1983

Effects and Interactions of Nitrogen and Soil Moisture Status Under a High Yield Irrigated Corn Environment

Dwayne L. Beck

EFFECTS AND INTERACTIONS OF NITROGEN AND SOIL MOISTURE STATUS UNDER A HIGH YIELD IRRIGATED CORN ENVIRONMENT

BY

DWAYNE L. BECK

A thesis submitted
in partial fulfillment of the requirements for the
degree Doctor of Philosophy
Major in Agronomy
South Dakota State University
1983

EFFECTS AND INTERACTIONS OF NITROGEN AND SOIL MOISTURE STATUS

UNDER A HIGH YIELD IRRIGATED CORN ENVIRONMENT

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Doctor of Philosophy, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Paul L. Carson — Date
Major Adviser

Maurice L. Horton — Date
Head, Plant Science Dept.

Dedication

This thesis is dedicated to my father and mother, George and Rekie Beck. They instilled the thirst for knowledge and a love of the land that have led to my present vocation.

Acknowledgments

The completion of this research project and the degree with which it was associated depended either directly or indirectly on the inspiration, encouragement, and assistance of literally hundreds of people. It would be impossible to acknowledge all of these contributions individually, a few do deserve special recognition.

No one has exerted more influence on this work and my graduate education than Professor Paul Carson. He served as a source of encouragement, inspiration, and expertise. His insistence that graduate students take an active role in all phases of the soil fertility program and accept primary responsibility for a specific project greatly enhanced my preparation in the "non-academic" skills of budget, finance, personnel management, and public relations so essential to success in the world of agricultural research and extension. This philosophy requires the project leader to sacrifice some of his notoriety to enhance the learning experience of his students. In an era that rewards prolific publication there is less of an inclination for researchers to adopt these practices. I feel fortunate to have done my training with an adviser wise and unselfish enough to recognize the tangible and intangible values of adopting this approach.

The applied research background supplied by Paul Carson was augmented by Darrel "Red" Pahl who shared his substantial knowledge and experience in the field of extension. The period of time spent at the University of California - Davis, was made invaluable due to insights on theoretical research supplied by Dennis Rolston. Besides the

professional guidance given by these men, they and their wives (Evelyn, Jean, and Mada) often offered hospitality to a very appreciative bachelor.

The research was supported financially by the Water Resources Institute (John Wiersma, Director) and The Plant Science Department (Maurice Horton, Head). Sample analysis and data collection could not have been accomplished without the help of LuAnn, Ron, Ginny, Merideth, Carol, Becky, Dale, Bob, and others. Dawne deserves special thanks for typing this thesis.

The in-field portion of this research depended on Dan Cronin and the other irrigators that generously donated the use of their land and facilities.

The academic guidance and other support received from my graduate committee members (David Hilderbrand, Carl Edeburn, Larry Fine, Maurice Horton, and Paul Carson) was deeply appreciated.

EFFECTS AND INTERACTIONS OF NITROGEN AND SOIL MOISTURE STATUS UNDER A HIGH YIELD IRRIGATED CORN ENVIRONMENT

Abstract

Dwayne L. Beck

A two-part study was conducted during the 1979 and 1980 growing seasons on irrigated lands adjoining the Missouri River in central South Dakota. Emperical models were developed to describe the response of irrigated corn (Zea mays L.) to soil water status and nitrogen fertilization at a location recently developed for sprinkler irrigation. Nitrogen fertilizer rates of 0, 100, 200, and 400 kg of N/ha were used under water treatments consisting of a 2.5 cm irrigation when soil water matric potential at a depth of 40 cm decreased to -35, -50, and -75 kPa. Yield differences due to soil water matric potential levels were more pronounced under the hot, dry conditions that existed during the 1980 growing season than under the cooler conditions present in 1979. Maximum treatment yields of 13,500 kg/ha and 12,000 kg/ha were obtained in 1979 and 1980 using 200 kg of fertilizer nitrogen/ha with a soil water matric potential of -35 kPa. Yields were 7 and 14% less in 1979 and 8 and 25% less in 1980 at the -50 and -75 kPa matric potential levels where 200 kg of fertilizer N/ha was used. The highest rate of nitrogen did not improve yield under the -35 kPa water treatment but did increase yields from 1 to 5% under the other water treatments. The zero fertilizer nitrogen treatments produced only 50 to 60% of maximum grain yield. Plant tissue nitrogen levels increased with both nitrogen

additions and water stress.

The relationship between leaf and grain nitrogen contents and percent attainment of maximum yield varied with water stress. Where water stress was limited, lower grain nitrogen contents were associated with adequate nitrogen nutrition than when water stress was more severe. These effects were not as pronounced, over the range tested, for the leaf nitrogen content relationship.

The emperical models calibrated at the newly developed site were tested on nitrogen response data gathered under farmer managed center-pivot systems. These fields reflected diverse past management and irrigation histories. This process revealed that preseason soil nitrate nitrogen levels accurately predicted response to fertilizer N additions. Differences due to past management and nitrogen mineralization were less than the variability found in assessing nitrate-N. The available organic nitrogen as measured by sodium bicarbonate extraction techniques appeared to increase with the number of years these soils were irrigated and fertilized.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

Table		Page

LIST OF FIGURES

APPENDIX TABLES AND FIGURES

INTRODUCTION

The state of South Dakota is presently in the infancy stage of developing its land and water resources for irrigation. The construction of four main stem reservoirs on the Missouri River in Central South Dakota as a part of the Pick-Sloan Project had as its primary purpose the control of seasonal water flows to prevent flooding on the lower portions of the Missouri and Mississippi River systems. Secondary goals of this project include generation of hydroelectric power and the stabilization of water flow downstream from the reservoirs for navigational purposes. To compensate the state of South Dakota for the loss of farmland inundated by water from these reservoirs, a substantial portion of the 2.6×10^{10} m^3 (21 million acre-foot) annual throughput of these dams has been reserved for irrigation development in South Dakota. Due to various economic, cultural, political, and technological factors, this potential remains largely undeveloped over twenty years after the completion of the last reservoir in the system.

The lands immediately adjoining the east side of these reservoirs are primarily developed from loess or from late Wisconsin glacial drift parent materials. This factor, combined with the semi-arid climate in the area, has led to the development of soils with relatively thin (15-20 cm) A horizons. As a consequence, this area which is typified by a gently sloping topography did not lend itself to the leveling necessary for the employment of gravity irrigation techniques.

Since the lands adjacent to the reservoirs were primarily unsuited to gravity techniques and mechanized sprinkler systems as they

presently exist had not been developed when the Pick-Sloan project was in the planning phase, the main thrust of water development for irrigation was originally directed to the Lake Dakota Plain in Brown, Spink and Beadle counties. This area had level to nearly level soils developed from alluvial lacustrine materials. These soils were deep and level enough to allow the grading necessary for surface irrigation to take place on a wide scale.

The Oahe Project, as this development was called, has not become a reality at this time, and probably never will be completed as it was originally designed. The factors surrounding the demise of the Oahe Project as it was originally conceived are varied, complex, and to a certain extent speculative, so they will not be discussed here. The consequences resulting from the failure of this project to be completed do, however, bear direct significance on the research to be discussed.

Innovations and improvements in mechanized sprinkler irrigation technology (in the time period since the Oahe project was originally proposed) have drastically changed the thrust of water development in South Dakota. Center-pivot sprinkler irrigation systems make the application of irrigation techniques to large areas of land adjacent to the main-stem reservoirs possible. This includes many hectares that could not be irrigated by surface methods.

Preoccupation with the Oahe project delayed a shift of emphasis in public development projects to the river front areas. Private development projects have been built. Large increases in the amount of irrigation took place throughout the decade of the seventies. Several

private and public irrigation projects are presently being planned or are in the feasibility study stage.

As the emphasis in irrigation development shifted to the river front, it became clear that more research was needed to meet the needs of producers in this area. In particular, it was felt that since these soils were farmed primarily in a small grain-fallow or small grain-forage-fallow rotation or were in native grass prior to their development for irrigation, the release of nitrogen from organic materials (nitrogen mineralization) in these soils might be quite different when irrigated than under rainfed conditions. There was also uncertainty surrounding the response of corn (the primary irrigated crop) to water and nitrogen management in this area. This uncertainty was due to the warmer, less humid climate experienced near the Missouri River as compared to areas in the state where irrigation research had been performed.

The first research to address these questions was initiated in 1978. This experiment consisted of several water treatments applied to main plots in a split plot design. Set rates of preplant nitrogen fertilizer were applied to the subplots. The water management treatments consisted of a total of either 10.2 or 20.4 cm of total water to be applied in increments of 5.1 cm or 10.2 cm at various plant growth stages. A treatment consisting of a 5.1 cm application of water when available soil moisture was depleted to the 50% level was also included.

Papendick[1] found no response to nitrogen additions in this study even though the soil initially tested low (1-2 ppm) in soil nitrate-N in a 120 cm profile. This highly unexpected lack of crop response to nitrogen additions and high levels of residual nitrates in the check plots could not be fully explained by Papendick's data. It was theorized that either nitrogen mineralization rates greatly exceeded expected values or an extraneous source of nitrogen had affected the results. Several possibilities were investigated but no definitive explanation was found.

Most of the water treatments used did not produce results that are readily applicable by operators using center-pivot systems. The treatments involving application depths of 10.4 cm per event in particular, and to a certain extent the 5.2 cm per event depths, did not lend themselves to mechanized sprinkler irrigation utilization due to engineering considerations and the water infiltration characteristics of soils in this area. These results do have relevance to irrigators in the area using gravity techniques.

A research project was initiated in 1979 to address the questions raised by Papendick's work. A search of related literature and pertinent data was made to define water treatments in a manner that (1) could be easily and directly adapted by irrigators using mechanized sprinkler systems (over 95% of the irrigated land in this area employs center-pivot systems), (2) would give consistent results from year to year, (3) employed accurate and economical monitoring techniques readily

[1]Papendick, S. E., Unpublished M.S. Thesis, S.D.S.U. Library.

available to the user, and (4) included the range of soil moisture regimens most appropriate for irrigated corn in this area.

The nitrogen related aspects of this research were directed toward several factors involved in nitrogen management. The ultimate goal was to develop models designed to define irrigated corn response to nitrogen fertilizer additions on these soils.

The nitrogen used by non-leguminous plants such as corn comes from three primary pools. Only one of these, inorganic nitrogen fertilizer additions, is directly controlled by the irrigator. The other two, residual inorganic nitrogen (mostly in the form of soil nitrate) and nitrogen released through decomposition of organic materials (nitrogen mineralization), depend heavily on past management practices and inherent soil characteristics. For the models to be effective it was necessary to consider the primary sources of nitrogen and the major factors that could affect the amount of this nutrient they were capable of supplying to the crop.

After reviewing related literature and other pertinent data in the perspective of the financial and experimental resources available, a three phase project was proposed. Two of these phases were included in a field study with the third phase, if necessary, being a laboratory investigation.

The first phase involved the defining of water and nitrogen response on a researcher-managed area that theoretically possessed high potential for supplying nitrogen through the process of mineralization. This area was designed to allow (1) the evaluation of nitrogen

mineralization and crop response to fertilizer nitrogen additions as affected by soil water status, and (2) the study of corn response to soil water status in the region bordering the Missouri River Reservoir.

The second phase of the project initially involved twenty-two farmer-cooperator sites. These sites were selected to serve two primary purposes. They were chosen to possess widely different past management in terms of years developed for irrigation of continuous corn and years farmed and therefore should theoretically reflect differences in the amount of nitrogen supplied through the process of mineralization. These sites provided a means for evaluating the significance of the mineralization process in these soils and the data base needed to calibrate predictors of nitrogen mineralization. The second primary purpose of these cooperator fields was to serve as a diverse but representative sample on which the models developed at the researcher-managed area could be tested.

The third phase involved a laboratory study to develop, modify, or adapt laboratory predictors of nitrogen mineralization for use in routine soil analysis procedures. This phase of the project was to be performed if the first two phases of the project indicated that such input was necessary for the nitrogen response model to perform adequately.

The multifaceted nature of this research project made it difficult to decide on the most appropriate format for reporting the experimental methods, and the research results and conclusions. It was decided that the most straightforward method would involve the use of

two separate but related segments. The first segment deals with the development of the water-nitrogen management models on the researcher-managed area. This is followed by analyses of the applicability of these models to the farmer-cooperator sites and the subsequent testing of these models that occurred. Peripherally related topics will be presented in an appendix section.

REVIEW OF LITERATURE

The growth of agricultural plants is limited more often by a deficiency of nitrogen than any other nutrient (Black, 1968). Viets (1965) calculated that plants contain more atoms of nitrogen than any other element except hydrogen derived from soils. Under conditions of nitrogen deficiency, the leaves of plants are small and the stems are thin. The leaves usually have a pale, yellowish-green color in the early stages of growth because of limited synthesis of chlorophyll. Symptoms are most pronounced in older leaves.

The nitrogen used by non-leguminous plants such as corn is primarily absorbed in the form of inorganic ammonium, nitrite and nitrate. This inorganic nitrogen in agricultural soils is derived predominantly from two sources:

(1) nitrogen mineralization: decomposition of nitrogen containing organic materials and/or

(2) direct additions of inorganic nitrogen forms through fertilization.

The amount of N supplied for plant growth from each of these sources is dependent on a combination of environmental, topographical, edaphological, cultural and past management factors. Due to the importance of nitrogen to agricultural crop production, an extensive amount of literature exists on all aspects of the nitrogen cycle including the use of nitrogen fertilizers.

Most arable soils contain between 0.02 and 0.4% nitrogen in their plow layer. The amount present is affected by many factors (Black,

1968). This material has accumulated over geologic time due to a difference in the rate of organic nitrogen compound formation through various biological nitrogen fixation processes and the rate of organic nitrogen decomposition through the concurrent process of mineralization. Jenny (1930), in a classical work, showed a marked decrease in soil nitrogen content with an increase in mean annual temperature. It was found that if all other factors are the same, an increase in water supply will increase the soil nitrogen content. This increase was attributed to an increase in the rate of production of vegetation, with associated biological nitrogen fixation, and not to a decrease in the rate of decomposition. Jenny described the combined effects of temperature and water supply by the equation

$$N = 0.55\, e^{-0.08T}\,(1-e^{0.005H})$$

where N is the nitrogen percentage of the surface soil, T is the mean annual temperature in degrees centigrade and H is a humidity factor based on effective precipitation.

Many researchers, including Jenny (1941), Keeney and Bremmer (1964), and Hinmon (1964) have shown a decrease in total organic nitrogen on cultivated soils as compared to virgin lands. Haylett and Theron (1955) and Theron (1965) found that soil organic nitrogen increased when inorganic fertilizers were applied to grasslands in South Africa. They attributed this to the increased production of organic nitrogen that resulted from increased plant growth; i.e., the capability of plants to immobilize nitrogen was thought to exceed the amount of mineral nitrogen produced through decomposition of organic nitrogenous compounds.

It is obvious from this research that the organic nitrogen content in soils as it exists under native conditions can be drastically altered by the activities of man. It is generally assumed the nitrogen mineralization and biological fixation processes have reached or nearly reached equilibrium in virgin soils. Change in the environment or in cultural practices leading to a gain or loss in soil organic nitrogen content often is the result of change in rate of one or both of these reactions.

Because of the importance of these processes, their complexity, and the many factors that may affect them, much research has been done in an attempt to discover their underlying principles. Reviews of this work include Harmsen and von Schreven (1955). The microbially mediated process known collectively as organic nitrogen mineralization is as follows:

$$\text{Organic N} \xrightarrow[\text{slow}]{} NH_4^+ \xrightarrow[\text{fast}]{} NO_2^- \xrightarrow[\text{v. fast}]{} NO_3^-$$

In general, the first step is the rate controlling step of this reaction series. Very little ammonium and nitrite, therefore, accumulate under cropping conditions. The processes known collectively as nitrogen immobilization encompass all conversions of mineral nitrogen in a soil into organic nitrogen forms. Without the use of nitrogen-15 isotope tracer techniques it is impossible to evaluate mineralization and immobilization separately; therefore, the term "net mineralization" is often applied to the net effect of these concurrent processes.

Since organic nitrogen compounds are the source of substrate

feeding the process of mineralization, it is logical to assume from chemical kinetics that the total soil organic nitrogen should show a relationship to the amount of mineralization. Allison and Sterling's (1949) early work, however, demonstrated that the total amount of organic nitrogen is not the sole factor affecting mineralization even under the controlled environment of an incubation experiment. This was attributed to the heterogeneous nature of the organic nitrogen in terms of its susceptability to mineralization. This is especially true when substantial amounts of crop residues are being returned to the soil or when manures are used. In general, if organic material containing less than 1.5% nitrogen is involved, the immobilization rate will exceed the mineralization rate. If the N percentage is greater than 1.5%, net mineralization will be positive (Black, 1968).

Various chemical and incubation methods have been developed in an attempt to predict a soil's potential for supplying nitrogen through mineralization. Early work was reviewed by Bremmer (1965), later work on incubations has been performed by, among others, Stanford and Smith (1972) and Stanford et al. (1974). Chemical indexes of potential mineralization can be found in MacLean (1964), Keeney and Bremmer (1966), and Fox and Piekelek (1978). Most of the indexes of determining potential mineralization involve methods that are not readily suited for use in routine soil analysis procedures. MacLean's sodium bicarbonate extraction techniques show promise, but still require distillation and Nesslerization steps. Fox and Piekelek altered the procedure by using ultraviolet spectroscopy to analyze the extract. This worked well for

them, however, the 250 ml flasks and the large extractant volumes used would limit routine laboratory throughput with this procedure.

Even if these availability indexes very accurately predict potential mineralization, great difficulty is usually encountered when applying these indicators to a field situation. This difficulty has been attributed to many factors including environmental effects on mineralization rate and time of sampling variations.

Robinson (1957), and Stanford and Epstein (1974) found a relationship between soil moisture and mineralization rate. Stanford and Epstein attributed 93 to 95% of within soil variability to associated variation in soil water content. Their equation related the percentage of total mineralization taking place (Y) to (X) the soil water percentage (w/w) expressed as a percent of the optimum soil water percentage, i.e., if $\theta_m = 21\%$ and optimum $\theta_m = 42\%$, then $X = 50\%$. Their equation was $Y = -3.7 + 1.02X$. In this instance only 47% as much nitrogen would be mineralized at 21% as compared to 42% soil water. The data of Robinson indicates that this relationship may vary with period of incubation. Miller and Johnson (1964) reported a wide range of nitrate accumulations by incubation methods when soil matric potential was varied from 0 to -5000 kPa. Their curve shows little response in the -30 to -80 kPa range. These types of studies have generally not been applied to a field situation or even to greenhouse experiments because of the difficulty encountered in accurately controlling soil moisture levels in these situations.

Stanford et al. (1977) related N uptake of irrigated sugar beets

to soil nitrate-N and an estimate of actual mineralized nitrogen. The prediction of actual mineralized N was made using incubation techniques to predict potential mineralization. This value was then modified to reflect the actual field conditions in terms of soil moisture and temperature. Their N uptake prediction equation had an R^2 of .64, which was much lower than values obtained in laboratory studies, but better than field studies not attempting to modify a nitrogen availability index to predict environmental conditions. The inclusion of residual soil nitrate into the equation was found to be essential.

Freezing, drying and tillage have been shown to enhance net mineralization in most instances. Landreau (1953) found that air dried soil samples produced more mineral nitrogen when incubated than did samples kept continuously moist. As compared to the pronounced effect of drying on subsequent mineralization of nitrogen, the effect of freezing seems to be moderate and sometimes absent. Harding and Ross (1964) report findings of their work and cite other research on the subject of freezing effects on mineralization rate. Evidence of the effect of field cultivation was obtained by During et al. (1963) comparing nitrogen mineralization under no-till and conventional tillage treatments. Cultivation produced higher soil nitrate, higher yield of nitrogen in the crop and higher yield of dry matter than did chemical control of vegetation. A relationship between yields and soil nitrate existed both within and between treatments. The effects of freezing, drying and tillage have been explained in terms of increased exposure of substrate to microbial attack as a result of these physical events.

Although higher plants play no direct role in nitrogen mineralization, a substantial amount of evidence exists which indicates that net mineralization of nitrogen is not entirely independent of plant growth. Goring and Clark (1949) showed that the amount of nitrogen mineralized in a fallow and cropped soil was about the same during the first six weeks, but after this time more nitrogen was mineralized in the fallow soil than in the cropped soil. Subsequent incubation of these soils (Clark, 1949) produced an increased amount of mineralization in the previously cropped soil over the fallow that approximately equalled the decrease noted while the crop was being grown. These results were explained in part on the basis of an increased microbial immobilization of nitrogen resulting from plant root exudates in the cropped soil. Further evidence of the immobilization of nitrogen as a result of root exudates was found by Legg and Allison (1961) in a study using ^{15}N techniques. Bartholomew and Clark (1950) inferred that both total mineralization and total immobilization were greater in cropped soil than in fallow soil; therefore, the smaller net mineralization was due to the difference in the amount of change in these processes.

This factor becomes even more complex in light of the fact that increased uptake of soil N has been shown to result from fertilizer N additions in ^{15}N tracer studies. Legg and Allison (1968) implicated the higher C/N ratio of root exudates in their greenhouse study. Andreeva and Scheglova (1968), however, saw the same phenomena even on fallow pots and like Westermann et al. (1973) attributed this "priming effect" to increased microbial activity in the soil. Laura (1974) and (1975)

felt that ammonium had more effect than nitrate, due to the protolytic nature of water; i.e., the increase depends on ammonia as a direct source of protons. Broadbent (1965) had also reported increased effect of ammonium over nitrate but attributed it to preferential uptake of this N form by microorganisms. Other researchers (Legg and Stanford 1967, Fried and Broeshart 1974) support the A value concept and maintain that this value does not change with fertilization. (The A value is the proportion of soil N uptake to fertilizer N uptake multiplied by the fertilizer rate.) The results of this research indicate that if all other factors are held constant, N fertilization seems to cause slightly more net mineralization to take place, but the ratio of soil derived N to fertilizer N in the plant actually decreases. This research and much similar work clearly illustrates some of the difficulties encountered in attempting to predict the amount of mineralized N produced under field conditions.

The adoption of management practices capable of increasing the amount of mineral nitrogen that becomes available for plant growth has taken place since the inception of crop production. Originally, this involved the use of nomadic farming practices. Later developments involved organic nitrogen additions such as manures, or the use of a legume or fallow rotation.

The development of the Haber process for reducing molecular nitrogen to ammoniacal forms through the use of a catalyst and a hydrogen source at high temperature and pressure has led to increased availability and use of inorganic nitrogen fertilizers. The availability of

inorganic N sources has made it possible for producers to accurately apply a desired amount of inorganic nitrogen to supplement that produced through the mineralization process. The determination of the proper amount of supplemental nitrogen to apply in any particular situation is a complex one to which much research has been directed. The primary factor that must be considered in any situation is the nitrogen requirement relationship to relevant yield and quality parameters for the crop to be grown. Inorganic nitrogen fertilizer additions can then be made to supplement other sources of nitrogen to increase the producers' economic return. Care must be exercised in making these additions to minimize the potential for non-point source pollution of ground and surface waters.

Adams et al. (1978) reported that corn capable of producing 12,600 kg/ha would require 1 kg of fertilizer nitrogen for every 37 kg of grain produced. These calibrations included fertilizer nitrogen and residual soil nitrate-N to a depth of 60 cm as equivalent nitrogen sources. Other researchers (Herron et al. 1971) had also outlined the importance of measuring residual soil nitrate when assessing the need for fertilizer additions. Nitrate accumulation in soils results when fertilizer additions and mineralized nitrogen exceed the amount of N needed for crop production. This is especially true in the Northern Great Plains where leaching is minimal since effective precipitation occurs primarily during periods of active plant growth and overwinter losses of nitrate are minimized by frozen soils. Olson (1982) cites the necessity to measure nitrate-N to a 120 cm depth under irrigated corn in

Nebraska.

The calibrations of Adams et al. (1978) did not, however, attempt to account for the nitrogen supplied through the process of mineralization. Many factors could have been involved in their decision to not evaluate this source of nitrogen. First, the calibration curves were predominantly developed by studies under rainfed conditions in eastern South Dakota. Prediction of the soil moisture status of these soils and consequently prediction of mineralized N would be impossible under these conditions. Since water usually is yield limiting, farmers in this area primarily submit yield goals based on the rainfall received in a "normal" year. If more rainfall is received than normal, the increased mineralization that results will allow the crop to express this expanded yield potential without being limited by nitrogen. In years that are drier than normal, reduced mineralization will parallel a water stress induced yield limitation. Excess nitrate that results by use of these methods can normally be used during the subsequent growing season in this area. Nitrogen credits were given in their system for manure applications and legume rotations. The soils in the area where these calibrations were developed have also been cultivated for a substantial period of years, which theoretically reduces the variability in mineralization rates that would be evident in areas having both newly developed soils and soils that have been cropped for long periods.

The factors that allow this method to work well under eastern South Dakota rainfed conditions do not necessarily apply to the irrigated lands adjoining the Missouri River in the central part of the

state. Olson and Onstad (1974) concluded that the nature of a fertilizer N response depends on water status factors during the growing season. Since the water status that exists under an irrigated environment logically is much different than that under rainfed conditions, it follows that the N response on these irrigated lands may differ considerably from the response found in eastern South Dakota under rainfed conditions. The lower organic matter content soils at the river front that have not been intensively farmed or fertilized for long periods of time, if at all, may demonstrate quite different mineralization patterns than the soils used for calibrating the present test. The possibility of a higher than expected mineralization rate was used by Papendick[2] to explain the lack of response to nitrogen fertilizer additions observed in his research. It was postulated that since the study took place the first year this particular soil had been irrigated, a dramatic increase in mineralization rate resulted from the increase in soil moisture status over "native" conditions. Sufficient data was not available to conclusively implicate mineralization as the source of excess nitrogen in this study.

Application of nitrogen balance techniques to Papendick's data using the present uptake calibration curves (no whole plant samples were taken), produces net mineralization values in excess of 250 kg/ha. If Papendick's hypothesis is valid, and normal fertilization procedures were followed, total profile nitrates would equal or exceed this value

---

[2] ad ibid

for at least part of the season. Muir et al. (1976), Hahne et al. (1977), Stewart (1970), and Rhoades et al. (1978) all emphasized the importance of avoiding excess nitrogen fertilizer applications in order to minimize movement of nitrates beyond the root zone. Nitrate leaching not only involves the economic loss of this pool of nitrogen, but also increases the potential for non-point source pollution of ground and surface waters (Olsen 1974). Rhoades et al. (1978) and Herron et al. (1971) found reductions in leaching associated with delayed applications of nitrogen fertilizers. The use of nitrification inhibitors has also been linked to reduced nitrate leaching when ammoniacal sources of nitrogen are used under conditions that favor this nitrogen loss (Turner and Goring 1966). Leaching and dentrification losses are not a major concern under rainfed cropping systems in central South Dakota due to the ustic moisture regime. The adaptation of irrigation practices greatly enhances the potential for these nitrogen losses occurring, especially when profile nitrates are high and improper water management practices are used. Smika et al. (1977) and Hahne et al. (1977) stressed the importance of proper water management in the limitation of nitrogen losses. It is clear from this research that nitrogen and water management are highly interrelated factors that cannot be considered independently. Each factor not only can produce a plant growth response on its own, it also can impact the effect and efficiency of the other.

