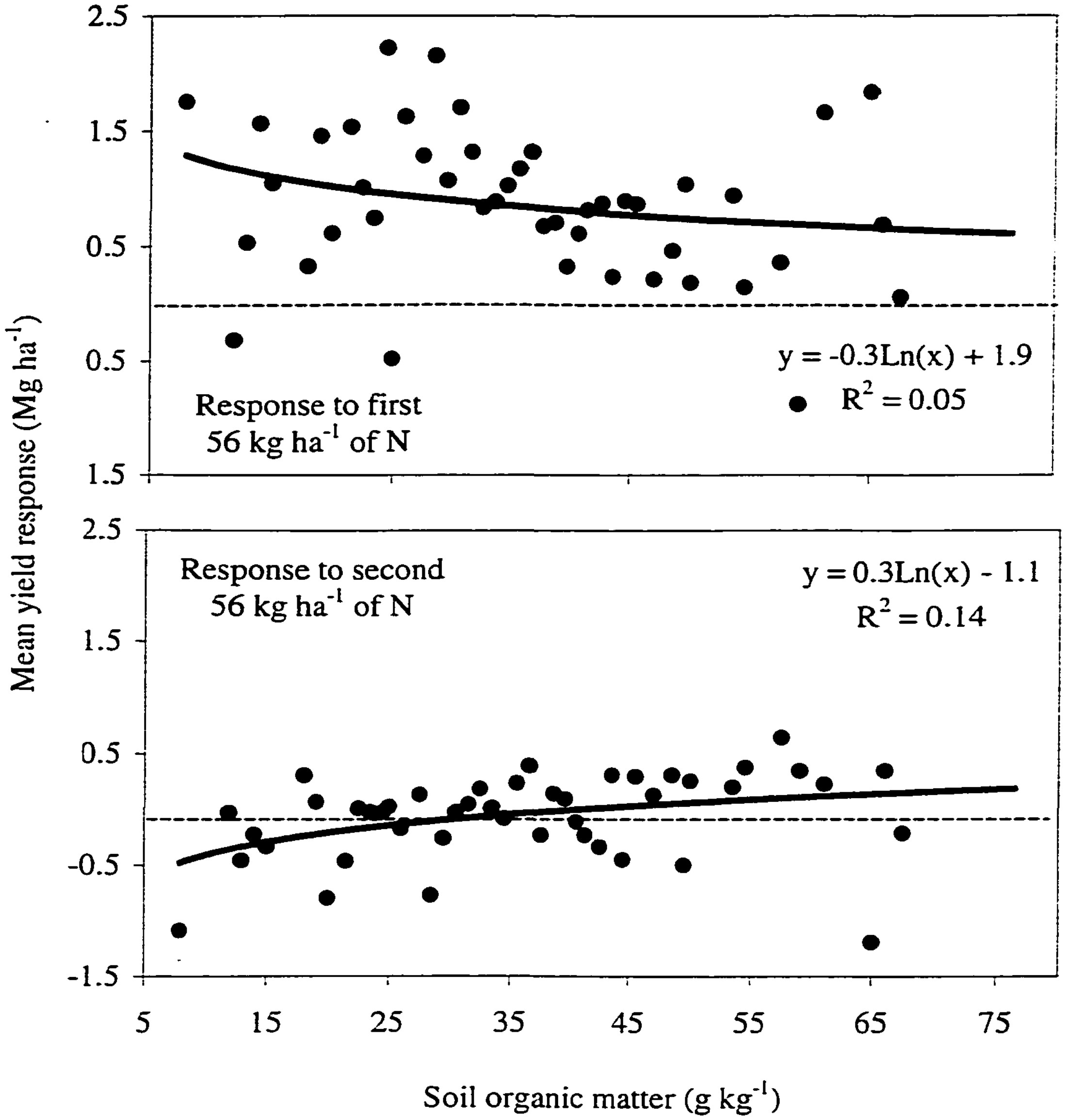

Fig. 7. Relationship between mean yield response and soil organic matter within each soil map unit.