Under conditions of unlimited availability, economic considerations play a large role in determining the type of water and nitrogen management practices employed by irrigators. Other

considerations often enter the decision-making process however. For instance, it is obvious that the water management choices available to a producer using gravity techniques are often quite different from those available to a producer using sprinkler systems. The differences between and within system types are to a large extent area, soil, crop, and system specific. Water management as it applies to corn producers using continuously moving sprinkler systems on the soils adjoining the Missouri River in South Dakota will be considered. The predominance of these types of systems (primarily center-pivots) in the area was the reason for this choice. The work of Papendick should serve as a guide for the producers capable of using surface techniques.

Pair (1975) stated that the variable application rate of continuously moving sprinkler systems complicates the selection of application rate for system design. In general, the peak application rate of a center-pivot system is controlled by three factors: system capacity, lateral length, and sprinkler type. Center-pivot systems are usually designed to cover 53 ha of the 65 ha fields common to this area. This entails the use of a lateral approximately 400 m in length. The system capacity is then designed to match the peak water use characteristics of the crop to be grown. A system capacity of .25 l/s/m near the distal end of a center-pivot is required to match gross water use of 10 mm/da. Even with the use of sprinklers having a large wetted diameter, runoff may be a problem near the outer end of center-pivot systems (Pair et al. 1975, Kincaid 1969). They suggest the use of frequent applications of limited depth to minimize runoff under these conditions. DeBoer and

Beck (1982) demonstrated that runoff could be nearly eliminated through the use of proper tillage techniques on soils in this area watered with conventional continuous move sprinkler systems. Application depths of approximately 2.5 cm were used in their experiment. Sprinkler infiltrometer investigations which were performed as a preliminary phase of that project indicated that larger irrigation depths could lead to substantially more runoff (unpublished data). Modification of system design by shortening the length of the lateral would allow the use of capacities capable of applying large quantities of water in short periods of time without danger of runoff. This option is not viable since the development cost per hectare increases rapidly when lateral length is shortened. Other practical management factors also favor the larger field size.

Because of the previously mentioned considerations, center-pivot systems in this area are capable of applying an amount of water approximately equal to the amount of this water used by corn during periods of peak atmospheric demand. The irrigator cannot, however, maintain his soil moisture at a low status during part of the growing season and then quickly apply large amounts of water when critical growth stages or periods of high atmospheric demand occur. Farmers with these systems must schedule irrigations to establish the proper soil moisture level prior to these periods.

It is necessary to determine the most appropriate range of soil moisture levels for irrigated corn production in this area. If irrigation is viewed as a method of reducing water stress for the purpose of economically increasing crop yield, water management guidelines should

be developed that will maximize return to investment. Management schemes for maximizing yield, minimizing water pumped from a limited supply, etc., may produce quite different results.

Several excellent reviews have been published on the subject of water stress in plants (Hsaio 1973, Hsaio et al. 1976). These articles deal primarily with the plant response to water stress. Water loss from plant tissues of only 10-15%, (lowering leaf water potential by only 60 kPa) can markedly influence metabolic processes. Other growth characteristics such as cell growth and cell wall synthesis are affected even more quickly. Acevedo (1971) reported that the elongation of young maize leaves was depressed when water availability of the root medium decreased from -10 to -20 kPa. The corresponding leaf water potentials were -280 and -700 kPa respectively.

From these data it appears that the ideal water management system would involve the monitoring of leaf water potential with water applications scheduled just prior to the inception of leaf water potentials low enough to cause economic stress. In reality this approach is not feasible since it would entail the use of an irrigation system capable of applying water to an entire field simultaneously. A more practical approach would be to define a soil moisture parameter related to leaf water potential for use in scheduling irrigations. This requires a closer look at the soil water related factors affecting leaf water potential declines in plants. Reductions in leaf water potentials occur because the soil-root-plant system is unable to supply water to the leaf at a rate equivalent to loss of this water by transpiration. An

observed leaf water potential value is a function of the atmospheric demand and the various resistances to water movement that exist in the soil-root-shoot system. A complete discussion of these factors is beyond the scope of this review. A few key points, however, need to be made. The movement of water is proportional to differences in water potential much like flow of electricity. It is inversely proportional to the resistances this flow encounters. Mathematically this can be stated:

$$\text{Quantity of flow} = \frac{\text{potential difference}}{\text{resistance to flow}}$$

From this relationship it follows that under high atmospheric demand conditions, a larger difference in potential must exist between the leaf water and the bulk soil water than when low demand periods occur. Therefore, under given soil, soil water, and plant resistance conditions, water stress would depend on the amount of atmospheric demand present.

It also seems logical to assume that for a given transpiration rate, in a given soil at varying soil water potentials, the difference between leaf water potential and soil water potential would be a constant. This is not true, however, since the amount of resistance to water flow varies with the soil moisture status of a soil. It has been known for many years that the ability of a soil to conduct water declines rapidly from saturated conditions (soil water matric potential = 0) to field capacity (where no appreciable water movement is caused by potential differences associated with gravity). Gardner (1956)

developed a method to assess soil conductivity in the soil water matric potential range from field capacity to at least -1500 kPa. His data indicate an increase in resistance to water flow of 100,000 percent in the range from field capacity (-10 kPa on the soil he used) to -100 kPa. This is 10 times as much relative change in resistance as that noted between -100 kPa and -1500 kPa and 1000 times the absolute change made in this range. The effect of this rapid change in soil water conductivities does not cause changes in the leaf water potential in the same order of magnitude for various reasons outlined by Newman (1974). The primary reason is that for low evaporative demand conditions, sufficient amounts of water can be transported even at high resistance values. In addition, root growth into areas of higher water potential can reduce the resistance to flow. The roots of plants also act as parallel resistors, therefore, increased flow can occur from roots in parts of the profile with higher water potential as the water potential in other portions of the soil dry. However, when evaporative demand conditions become high, water stress can result from the reductions in water flow associated with higher resistance conditions.

The changes in water flow associated with various soil water potentials were investigated by Denmead and Shaw (1962). They found no reduction in evapotranspiration until the soil water potential fell below -500 kPa when the evaporative demand produced potential ET of 1.4 mm/da. Potential ET conditions of 4.1, 5.6, and 6.4 mm/da produced significant reductions in ET at -150, -70, and -35 kPa respectively.

The evaporative demand conditions that exist along the Missouri

en extensively studied, so no long term data are the climatic data available it has generally been alues for corn can equal or exceed 7 mm/da. Based on ted research it appears that the most appropriate soil evels for this area in central South Dakota during tages with simultaneous periods of peak demand lie in eld capacity to -75 kPa.

by Pair et al. (1975) concluded that tensiometers pro- ropriate means of directly evaluating soil water matric s range. They recommend the placement of instruments nd 90 cm in the soil profile for use in irrigated corn iometers are both easily available commercially and t, making it possible for irrigators to transfer to practical application.

MATERIALS AND METHODS

I. Development of Nitrogen and Water Response Models on the Researcher Managed Area:

This phase of the research was designed to evaluate the response of irrigated corn (Zea mays L.) to nitrogen fertilizer additions over a range of soil water matric potentials and to investigate the effect of this range on net mineralization in this soil. A series of randomized, complete block fertilizer experiments were conducted during the 1979 and 1980 cropping seasons. These consisted of four rates of nitrogen (0, 100, 200, and 400 kg/ha) replicated four times where soil water matric potential was maintained at levels greater than -35, -50 and -75 kPa. Water was scheduled using matric potential data gathered at least once or twice weekly from three sets of four tensiometers in every water level. The instruments were placed with the ceramic tip at depths of 25, 50, 75 and 120 cm. A solid set sprinkler system was used to apply 2.5 cm of water when the bulk soil water matric potential fell to -35, -50 and -75 kPa as determined by the instruments located at the 25 and 50 cm depths. The sprinkler system applied water from the Oahe Reservoir on the Missouri River (E.C. = 800 umhos SAR = 2.4) at a rate of 1.3 cm/hr. The system was operated only at night when wind speed fell below 2 m/s. Net application depths were measured by use of rain gauges at crop canopy height in the same location as the tensiometer sets.

The experimental site was located in Section 8, Township 118 north, Range 78 west in Potter County, South Dakota. It consisted of

approximately three hectares of land owned by Dan Cronin and occupied the unused corner of a field irrigated with a center pivot system. This land had been broken from native sod interseeded with alfalfa and managed for rainfed production of forage sorghum the year prior to the commencement of this experiment.

The soil on this site was mapped as an Agar silt loam (typic argiustoll, fine silty, mixed, mesic). This is the predominant soil found on irrigable land adjoining the Oahe Reservoir in Potter and Sully counties of South Dakota (Westin and Malo, 1978). This area had 0% slope and contained no discernible variability in soil type.

Undisturbed soil cores were sampled from this area for determination of soil water matric potential release characteristics using the pressure plate method. Conversion of the water levels to values of volumetric and gravimetric water content can be made by use of the water release curves and bulk density data in Appendix A. Individual plots measuring 5.8 m by 9.1 m were soil sampled at various times throughout the year. Each sampling consisted of collecting three cores per plot to a depth of 120 cm. Each soil core was divided into five subsamples representing profile depths of 0-15, 15-30, 30-60, 60-90, and 90-120 cm. The three subsamples from each plot-depth combination were then composited. These samples were forced air dried at 45°C and ground to pass a 2 mm sieve before analysis.

All samples collected were analyzed for nitrate nitrogen ion concentration using the specific ion electrode method. Selected surface layer samples were analyzed for total non-nitrate nitrogen content using

macro-Kjeldahl techniques. In addition, spring samples from the 0-15 cm depth were analyzed for phosphorus and potassium availability, Wakley-Black easily oxidizable organic matter content, pH, and electrical conductivity of a 1:1 suspension. Zinc availability was determined on a random number of these samples using DTPA extraction techniques. Nutrients other than nitrogen were applied according to SDSU recommendations based on a yield goal of 12,600 kg/ha. A complete listing of the uniform management practices employed on this area is contained in Table 1.

Nitrogen fertilizer in the form of ammonium nitrate was broadcast by hand on the appropriate plots at rates of 0, 100, 200 and 400 kg of N per hectare immediately after planting. Two cm of water was applied to incorporate this fertilizer and activate weed control chemicals. Soil samples were collected from each plot prior to spring tillage, at silking and after harvest in both 1979 and 1980. In addition, a soil sampling was conducted at the 6-8 leaf stage of growth in 1980. The midseason samplings were performed in conjunction with leaf sampling operations. Leaf samples were collected from ten random plants per plot by removing the leaf immediately below and opposite the lower ear leaf at silking. The early leaf sampling in 1980 consisted of removing the last fully extended leaf from 10 randomly selected plants per plot when the corn was in the 6-8 leaf stage of growth (specifically on July 3 in 1980). This sampling was included to allow the evaluation of an early midseason soil and leaf sampling procedure to assess the nitrogen status of the plants and soil just prior to the period of maximum nitrogen

Table 1. Soil Test Results and Uniform Management Practices - Researcher Managed Area.

Soil Type - Agar Silt Loam (Typic Arguistoll, Fine Silty, Mixed, Mesic)

P - 22 kg/ha	pH - 7.4
K - 780 kg/ha	Conductivity - 0.3 mhos/cm
O.M. - 2.0%	Zinc - 1.2 ppm

Nitrate nitrogen - 17 kg/ha (0-60 cm), 33 kg/ha (0-120 cm)

Legal Description - Section 8, Town 118 North, Range 78 West

1979: Crop - Corn (var. Pioneer 3780)
Seeded at 72,000 seeds/hectare

Planting Date: May 11, 1979
Broadcast Phosphorus: 125 kg/ha of Diammonium Phosphate (18-46-0)
Starter Fertilizer: 112 kg/ha of 10-40-10 banded 5 cm below and 5 cm to the side of the seed row.
Herbicide: Lasso + Bladex, broadcast pre-emergence.
Preplant tillage: Tandem disk (two passes).
Insecticide: Counter 10G
Post-emergence tillage: Cultivated 6-6-79.
Subsurface Tilled 6-14-79.
Harvest: Grain 10-2-79

1980: Crop - Corn (var. Pioneer 3732)
Seeded at 72,000 seeds/hectare

Planting Date: May 3, 1980
Broadcast Phosphorus: 75 kg/ha of 0-44-0 + 6 kg/ha Zn as $ZnSO_4$
Starter Fertilizer: 112 kg/ha of 10-40-10 as in 1979.
Herbicide: Lasso + Bladex, broadcast pre-emergence.
Preplant tillage: Tandem disk (two passes)
Insecticide: Furadan 10G
Post-emergence tillage: Cultivated 6-11-80.
Subsurface tilled 6-16-80.
Harvest: Whole Plant 9-5-80.
Grain 9-30-80.

uptake. Leaf samples were forced air dried at 45°C, ground and analyzed for non-nitrate nitrogen content using macro-Kjeldahl techniques.

Grain yields were determined by hand harvesting 6.1 m from each of two rows per plot. Ten ears from this sample were selected at random for determination of moisture content, test weight, and shelling percentage. The grain obtained from these ears by mechanical shelling was ground and used for determination of non-nitrate grain nitrogen content using macro-Kjeldahl techniques. Whole plant samples were collected at physiological maturity by harvesting 3 m from each of two rows per plot. A subsample of this material was collected for determination of moisture and nitrogen content. Procedures used were the same as those employed for analysis of leaf and grain samples. All routine soil and plant analysis procedures were performed by the Soil Testing Laboratory at South Dakota State University. For further information on these procedures see Carson and Gelderman (1980) and Gelderman and Carson (1980).

II. Evaluation of the Applicability of the Models Developed to Farmer Cooperator Fields.

The primary purpose of this portion of the research was to provide the data base necessary to test the models developed on the researcher-managed area. The farmer-cooperator fields were chosen to reflect wide but representative variation in the number of years they had been farmed and irrigated. Since the models were developed on a soil that had only recently been broken from sod, it is logical to

assume that if mineralization rates vary markedly with time in this area, the models should not accurately predict nitrogen response over this range of conditions. If modification of the models was necessary to make them applicable over this range of management histories, laboratory predictors of nitrogen mineralization would be evaluated for their ability to improve the models.

Twelve farmer-cooperator center-pivot irrigated sites were selected for study during the 1979 growing season. These fields were similar in terms of soil type, water source, environment, cultural practice, water distribution system, and present cropping system (continuous corn); but varied in cropping and irrigation history. These factors are listed in Table 2.

A uniform area was selected and divided into four replicates. Each replicate was divided into 5 treatment plots measuring 9.1 m in length and 6 corn rows (5.5 to 5.8 m) in width. Soil, plant and yield sampling procedures were identical to those used on the researcher managed area. Initial soil test results are listed on Table 3.

Nitrogen fertilizer treatment rates for the farmer-cooperator sites were based on the results of the pre-season nitrate levels in each plot. As stated before, SDSU recommendations used in 1979 called for a total of 337 kg of nitrate (0-60 cm) plus fertilizer nitrogen per hectare in the production of 12,600 kg of grain/ha. Since soil sampling procedures were to a 120 cm depth it was felt adjustment should be made to allow for the nitrate in the 60-120 cm portion of the profile. Shackley (1953) and Pair et al. (1975) both cite numerous studies in

Table 2. History and Past Management Data: Farmer-Cooperator Sites and Researcher Managed Area

Site Number	Site Designation*	Year	Years Farmed	Years Irrigated	Soil Type	Slope (%)
1	DC	79	13	13	Agar	0-2
2	DAR	79	15	5	Agar	0-2
3	WDAR	79	0	0	Lowry	0-2
4	EH	79	20	3	Lowry	0-2
5	RH	79	15	3	Agar	0-2
6	MON	79	20	1	Lowry	2-4
7	NNSW	79	2	2	Agar	0-2
8	NNSWO	79	2	2	Agar	0-2
11	ZNSO	79	13	13	Akaska	2-4
12	ZNST	79	13	13	Akaska	2-4
22	EH80	80	21	4	Lowry	0-2
23	RH	80	15	4	Agar	0-2
24	RHS	80	0	0	Lowry	2-4
27	NNSW	80	3	3	Agar	0-2
28	NNSWO	80	3	3	Agar	0-2
29	ZNSO	80	14	14	Akaska	2-4
30	ZNST	80	14	14	Akaska	2-4
RESEARCHER MANAGED AREA		79	1	0	Agar	0
		80	2	1	Agar	0

Agar - Typic Argiustoll (fine silty, mixed mesic)
Akaska - Typic Argiustoll (fine silty over sand or sandy skeletal)
Lowry - Typic Haplustoll (coarse silty, mixed mesic)

*Sites with the same designation are sites repeated in 1980.

Table 3. Initial Fertility Levels of Farmer Cooperator Sites

Site Number	Year	P (kg/ha)	K (kg/ha)	OM (%)	pH	EC (mmhos/cm)	Nitrate-N (kg/ha) 0-60	Nitrate-N (kg/ha) 60-120
1	79	50	670	2.5	7.0	.4	131	352
2	79	16	999+	2.3	7.1	.4	32	60
3	79	18	440	2.7	7.3	.3	42	61
4	79	40	670	2.1	7.0	.3	152	224
5	79	13	690	2.0	7.0	.3	72	120
6	79	22	660	1.5	7.8	.3	25	62
7	79	22	560	2.4	7.4	.3	92	169
8	79	22	560	2.4	7.4	.3	92	169
11	79	50	670	1.8	7.0	.4	201	402
12	79	50	670	1.8	7.0	.4	261	534
22	80	28	670	2.1	7.0	.3	98	148
23	80	22	690	2.1	7.0	.3	*	*
24	80	25	710	2.1	7.4	.3	19	35
27	80	22	560	2.4	7.4	.3	*	*
28	80	22	560	2.4	7.4	.3	*	*
29	80	50	670	1.8	7.0	.4	*	*
30	80	50	670	1.8	7.0	.4	*	*

* These sites were repeated from the 1979 season; therefore, the nitrates varied with the treatment applied the previous year.

western states in evaluating water uptake patterns of corn. They reported 65-70% of the water was removed from the surface 60 cm of the profile and 30-35% from the 60-120 cm level. If it is assumed that nitrate extraction patterns follow that of water, the present calibration indicates that a total of 500 kg of nitrogen/ha in a 120 cm profile would be equivalent to 337 kg/ha in a 0-60 cm profile. Although faults can be found in this conversion, the lack of research on deep sampling in South Dakota led to use of this value as a target during the 1979 season. Total nitrate (to 120 cm) plus fertilizer nitrogen rates equal to 500 kg/ha and 100 and 200 kg/ha above and below this value were used as the nitrogen rates in the farmer-cooperator fields that year. To obtain data over a wide range of nitrogen management systems, farmers who normally applied part of their nitrogen through the sprinkler system were allowed to continue this practice. The amount of N supplied in this manner, and through broadcast and starter applications of phosphorus sources were subtracted from broadcast applications. In cases where this procedure produced an amount of fertilizer less than 0 kg/ha to be researcher applied, set rates of 0, 50, 100, 200 and 400 kg/ha were used.

An attempt was made to keep all non-research related parameters as constant as possible on these fields. Nutrients other than nitrogen were applied according to SDSU recommendations. A summary of uniform management practices is contained in Table 4.

The 1979 field results at both the researcher and farmer-cooperator sites indicated that the conversion made for deep sampling

Table 4. Uniform Cultural Factors Applied to Farmer-Cooperator Fields

Site	Primary Tillage	Planting Date	Broadcast Fertilizer (kg/ha)	Starter Fertilizer (kg/ha)	Nitrogen Through Irrigation Water (kg/ha)	Legal Description
1	Plow	5-11-79	0-0-0	11-44-11	0	8-117N-78W
2	Disk	5-22-79	0-0-0	11-34-11	0	1-115N-80W
3	Disk	5-31-79	0-0-0	11-34-11	0	2-115N-80W
4	Plow	5-14-79	28-70-0	9-36-9	33	15-118N-78W
5	Plow	5-07-79	22-56-0	11-44-11	112	14-118N-78W
6	Disk	4-27-79	10-40-10	11-44-11	180	9-114N-81W
7	Plow	5-5-79	26-65-0	11-44-11	0	9-93N-80W
8	Plow	5-5-79	26-65-0	11-44-11	0	9-93N-80W
11	Plow	5-11-79	0-0-0	11-44-11	0	8-118N-78W
12	Plow	5-11-79	0-0-0	11-44-11	0	8-118N-78W
22	Plow	5-08-80	0-0-0	10-40-10	44	15-118N-78W
23	Plow	5-03-80	0-0-0	11-44-11	55	14-118N-78W
24	Disk	5-01-80	20-50-0	11-44-11	84	14-118N-78W
27	Plow	5-01-80	0-0-0	11-44-11	11	9-93N-80W
28	Plow	5-01-80	0-0-0	11-44-11	11	9-93N-80W
29	Plow	5-02-80	0-0-0	11-44-11	11	8-118N-78W
30	Plow	5-02-80	0-0-0	11-44-11	11	8-118-78W

All sites were planted to 3780 Pioneer in 1979 except site 6 where Pioneer 3709 was planted. Pioneer 3732 was planted at all sites in 1980. A seeding rate of 68,000 to 72,000 seeds/hectare was used at all sites.

and/or the calibration proposed by Adams et al. predicted higher levels of fertilizer and nitrate-nitrogen than needed. The target value for the 1980 growing season was therefore adjusted to a value of 250 kg/ha of total N with treatments equal to and 50 and 100 kg/ha above and below this target. As in 1979, fields calling for a negative fertilizer applications received set rates of fertilizer as treatments. Site number twenty four which was broken from sod in 1980 received three additional treatments including treatments 25 kg/ha above and below the target and a no additional N treatment.

The high fertilizer rates used in 1979 created a situation where residual nitrates varied from low to high values depending on the treatment applied the previous year. Therefore, three of the 1979 sites were monitored in 1980 with no additional researcher applications of nitrogen being made. The results of this plot by plot fertilization scheme produced a wide range of fertilizer nitrogen rate-nitrate-nitrogen level combinations. The range of each of these parameters and the range of total nitrogen values at each site is shown in Table 5.

Water scheduling on these sites was left to the individual operator based on advice from researcher personnel. Three tensiometer - rain gauge stations were installed at each site to monitor soil moisture status. Each station consisted of three tensiometers. These instruments were placed with the ceramic tip at depths of 25, 50 and 75 cm. Soil water matric potential and water application depths were recorded once or twice weekly throughout the growing season. Farmers were encouraged to maintain the soil water matric potential within the range

Table 5A. Rates of Fertilizer Nitrogen Applied and Total Inorganic Nitrogen present at the Farmer Cooperator Sites:

Total Fertilizer Nitrogen Applied (kg/ha)

Sites Receiving Rates of Fetilizer Nitrogen Based on Soil Nitrate-N Content.

Site	Year	N Treatment Level 1	2	3	4	5
2	1979	241	319	450	554	651
3	1979	247	347	440	544	635
4	1979	133	195	222	307	561
5	1979	158	301	371	517	603
6	1979	243	341	464	546	634
7	1979	150	184	365	431	554
8	1979	150	184	365	431	554
22	1980	65	122	221	421	72
24*	1980	117	167	217	267	300

*Rates of 114, 192, and 142 kg/ha were also used at site 24.

Sites Receiving Set Rates of Broadcast Nitrogen

Site	Year	1	2	3	4	5
1	1979	11	111	211	411	61
11	1979	11	111	211	411	-
12	1979	11	111	211	411	-
29	1980	22	122	222	422	-
30	1980	22	122	222	422	-

Sites Repeated from 1979; Receiving Nitrogen only from Phosphorus Sources and with the Irrigation Water.

Site	Year	1	2	3	4	5
23	1979	66	66	66	66	66
27	1979	22	22	22	22	22
28	1979	22	22	22	22	22

Table 5B. Rates of Fertilizer Nitrogen Applied and Total Inorganic Nitrogen present at the Farmer-Cooperator Sites:

Initial Total Inorganic Nitrogen Present
Based on Plot by Plot Sampling (kg/ha)

Sites Receiving Rates of Fetilizer Nitrogen Based on Soil Nitrate-N Content.

		N Treatment Level									
		1		2		3		4		5	
		Sampling Depth (cm)									
Site	Year	60	120	60	120	60	120	60	120	60	120
2	1979	274	305	360	405	479	505	582	605	688	705
3	1979	286	305	385	405	483	505	585	605	684	705
4	1979	256	305	323	405	439	505	496	605	659	705
5	1979	269	335	359	435	456	535	568	635	656	735
6	1979	266	305	361	405	483	505	568	605	659	705
7	1979	234	305	314	405	438	505	526	605	629	705
8	1979	234	305	314	405	438	505	526	605	629	705
22	1980	167	213	162	225	207	254	245	300	308	350
24*	1980	138	150	184	200	234	250	284	300	334	350

*Rates of 131, 225, and 275 kg/ha (to 120 cm) were also used at site 24. These were numbered 0, 7, and 8, respectively.

Sites Receiving Set Rates of Broadcast Nitrogen.

1	1979	125	234	266	543	408	654	540	740	177	413
11	1979	244	419	279	490	477	692	588	790	-	-
12	1979	287	532	347	613	472	748	722	1020	-	-
29	1980	138	415	262	529	532	963	986	1323	-	-
30	1980	156	438	315	610	524	915	902	1300	-	-

Sites Repeated from 1979; Receiving Nitrogen only from Phosphorus Sources and with the Irrigation Water.

23	1980	130	174	179	264	268	361	296	425	366	353
27	1980	100	212	121	243	137	280	113	234	140	306
28	1980	96	207	94	253	123	272	202	360	188	358

Table 5C. Rates of Fertilizer Nitrogen Applied and Total Inorganic Nitrogen Present at the Farmer Cooperator Sites:

Initial Total Inorganic Nitrogen Present Based on Mean Nitrate-N Concentration First Time Sites; Values are Fertilizer N Plus Mean Site Nitrate-N

	N Treatment Level									
	1		2		3		4		5	
	Sampling Depth (cm)									
Site	60	120	60	120	60	120	60	120	60	120
1	153	372	273	472	352	572	552	772	202	422
2	279	305	352	378	481	508	587	614	684	710
3	288	308	388	408	481	502	585	604	677	697
4	284	356	346	418	373	445	458	530	712	784
5	229	278	372	420	442	490	589	636	675	722
6	256	293	364	420	488	491	570	607	657	695
7	241	319	274	352	457	533	521	600	645	721
8	241	319	274	352	457	533	521	600	645	721
11	222	423	322	523	422	623	622	823	-	-
12	282	554	382	654	482	754	682	854	-	-
22	162	212	162	213	214	264	266	317	283	334
24	136	150	186	200	236	250	286	300	336	350

Sites Repeated from 1979: Values are Fertilizer N Plus Mean Nitrate-N for Each N Treatment Level in 1979.

23	130	174	179	264	268	361	296	425	366	358
27	100	212	121	243	137	280	113	234	140	306
28	96	207	94	253	123	272	202	360	188	358
29	138	415	262	529	532	963	986	1323	-	-
30	156	438	315	610	524	915	902	1300	-	-

covered by the experiments on the researcher-managed area.

Due to fiscal and manpower constraints, whole plant sampling at physiological maturity and mid-season soil samplings were performed at the discretion of the researchers. Table 6 contains a summary of the information gathered on both the research area and farmer-cooperator fields. Five sites that were abandoned are not included. Site number 9 contained large skip areas due to a malfunction in the farmer's planter in this area. Site ten was subjected to severe hail and subsequent army worm damage. Sites 21 and 25 were both severely water stressed due to mechanical difficulties with the sprinkler systems used to irrigate them. Site 26 was accidently fertilized by the farmer during operations on non-plot areas of the field. A total of seventeen site-years of information remained available for testing the models. Since each plot in each site was sampled and treated separately, this is equivalent to 374 plot years of data.

Table 6. Summary of Data Available for Each of the Cooperator Sites and the Researcher Managed Area.

Site Number and Designation		Year	Data Available: Soil Data: Initial	Mid-season	Final	Leaf and Yield Data: Silking	Silage	Grain
1	DC	1979	x		x	x		x
2	DAR	1979	x		x	x		x
3	WDAR	1979	x	x	x	x	x	x
4	EH	1979	x	x	x	x	x	x
5	RH	1979	x	x	x	x	x	x
6	MON	1979	x	x	x	x		x
7	NNSW	1979	x	x	x	x	x	x
8	NNSWO	1979	x	x	x	x	x	x
11	ZNSO	1979	x	x	x	x		x
12	ZNST	1979	x	x	x	x		x
22	EH80	1980	x	x	x	x	x	x
23	RH	1980	x	x	x	x	x	x
24	RHS	1980	x	x	x	x	x	x
27	NNSW	1980	x		x			x
28	NNSWO	1980	x		x			x
29	ZNSO	1980	x	x	x	x		x
30	ZNST	1980	x	x	x	x		x
Researcher Managed Area		1979	x		x	x		x
		1980	x	x	x	x	x	x

RESULTS AND DISCUSSION

Excellent yields of corn were obtained at most sites in both 1979 and 1980. Since one of the primary goals of this research was to obtain data for corn with potential yields of 12,600 kg/ha, (200 bu/a) and many of the nitrogen rates were based on this value; it was imperative that yields in this range be obtained. The actual yields obtained on individual plots where nitrogen was not limiting averaged 12,200 kg/ha (194 bu/a) with a C.V. of 6.5. An average of 12,700 kg/ha (201 bu/a) was obtained where neither water management or nitrogen proved limiting. Results obtained and models developed at the researcher-managed area will be discussed first followed by an analysis of the testing of these models on the farmer sites.

I. Researcher-Managed Area

Dramatic visual responses to fertilizer nitrogen and soil water matric potential level were noted at this site in both 1979 and 1980. The plants on the plots receiving no broadcast nitrogen applications (some N was added as a result of broadcast and starter phosphorus fertilization with Diammonium Phosphate) yellowed early in the year and showed severe N deficiency symptoms at tasseling. Plants on the plots receiving 200 and 400 kg of broadcast nitrogen/ha showed increased size, dark green color and lush growth. The response over soil water matric potential levels manifested itself predominantly in visual plant size differences with the -35 kPa treatment having the largest plants and the -75 kPa area the smallest. A differential water response by year interaction also seemed evident. The plants were visibly taller and

more lush during the 1979 growing season than during the 1980 season. Since water stress is a function of both atmospheric demand conditions and soil water potential (soil water matric potential was controlled), it was thought this differential response was due to the widely different atmospheric demand conditions that existed in 1979 as compared to 1980. This factor is demonstrated by the data in Table 7.

The pre-season soil nitrate-N concentration on this area was very low (1 ppm). Therefore only 33 kg of residual nitrate-nitrogen/ha in a 120 cm profile was available for plant growth in 1979. Based on fertilizer recommendation procedures used at that time, 320 kg (using a 60 cm sampling depth) of fertilizer nitrogen/ha would be recommended for production of 12,600 kg of corn grain/ha. Maximum treatment yields were achieved with 200 kg of broadcast nitrogen/ha (plus N added with P, see Table 2) where soil water matric potential was maintained at -35 kPa or above. No increase in yield was obtained with increased fertilization at this water level. Increases in yield did occur between the 200 and 400 kg/ha treatments under the -50 and -75 kPa water levels. Since grain nitrogen percentage remained constant or increased as soil moisture potential decreased from -35 to -75 kPa and the total amount of N contained in the grain did not differ significantly across water treatments, it seems unlikely that this yield increase at N levels above 200 kg of added nitrogen/ha (when water was limiting) was due to a reduction in removal of N from the soil or partitioning of N to plant parts (see Table 8). It appears more likely that the increased yield resulted from the greater production of dry matter at the high nitrogen

Table 7. Weather Temperature Data from Official Weather Service Stations in the Area Covered by the Research.

	Location							
	Gettysburg 16 mi. WSW				Pierre Airport			
Time Period	Mean Maximum Temperatures							
	1979		1980		1979		1980	
	°F	°C	°F	°C	°F	°C	°F	°C
JUNE								
1-10	77.6	25.3	78.7	25.9	75.2	24.0	79.8	26.6
11-20	85.0	29.4	82.3	27.9	83.0	28.3	85.3	29.6
21-30	82.4	28.0	91.0	32.8	80.1	26.7	94.8	34.9
JULY								
1-10	87.9	31.1	93.3	34.1	84.6	29.2	94.6	34.8
11-20	82.5	28.1	94.6	34.8	80.5	26.9	95.9	35.5
21-31	85.6	29.8	94.0	34.5	84.0	28.9	94.8	34.9
AUGUST								
1-10	86.8	30.4	90.8	34.4	87.4	30.8	94.2	34.6
11-20	79.4	26.3	86.4	30.2	77.8	25.4	87.4	30.8
21-30	79.4	26.3	83.6	28.7	82.4	28.0	85.1	29.5
JUNE 1 - AUGUST 30	83.0	28.3	88.3	31.3	81.6	27.6	90.2	32.3
	Number of Days Where Max. Temp. Exceeded 35°C (95°F)							
JUNE								
1-10	0		0		0		0	
11-20	2		0		2		0	
21-30	0		3		0		5	
JULY								
1-10	0		4		0		5	
11-20	0		7		0		6	
21-31	1		5		0		6	
AUGUST								
1-10	1		3		1		5	
11-20	0		1		0		2	
21-30	0		0		1		1	
JUNE 1 - AUGUST 30	4		23		4		30	

level where water was limiting (13,600 kg/ha to 14,900 kg/ha) for the 200 and 400 kg/ha treatment under the -75 kPa water level in 1980. Less drymatter production increase was noted between these two nitrogen levels under the -35 kPa water treatment. Since the total N contained in this drymatter did not differ significantly across water treatment, it is evident that the higher water potential levels made more efficient use of similar amounts of nitrogen for the production of drymatter. This larger "factory" subsequently led to higher yields. Since cell elongation is one of the first physiological functions interrupted by water stress, it appears that mild to moderate water stress occurred across these soil moisture levels.

Differences were not as evident in 1979 partially due to natural rainfall relieving water stress on limited water treatments. More important was the substantial difference in atmospheric conditions that existed between the 1979 and 1980 growing season.

In both years it was evident that excellent yields could be obtained while simultaneously reducing residual soil nitrate ion concentrations to a level that will minimize overwinter losses. The 200 kg/ha nitrogen treatment provided maximum or near maximum yields on the researcher-managed area and resulted in a carryover nitrate-N concentration of only 1-2 ppm in 1979 and 2-4 ppm in 1980. The effects of both water and nitrogen levels will be discussed in more detail later.

One of the primary reasons for establishing this research area with the varying soil water potential treatments was to determine what effect the range of soil moisture potentials most appropriate for corn

production in this area would have on the amount of nitrogen supplied for crop production through the process of mineralization. As stated before, environmental conditions partially eliminated 1979 differences. The 1980 growing season, however, was characterized by limited rainfall and high evaporative demand conditions. Soil water matric potential remained in the desired range throughout the year. In 1980, the zero additional N treatments averaged 76, 75, and 75 kg of total N content in the plants/ha at physiological maturity for the -35, -50 and -75 kPa water treatments respectively. Using nitrogen balance techniques, values for total nitrogen mineralized from the end of the 1979 season to the end of the 1980 season were 65, 64 and 64 kg/ha (11 kg of N/ha was applied as a starter in 1980). The nitrogen balance techniques used in this study were not as accurate as methods employing the use of ^{15}N isotope depleted or enriched materials. It appears from this data and the response to nitrogen additions shown here (Table 8) that relatively large amounts of nitrogen were not being mineralized in this environment. The area was chosen on the basis that it should, theoretically, have high mineralization potential as compared to soils that had been farmed for longer periods of time. Since the techniques used allowed measurement of only <u>net</u> mineralization, which is the combined result of mineralization and nitrogen immobilization, both processes may have increased substantially through irrigation and the active growth of the corn plants. Support for this hypothesis will be presented later since an understanding of the plant's response to soil water matric potential and fertilizer rate in this environment is a

Table 8A. Response of Selected Parameters to Nitrogen and Soil Water Matric Potential at the Research Area.

Yield Parameters					
Year	Soil Water Matric Potential (kPa)	Broadcast Fertilizer Nitrogen (kilograms/hectare) 0	100	200	400
		Grain Yield in kg/ha @ 14% Moisture			
1979	-35	7,500	11,800	13,500	13,500
	-50	8,200	11,900	12,600	13,300
	-75	8,300	11,600	11.700	12,600
1980	-35	6,700	10,500	12,000	11,600
	-50	6,000	10,300	11,000	11,100
	-75	6,200	8,900	9,000	9,400
		Grain Yield Expressed as a Percent of the Maximum Nitrogen Treatment Mean Under Each Water Level			
1979	-35	55	87	100	99
	-50	61	89	95	100
	-75	65	92	93	100
1980	-35	56	87	100	97
	-50	54	93	99	100
	-75	66	94	96	100
		Grain Yield Expressed as a Percent of the Maximum Water-Nitrogen Treatment Mean in Each Year			
1979	-35	55	87	100	99
	-50	61	88	93	99
	-75	61	86	86	93
1980	-35	56	87	100	97
	-50	50	86	92	93
	-75	52	74	75	78

Table 8B. Response of Selected Parameters to Nitrogen and Soil Water Matric Potential at the Research Area

Plant Tissue Nitrogen Content					
Leaf Nitrogen Content at Silking (%)					
1979	-35	1.49	2.37	2.70	2.78
	-50	1.67	2.63	2.78	2.94
	-75	1.94	2.68	2.80	2.94
1980	-35	1.86	2.20	2.86	2.97
	-50	1.89	2.56	2.90	2.99
	-75	1.75	2.48	2.75	2.92
Grain Nitrogen Content (%)					
1979	-35	0.88	1.07	1.37	1.35
	-50	1.03	1.30	1.52	1.56
	-75	1.05	1.41	1.58	1.58
1980	-35	1.11	1.37	1.38	1.45
	-50	1.10	1.37	1.49	1.47
	-75	1.14	1.57	1.68	1.76
Leaf Nitrogen at the 6-8 leaf stage (%) (sampled July 3, 1980)					
1980	-35	2.17	3.24	3.63	3.82
	-50	1.91	3.06	3.36	3.34
	-75	1.89	3.22	3.37	3.57

Table 8C. Response of Selected Parameters to Nitrogen and Soil Water Matric Potential at the Research Area.

Soil Nitrate-Nitrogen

Year	Soil Water Matric Potential (kPa)	Broadcast Fertilizer Nitrogen: 0, Sampling Depth 0-60	0: 0-120	100: 0-60	100: 0-120	200: 0-60	200: 0-120	400: 0-60	400: 0-120
Preseason Nitrate-N (kg/ha)									
1979	All	17	33	17	33	17	33	17	33
1980	-35	21	38	23	39	49	88	120	238
	-50	19	36	23	38	74	90	263	290
	-75	30	45	25	41	42	58	241	286
Final Nitrate-N (kg/ha)									
1979	-35	17	33	17	33	17	38	88	227
	-50	17	33	17	33	28	44	249	282
	-75	17	33	17	33	19	39	235	254
1980	-35	17	33	19	41	34	87	148	341
	-50	17	33	18	33	101	138	339	463
	-75	17	33	17	33	120	143	404	490
Early Midseason (6-8 leaf stage) Nitrate-N (kg/ha)									
1980	-35	24	48	40	94	114	212	433	570
	-50	18	34	45	63	195	216	303	362
	-75	23	40	81	102	178	243	329	406
Nitrate-N at Silking (kg/ha)									
1980	-35	18	34	17	42	41	126	260	476
	-50	17	33	20	39	141	184	413	537
	-75	17	33	26	44	162	188	453	571

prerequisite to this discussion.

Water stress, as experienced by the plant, is a function of both soil moisture parameters and atmospheric demand. The area of central South Dakota where this research took place can have periods of very high temperatures and low humidities during the growing season. These conditions, when coupled with strong winds, can produce large atmospheric demands for periods of several weeks. The 1980 growing season had several of these periods. The data in Table 9 demonstrates the amount of consumptive use encountered during that season. The water applied figure represents net applications measured at canopy height. In the case of the research managed area, all water applications were made at night under low wind conditions. The total consumptive use values were obtained by soil water balance methods. These two sites were chosen for analysis since the systems used to water them had sufficient capacity to maintain the plants in a "well watered" condition during this period of time.

Periods as long as two weeks with atmospheric demand large enough to cause average consumptive use of 1.2 cm/da will cause water stress in plants at soil moisture potentials where no stress would occur under less erosive conditions. The -35 kPa treatment resulted in the highest yields in both 1979 and 1980 when nitrogen was not limiting (see Table 8).

Since the effects of nitrogen level and water matric potential are additive, it is difficult to assess water use efficiency and economic returns of a water treatment without also considering nitrogen level.

At the 200 kg/ha level of added nitrogen, the -35, -50 and -75 kPa water treatments produced equal water use efficiencies in 1979 (Table 10). At the 400 kg/ha level of nitrogen the -50 kPa treatment produced slightly better water efficiencies than the -35 kPa treatment. Results from the -75 kPa treatment indicate that it produced slightly higher water use efficiencies than the other treatments in 1979 and lower efficiencies in 1980 at the high nitrogen level. This phenomenon results from the difference in atmospheric demand that existed between these two growing seasons. The absence of long periods of erosive conditions minimized the effects of the -75 kPa water treatment in 1979. The high demand conditions in 1980 caused more severe water stress and a lower water use efficiency at this soil water matric potential level. Fertilizer N use efficiencies are presented in Table 11.

The irrigator is most interested in maximum economic return to his investment. The increased rates of nitrogen required to produce maximum yields at the -50 and -75 kPa water levels represent an increased investment in both energy and production costs. The investment in equipment, land and other fixed costs remain the same over all water treatments. These costs must, however, be spread over less yield where the -50 and -75 kPa treatments are concerned. Table 10 shows the water use efficiencies obtained and a sample economic return analysis for the water levels under the 200 kg nitrogen/ha treatment. The pumping cost, production cost and commodity price figures are based on actual costs and prices obtained from one of the farmer-cooperators in this study.

Table 9. Consumptive Water Use Experienced Under the Erosive Conditions of the 1980 Growing Season.

Site	Time Period	Total Consumptive Water Use* (cm)	Average Consumptive Water Use (cm/da)
RHS	July 1 - July 18	21.1	1.2
	July 1 - August 5	33.0	1.0
Researcher Area (-35 kPa treatment)	July 1 - July 18	20.3	1.2
	July 1 - August 5	32.3	0.9

*Total consumptive use figures calculated using water balance methods. (Water applications were measured at crop canopy height).

Table 10. Water Use Efficiency and Economic Analysis of Water Treatments

Soil Water Matric Potential	Year	Yield* (Bu/A)	Total Water Rainfall & Irrigation (inches)	(mm)	Water Use Efficiency (Bu/A in)	(kg/ha/mm)	Unit Cost* ($/Bu)	Profit* ($/A)
-35 kPa	1979	214	24.5	620	8.7	21.5	1.86	244
	1980	190	29.9	760	6.4	15.8	2.21	150
-50 kPa	1979	201	23.2	590	8.7	21.5	1.95	211
	1980	175	26.5	670	6.6	16.3	2.32	119
-75 kPa	1979	186	21.4	540	8.7	21.5	2.07	173
	1980	143	24.5	620	5.8	14.3	2.78	31

*Figures above calculated using yields from the 200 kg/ha nitrogen treatment:

Non-water related production costs = $300/acre
Pumping costs = $4.00/acre-inch
Corn price = $3.00/bushel

(English units of measure were used to enhance the data's relevance for users)

Table 11. Fertilizer Nitrogen Efficiency as Affected by Water Level and Nitrogen Rate on a Soil Testing Low in Nitrate.

Year	Matric Potential (kPa)	0	100	200	400
		Fertilizer N Efficiency = kg of corn grain / kg of fertilizer applied.			
1979	-35	219	88	58	31
	-50	239	89	54	31
	-75	243	86	50	30
1980	-35	605	94	56	28
	-50	541	92	52	27
	-75	562	80	42	23
		Net Nitrogen Efficiency = kg of corn grain / Initial Total N - Residual N			
1979	-35	110	70	51	52
	-50	121	70	49	72
	-75	118	69	45	88
1980	-35	231	90	55	48
	-50	198	80	66	67
	-75	171	68	71	53

The irrigator is also concerned in establishing a management program that will provide consistent results over varied weather conditions. This is especially true in the case of center pivot operators since (due to the engineering and water application characteristics of these systems) it is impossible to apply large quantities of water during short periods of time. An irrigator using center pivots cannot maintain his soil at a low soil moisture potential, (say -75 kPa) then quickly add sufficient amounts of water to maximize yields if rainfall doesn't precede periods of high atmospheric demand. The inability to predict the occurrence and duration of these erosive periods further complicates the farmer's decision.

Models were developed using multiple regression techniques to describe the effects of nitrogen and soil water matric potential levels on corn grain yields, leaf nitrogen content at silking and corn grain nitrogen at the researcher site. Since the researcher-managed area was low and very uniform in soil nitrate-nitrogen (1 ppm) in 1979 and had residual nitrates under the high rates in 1980, this factor was included with the fertilizer added to form a variable TotalN14 that includes all nitrogen fertilizer additions plus the nitrate-N in a 120 cm (4 ft) profile. Since soil nitrate-N was included in the variable TotalN14 it will have a base value of 32.5 kg/ha due to the 1 ppm lower limit of the test used for nitrate-N determination. Similarly, the soil water matric potential will have a base value of -35 kPa. Stepwise multiple regression techniques were used to determine significant main effects. Variables tested for contribution to yield variation included: multiple

powers of TotalN14 (Fertilizer N + soil nitrate N to 120 cm); powers of Potential (soil water matric potential); Season - a dummy variable to allow for seasonal atmospheric differences - 1979 = 0, 1980 = 1. Following determination of main effects, all possible interactions were tested for significance. Residual analysis was performed on all models to test for appropriateness of fit. Predicted parameters and actual values were also graphically compared.

Several models were developed to predict the response of each parameter to various combinations of independent variables: i.e., grain yield is described based on nitrogen parameters only (TotalN14), based on nitrogen parameters and soil water matric potential, and using nitrogen parameters and matric potential levels as affected by growing season. The same procedure was repeated for percent attainment of maximum treatment yield, leaf nitrogen content, and grain nitrogen content. These models are shown on Table 12 through Table 15. Each model shown is significant at the .0001 level. The significance of each independent term is shown on the table.

The nitrogen only model does an acceptable job of describing the response of corn grain yields to nitrogen that could be expected for irrigated corn grown under specified conditions (capable of producing maximum potential yields of 12,600 kg/ha) (Table 12). This range of conditions may include various atmospheric demand-soil water matric potential combinations depending on the geographical area in which it is applied.

A substantial increase in R^2 (0.725 to 0.762) is obtained by

Table 12. Models Developed for the Prediction of Grain Yield from Soil Parameters

Grain Yield expressed in kilograms per hectare

INDEPENDENT VARIABLE	MODEL 1 Factor	MODEL 1 Prob.	MODEL 2 Factor	MODEL 2 Prob.	MODEL 3 Factor	MODEL 3 Prob.	MODEL 4 Factor	MODEL 4 Prob.
Intercept	3300		4800		6000		4400	
TotalN14	56.1	.0001	56.6	.0001	51.6	.0001	56.9	.0001
$TotalN14^2$	$-1.06x10^{-1}$	.0001	$-1.08x10^{-1}$	.0001	$-9.83x10^{-2}$	.0001	$-1.1x10^{-1}$	.0001
$TotalN14^3$	$5.88x10^{-5}$	.0001	$6.04x10^{-5}$	.0001	$5.68x10^{-5}$	.0001	$6.9x10^{-5}$	.0001
Potential			28.2	.0003	28.5	.0001	16.0	.01
Season					-1250	.0001	-	-
Season*Potential*TotalN14							8.5×10^{-2}	.0001
Prob. of F associated with the model	.0001		.0001		.0001		.0001	
R^2 of the model	.725		.762		.821		.849	

TotalN14 = fertilizer nitrogen + soil nitrate-nitrogen in a 120 cm profile (spring sampling) (kilograms/hectare)

Potential = soil water matric potential as measured with tensiometers. (kiloPascals)

Season - Dummy variable 1979 = 0 1980 = 1

Table 13. Models for Prediction of Percent Attainment of Maximum Yield Utilizing Soil Parameters.

INDEPENDENT VARIABLE	MODEL 1 Factor	MODEL 1 Prob.	MODEL 2 Factor	MODEL 2 Prob.
Intercept	33.7		11.5	
TotalN14	0.42	.0001	0.56	.0001
$TotalN14^2$	$-8.3x10^{-4}$	.0001	$-1.0x10^{-3}$	.0001
$TotalN14^3$	$5.1x10^{-7}$	.0001	$5.1x10^{-7}$	.0001
Potential			-.42	.004
Potential*TotalN14			$2.7x10^{-3}$	.005
$Potential*(TotalN14)^2$			$-3.2x10^{-6}$	.07
Prob. of F associated with the model	.0001		.0001	
R^2 of the model	.779		.800	

TotalN14 = fertilizer nitrogen + soil nitrate-nitrogen in a 120 cm profile (spring sampling) (kilograms/hectare)

Potential - soil water matric potential (kPa)

Table 14. Models for Prediction of Leaf Nitrogen Contents at Silking from Soil Parameters

Leaf Nitrogen Content in %

INDEPENDENT VARIABLE	MODEL 1 Factor	MODEL 1 Prob.	MODEL 2 Factor	MODEL 2 Prob.	MODEL 3 Factor	MODEL 3 Prob.	MODEL 4 Factor	MODEL 4 Prob.
Intercept	1.15		1.00		0.84		0.85	
TotalN14	9.85×10^{-3}	.0001	9.79×10^{-3}	.0001	1.05×10^{-2}	.0001	1.07×10^{-2}	.0001
$TotalN14^2$	-1.76×10^{-5}	.0001	-1.74×10^{-5}	.0001	-1.87×10^{-5}	.0001	-1.93×10^{-5}	.0001
$TotalN14^3$	1×10^{-8}	.0001	1×10^{-8}	.0001	1×10^{-8}	.0001	1×10^{-8}	.0001
Potential			2.78×10^{-3}	.08	-2.80×10^{-3}	.07	-1.8×10^{-3}	.3
Season					.18	.002	-	-
Season*Potential*TotalN14							9.1×10^{-6}	.08
Prob. of F associated with the model	.0001		.0001		.0001		.0001	
R^2 of the model	.747		.755		.781		.777	

TotalN14 = fertilizer nitrogen + soil nitrate-nitrogen in a 120 cm profile (spring sampling) (kilograms/hectare)

Potential = soil water matric potential as measured with tensiometers. (kiloPascals)

Season - Dummy variable 1979 = 0 1980 = 1

Table 15. Models for Prediction of Grain Nitrogen Content from Soil Parameters

Grain Nitrogen Content in %

INDEPENDENT VARIABLE	MODEL 1 Factor	MODEL 1 Prob.	MODEL 2 Factor	MODEL 2 Prob.	MODEL 3 Factor	MODEL 3 Prob.	MODEL 4 Factor	MODEL 4 Prob.
Intercept	0.84		0.57		0.41		0.61	
TotalN14	3.79×10^{-2}	.0001	3.69×10^{-2}	.0001	4.38×10^{-3}	.0001	4.10×10^{-3}	.0001
$TotalN14^2$	-6.6×10^{-6}	.0001	-6.3×10^{-6}	.0001	7.6×10^{-5}	.0001	8.2×10^{-6}	.0001
$TotalN14^3$	6.8×10^{-9}	.01	6.8×10^{-9}	.004	6.8×10^{-9}	.0005	6.8×10^{-9}	.0001
Potential			-5.0×10^{-3}	.0001	-5.0×10^{-3}	.0001	3.7×10^{-4}	.8
Season					1.6×10^{-1}	.0001	-	-
Potential*Season							-4.6×10^{-3}	.0001
Potential*TotalN14							-1.1×10^{-5}	.0004
Season*Potential*TotalN14							6.5×10^{-6}	.01
Prob. of F associated with the model	.0001		.0001		.0001		.0001	
R^2 of the model	.554		.674		.785		.803	

TotalN14 = fertilizer nitrogen + soil nitrate-nitrogen in a 120 cm profile (spring sampling) (kilograms/hectare)

Potential = soil water matric potential as measured with tensiometers. (kiloPascals)

Season - Dummy variable 1979 = 0 1980 = 1

including matric potential parameters in the model. The inclusion of this parameter makes the model more specific for the climatic conditions under which it was developed. Figure 1A shows the three dimensional response surface generated by Model 2. Figure 1B shows the model in conventional format.

Inclusion of the dummy variable Season increases the R^2 to 0.821 (the 1979 season = 0, 1980 = 1). Further improvement (to R^2 = .849) is achieved by replacing Season by the interaction term Season*Potential* Total N14. The last two models do not improve the ability to predict behavior in future years. They do, however, support the belief that yield response to nitrogen and soil moisture potential is dependent on atmospheric conditions. More extensive studies would be required before these interactions could be fully described.

Models were also developed to describe yield on the basis of the percent attainment of maximum yield under each water treatment; i.e., the nitrogen treatment expressing maximum yield under each water treatment was assigned a relative yield value of 100 percent. Each water-nitrogen treatment was assigned a PctMaxT value based on the relationship between its yield and the maximum yield under the same water treatment (see Table 8A). This approach eliminates expression of the direct effects of soil water matric potential on yield and allows evaluation of the interaction between nitrogen treatment and water stress. The two models developed for prediction of PctMaxT are shown on Table 13. Figure 2A depicts the second model in three-dimensional form. This diagram clearly demonstrates the interactions that take place. These will be discussed in more detail later.