CHAPTER 4: GENERAL CONCLUSIONS

General Discussion

Results of this study show that the optimal sampling density for non-fertilized fields of corn after soybean depends on variation in soil organic matter concentrations. This is not a problem, however, because soil nitrate and soil organic matter tend to share a similar relationship across groups of fields that are managed similarly and have similar rainfall. This common relationship means that soil nitrate concentrations can be predicted with reasonable accuracy even with extremely low-density sampling of soil organic matter concentrations are used to guide the sampling. Under conditions of intensive corn production, as found in Iowa, it is possible that a few dozen samples collected appropriately would provide reasonable assessments of soil nitrate concentrations across thousands of hectares.

The strategy of collecting a group of samples to characterize a range of soils should not be expected to work under all conditions. Studies in Iowa over the past decade indicate spatial patterns in soil nitrate within cornfields recently treated with fertilizers are not as predictable as in soils studied here. Part of the problem is nonuniform applications of fertilizer as discussed by Blackmer and White (1998). Part of the problem seems to be nonuniform losses of fertilizer N during the period between application and sampling. Spatial patterns in nitrate concentrations in fields of corn after corn may be dominated by variability in amounts of fertilizer N remaining from the previous year. Efficient sampling strategies for nitrate, therefore, require reasonable amounts of information concerning which fields on the landscape can be (or cannot be) grouped into a predictable categories. Learning how to characterize spatial patterns of soils not recently fertilized seems to be an essential first step of the more complicated task of learning how to characterize spatial patterns in nitrate in soils that are recently fertilized.

Several important questions are raised by these studies about the practice of estimating N fertilizer needs based on the concept of N balance. The first question relates to what is denoted by published yield potentials. This term is related to average yields over a five-year period for fields under best management practice. It is not directly linked to specific weather and cultural practices.

Another major question relates to the assumption that N fertilizer needs should be expected to be proportional to yields of corn. Although it is obvious that the amount of nutrients needed by plants tends to increase with yields, it does not necessarily follow that N fertilizer needs also increase with plant yields. Under some conditions, it seems that amounts of N available for plant growth tend to be correlated with factors that also determine plant yields by mechanisms unrelated to N availability. Under conditions found when producing corn after soybean in Iowa, the independent effects of organic matter on supplies of water and N for growth seem to obscure any relationship between N fertilizer needs and yields. Such relationships should not necessarily be expected, however, in other cropping sequences or in regions having lower concentrations of soil organic matter or different rainfall patterns.

The results of this study clearly suggest that soil organic matter concentrations deserve attention when making N fertilizer recommendations for corn after soybean in Iowa. The assumption that soil organic matter is not an important factor when estimating N fertilizer needs in Iowa seems to originate from a period when farming systems were different than today (Fitts et al., 1953; Hanway and Dumenil, 1955). Earlier farming systems included great variability in cropping systems and previous crop which had great effects on the amounts of N mineralized in the soil during the growth of corn. Fields were relatively small and often divided for reasons (landscape position, drainage, etc.) that correlated with soil organic matter concentrations. Corn tended to be grown on soils best suited for corn, which imposed some restraints on the range in organic matter concentrations on which this crop was grown. Assumptions that were valid with such farming systems should not be expected to apply where corn is planted after soybeans in large fields that include essentially all soils found on the landscape.

Recommendations for Future Research

Soil nitrate concentrations in late spring have been found to be predictable for fields in Iowa with a corn after soybean rotation. The next step is to determine the predictability of soil nitrate concentrations on fields having received either fall fertilization, spring fertilization, or animal manure.

Soil organic matter and spring rainfall have been shown to have reasonably predictable effects on corn yield response to fertilizer nitrogen. More work needs to be done to determine if optimum nitrogen rates can be determined for a field based on some easily measured characteristics such as landscape position, soil organic matter concentration, late spring soil nitrate test results, or spring rainfall amounts.

References

Blackmer, A.M. and S.E. White. 1998. Using precision farming technologies to improve management of soil and fertiliser nitrogen. Aust. J. Agric. Res. 49:555-564.

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

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. Amer. Proc. 19:77-80.