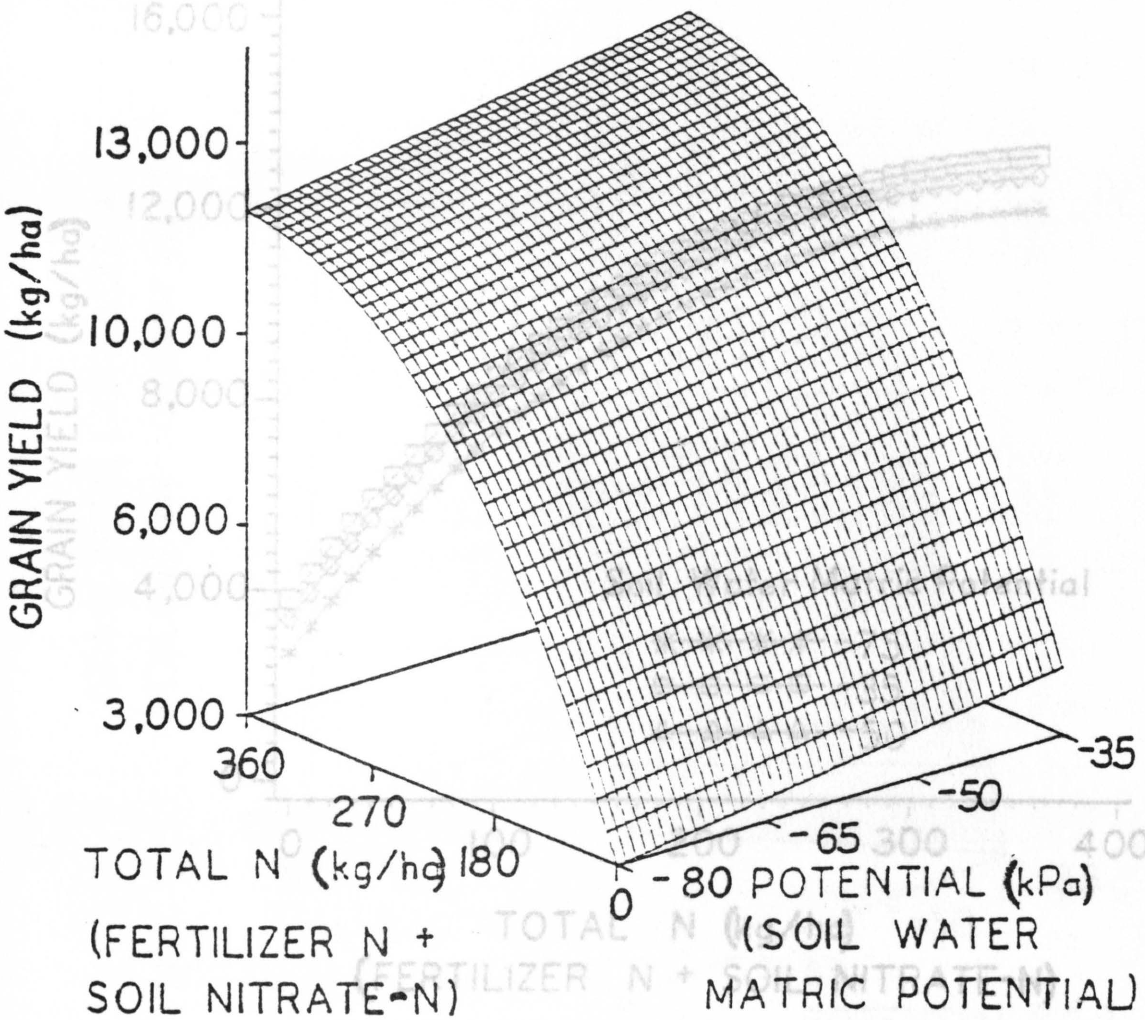

Figure 1A: Response of Grain Yield to Total N and Soil Water Matric Potential as Predicted by Model 2 on Table 12 (three dimensional response surface).

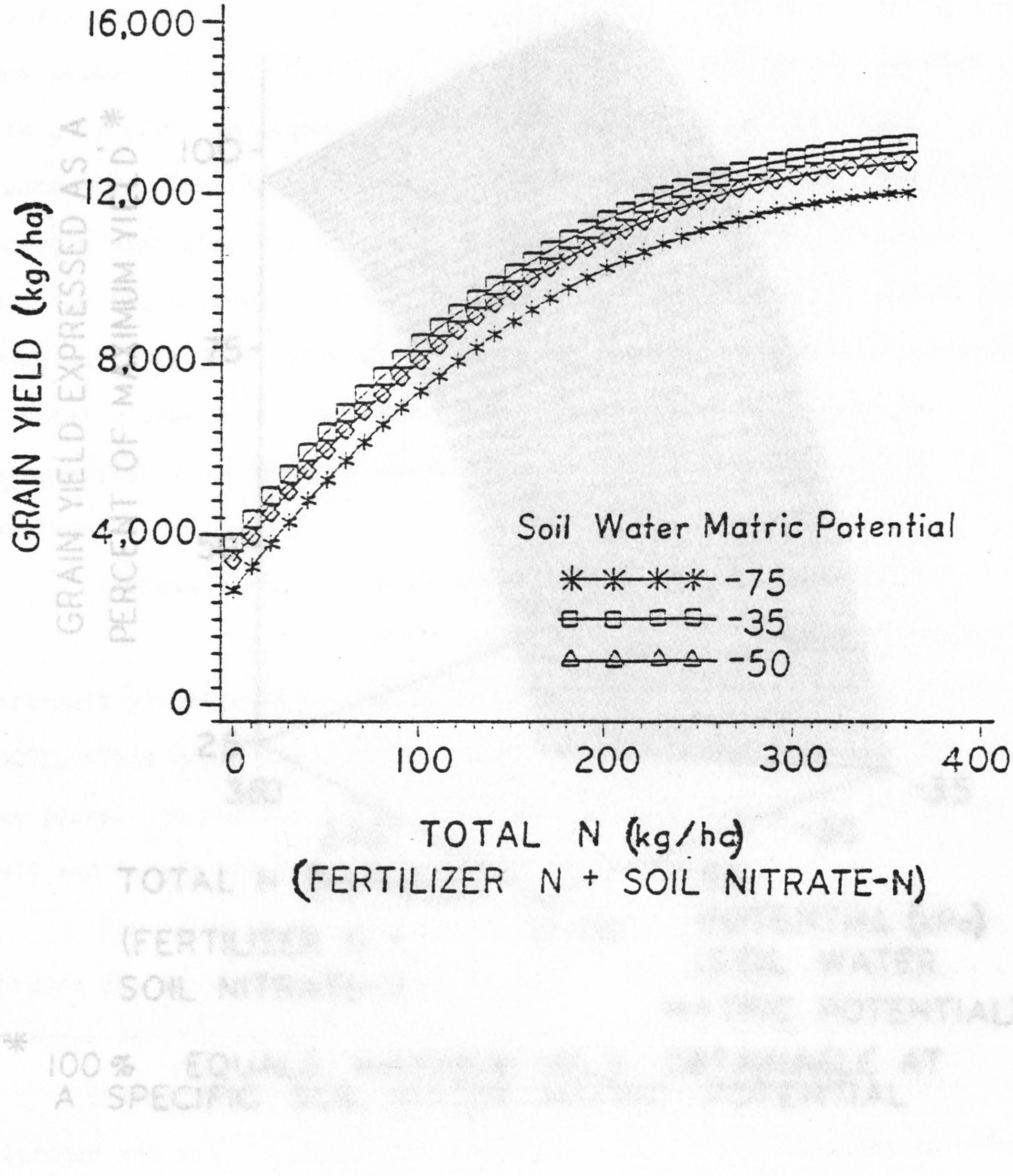

Figure 1B: Response of Grain Yield to Total N and Soil Water Matric Potential as Predicted by Model 2 on Table 12 (conventional representation).

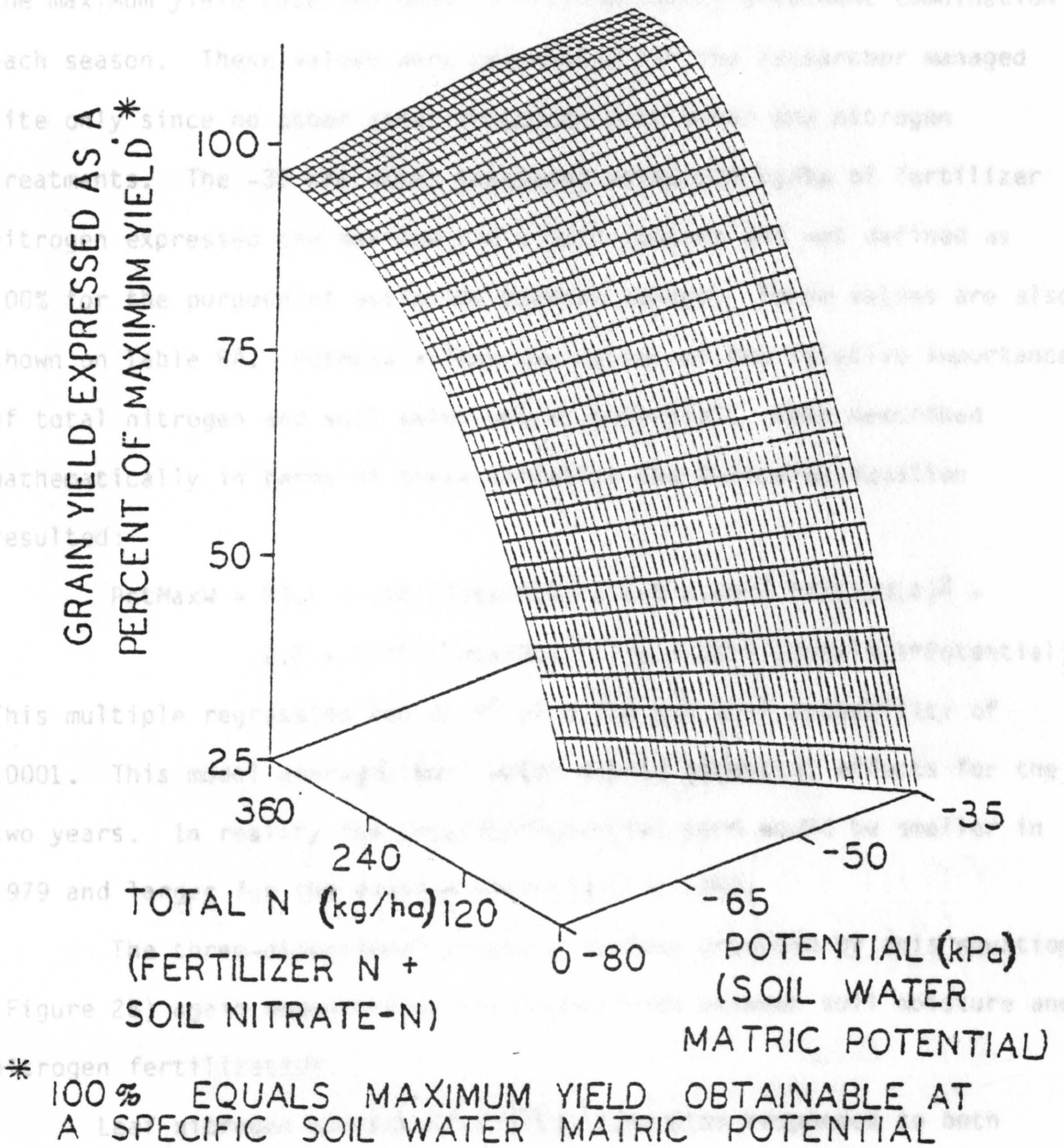

Figure 2A: Response of PctMaxT to Total N and Soil Water Matric Potential as Predicted by Model 2 on Table 13.

A variable PctMaxW was defined to be the percent attainment of the maximum yield observed under a nitrogen-water treatment combination each season. These values were calculated for the researcher managed site only since no other sites contained both water and nitrogen treatments. The -35 kPa water treatment using 200 kg/ha of fertilizer nitrogen expressed the maximum yield both seasons and was defined as 100% for the purpose of assigning PctMaxW values. These values are also shown on Table 8A. PctMaxW allows evaluation of the relative importance of total nitrogen and soil water matric potential. When described mathematically in terms of these variables the following equation resulted:

$$\text{PctMaxW} = 23.1 + .64\ (\text{TotalN14}) - 1.5 \times 10^{-3}\ (\text{TotalN14})^2 + 1.2 \times 10^{-6}\ (\text{TotalN14})^3 + 1 \times 10^{-3}\ (\text{TotalN14*Potential})$$

This multiple regression had an R^2 of 0.748 and an F probability of .0001. This model averages soil water matric potential effects for the two years. In reality the TotalN14*Potential term would be smaller in 1979 and larger for the erosive conditions of 1980.

The three-dimensional response surface produced by this equation (Figure 2B) again demonstrates the interaction between soil moisture and nitrogen fertilization.

Leaf nitrogen content at silking time also responded to both nitrogen and soil moisture potential (see Table 14). Nitrogen additions on this soil increased nitrogen content of the leaves substantially. The leaf N also increased as soil water matric potential decreased. The decreased dry matter accumulation as a response to water stress, coupled with the lack of response that is shown by total N uptake to water

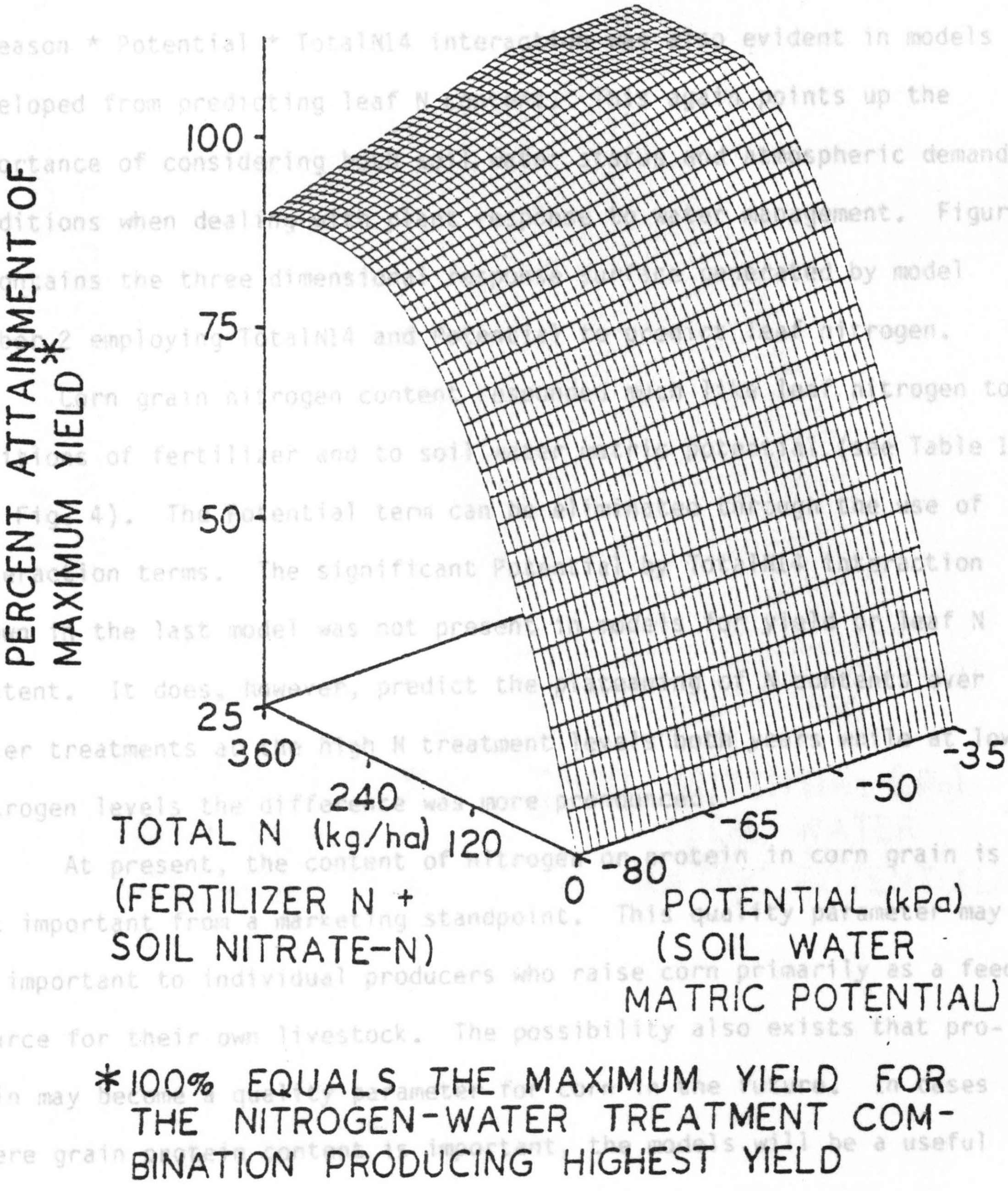

Figure 2B: Response of PctMaxW to Total N and Soil Water Matric Potential as Predicted by the Model on Page 64.

treatments supports this phenomena. A significant effect to Season and a Season * Potential * TotalN14 interaction was also evident in models developed from predicting leaf N content. This again points up the importance of considering both soil water status and atmospheric demand conditions when dealing with plant response to water management. Figure 3 contains the three dimensional response surface generated by model number 2 employing TotalN14 and Potential to predict leaf nitrogen.

Corn grain nitrogen content responded much like leaf nitrogen to additions of fertilizer and to soil water matric potential (see Table 15 and Fig. 4). The Potential term can be eliminated through the use of interaction terms. The significant Potential by TotalN14 interaction shown in the last model was not present in models for yield or leaf N content. It does, however, predict the plateauing of N contents over water treatments at the high N treatment levels both years while at low nitrogen levels the difference was more pronounced.

At present, the content of nitrogen or protein in corn grain is not important from a marketing standpoint. This quality parameter may be important to individual producers who raise corn primarily as a feed source for their own livestock. The possibility also exists that protein may become a quality parameter for corn in the future. In cases where grain protein content is important, the models will be a useful management tool for producers.

The most important practical function associated with leaf nitrogen content is its use as a predictor of nitrogen sufficiency levels. Similarly, there has been substantial interest recently in using grain N

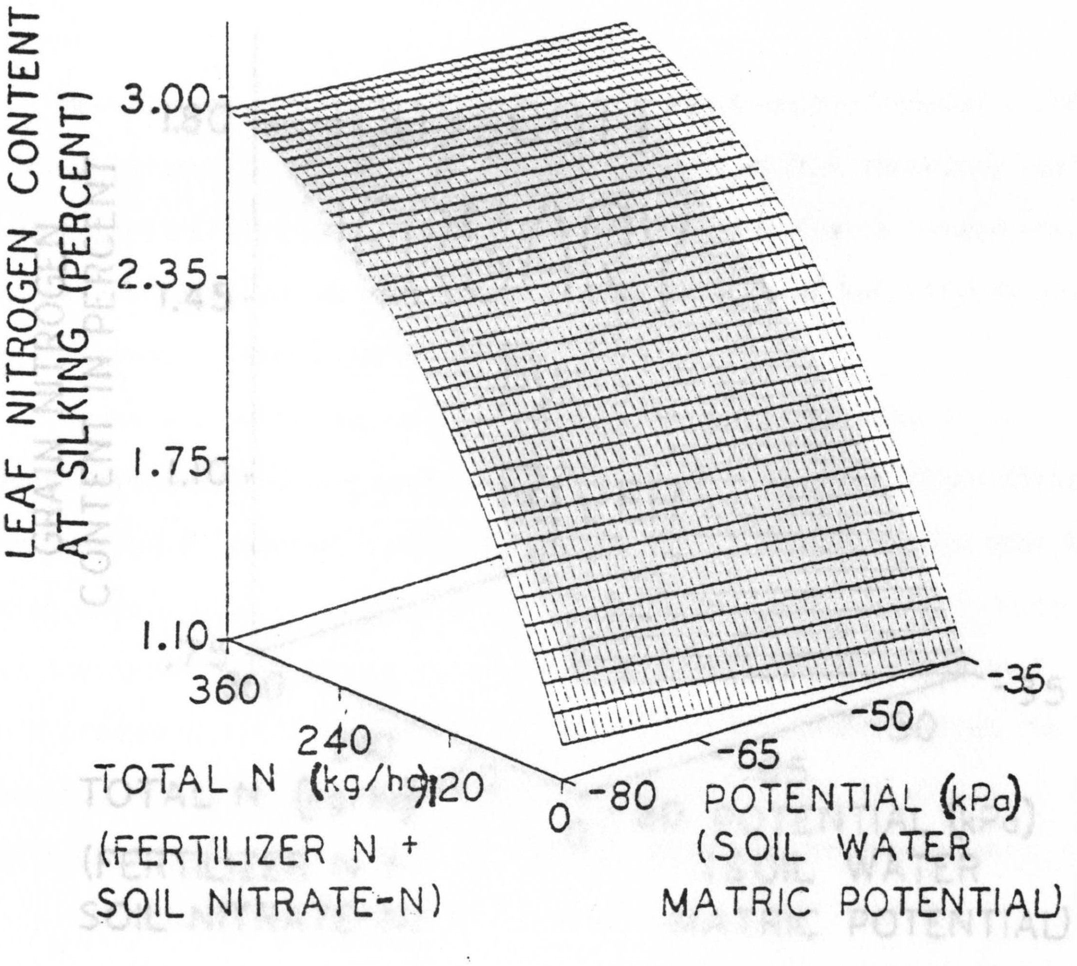

Figure 3: Response of Leaf Nitrogen Content to Total N and Soil Water Matric Potential as Predicted by Model 2 on Table 14.

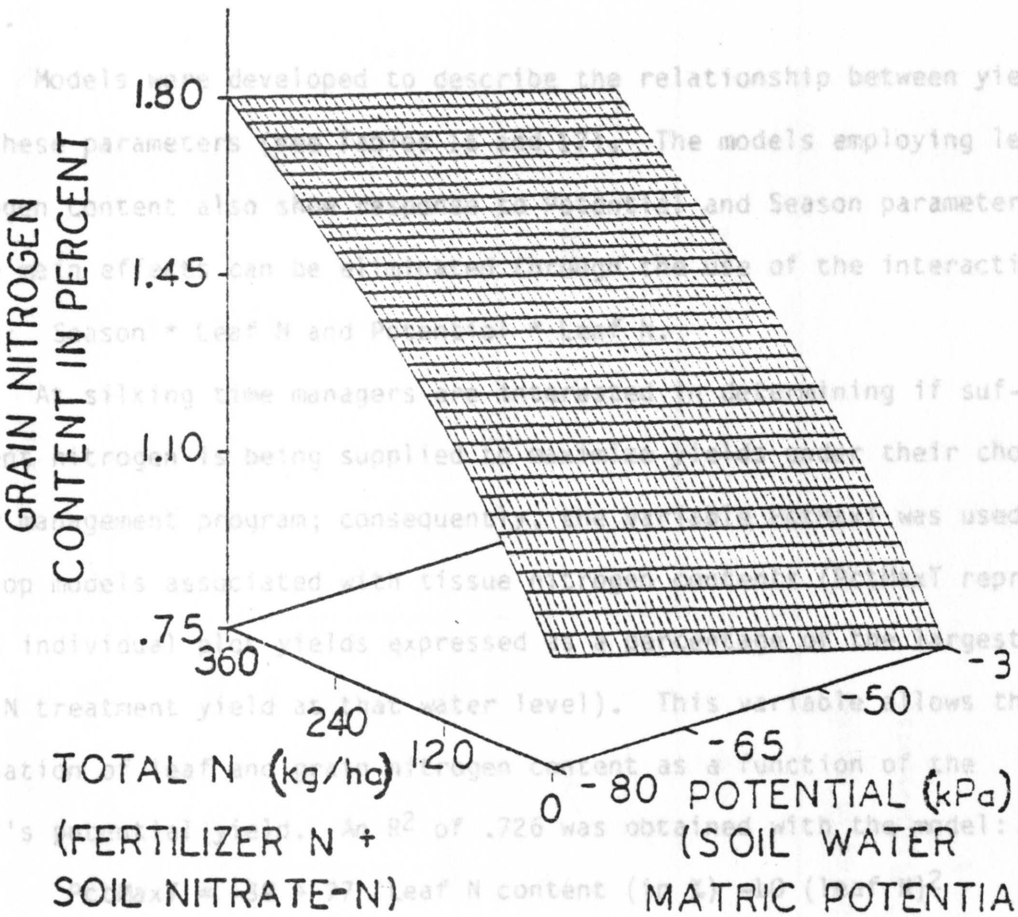

Figure 4: Response of Grain Nitrogen Content to Total N and Soil Water Matric Potential as Predicted by Model 2 on Table 15.

levels as an indicator capable of determining if sufficient amounts of nitrogen were present while the crop was being grown (Pierre,et al. 1977).

Models were developed to describe the relationship between yield and these parameters (see Tables 16 and 17). The models employing leaf nitrogen content also show response to Potential and Season parameters. These main effects can be eliminated through the use of the interaction terms: Season * Leaf N and Potential * Leaf N.

At silking time managers are interested in determining if sufficient nitrogen is being supplied to maximize yields under their chosen water management program; consequently, the variable PctMaxT was used to develop models associated with tissue nitrogen contents (PctMaxT represents individual plot yields expressed as a percentage of the largest mean N treatment yield at that water level). This variable allows the evaluation of leaf and grain nitrogen content as a function of the plant's potential yield. An R^2 of .726 was obtained with the model:

$$\text{PctMaxT} = -39 + 77 \text{ Leaf N content (in \%)} - 10 \text{ (leaf N)}^2$$

This model indicated that sufficient nitrogen has been supplied to produce at least 90% of the potential yield if leaf nitrogen content equals or exceeds 2.7% at silking (specifically 93%). The soil water matric potential was not significant in any models developed to predict PctMaxT from leaf N at silking.

Models developed to predict PctMaxT from grain N levels include several other parameters (see Table 17). The fact that these models contain soil water potential and season is not surprising when viewed in

Table 16. Models for Prediction of Yield Parameters from Leaf Nitrogen Content at Silking.

INDEPENDENT VARIABLE	PREDICTION OF ACTUAL YIELD (kg/ha) MODEL 1 Factor	Prob.	MODEL 2 Factor	Prob.	PREDICTION OF PERCENT ATTAINMENT OF MAXIMUM YIELD MODEL 1 Factor	Prob.
Intercept	-3000	.0001	-6200		-39	
Leaf N	9600	.03	10,800	.0001	77	.0001
$(\text{Leaf N})^2$	-1300	.0001	-1100	.009	-10	.005
Potential	39		-40	.23		
Potential*Leaf N			32	.02		
Season*Leaf N			-860	.0001		
Prob. of F associated with the model	.0001		.0001		.0001	
R^2 of the model	.611		.818		.726	

Leaf N - Leaf nitrogen content at tasseling in percent.

Potential - Soil water matric potential (kiloPascals).

Season - Dummy variable 1979 = 0, 1980 = 1.

Table 17. Models for Prediction of Yield Parameters from Grain Nitrogen Content

INDEPENDENT VARIABLE	PREDICTION OF ACTUAL YIELD (kg/ha) MODEL 1		MODEL 2		PREDICTION OF PERCENT ATTAINMENT OF MAXIMUM YIELD MODEL 1		MODEL 2		MODEL 2	
	Factor	Prob.	Factor	Prob.	Factor	Prob.	Factor	Prob.	Factor	Prob.
Intercept	-13,700		-17,100		-130		-105		-150	
Grain N	34,700	.0001	40,000	.0001	269	.0001	246	.0001	328	.0001
$(\text{Grain N})^2$	-10,700	.0004	-12,600	.0001	-81	.0001	-70	.0001	-105	.0001
Potential	49	.0001	30	.0002			.18	.01	-13	.05
Potential*Season			108	.0002					.87	.0002
Potential*Grain N*Season			-41	.03					-.55	.0008
Prob. of F associated with the model	.0001		.0001		.0001		.0001		.0001	
R^2 of the model	.460		.791		.648		.671		.728	

Grain N - Grain nitrogen content in percent.

Potential - Soil water matric potential (kiloPascals).

Season - Dummy variable 1979 = 0, 1980 = 1.

the perspective of the yield data. Higher levels of soil and/or fertilizer nitrogen were required to maximize yield at the -50 and -75 kPa water treatment than at the -35 kPa level. As stated before, total N uptake did not vary across treatments leading to the expectation of higher grain N levels to be required for maximum potential yields to be achieved under reduced soil water matric potential conditions.

The models developed for prediction of PctMaxT from grain nitrogen contents are both similar and different from the relationships reported by Pierre et al. (1977). These researchers and the regression procedures used to develop Model 1 (Table 17) found best fit using a quadratic function of grain nitrogen content to predict percent attainment of maximum yield. Their equation: PctMaxT = -489.9 + 758.3 grain N - 243.6 (grain N)^2, however, predicts a relative yield of only 24% at grain N contents of 1.0%. Model 1 predicts 58% relative yield at grain N of 1.0%. The data from the researcher managed area shows relative yields of 55, 61, and 65% for grain N contents of 0.88, 1.03, and 1.05% in 1979 and 56, 54, and 66% for grain N contents of 1.11, 1.10, and 1.14% in 1980 for the check nitrogen treatments maintained at soil water matric potentials of -35, -50, and -75 kPa respectively (Tables 8A and 8B). This data and Model 1 (Table 17) indicate that lower grain N contents are associated with attainment of maximum yields than would be predicted by Pierre et al. The grain N content present when 100% of potential yield was attained at the researcher site differed substantially over the range of soil water matric potentials used. This factor is demonstrated by Model 2 and Model 3 (Table 17). Grain N

contents associated with attainment of 100% potential yield varied directly with the amount of water stress encountered. These models cannot be applied to the data of Pierre et al. since soil moisture and atmospheric demand criteria were not defined. Examination of their data indicates maximum yields of 3,000 to 10,500 kg/ha with a mean maximum yield of 7,100 kg/ha. The data used to develop the models on Table 17 had maximum yields ranging from 9,400 to 13,500 kg/ha with a mean maximum yield of 11,900 kg/ha. Since their yields were much lower, it is logical to assume that water stress on the sites used by Pierre et al. may have been greater than those encountered at the researcher managed area. If this assumption is true, it follows that higher grain N contents would be expected when maximum yield was attained under their conditions. Pierre et al. had assumed that water stress did not affect the relationship of grain N content to percent attainment of maximum yield. The failure of their equation under the irrigated conditions of this study and the significant effect of water stress related parameters in Model 2 and Model 3 tend to indicate that this assumption was not valid.

Soil nitrate level at silking time was not a significant factor in models developed to predict grain yield or PctMaxT from leaf nitrogen content. Similarly, final soil nitrate-N was not significant in the models using grain nitrogen content. These data should, however, not be ignored as diagnostic tools since low leaf or grain nitrogen content can result from factors other than nitrogen insufficiency in the soil. Concurrent soil sampling procedures should accompany analysis of the

nitrogen content of plant parts to aid in the decision making process.

Corn grain N content and to a certain extent leaf N content at tasseling are post-mortum measures of nitrogen sufficiency. By the time samples are collected and analyzed the growing season has progressed to a point where N additions are of little or no value; therefore, they are not a useful tool for making management decisions for the present season.

The researcher-managed site and one farmer-cooperator site (RHS) were chosen in 1980 to conduct a preliminary study on the feasibility of using early (6-8 leaf stage) leaf samples in conjunction with simultaneous soil nitrate measurements to 120 cm as a means of predicting nitrogen sufficiency. Since the sampling time used immediately preceeds the period of greatest N uptake by the corn plant and follows the period of greatest potential for N losses, this method would allow fine tuning of nitrogen additions as close as possible to its use.

The models developed from this preliminary study are shown on Table 18. Although these models show good predictive capability on this limited data, they should be extensively tested and calibrated.

The ultimate goal of this research was to develop nitrogen-water status models that could be applied to irrigated corn production on farmer-cooperator sites adjoining the Missouri River Reservoir system in central South Dakota. As stated previously, these lands vary greatly in terms of the number of years they have been farmed and/or irrigated. At the inception of this experiment it was felt that soils developed for long periods of time would produce less nitrogen from the process of

Table 18. Model for Prediction of Grain Yield Using Early (6-8 Leaf Stage) Soil and Leaf Samples in 1980.

Yield expressed in kg/ha.

INDEPENDENT VARIABLE	MODEL 1 Factor	MODEL 1 Prob.	MODEL 2 Factor	MODEL 2 Prob.
Intercept	6300		-5700	
Soil N	51.7	.0001	48.5	.0001
$(\text{Soil N})^2$	-0.11	.0001	-0.10	.0001
Potential	53.3	.0001	41.8	.0001
Leaf N	787	.02	9980	.0002
$(\text{Leaf N})^2$	--		-1702	.002
Prob. of F associated with the model	.0001		.0001	
R^2 of the model	.788		.818	

Soil N - Total nitrate-N (kg/ha) to 120 cm at sampling time.

Potential - soil water matric potential (kPa).

Leaf N - nitrogen content in %, (last fully extended leaf).

mineralization than those that had been recently developed. The researcher managed area was chosen on this assumption. If it produced relatively high rates of net mineralization and the farmer-cooperator sites produced much lower values, it was hoped the models could be modified through the use of a rapid nitrogen availability indicator such as the sodium bicarbonate extraction technique. (See appendix D).

As stated before, it became obvious during the performance of this experiment that net mineralization rates were not of the magnitude anticipated on this newly developed site. Nitrogen balance techniques produced net mineralization values of 64 kg/ha (Table 19) for the period from the fall of 1979 to the fall of 1980 under the check rates of nitrogen. The fall of 1979 was chosen as a base to predict mineralization since some mineralization took place between the fall and spring sampling period that year. The fall samples were collected in late fall (mid-October) and the spring 1980 samples were taken very early in the spring (mid-March). The winter of 1979-1980 was very mild which probably contributed to this factor.

There was a definite response trend in the total net mineralization rates obtained over both water level and nitrogen rate during the 1980 season. At the 0 kg/ha rate of added nitrogen net mineralization rates were the same over water treatments. Under the -35 kPa water level, net mineralization rates trended lower with increased fertilization than under the 0 kg/ha rate. The other two water levels showed a decrease in net mineralization between the 0 and 100 kg/ha rate, an increase between the 100 and 200 kg/ha rate, and a decrease between the 200 and 400 kg/ha rate of added fertilizer nitrogen (see Table 19A).

Table 19A. Nitrogen Uptake and Mineralization Data for the 1980 Season at the Researcher Managed Area.

Year	Matric Potential (kPa)	Broadcast Fertilizer Nitrogen (kilograms/hectare) 0	100	200	400
		Total Drymatter Production (kg/ha)			
1980	-35	9,400	15,500	16,300	16,800
	-50	9,600	15,500	15,400	15,800
	-75	10,100	13,500	13,600	14,900
		Drymatter Expressed as a Percentage of the 0 kg/ha N at -35 kPa treatment			
1980	-35	100	165	175	179
	-50	105	165	164	168
	-75	107	144	145	159
		Nitrogen Content at Physiological Maturity (% N)			
1980	-35	.78	.92	1.13	1.24
	-50	.79	.91	1.23	1.35
	-75	.74	.103	1.41	1.43
		Nitrogen Content Expressed as a Percentage of the 0 kg/ha N at -35 kPa treatment			
1980	-35	100	118	145	159
	-50	101	117	159	173
	-75	95	132	181	183
		Total N Contained in Plants (kg/ha)			
1980	-35	75	142	206	208
	-50	74	140	192	213
	-75	75	139	192	213
		Net Mineralization as Determined by Nitrogen Balance Techniques (kg/ha)			
Fall 1979 to Fall 1980	-35	64	40	44	-89
	-50	64	29	74	-17
	-75	64	28	85	38

Table 19B. Nitrogen Uptake and Mineralization Data for the 1980 Season at the Researcher Managed Area.

Year	Matric Potential (kPa)	Broadcast Fertilizer Nitrogen (kilograms/hectare) 0	100	200	400
		Total Stover (kg/ha)			
1980	-35	3,600	6,500	6,000	6,800
	-50	4,400	6,600	5,900	6,300
	-75	4,768	5,800	5,900	6,800
		Nitrogen Percentage of the Stover			
1980	-35	.49	.46	.84	1.14
	-50	.54	.50	1.12	1.39
	-75	.44	.71	1.29	1.24
		N Contained in Stover (kg/ha)			
1980	-35	18	30	51	78
	-50	24	33	67	88
	-75	21	42	76	85
		Estimated Immobilization Based on N Content of Plants and Total Drymatter Produced (kg/ha)			
1980	-35	67	90	67	44
	-50	68	91	41	24
	-75	77	64	12	10
		Estimated Change in Net Mineralization Calculated from Estimated Change in Immobilization (kg/ha)			
1980	-35	0	-23	0	+23
	-50	-1	-24	26	+43
	-75	-10	3	55	+57
		Actual Change in Net Mineralization by N Balance Methods (kg/ha)			
1980	-35	0	-24	-20	-153
	-50	-1	-34	10	-80
	-75	0	-35	21	-26

The results of the N balance calculations present a complex problem that is unsolvable since ^{15}N labeled fertilizer sources were not used. If it is assumed that nitrogen losses from the system due to dentrification, leaching, volatilization, etc. were small and uniform across treatments, N balance differences result from differential stimulation of the separate processes of mineralization and immobilization over the range of water levels and fertilizer rates used. The nitrogen balance calculations listed on Table 19A are for the second year of the study, therefore one year of crop production at differential N and water levels had already occurred. The plant residues from that crop were returned to the soil. One hypothesis for the observed differences in net mineralization is related to the response of plant growth taking place and the nitrogen status of that growth as affected by treatments. The fact that organic materials having nitrogen concentrations in excess of 1.5% generally enhance mineralization rates when added to soil was mentioned in the review of literature. Materials with less than 1.5% N favor the immobilization process. The 1.5% value is arbitrary at best but will be used since no better estimate is available. The N concentration in the plants at physiological maturity was lower than 1.5% in all cases, so the immobilization rate after addition of these residues would be enhanced. In other words, the net mineralization rate would be less than if these residues were removed.

The actual amount of N immobilized by the decomposition of residues is related to the amount of residues decomposed, the level of N in that material, and many other factors that could not be evaluated. Some

estimation procedures will be employed based on the assumption that 1.5% N is the level of nitrogen needed to balance the process. Total dry-matter accumulation and N content for the 1980 crop will be used since these data are not available for the 1979 season. This should cause few problems since this is only an estimation procedure designed to indicate possible trends. The data on Table 19 show total drymatter production in kg/ha and N content in percent for each of the treatments. These values are also expressed on a percentage basis using the value obtained on the plots receiving the 0 kg/ha fertilizer rate under the -35 kPa water level as 100%. These data show that at the 100 kg/ha rate the drymatter produced increased more rapidly on a percentage basis than did the nitrogen content of the drymatter. The -35 kPa and -50 kPa water levels also increased drymatter more rapidly than N content between the 0 and 200 kg/ha of fertilizer N levels while under the other water treatment nitrogen content increased more rapidly than the drymatter production. The relative changes between the 0 kg/ha and 400 kg/ha N rates show the same trend as the changes between the 0 and 200 kg/ha rate for the -35 kPa level, but N content increased more rapidly than drymatter production under the other water levels.

Based on this analysis, a decrease in net mineralization would be expected to occur with increasing N fertilization under the -35 kPa water level. The -50 kPa water treatments would be expected to produce a decrease in net mineralization under the 100 and 200 kg/ha fertilizer rates as compared to the 0 kg/ha rate. The 400 kg/ha fertilizer rate should produce an increase in net mineralization. According to this

scheme the -75 kPa treatment is expected to produce reduced net mineralization at the 100 kg/ha level of fertilization and increased mineralization at the higher rates as compared to the 0 kg/ha treatment. The nitrogen balance data on Table 19 show that trends similar to this occur.

"Estimates" of N immobilized were also made by multiplying the difference between N content of the drymatter and the 1.5% N standard value by the amount of drymatter production. This procedure again serves only a demonstration purpose since the determination of actual values would have required the use of tagged fertilizers. The estimated values show relatively the same trend as the assessment of percent increase values. The exception is that they predict a decrease in immobilization under the high nitrogen treatment for all water levels as compared to the check treatment.

The purpose of these analysis procedures was to demonstrate the interactive effect that the plant response to soil water matric potential and fertilizer rate can have on net mineralization rate. This effect could be manifested during the year of crop growth due to immobilization caused by the decomposition of root exudates and sloughed root material and/or during the subsequent year as a result of incorporation of low nitrogen content plant materials and decomposition of dead root material.

The low N balance values obtained at the 100 kg/ha rate of fertilizer can probably be attributed to the enhancement of immobilization at this insufficient rate of nitrogen. The range in net mineralization

rates over water levels at the 200 kg/ha fertilizer treatment could be the result of this phenomenon and/or losses through leaching and dentrification. The tensiometers located at the 120 cm depth on the researcher-managed area were included to aid the management of water applications to prevent leaching of nitrates and to provide evidence of this loss if heavy rains occurred. These data indicate that significant nitrate movement beyond the 120 cm depth was unlikely. The low net mineralization rates determined by balance techniques at the 400 kg/ha N rate seem to be the result of a combination of the following factors: nitrogen immobilization effects, denitrification losses and/or sampling error associated with high soil nitrate levels. The potential for sampling error and denitrification are especially high under the 400 kg/ha fertilizer rate. Soil nitrate-N ranged from 300 to 460 kg/ha for these plots. Both the high level of substate and the ample amount of energy supplied by plant residues favor denitrification.

Since the amounts of nitrogen added to this system in the form of fertilizers and removed from the system at harvest are large, it was decided to investigate this factor. Prior to being broken from sod, this soil was essentially a closed system with respect to nitrogen. (No large additions or removals of this element occurred.) The combined effects of enhanced plant growth due to irrigation and the additions of nitrogen as fertilizers drastically alter the system as shown on Table 20. Under the 0 kg/ha treatments a net loss to the system occurred in both 1979 and 1980 (more nitrogen was removed in the grain than added with starter and phosphorus fertilizer sources). The 200 and 400 kg/ha

treatment resulted in a net gain in nitrogen for both 1979 and 1980. A portion of this nitrogen could be accounted for as residual nitrate-N in the fall of 1980. There is a certain amount of nitrogen that could not be accounted for over the two years. This N was either immobilized to organic N forms and/or lost from the system through denitrification and/or leaching. The fate of this nitrogen could not be determined without the use of tracer techniques.

Based on the data in tables 19 and 20, it appears that irrigated corn production with proper fertilization may add as much or more organic nitrogen material to these soils as is removed. The large values of "unaccounted for nitrogen" associated with the 400 kg/ha level of fertilization cannot be justified. These levels of fertilization probably led to losses from the system due to the high nitrate concentration in the soil.

The small amount of net change in organic N, if it exists, is very difficult to assess due to the short term nature of this study. Kjeldahl nitrogen and Wakley-Black easily oxidizable organic matter techniques do not possess sufficient sensitivity to detect the small changes anticipated. Sodium bicarbonate extraction techniques are assumed to be more sensitive to changes in readily decomposable organic matter (Stanford 1982) so they were applied to this problem.

Initial and final surface soil samples from the research area were analyzed. The initial soil samples from the researcher area showed an absorbance of .385 in 1979 (Kjeldahl N = .13%). The final samples in 1979 had absorbances of .427, .459, .497 and .487 for the 0, 100, 200

Table 20. Nitrogen Added to or Removed from the System During the Study

Year	Matric Potential (kPa)	Broadcast Fertilizer Nitrogen (kilograms/hectare) 0	100	200	400
		Total Nitrogen Fertilizer Added (kg/ha)			
1979	all	33	133	233	433
1980	all	11	111	211	411
		N Removed from the System in Grain (kg/ha)			
1979	-35	50	83	142	144
	-50	65	129	143	163
	-75	67	117	149	153
1980	-35	57	112	126	130
	-50	50	107	125	125
	-75	54	108	116	128
		N Returned to the Soil as Stover (kg/ha)			
1980	-35	18	30	80	78
	-50	24	33	67	88
	-75	21	42	76	85
		Net Change in the System (kg/ha) (Fertilizer N added - N Removed in Grain)			
1979	-35	-17	50	91	292
	-50	-32	4	84	270
	-75	-34	16	92	260
1980	-35	-46	-1	85	289
	-50	-39	4	86	294
	-75	-43	3	95	297
		Gain in Soil Nitrate-N Over Spring 1979 Values (kg/ha)			
1979	-35	0	0	6	195
	-50	0	0	11	250
	-75	0	0	7	222
1980	-35	0	0	45	309
	-50	0	0	105	431
	-75	0	0	111	458
		Total Nitrogen Not Accounted For (kg/ha) (Lost from the system or immobilized in organic N)			
	-35	-63	40	131	272
	-50	-71	8	65	133
	-75	-77	19	76	99

and 400 kg/ha nitrogen treatments, respectively, under the -35 kPa treatment (Kjeldahl N = .16%). The spring 1980 samples showed values of .387, .418, .396 and .399 (Kjeldahl N = .15%) after some overwinter mineralization had taken place.

This limited amount of data does not provide a sufficient amount of information to draw any conclusions. Long term studies would, of course, be required to support this hypothesis. It was thought that some circumstantial evidence could be gathered from the farmer-cooperator sites. Three sites in particular were of interest. These sites were all located under the center pivot adjacent to the researcher managed area. Site 1 occupied a very similar landscape position and was of the same soil type. Sites 11 and 12 occupied a backslope position on a soil type similar to the researcher managed area. This center pivot had been in irrigated corn production for 13 years at the inception of this research. The absorbance values associated with sites 1, 11 and 12 were .690, .508 and .533 respectively in the spring of 1979. These sites had Wakley-Black organic matter contents of 2.5, 1.8 and 1.8%.

The results obtained when this procedure was applied to all the sites are included in Table 21. A survey analysis of this type cannot be used to draw definitive conclusions but it does appear the trend in these soils is to higher values of absorbance as the number of years irrigated increases. If the land had been farmed for a number of years prior to the application of irrigation the values seem to be lower. The exception to this is the field in which sites 4 and 22 were located. This field had been in an alfalfa rotation prior to being irrigated, which may explain this variation from the trend.

Table 21. Absorbance of Sodium Bicarbonate Extracts and Total Soil Organic Nitrogen as Affected by Past Management

		Researcher Managed Area (-35 kPa Water Level)			
Broadcast Nitrogen Rate =		0	100	200	400
Spring 1979	Absorbance at 260 nm	0.391	0.388	0.388	0.373
	Kjeldahl N in %	0.13	0.13	0.13	0.13
Fall 1979	Absorbance at 260 nm	0.427	0.459	0.497	0.487
	Kjeldahl N in %	0.16	0.16	0.16	0.17
Spring 1980	Absorbance at 260 nm	0.387	0.418	0.396	0.399
	Kjeldahl N in %	0.15	0.15	0.15	0.15
Increase in Nitrate-N from Fall 1979 to Spring 1980		6 kg/ha	7 kg/ha	40 kg/ha	10 kg/ha

Application of These Techniques to Farmer Cooperator Sites (initial soil samples from non-repeated sites)

Site	Year	Wakley-Black Organic Matter (%)	Absorbance at 260 nm $NaHCO_3$ Extract	Kjeldahl N (%)	Years Farmed	Years Irrig.
1	1979	2.5	0.690	0.16	13	13
2	1979	2.3	0.401	0.18	15	3
3	1979	2.7	0.433	0.19	0	0
4	1979	2.1	0.550	0.13	20	3
5	1979	2.0	0.466	0.14	15	3
6	1979	1.5	0.393	0.13	20	1
7	1979	2.4	0.509	0.19	2	2
8	1979	2.4	0.509	0.19	2	2
11	1979	1.8	0.508	0.12	13	13
12	1979	1.8	0.533	0.12	13	13
22	1980	2.1	0.551	0.13	21	4
24	1980	2.1	0.447	0.20	0	0

The application of nitrogen balance techniques to the farmer-cooperator sites did not provide the quality of data hoped. The inability to carefully control all nitrogen additions, the small nature of the net mineralization rates experienced, and the nitrogen rate-water management effects noted at the researcher-managed area probably contributed to the problems encountered with this procedure.

The nitrogen balance values achieved at the sites would be expected to vary with the amount of nitrogen present and the moisture status of the soil. When the treatment receiving the lowest fertilizer rate producing greater than 95% of the maximum treatment yield was used to analyze this factor, all but one net mineralization value falls in the range from -17 to + 35 kg of N/ha. The standard deviation of these values nearly always exceeded half of the value itself (C.V.'s > 50). The site excluded from this analysis had standard deviation values larger than the balance achieved.

Since the results of these data are questionable, it was decided to test the models developed at the researcher managed area on the farmer cooperator fields without attempting to modify them for differences in mineralization rates. Results of sodium bicarbonate extract analysis and the data outlined previously indicate that mineralization rates did not decrease dramatically, if at all, as the number of years under irrigation increased. It also did not appear that the differences exceeded the sampling error encountered in measurement of nitrate ion concentration. If these assumptions are true, use of the models should adequately predict behavior on these sites.

If the corn response to nitrogen on fields irrigated for short periods of time is a different response from corn on fields developed for longer periods, residual analysis techniques applied to the regression of predicted response onto actual response should produce systematic error with years farmed and irrigated.

Prior to this analysis it is necessary to assess the techniques for obtaining the data base to be used. For purposes of clarity grain yield response to nitrogen additions will be evaluated completely with respect to suitability of the data base, applicability of the models, and residual analysis followed by complete analysis of leaf nitrogen response, etc.

II. Analysis of the Data Base and Testing of the Models.

The farmer-cooperator sites, as stated in the materials and methods section, were fertilized on a plot by plot basis depending on the preseason nitrate-N level in the 120 cm profile. Fertilizer was applied based on a modification of the calibrations found in Adams et al. (1978) to establish fertilizer N plus nitrate-N (to 120 cm) levels of 300, 400, 500, 600, and 700 kg/ha. Nitrogen to be added by the farmer in starter and P fertilizer sources and through the irrigation system was subtracted from researcher additions. On sites where this procedure would result in negative additions of fertilizers (fields with high residual nitrate-N), set rates of 0, 100, 200 and 400 kg of N/ha were used. The results from the 1979 research led to modification of this procedure in 1980 to use total N levels of 150, 200, 250, 300, and 350 kg/ha. As before, high nitrate sites received set rates of

nitrogen. Three of the five sites repeated from the 1980 season received only uniform fertilizer applications while the other two received set rates of 0, 100, 200, and 400 kg of N/ha as they had in 1979. This scheme created a wide range of total nitrogen, fertilizer nitrogen and nitrate-nitrogen values. The range of values in terms of total N (fertilizer + nitrate) to 120 and 60 cm, fertilizer rates used and nitrates to 120 and 60 cm were shown on Tables 5A, 5B, and 5C.

The lack of yield response (Table 22A and 22B) over the range of total nitrogen values used in 1979 indicated that either the nitrogen fertilizer calibrations of Adams et al. (1978) did not translate well to the high yield irrigated environment of 1979 and/or the assumptions used to modify this calibration were in error. After investigating this further, it appears that both of these factors contributed to this phenomenon. Table 22A shows an analysis of the response in yields obtained to N fertilizer on the farmer-cooperator sites. A field was designated as showing a response if a treatment expressed less than 95% as much grain yield as the treatment producing highest mean yield. The response models of Adams et al. and yield prediction Model 4 developed at the researcher area were applied to this data. For responsive sites the mean grain yield from the treatment producing maximum yield was used to predict expected nitrogen requirement. On non-responsive sites the mean site yield was used for predictive purposes.

The original intent of establishing the variable N rate scheme at the farmer cooperator sites was to obtain responses in the range from 80-100% of maximum yield. Specifically the range from 90-100% was of

Table 22A. Actual Vs. Expected Response to Nitrogen Using Various Models

Plot by Plot Sampling*

	Levels Expressing Less Than 95% of Maximum Yield		
Site	Actual	Predicted by Adams	Predicted by Yield Model 4
1	1,2,5	1,2,5	1
2	NR	1	NR
3	1	1	NR
4	NR	1	NR
5	NR	1	NR
6	NR	1	NR
7	NR	1,2	NR
8	1	1,2	NR
11	NR	1,2	NR
12	NR	1	NR
22	1,3	All	1,2,3
23	1	1,2,3	1
24	1	All	1,2,3
27	1,2	All	1,2,4
28	NR	All	1,2
29	NR	1,2	NR
30	1	1	NR

NR - No response

*Total nitrogen values entered in the models are the mean values from 4 plots per level.

Table 22B. Actual Vs. Expected Response to Nitrogen using Various Models

Based on Mean Nitrate-N and Added Fertilizer N

Site	Levels Expressing Less Than 95% of Maximum Yield Actual	Predicted by Adams	Predicted by Yield Model 4
1	1,2,5	1,2,5	NR
2	NR	1	NR
3	1	NR	NR
4	NR	1	NR
5	NR	1	NR
6	NR	1	NR
7	NR	1,2	NR
8	1	1,2	NR
11	NR	1,2	NR
12	NR	1	NR
22	1,3	All	1,2,3
*23	1	1,2,3,4	1,2,3
24	1	1,2,3,4	1,2,3
*27	1,2	All	1,2,3
*28	NR	All	1,2,3
*29	NR	1,2	NR
*30	1	1,2	NR

NR - No response

*Sites repeated from 1979. Soil nitrate-N values used reflect the mean of four plots on these sites.

most interest. An ideal rate of nitrogen from both an economic and environmental standpoint would produce at least 95% maximum yield and leave few nitrates in the soil at the end of the season. The nitrate N remaining at each of the sites is shown in Appendix Table B-7.

It is obvious from Tables 22A and 22B that the calibration of Adams consistently over-estimated the need for nitrogen on these sites. It also indicates that the conversions made to allow 120 cm sampling were not valid. If the model of Adams was based on 120 cm nitrate-N it would have provided sufficient nitrogen on all sites except site 1 and site 30. Site 1 was subjected to excessively wet soil moisture conditions for a substantial period of time due to runoff from other portions of the field. This most likely led to losses that increased nitrogen requirement substantially. Site 30 was a 1979 site repeated in 1980. The plots that received no additional nitrogen in either 1979 or 1980 (except 11 kg/ha of starter N and 11 kg/ha of N through the system) showed yield reduction. These plots had only 75 kg/ha of nitrate-N in the 0-60 cm profile. The 120 cm nitrate-N was 416 kg/ha. Perhaps this non-uniform distribution of nitrogen caused nitrogen insufficiency early in the season that could not be compensated for later in the season when roots reached the N at deeper levels in the profile. Site 29 had similar nitrate distribution but did not show yield reductions. Clearly the effect of non-uniform distribution needs to be studied further.

The data shown on Table 22A are based on the level means of plot by plot nitrate-N and fertilizer N values. Soil nitrate-N values were very consistent on sites testing low in nitrates, but showed considerable

variability on soils having high concentrations of this ion. For instance the initial samples from the researcher area showed 120 cm levels of 33 kg of N/ha with a standard deviation of 1.9 (C.V. = 5.9). Site 1 showed largest variability with a mean site nitrate-N level of 350 kg/ha and standard deviation of 265 kg/ha (C.V. = 75.7). The C.V. values generally ranged from 30 to 50 on soils where mean site nitrate-N exceeded 150 kg/ha. It was felt that the non-uniformity of nitrate-N in the farmer fields might adversely affect the capability of the models to adequately predict nitrogen response on a plot by plot basis. For this reason a response analysis table was constructed (Table 22B) using mean site nitrate-N values for determination of total nitrogen levels. The 1979 sites repeated in 1980 could not be included using site mean in this analyses since the nitrate-N levels present were partially dependent on the previous year's fertilizer rate. They were included on a level by level basis (means of four plots).

The data from the farmer-cooperator sites (Appendix B) indicates that good to excellent yields can be achieved while drawing nitrate-N to a relatively low level. These fields were fertilized assuming the capability of producing 12,600 kg/ha yields. Where much lower yields were obtained, nitrates were high even under the lowest rates of nitrogen.

No explanation can be found for the extremely high rates of nitrate-N found on site 2 following the season. The yields at this site were lower than projected yields but residual nitrate-N levels are at least 100 kg/ha larger than expected. The ever present problem of accurately sampling soils with high nitrates probably played a role.

All sites except sites 1, 3, and 30 produced maximum yields at total nitrogen rates of 300 kg/ha (to 120 cm) or less. The rationale for sites 1 and 30 have been outlined. Site three was planted extremely late. Perhaps there is also a planting date effect on nitrogen response. The relatively high rate of residual nitrates under the responding treatment supports that assumption.

The researcher model used in the construction of Tables 22A and 22B includes the parameter of soil water matric potential. The farmer cooperators could not and/or did not maintain their soil moisture at as constant a level as was possible on the researcher managed area. The soil water matric potential term entered into the model for the farmer cooperator sites was therefore selected as the average soil water matric potential at 50 cm for the period from July 21 to August 10 for both years (Table 23). This period was selected since it included tasseling and pollination (which is considered a critical time to avoid water stress in the production of corn) in conjunction with high atmospheric demand conditions. This included 1 and 2 days where maximum air temperature equalled or exceeded 35°C in 1979 and 8 and 11 days in 1980 for the official weather service stations at Gettysburg and Pierre, respectively.

Closer examination of this data indicates that the farmer-cooperators had much more difficulty maintaining soil water matric potentials at a specified level during the 1980 cropping season than in 1979. Failure to maintain constant soil moisture conditions in 1979 (Sites 1, 2, 3, and 4) could be traced to system failures or runoff

Table 23. Soil Water Matric Potential at a 50 cm Depth on Farmer-Cooperator Sites

Highest Reading in the Time Period
(Average of three tensiometers)

		Soil Water Matric Potential (kPa)								
		June			July			August		
Site	Year	1-10	11-20	21-30	1-10	11-20	21-30	1-10	11-20	21-30
1	1979	35	35	20	35	20	20	20	35	35
2	1979	35	35	35	35	45	50	70	70	70
3	1979	35	35	35	45	35	35	55	65	65
4	1979	35	35	35	45	35	65	70	70	60
5	1979	35	35	35	35	35	35	35	35	35
6	1979	35	35	35	35	35	35	35	35	35
7	1979	40	40	35	40	40	35	35	35	35
8	1979	40	40	35	40	40	35	35	35	35
11	1979	35	35	35	35	35	35	35	35	35
12	1979	35	35	35	35	35	35	35	35	35
22	1980	65	55	60	65	70	70	75	65	70
23	1980	35	35	35	65	65	50	65	65	65
24	1980	35	45	45	45	45	45	35	35	35
27	1980	55	50	60	70	70	65	45	45	45
28	1980	55	50	60	70	70	65	45	45	45
29	1980	30	30	35	45	55	60	50	50	40
30	1980	30	30	35	45	55	60	50	50	40

problems. Only Site 24 had relatively constant soil moisture content in 1980. This field is smaller than the others in the study, consisting of approximately 25 ha. The capacity of the center pivot on this field in terms of liters per irrigated hectare was 40% greater than the other systems used. Under the high demand conditions of the 1980 season, this increased capacity more closely matched the peak consumptive use of water encountered. Increasing the specific capacity (l/ha) of longer systems would probably not be feasible due to the engineering and runoff considerations mentioned earlier. These data do reinforce the desirability of producers adopting tillage practices to reduce runoff losses and the necessity of establishing a relatively high soil water matric potential level prior to periods when high demand conditions are common.

Yields were predicted using all models and a linear regression of these data on actual yields was forced through the intercept. Analysis of residuals revealed that predictive capability did not vary systematically with years farmed or irrigated. This tends to indicate that with the methods used there was not a detectable difference in yield response on sites irrigated for long periods as compared to sites developed for shorter periods of time. This does not mean that differences in mineralization did not exist. The methods were not sensitive enough to detect these differences if they existed. The complex nature of the mineralization-immobilization system as affected by water level and nitrogen rate undoubtedly reduced the ability to detect differences with these methods.

It appears that other factors played a much larger role in determining fertilizer nitrogen requirements than did net mineralization differences on the sites tested. Systematic variation of yield prediction was associated with planting date, soil moisture status earlier in the season than the time chosen for inclusion in the models and harvest population. These parameters and other secondary management factors can obviously affect the ability to predict yields especially at the high end of the yield curve since they become relatively more important in this area.

The models produced systematic under-prediction of yields (over-prediction of N required) as total nitrogen values become very large. This is due to the polynomial nature of the models and not to real phenomena. Therefore, they were modified so that total nitrogen values in excess of 340 kg/ha were set equal to this value. Figure 5 demonstrates the relationship between actual and predicted yields for yield Model 2. Data from all sites was entered on a plot by plot basis. Predicted yields from all models were correlated with actual plot yields. The correlation coefficients and the probability associated with the F statistic for this analysis is shown on Table 24A.

The tabular and graphical presentations both illustrate the importance of secondary management and environmental factors on corn yield response to soil water matric potential and nitrogen rate especially near the top end of the yield curve. Since irrigators and agencies responsible for recommending fertilizer additions to irrigated

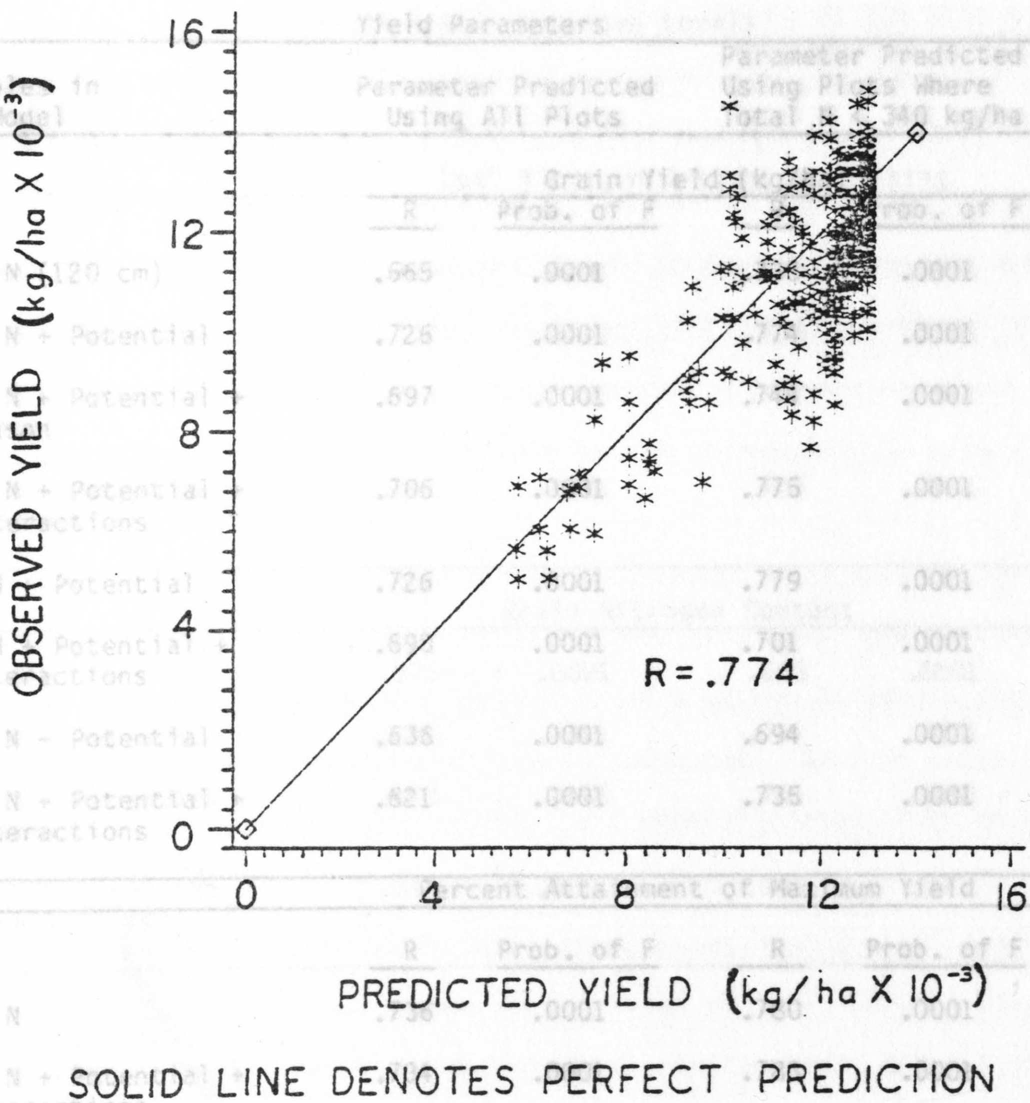

Figure 5: Relationship Between Observed Grain Yield and the Yield Predicted Using Model 2 on Table 12.

Table 24A. Correlation of Observed Values at Cooperator Sites with Values Predicted using Various Models.

Variables in the Model	Yield Parameters: Parameter Predicted Using All Plots		Parameter Predicted Using Plots Where Total N $<$ 340 kg/ha	
	Grain Yield (kg/ha)			
	R	Prob. of F	R	Prob. of F
Total N (120 cm)	.665	.0001	.735	.0001
Total N + Potential	.726	.0001	.774	.0001
Total N + Potential + Season	.697	.0001	.744	.0001
Total N + Potential + Interactions	.706	.0001	.775	.0001
Leaf N + Potential	.726	.0001	.779	.0001
Leaf N + Potential + Interactions	.690	.0001	.701	.0001
Grain N + Potential	.636	.0001	.694	.0001
Grain N + Potential + Interactions	.621	.0001	.735	.0001
	Percent Attainment of Maximum Yield			
	R	Prob. of F	R	Prob. of F
Total N	.736	.0001	.780	.0001
Total N + Potential + Interactions	.734	.0001	.783	.0001
Leaf N	.711	.0001	.793	.0001
Grain N	.631	.0001	.740	.0001
Grain N + Potential	.640	.0001	.751	.0001
Grain N + Potential + Interactions	.670	.0001	.762	.0001

Table 24B. Correlation of Observed Values at Cooperator Sites with Values Predicted using Various Models.

Plant Tissue Nitrogen Levels				
Variables in the Model	Parameter Predicted Using All Plots		Parameter Predicted Using Plots Where Total N < 340 kg/ha	
Leaf Nitrogen Content at Silking				
	R	Prob. of F	R	Prob. of F
Total N	.764	.0001	.791	.0001
Total N + Potential	.762	.0001	.796	.0001
Total N + Potential + Season	.713	.0001	.767	.0001
Total N + Potential + Interactions	.743	.0001	.783	.0001
Grain Nitrogen Content				
Total N	.573	.0001	.663	.0001
Total N + Potential	.660	.0001	.711	.0001
Total N + Potential + Season	.618	.0001	.761	.0001
Total N + Potential + Interactions	.657	.0001	.774	.0001

lands in this area cannot determine in advance what environmental conditions will occur prior to the growing season, and soil testing laboratories, in particular, have no way of determining at the time a recommendation is made what management factors will be employed by a producer; attempts should not be made to apply them directly. This is especially true since the models were tested over data gathered in the same period of time they were developed. The insight these models cast on the interactive effects of environment and nitrogen response and the apparently minor role played by nitrogen mineralization may be of value in the development of fertilizer recommendation techniques for this area.

Leaf nitrogen and corn grain nitrogen prediction models as stated before are of little practical value at the present time. The construction and testing of these models serve only as a method to assess the effects total nitrogen and especially water management have on these parameters. Knowledge of these effects will hopefully shed light on the suitability of these tools for predicting the nitrogen status of plants. The significant Year*Potential*TotalN14 interaction term in leaf prediction Model 4 is small. An increase in the range of leaf nitrogen contents encountered as a result of differential environmental effects of only .13% is predicted over the range of water potentials tested at 300 kg/ha of added nitrogen. Likewise the effect of Potential and Potential*Season in this model is small. When the interaction term is included the combined effects of the Potential, Potential*Season, and Season*Potential*TotalN14 are large enough, however, that they can not

and probably should not be ignored.

Residual analysis procedures utilizing predicted and actual leaf nitrogen content indicate the secondary management factors such as planting date have a systematic effect on leaf nitrogen as they had on yield. Site number 3 was planted very late and shows higher leaf nitrogen contents than expected. Site 6 which was planted early also exhibits high leaf N. This site was mistakenly planted by the farmer to a variety of corn different from the variety used on the other sites and the researcher area. It also received a substantially larger proportion of its nitrogen with the irrigation water than the other sites. Sites 22 and 23 had lower leaf nitrogen contents than expected. These sites had adequate moisture status earlier in the year which produced large plants lower in nitrogen. Water stress later in the year reduced yields and maybe nitrogen response. Another contributing factor that may have been exhibited on sites 23 and 30 was the uneven distribution of nitrogen in the profile. These sites had lower leaf nitrogen contents than expected at some total N levels. These levels were characterized by fewer nitrates in the 0-60 cm profile than in the 60-120 cm profile. The residuals, of course, did vary systematically with soil moisture levels earlier in the season (the same soil matric potential levels were used in these models as in the yield models).

Grain nitrogen content also showed response to soil moisture potential and season. The main effect Season could, however, be eliminated through the use of the interaction terms Season*Potential, Potential*TotalN14 and Season*Potential*TotalN14 (Model 4). Residual

analysis procedures indicated that prediction error did vary with Potential earlier in the season. This implies that grain nitrogen content response to soil water matric potential may be more of a response to grain yield and plant nitrogen status (which is affected by Potential) than the result of a direct response to soil moisture. Sites producing very high yields had low grain nitrogen content at all rates of nitrogen even if substantial amounts of N remained in the soil. The relationship between actual and predicted leaf and corn grain nitrogen contents are shown in Figures 6 and 7, respectively. The models used for these predictions were the second models in both cases. These contain only the parameters of total N and soil water matric potential. Use of higher models did not improve predictive capability on the farmer sites for leaf N but did show improvement for grain N (see Table 24B).

The real values of these parameters as stated before lies in their ability to monitor the sufficiency status of nitrogen for crop production. The models developed for prediction of grain yield from leaf nitrogen content at silking and grain nitrogen content of course contained the factors of Potential and Season. The Season*Leaf N interaction was also present in the "best" model developed using leaf nitrogen as was the interaction term Potential*Leaf N. Inclusion of these interaction terms allowed the elimination of the dummy main effect Season. Inclusion of interaction terms also increase the ability to predict yields and allow the elimination of the main effect Season in the models using grain nitrogen content at the researcher site. Residual analysis procedures again revealed systematic variation with

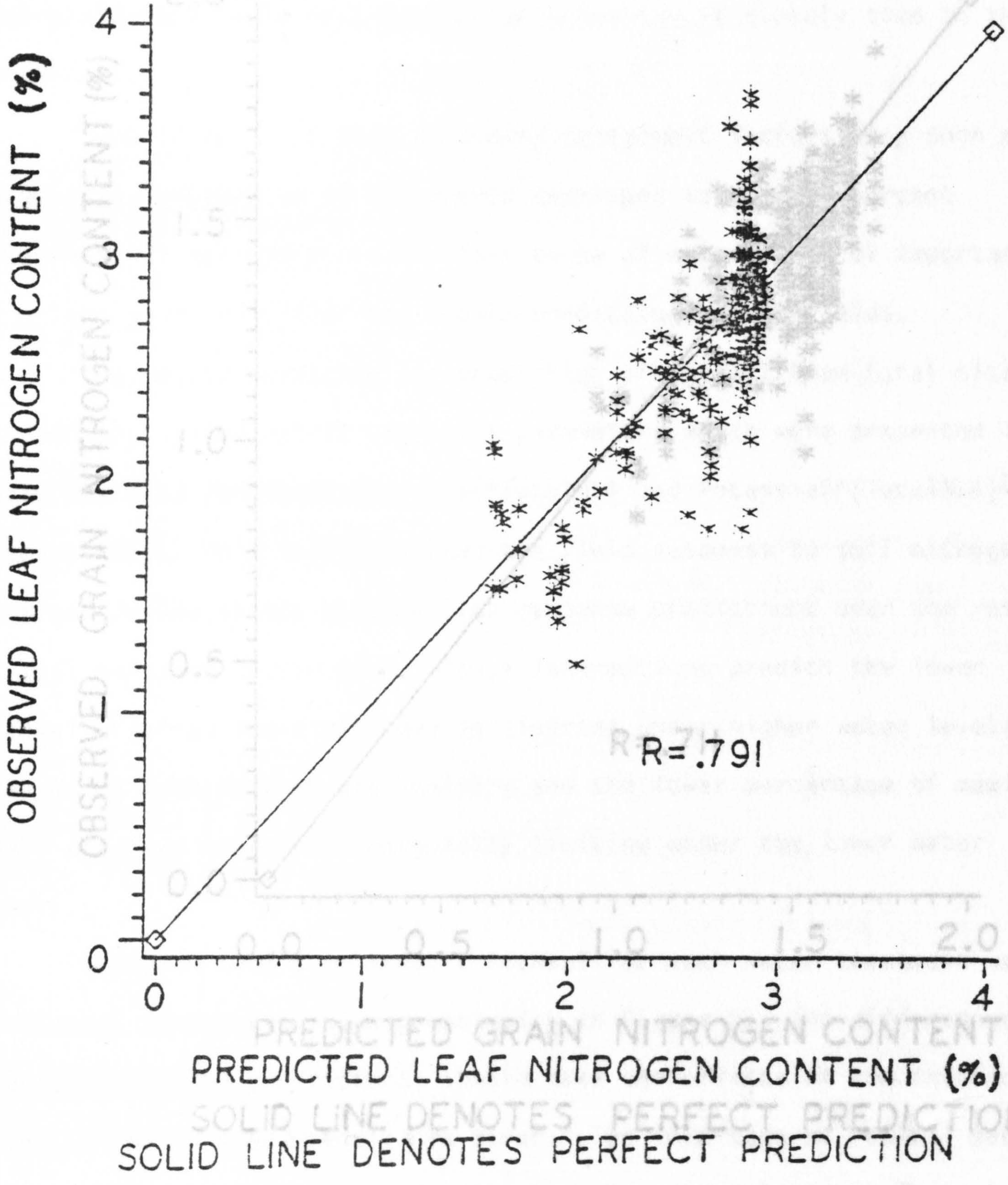

Figure 6: Relationship Between Observed Leaf Nitrogen Content at Silking and Values Predicted by Model 2 on Table 14.

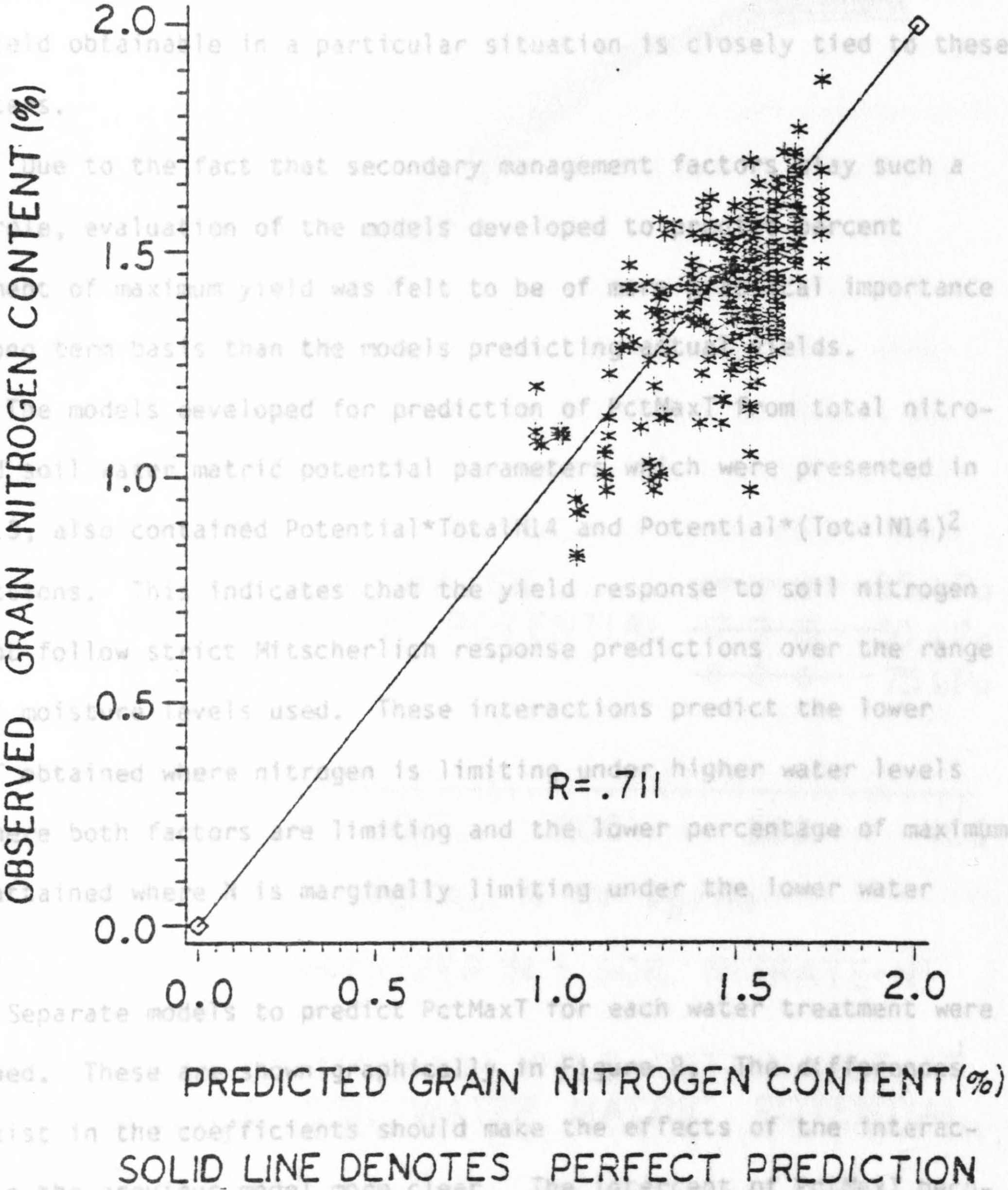

Figure 7: Relationship Between Observed Grain Nitrogen Content and Values Predicted by Model 2 on Table 15.

secondary management factors. This is to be expected since the potential yield obtainable in a particular situation is closely tied to these parameters.

Due to the fact that secondary management factors play such a large role, evaluation of the models developed to predict percent attainment of maximum yield was felt to be of more practical importance on a long term basis than the models predicting actual yields.

The models developed for prediction of PctMaxT from total nitrogen and soil water matric potential parameters which were presented in Table 13, also contained Potential*TotalN14 and Potential*$(TotalN14)^2$ interactions. This indicates that the yield response to soil nitrogen does not follow strict Mitscherlich response predictions over the range of soil moisture levels used. These interactions predict the lower PctMaxT obtained where nitrogen is limiting under higher water levels than where both factors are limiting and the lower percentage of maximum yield attained where N is marginally limiting under the lower water levels.

Separate models to predict PctMaxT for each water treatment were developed. These are shown graphically in Figure 8. The differences that exist in the coefficients should make the effects of the interactions in the previous model more clear. The intercept of PctMaxT becomes larger as water stress increases over the range tested. The rate of rise of this variable is lower as water stress increases.

The relative importance of environmental effects and secondary management factors are reduced when yields are expressed on a percentage

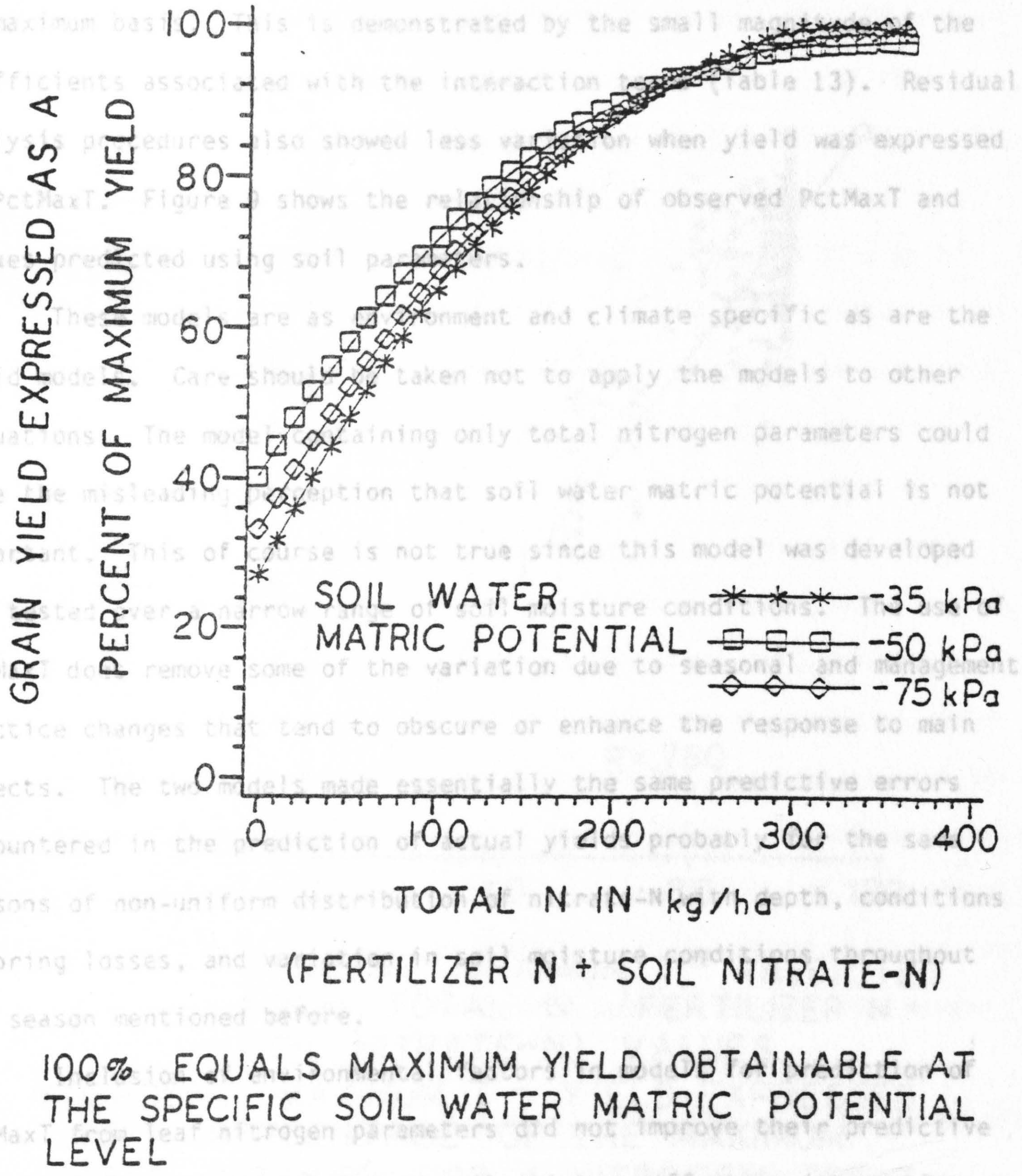

Figure 8: Response of PctMaxT to Total N at the Three Soil Water Matric Potential Levels Used at the Researcher Managed Area as Predicted by Model 2 on Table 15.

of maximum basis. This is demonstrated by the small magnitude of the coefficients associated with the interaction terms (Table 13). Residual analysis procedures also showed less variation when yield was expressed as PctMaxT. Figure 9 shows the relationship of observed PctMaxT and values predicted using soil parameters.

These models are as environment and climate specific as are the yield models. Care should be taken not to apply the models to other situations. The model containing only total nitrogen parameters could give the misleading perception that soil water matric potential is not important. This of course is not true since this model was developed and tested over a narrow range of soil moisture conditions. The use of PctMaxT does remove some of the variation due to seasonal and management practice changes that tend to obscure or enhance the response to main effects. The two models made essentially the same predictive errors encountered in the prediction of actual yields probably for the same reasons of non-uniform distribution of nitrate-N with depth, conditions favoring losses, and variation in soil moisture conditions throughout the season mentioned before.

Inclusion of environmental factors in models for prediction of PctMaxT from leaf nitrogen parameters did not improve their predictive capability. No environmental or soil moisture effect or interaction proved to be significant over the range of conditions tested. Significant effects may occur if a broader range were used. The residual analysis procedures produced much less systematic variation with secondary management factors when the model containing only leaf

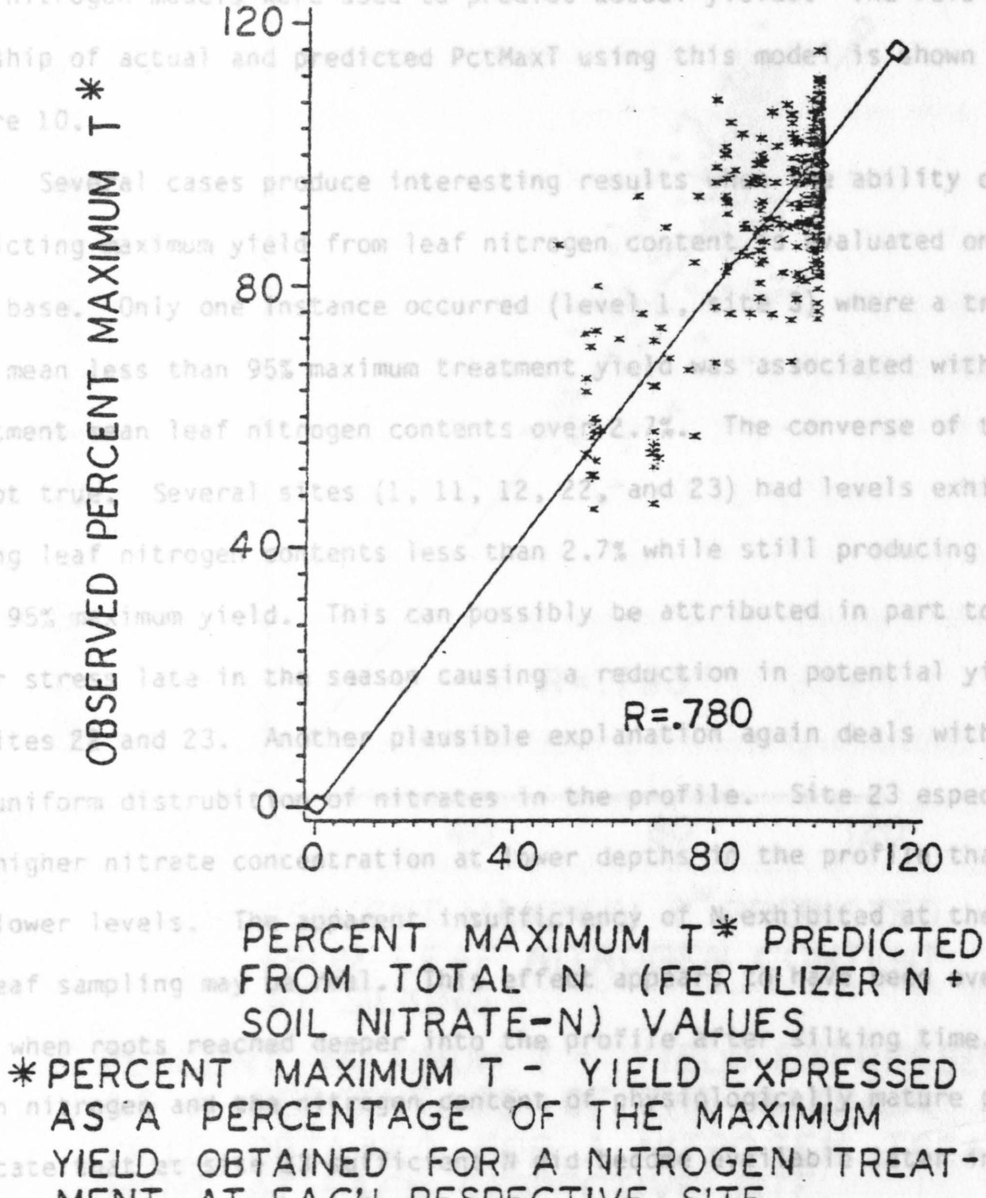

Figure 9: Relationship Between Observed PctMaxT and Values Predicted Using Model 2 on Table 13.

nitrogen content parameters to predict PctMaxT was evaluated than when leaf nitrogen models were used to predict actual yields. The relationship of actual and predicted PctMaxT using this model is shown in Figure 10.

Several cases produce interesting results when the ability of predicting maximum yield from leaf nitrogen content is evaluated on this data base. Only one instance occurred (level 1, site 3) where a treatment mean less than 95% maximum treatment yield was associated with treatment mean leaf nitrogen contents over 2.7%. The converse of this is not true. Several sites (1, 11, 12, 22, and 23) had levels exhibiting leaf nitrogen contents less than 2.7% while still producing more than 95% maximum yield. This can possibly be attributed in part to water stress late in the season causing a reduction in potential yields at sites 22 and 23. Another plausible explanation again deals with the non-uniform distrubition of nitrates in the profile. Site 23 especially had higher nitrate concentration at lower depths in the profile than at shallower levels. The apparent insufficiency of N exhibited at the time of leaf sampling may be real. This effect appears to have been overcome when roots reached deeper into the profile after silking time. Grain nitrogen and the nitrogen content of physiologically mature plants indicate that at site 23 sufficient N did become available later in the season. Another factor that may have played a role was the timing of fertilizer additions through the irrigation system. Sites 22 and 23 received N additions this way just prior to sampling. The higher than expected soil nitrate-N values associated with the low leaf N content

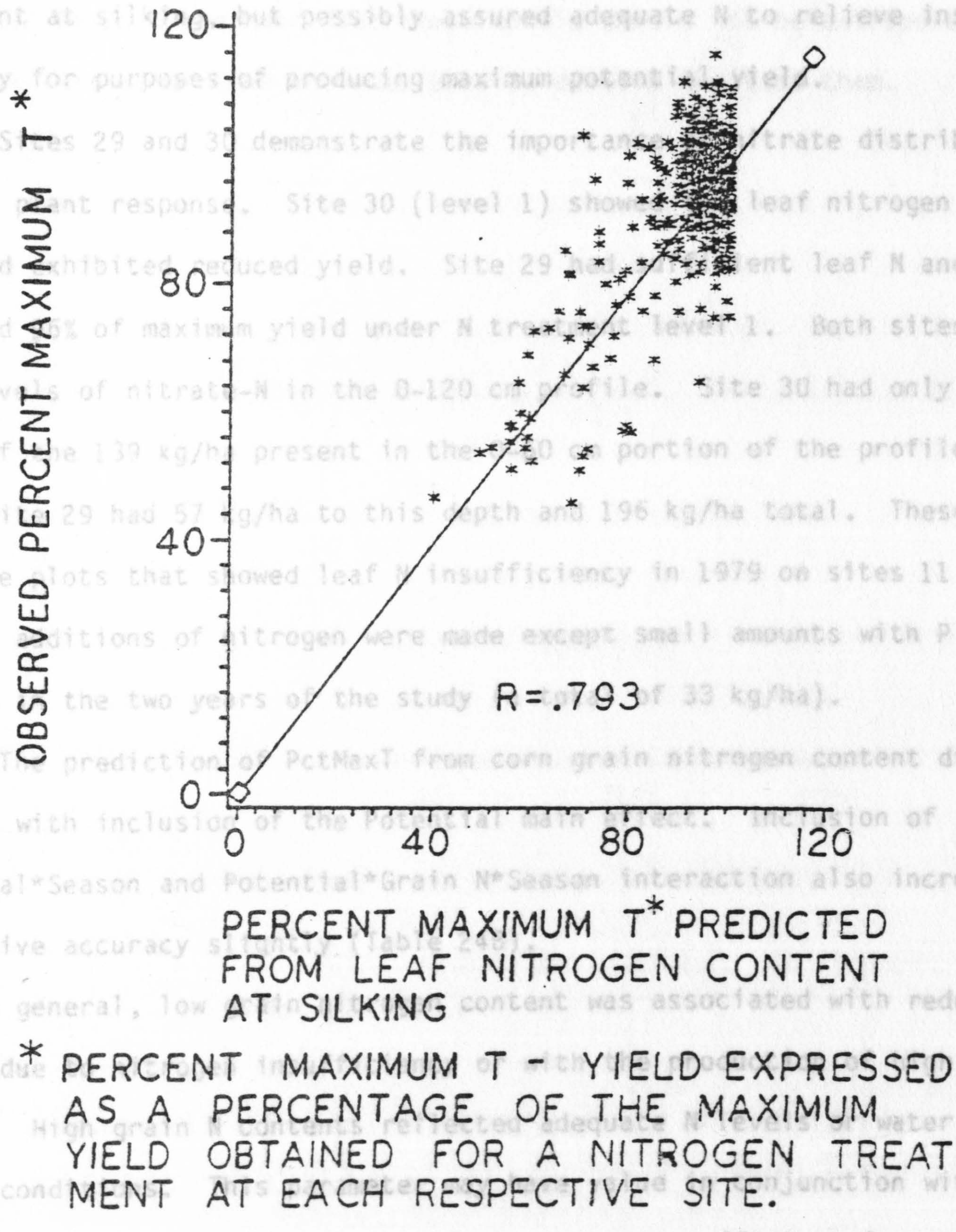

Figure 10: Relationship Between Observed PctMaxT and Values Predicted from Model 1 on Table 16.

indicate that these late additions had not been fully assimilated into the plant at silking, but possibly assured adequate N to relieve insufficiency for purposes of producing maximum potential yield.

Sites 29 and 30 demonstrate the importance of nitrate distribution to plant response. Site 30 (level 1) showed low leaf nitrogen content and exhibited reduced yield. Site 29 had sufficient leaf N and produced 96% of maximum yield under N treatment level 1. Both sites had high levels of nitrate-N in the 0-120 cm profile. Site 30 had only 25 kg/ha of the 139 kg/ha present in the 0-60 cm portion of the profile while site 29 had 57 kg/ha to this depth and 196 kg/ha total. These are the same plots that showed leaf N insufficiency in 1979 on sites 11 and 12. No additions of nitrogen were made except small amounts with P sources in the two years of the study (a total of 33 kg/ha).

The prediction of PctMaxT from corn grain nitrogen content did improve with inclusion of the Potential main effect. Inclusion of Potential*Season and Potential*Grain N*Season interaction also increased predictive accuracy slightly (Table 24B).

In general, low grain nitrogen content was associated with reduced yields due to nitrogen insufficiency or with the production of high yields. High grain N contents reflected adequate N levels or water stress conditions. This parameter may have value in conjunction with other information for determining if nitrogen was sufficient for crop growth. The relationship between observed PctMaxT and values predicted from grain nitrogen content is shown in Figure 11. It is apparent that the models work quite well over the conditions that exist in this data

base. The discussion on the work of Pierre et al. presented earlier again serves as a reminder that these models should not be extrapolated to conditions other than the ones used to develop and test them.

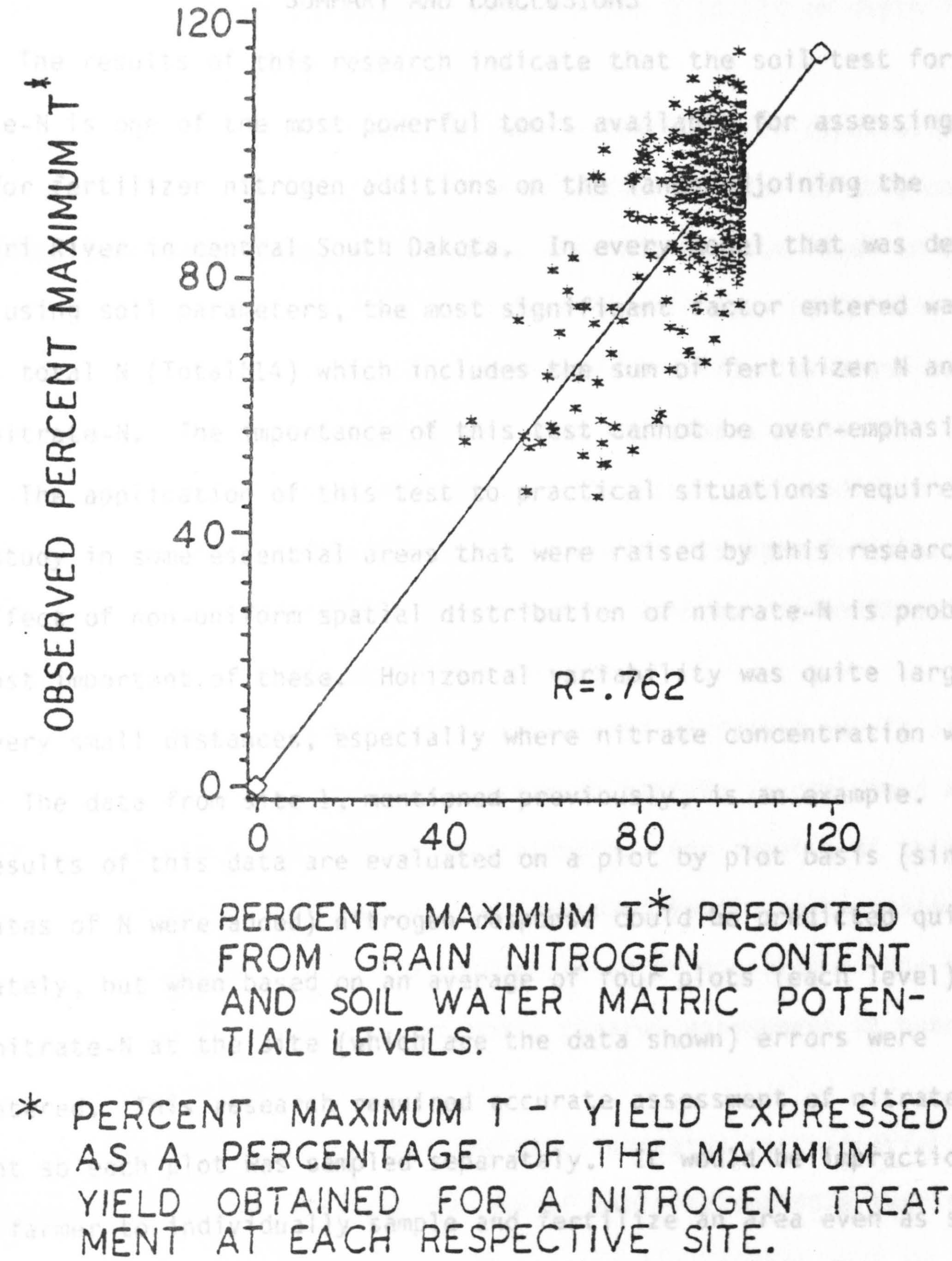

Figure 11: Relationship Between Observed PctMaxT and Values Predicted Using Model 3 on Table 17.

SUMMARY AND CONCLUSIONS

The results of this research indicate that the soil test for nitrate-N is one of the most powerful tools available for assessing the need for fertilizer nitrogen additions on the lands adjoining the Missouri River in central South Dakota. In every model that was developed using soil parameters, the most significant factor entered was always total N (TotalN14) which includes the sum of fertilizer N and soil nitrate-N. The importance of this test cannot be over-emphasized.

The application of this test to practical situations requires more study in some essential areas that were raised by this research. The effect of non-uniform spatial distribution of nitrate-N is probably the most important of these. Horizontal variability was quite large over very small distances, especially where nitrate concentration was high. The data from site 1, mentioned previously, is an example. When the results of this data are evaluated on a plot by plot basis (since set rates of N were added) nitrogen response could be predicted quite accurately, but when based on an average of four plots (each level) or a mean nitrate-N at the site (which are the data shown) errors were encountered. This research required accurate assessment of nitrate-N present so each plot was sampled separately. It would be impractical for a farmer to individually sample and fertilize an area even as small as that included in each of our sites (16-20 plots). The data indicate that mean nitrate-N values (average of all plots) also varied substantially from site to site in the same field. Sites 1, 11, and 12 were in the same field. Mean nitrate-N varied from 131 to 261 kg/ha for the

0-60 cm depth and from 352 to 534 kg/ha for the 0 to 120 cm depth for these sites.

Nitrates also showed vertical spatial variability especially on the sites repeated the second year. A situation similar to this could be encountered by a farmer attemptng to draw the nitrate level in a field to a lower value. The data indicate that if deep (0-120 cm) sampling is used, perhaps the samples should be divided by depth to assure adequate nitrogen nutrition prior to the time a plant root reaches the nitrates deep in the profile. The data also indicate that this deep nitrogen can be an important source of nitrogen for plant use late in the season and probably should not be ignored. (See Appendix C for a more thorough treatment of this subject).

Many of these problems can be avoided if carryover levels of nitrate-N are relatively low. Low carryover nitrate levels would also reduce the potential for loss of this element. The results of this research indicate that maximum or near maximum yields can be achieved while simultaneously drawing the concentration of nitrates in the soil to a low level. This requires extremely careful management of both primary and secondary factors.

One possible practice that the data indicates has potential for improving N management includes the use of early season (6-8 leaf stage of growth) leaf and soil samples. Since research methods were not precise enough to definitively quantify the net mineralization differences in these soils and other factors such as planting date, plant population, weed control, etc. affect potential yield so profoundly, this

sampling time would allow for tailoring nitrogen applications to compensate for some of these factors. If early planting is possible, stands are good, weed competition low, etc., a high yield goal could be used. The period of time when these samples would normally be collected (mid-June to early July) immediately precedes the period of maximum plant uptake of nitrogen. This time period falls after the effects of the immobilization-mineralization system have been at least partially expressed and when the potential for nitrogen losses because of untimely rains is reduced substantially. This time period also coincides with a subsurface tillage treatment used in this area to reduce runoff problems. Nitrogen applications could be made with this machine and/or by injecting nitrogen into the irrigation water. This project did not completely test the concept of early sampling but preliminary results and the logic just outlined indicate this method may have merit for further investigation.

Silking time leaf and soil samples may also be useful if laboratory turn around time can be reduced. These procedures could not be used as a primary means of assessing nitrogen needs but may be valuable in situations where high nitrates have existed and attempts are being made to reduce these levels. This evidence could be used to determine if sufficient N is being assimilated by the plant or if small additions are needed at this time to offset the effects of non-uniform nitrogen distribution. The excellent relationship between percent attainment of maximum yield and leaf nitrogen content at silking may be valuable for this purpose. More research is needed to determine the effectiveness

of nitrogen additions at silking and the proper amount of N needed to relieve nitrogen insufficiency.

The results of correlation analysis indicate that the variation encountered in the management practices at the farmer cooperator fields predominantly obscured the interaction and seasonal effects included in the higher models. This does not mean that these effects are not real; rather that the inability of the farmers to maintain a relatively constant soil water matric potential throughout the season caused confounding effects that could not be quantified. This may mean that for practical purposes, modifications of the models not containing interaction and seasonal effects may be as useful as the models containing these terms.

The very significant response that resulted from soil water matric potential as affected by atmospheric demand differences indicates that more research needs to be directed toward the definition of these interactions. Water management schemes to counteract the effects of high demand periods also need to be developed.

The failure of most of the farmers to maintain soil water matric potential in the desired range during the 1980 season could be traced to the inability of their systems to apply sufficient quantities of water to match plant needs during the most erosive part of the summer and/or losses of a portion of the water applied through runoff. Present research efforts to allow more efficient use and more uniform infiltration of irrigation water under center pivots should be continued not only because of the direct benefits to water management but also because

of the influence non-uniform water distribution can have on nitrogen management. Sites 1, 11 and 12 again serve as an example. Sites 11 and 12 were located on a backslope position that had historically produced poorer growth due to increased water stress (due to runoff losses) than lower portions of the field where site 1 was located. This fact is expressed in the relatively higher nitrate-N at sites 11 and 12 than at site 1 when the study began. Due to runoff losses, scheduling water for the backslope position led to excessive applications of water to the lower portions of the field and therefore losses of N at site 1. Non-uniform infiltration of water could also adversely affect the application of nitrogen through irrigation water.

Another concern surrounds the application of the models involving plant tissue nitrogen levels. The same variety of corn (Pioneer 3780) was used for all sites except one in 1979 and a very similar variety (Pioneer 3732) was used at all sites in 1980. Pioneer 3732 was used during the 1980 season since Pioneer 3780 is susceptible to Goss's Wilt. This disease did not affect any of the research sites in 1979 but was noted in surrounding fields. It was felt the error produced by switching varieties would cause less problems than the loss of data from a potential disease outbreak. It is possible that the seasonal effects noted were accentuated by a varietal difference but this is unlikely since the varieties are genetically closely related. The possibility of differential variety response must, however, be considered when developing techniques to use plant tissue analysis for predictive purposes on a field scale basis.

The residual analysis procedures and nitrogen balance techniques applied to the determination of nitrogen mineralization differences among fields with varying past management histories was a primary thrust of this research. The analysis of soil water matric potential and nitrogen fertilizer level effects on this parameter was also of interest. It appears from the data gathered on the researcher's area that soil water matric potential and nitrogen fertilization can drastically affect the amount of net mineralization taking place in a particular soil. These differences may be due more to the plant's response to water and nitrogen levels and the subsequent changes in immobilization that resulted, than to changes in the total mineralization that took place. The "net" effect of this change in immobilization was thought to be the reason for noted differences in net mineralization. This hypothesis cannot be definitively proven since heavy isotope tracer techniques were not employed.

Determination of net mineralization by nitrogen balance and residual analysis techniques on the farmer cooperator fields did not furnish definitive data. The effects of nitrogen and water level on this parameter, noted at the researcher area, probably were complicated by factors such as the non-uniformity of soil water status throughout the growing season on the cooperator fields, problems encountered in accurately measuring high nitrate concentrations and the variability encountered in secondary management techniques. It does not appear, however, that mineralization rates are large enough or show sufficient variability to cause major problems in nitrogen management on these soils.

The one site that appears to show the least use of nitrogen based on nitrogen budget analysis was site 2. Analysis of total nitrogen at the beginning of the season minus nitrates present at the end of the season shows very little difference. The low yield obtained at this site may have produced the numbers noted. They may also have been due to errors in measurement of nitrate-N or to a real difference in mineralization. Site 3 also indicated smaller than expected values of removal probably due to poor yields and late planting. Two sites high in nitrates (1 and 12) had nitrogen used values larger than expected possibly due to sampling error or losses of nitrogen. The other thirteen sites removed an amount of nitrogen (from the lowest nitrogen level producing at least 95% maximum yield) on the order of 220 kg/ha plus or minus 50 kg/ha in a 120 cm profile. These data agree with the data on the newly developed soil at the researcher managed area. The range in net mineralization values obtained where nitrogen balance techniques were applied as stated earlier, was even smaller. It seems unlikely therefore that attempts to compensate for mineralization differences in these soils would be fruitful at the present state of the art in nitrogen management.

Topographically induced differences in organic nitrogen content may cause more variability in mineralization within a field than exists between fields on soils in this area. Sites 1, 11 and 12 again serve as an example. Site 1 had higher organic nitrogen content, higher Wakley Black organic matter content and expressed a higher absorbance when sodium bicarbonate extraction techniques were applied to it than sites

11 and 12 in the same field but on a backslope position. Differential sampling and fertilization of these areas would probably not be practical even if mineralization differences were found.

In conclusion, this research indicates that the most powerful tool available for use in nitrogen management in this area appears to be the nitrate-N soil test. Leaf and soil sampling early in the season and at silking also show potential for use in "fine tuning" nitrogen applications.

It is hoped that the insight on the interactions of water and nitrogen management provided by this research can be combined with knowledge gained from present research on the spatial variability of nitrates in the soil, and methods of improving water infiltration uniformity on these soils to develop improved user-oriented management techniques for both water and nitrogen applications. As the cost of these inputs increase, it will become imperative to utilize them as efficiently as possible.

LITERATURE CITED

1. Acevedo, E. 1975. The growth of maize (Zea mays L.) under field conditions as affected by its water relations. Ph.D. thesis, Univ. of Calif., Davis.

2. Adams, E. P., E. J. Williamson, P. L. Carson, and R. Gelderman. 1978. Fertilizing Corn. Plant Science Pamphlet FS 432. South Dakota Ag. Expt. Sta., Brookings.

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

4. Allison, F. E. 1966. Fate of nitrogen applied to soils. Adv. Agron. 18:219-253.

5. Andreeva, E. A. and G. M. Scheglova. 1968. Uptake of soil nitrogen on application of nitrogen fertilizers and nitrification inhibitors as revealed in greenhouse experiments using nitrogen-15. Int. Congr. Soil Sci. Trans. 9th (Adelaide, Aust.) II:523-532.

6. Bartholomew, W. V., and F. E. Clark. 1950. Nitrogen transformations in soil in relation to the rhizosphere microflora. Fourth Internat. Cong. Soil Sci. (Amsterdam) Tans. 2:112-113.

7. Black, C. A. 1968. Soil plant relationships. Second Ed. John Wiley and Sons, Inc., New York.

8. Bremmer, J. M. 1965. Nitrogen availability indexes. Agronomy 9:1324-1345.

9. Bremmer, J. M. and D. R. Keeney. 1966. Determination and isotope ratio analysis of different forms of nitrogen in soils. Soil Sci. Soc. Am. Proc. 30:577-582.

10. Broadbent, F. E. 1965. Effect of fertilizer nitrogen on the release of soil nitrogen. Soil Sci. Soc. Am. Proc. 29:692-696.

11. Carson, P. L. and R. H. Gelderman. 1980. Soil testing procedures in use at the SDSU Soil Testing Laboratory. Plant Science Pamphlet 55, South Dakota Ag Expt. Sta., Brookings.

12. Clark, F. E. 1949. Soil microorganisms and plant roots. Adv. Agron. 1:241-288.

13. DeBoer, D. W. and D. L. Beck. 1982. Tillage practice to enhance infiltration under sprinkler irrigation. A.S.A.E. paper No. 82-2002. St. Joseph, Michigan.

14. Denmead, O. T. and R. H. Shaw. 1960. The effects of soil moisture stress at different stages of growth on the development and yield of corn. Agron. J. 52:272-274.

15. Denmead, O. T., and R. H. Shaw. 1962. Availability of soil water to plants as affected by soil moisture content and meterological conditions. Agron. J. 54:385-390.

16. During, C., G. S. Robinson, and M. W. Cross. 1963. A study of the effects of various intensities of cultivation on yields of Chou Moellier and on soil nitrate levels. New Zealand Jour. Agr. Res. 6:293-302.

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

18. Fried, M. and H. Broeshart. 1974. Priming effect of nitrogen fertilizers on soil nitrogen. Soil Sci. Soc. Am. Proc. 38:858.

19. Gardner, W. R. 1956. Calculation of capillary conductivity from pressure plate outflow data. Soil Sci. Soc. Am. Proc. 20:317-320.

20. Gelderman, R. H., and P. L. Carson. 1980. Plant tissue analysis procedures in use at the SDSU Soil Testing Laboratory. Plant Science pamphlet 42. South Dakota Ag. Exp. Sta., Brookings.

21. Goring, C. A. I., and F. E. Clark. 1949. Influence of crop growth on mineralization of nitrogen in the soil. Soil Sci. Soc. Am. Proc. 13:261-266.

22. Hahne, H. C. H., Wybe Kroontje and J. A. Lutz, Jr. 1977. Nitrogen fertilization I: Nitrate accumulation and losses under continuous corn cropping. Soil Sci. Soc. Am. Proc. 41:562-567.

23. Harding, D. E., and D. J. Ross. 1964. Some factors in low-temperature storage influencing the mineralizable nitrogen of soils. Jour. Sci. Food Agr. 15:829-834.

24. Harmsen, G. W., and D. A. van Schreven. 1955. Mineralization of organic nitrogen in soil. Adv. Agron. 7:299-398.

25. Haylett, D. G., and J. J. Theron. 1955. Studies on the fertilization of a grass ley. Union of South Africa Dept. Agr. Sci. Bul. 351.

26. Herron, G. M., A. F. Dreier, A. D. Flowerday, W. L. Coleville, and R. A. Olson. 1971. Residual mineral N accumulation in soil and its utilization by irrigated corn. Agron. J. 63:322-327.

27. Hinman, W. C. 1964. Fixed ammonium in some Saskatchewan soils. Canadian Jour. Soil Sci. 44:151-157.

28. Hsaio, T. C. 1973. Plant response to water stress. Ann. Rev. Plant Physiol. 24:519-570.

29. Hsaio, T. C., et al. 1976. Water stress and dynamics of growth and yield of crop plants. In O. L. Lange et al. (eds) Water and Plant Life. Springer-Verlag.

30. Jansson, S. L. 1963. Balance sheet and residual effects of fertilizer nitrogen in a 6-year study with Nitrogen-15. Soil Sci. 95:31-37.

31. Jenny, H. 1930. A study on the influence of climate upon the nitrogen and organic matter content of the soil. Missouri Agr. Exp. Sta. Res. Bul. 152.

32. Jenny, H. 1941. Factors of soil formation. McGraw-Hill, New York.

33. Keeney, D. R., and J. M. Bremner. 1964. Effect of cultivation on the nitrogen distribution in soils. Soil Sci. Soc. Am. Proc. 28:653-656.

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

35. Kincaid, D. C., D. F. Heerman and E. G. Kruse. 1969. Application rates and runoff in center-pivot sprinkler irrigation. Trans. ASAE 12:790-797.

36. Landreau, P., Jr. 1953. Influence of cropping and cultural practices on the seasonal trends in nitrification rates of soils used for growing corn in Nebraska. Puerto Rico Univ. Agr. Exp. Sta. Tech. Paper 10.

37. Laura, R. D. 1974. Effects of neutral salts on carbon and nitrogen mineralization of organic matter in soil. Plant Soil 41:113-127.

38. Laura, R. D. 1975. The "A value" and the priming effect of nitrogen fertilizers on soil nitrogen. Soil Sci. Soc. Am. Proc. 39:596.

39. Legg, J. O. and F. E. Allison. 1960. Role of rhizosphere microorganisms in the uptake of nitrogen by plants. Internat. Congr. Soil Sci. Trans. 7th (Madison, Wis.) II:545-550.

40. Legg, J. O. and G. Stanford. 1967. Utilization of soil and fertilizer N by oats in relation to the available N status of soil. Soil Sci. Soc. Am. Proc. 31:215-219.

41. MacLean, A. A. 1964. Measurement of nitrogen supplying power of soils by extraction with sodium bicarbonate. Nature:1307-1308.

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

43. Muir, J., J. S. Boyce, E. C. Smith, P. N. Mosher, E. J. Deibert, and R. A. Olson. 1976. Influence of crop management practices on nutrient movement below the root zone in Nebraska soils. J. Envir. Qual. 5:255-259.

44. Newman, E. I. 1974. Root-soil water relations. In E. W. Carson (ed.) The Plant Root and Its Environment. Univ. Press of Virginia, Charlottesville.

45. Olson, R. A. 1974. Influence of fertilizer practices on water and the quality of the environment. Water Resources Research Inst. Proj. B-004 Nebr. Completion Report. Univ. of Nebraska.

46. Olson, R. A., and L. T. Kurtz. 1982. Crop nitrogen requirements, utilization and fertilization. In F. J. Stevenson (ed.) Nitrogen in Agricultural Soils. Agronomy 22:567-598.

47. Olson, T. C., and C. A. Onstad. 1974. The effect of soil water supply on corn fertilizer response. Trans. of ASAE 17:914-916.

48. Pair, C. H. 1975. Application rates and uniformity of application from mechanical move sprinkler systems. Proc. Irrigation Association Annual Technical Conference, pp. 71-82.

49. Pair, C. H., W. W. Hinz, C. Reid, and K. R. Frost. 1975. Sprinkler irrigation. Sprinkler Irrigation Association, Silver Springs, Maryland.

50. Pierre, W. H., L. Dumenil, Von D. Jolley, J. R. Webb, and W. D. Shrader. 1977. Relationship between corn yield, expressed as a percentage of the maximum and N percentages in the grain: I. Various N-rate experiments. Agron. J. 69:215-220.

51. Rhoades, F. M., R. S. Maksell and L. C. Hammond. 1978. Influence of water and fertilizer management on yield and water input efficiency of corn. Agron. J. 70:305-308.

52. Robinson, J. B. D. 1957. The critical relationship between soil moisture content in the region of wilting point and the mineralization of natural soil nitrogen. Jour. Agr. Sci. 49:100-105.

53. Shackley, D. R. 1953. A method of estimating total readily available moisture. Proc. of Annual Meeting ASAE, Chicago.

54. Smika, D. E., D. F. Heermann, H. R. Duke, and A. B. Battchelder. 1977. Nitrate N percolation through irrigated sandy soil as affected by water management. Agron. J. 69:623-626.

55. Stanford, G. 1982. Assessment of soil nitrogen availability. In F. J. Stevenson (ed.) Nitrogen in Agricultural Soils. Agronomy 22:651-682.

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

57. Stanford, G. and E. Epstein. 1974. Nitrogen mineralization-water relations in soils. Soil Sci. Soc. Am. Proc. 38:103-107.

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

59. Stewart, B. A. 1970. A look at agricultural practices in relation to nitrate accumulation. In Nutrient Mobility in Soils: Accumulation and Losses. Soil Sci. Soc. Am. Special publications No. 4, pp. 47-60.

60. Theron, J. J. 1965. The influence of fertilizers on the organic matter content of the soil under natural veld. South African Jour. Agr. Sci. 8:525-534.

61. Turner, G. O. and C. A. I. Goring. 1966. N = Serve . . . a status report. Down to Earth 22, No. 2:19-25.

62. Viets, F. G., Jr. 1965. The plants' need for and use of nitrogen. Agronomy 10:503-547.

63. Westerman, R. L., L. T. Kurtz, and R. D. Hauck. 1973. Priming effect of nitrogen-15 labeled fertilizers on soil nitrogen in field experiments. Soil Sci. Soc. Am. Proc. 37:725-727.

64. Westerman, D. T., and J. J. Meisinger. 1977. Residual nitrate and mineralizable soil nitrogen in relation to nitrogen uptake by irrigated sugarbeets. Agron. J. 69:303-308.

65. Westin, F. C. and D. D. Malo. 1978. Soils of South Dakota. Plant Sci. Bul. 656. S. D. Ag. Expt. Sta., Brookings, S. D.

APPENDIX A. Soil Water Parameters for the Research Area and Selected Farmer-Cooperator Sites.

Table A-1: Soil Physical Properties

	Depth (cm)	Bulk Density	-10 kPa Water Percentage (g/g x 100)	-1500 kPa Water Percentage (g/g x 100)	Available Water (cm/cm)
Researcher	25	1.17	30	11	.22
Managed	50	1.31	29	13	.21
Area	75	1.35	35	17	.24
Sites	25	1.15	30	11	.24
7, 8	50	1.25	31	10	.26
27, 28	75	1.31	36	15	.28
Sites	25	1.41	26	10	.23
11, 12	50	1.40	28	8	.28
29, 30	75	1.45	31	12	.28
Site	25	1.14	29	16	.15
24	50	1.35	29	15	.19
	75	1.36	28	17	.15

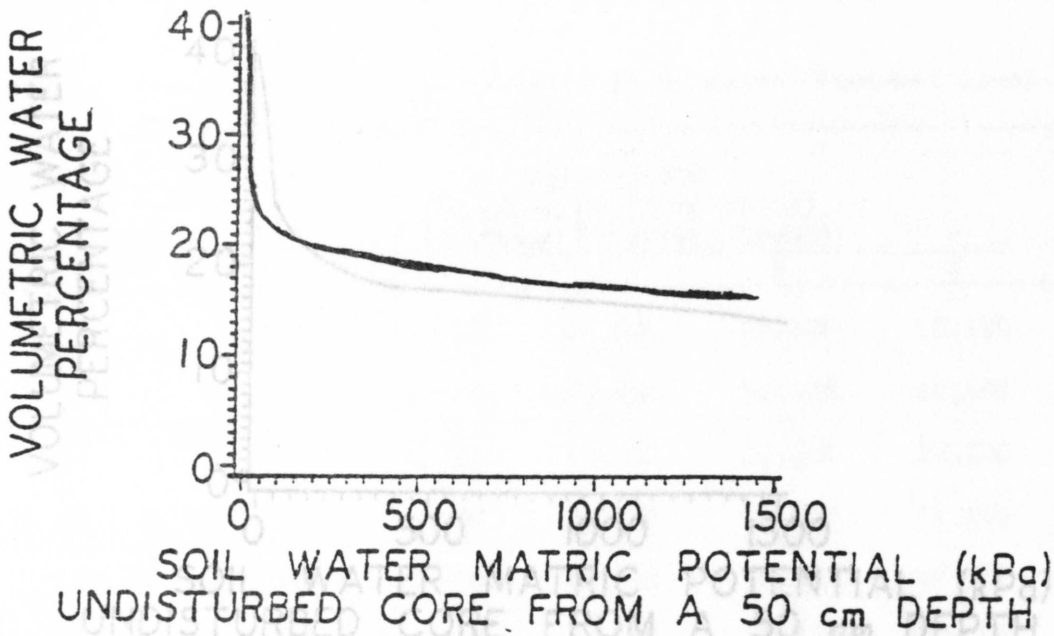

Figure A-1: Water Release Characteristic Curve for the Researcher Managed Area.

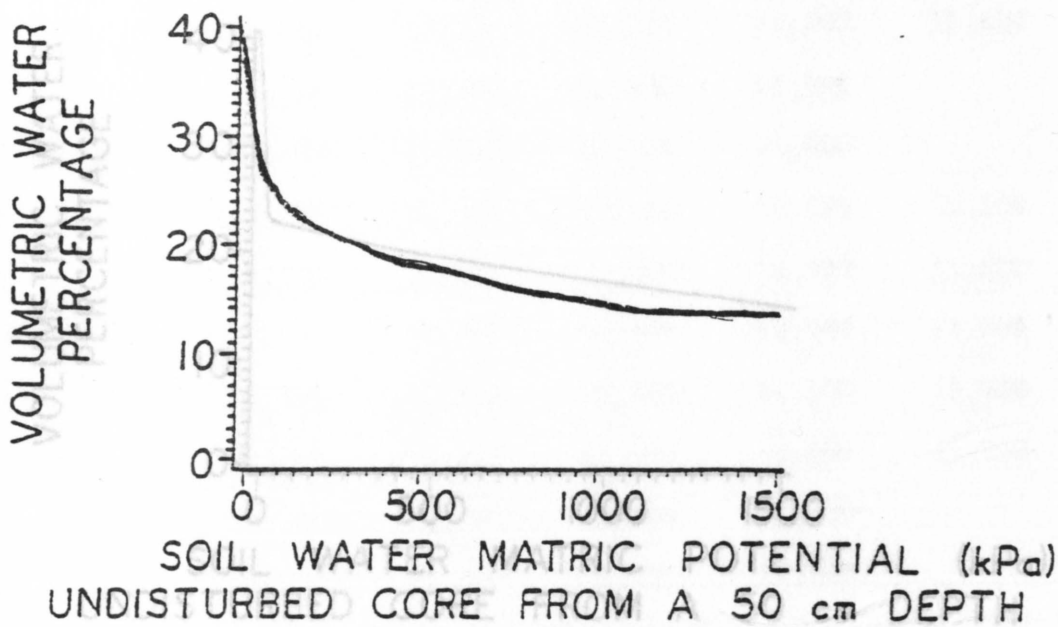

Figure A-2: Water Release Characteristic Curve for the NNSW and NNSWO Area (Sites 7, 8, 27, and 28).

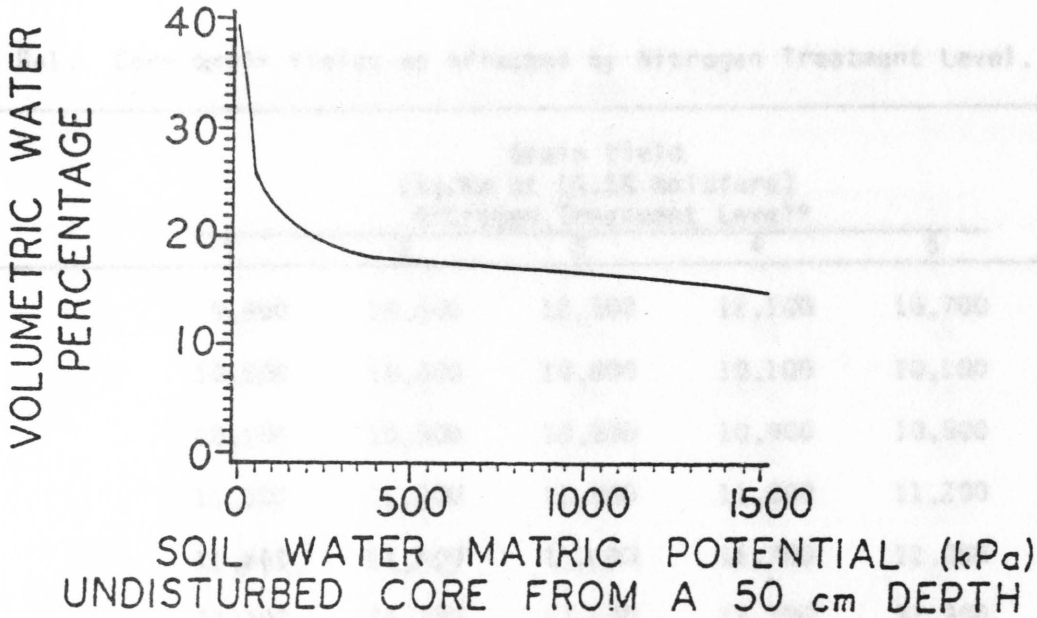

Figure A-3: Water Release Characteristic Curve for the ZNSO and ZNST Areas (Sites 11, 12, 29, and 30).

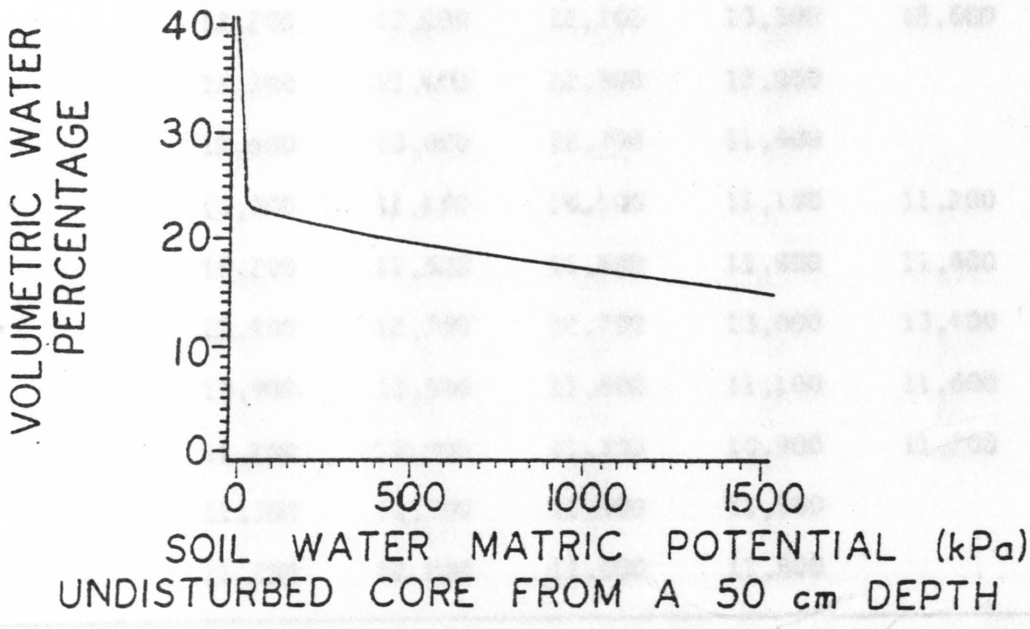

Figure A-4: Water Release Characteristic Curve for the RHS Area (Site 24).

APPENDIX B. Response of Selected Parameters at Farmer-Cooperator Sites.

Table B-1. Corn Grain Yields as Affected by Nitrogen Treatment Level.

Site	Grain Yield (kg/ha at 14.5% moisture) Nitrogen Treatment Level*				
	1	2	3	4	5
1	9,900	10,800	12,300	12,100	10,700
2	10,500	10,500	10,800	10,100	10,100
3	10,100	10,900	10,800	10,900	10,500
4	11,300	11,300	11,800	11,800	11,200
5	11,600	11,400	11,400	11,700	12,000
6	13,300	12,700	13,100	12,700	12,900
7	12,600	12,800	13,000	12,700	12,600
8	12,200	13,200	12,700	13,300	12,600
11	12,300	12,400	12,500	12,000	
12	12,600	13,000	12,700	11,900	
22	10,300	11,100	10,100	11,100	11,200
23	10,200	11,500	11,600	11,800	11,600
24**	12,400	12,700	12,700	13,000	13,400
27	10,900	10,500	11,600	11,100	11,600
28	11,200	10,900	11,300	10,900	11,200
29	11,300	11,700	11,800	11,500	
30	11,200	12,200	11,800	11,800	

* See Tables 5A, 5B, and 5C and the materials and methods portion of the text for definition of N treatment level.

**Levels 0, 6, and 7 yielded 12,000, 13,200, 12,800, respectively at site 24.

APPENDIX B. Response of Selected Parameters at Farmer-Cooperator Sites.

Table B-2. Percent Attainment of Maximum Nitrogen Treatment Yield at each Site as Affected by Nitrogen Treatment Level*

Site	Nitrogen Treatment Level*				
	1	2	3	4	5
1	81	88	100	98	87
2	97	97	100	94	94
3	93	100	99	100	96
4	96	96	100	100	95
5	97	95	95	98	100
6	100	95	98	95	97
7	97	98	100	98	97
8	92	99	95	100	95
11	98	99	100	96	
12	97	100	98	92	
22	93	99	91	99	100
23	86	97	98	100	98
24**	93	95	95	97	100
27	94	91	100	96	100
28	99	96	100	96	99
29	96	99	100	97	
30	92	100	97	97	

* See Tables 5A, 5B, and 5C and the materials and methods portion of the text for definition of N treatment level.

**Levels 0, 6, and 7 produces 90, 99 and 96 percent of maximum yield at site 24.

APPENDIX B. Response of Selected Parameters at Farmer-Cooperator Sites.

Table B-3. Leaf Nitrogen Content at Silking as Affected by Nitrogen Treatment Level.

Site	Leaf Nitrogen Content (%) Nitrogen Treatment Level*				
	1	2	3	4	5
1	2.13	2.54	2.64	2.75	2.49
2	2.81	2.81	2.80	2.81	2.81
3	2.90	2.91	2.87	2.96	3.01
4	2.73	2.76	2.73	2.78	2.89
5	2.76	3.05	3.09	2.96	3.00
6**	3.04	3.07	3.17	3.10	3.07*
7	2.75	2.80	2.91	2.95	2.90
8	2.87	2.82	2.89	2.93	2.92
11	2.63	2.76	2.75	2.88	
12	2.64	2.70	2.77	2.82	
22	2.49	2.49	2.37	2.70	2.72
23	2.29	2.50	2.53	2.61	2.72
24	2.34	2.47	2.70	2.73	2.82
27	Not available				
28	Not available				
29	2.75	2.92	3.13	3.10	
30	2.51	2.90	2.83	2.86	

* See Tables 5A, 5B, and 5C and the materials and methods portion of the text for definition of N treatment level.

**Corn hybrid Pioneer 3709 instead of Pioneer 3780.

APPENDIX B. Response of Selected Parameters at Farmer-Cooperator Sites.

Table B-4. Soil Nitrate-Nitrogen at Silking Time as Affected by Nitrogen Treatment Level.

	Nitrate-Nitrogen (kg/ha) Nitrogen Treatment Level*									
	1		2		3		4		5	
	Sampling Depth (cm)									
Site	60	120	60	120	60	120	60	120	60	120
2	255	331	238	380	156	213	206	301	261	390
3	57	104	116	171	166	214	286	408	300	507
4	63	121	85	171	162	256	264	327	158	335
5	49	84	72	151	132	231	241	371	348	467
6	125	184	169	267	208	336	208	375	198	361
7	32	88	30	146	45	169	45	121	60	179
8	38	125	31	127	68	167	48	171	60	151
22	98	171	39	86	25	65	35	100	62	149
23	32	60	47	114	77	158	131	262	309	579
24	49	67	84	101	159	186	43	56	75	93
29	57	196	84	278	277	532	617	900		
30	25	139	141	339	320	725	726	1141		

* See Tables 5A, 5B, and 5C and the materials and methods portion of the text for definition of N treatment level.

APPENDIX B. Response of Selected Parameters at Farmer-Cooperator Sites.

Table B-5. Nitrogen Content of Plants at Physiological Maturity as Affected by Nitrogen Treatment Level.

Site	Whole Plant Nitrogen Content (%) Nitrogen Treatment Level*				
	1	2	3	4	5
3	1.25	1.24	1.17	1.24	1.39
4	1.08	1.08	1.03	1.13	1.12
5	1.05	1.18	1.21	1.14	1.17
7	1.12	1.11	1.21	1.10	1.31
8	1.11	1.26	1.25	1.22	1.17
22	0.97	1.06	1.04	1.04	1.16
23	1.00	1.12	1.16	1.17	1.23
24**	1.05	1.18	1.20	1.22	1.26

* See Tables 5A, 5B, and 5C and the materials and methods portion of the text for definition of N treatment level.

**Levels 0, 6, and 7 showed concentrations of 1.00, 1.25, and 1.24%, respectively.

APPENDIX B. Response of Selected Parameters at Farmer-Cooperator Sites.

Table B-6. Grain Nitrogen Content as Affected by Nitrogen Treatment Level.

Site	Grain Nitrogen Content (%)				
	Nitrogen Treatment Level*				
	1	2	3	4	5
2	1.60	1.55	1.52	1.61	1.54
3	1.50	1.57	1.58	1.58	1.57
4	1.56	1.54	1.56	1.59	1.64
5	1.37	1.53	1.52	1.43	1.47
6**	1.29	1.21	1.30	1.30	1.35
7	1.46	1.54	1.48	1.49	1.40
8	1.44	1.39	1.50	1.44	1.45
11	1.45	1.50	1.50	1.49	
12	1.37	1.42	1.37	1.47	
22	1.39	1.36	1.28	1.41	1.36
23	1.28	1.35	1.37	1.40	1.33
24	1.31	1.43	1.37	1.47	1.45
27	1.35	1.48	1.42	1.49	1.44
28	1.38	1.42	1.47	1.49	1.51
29	1.44	1.43	1.43	1.42	
30	1.35	1.40	1.37	1.44	

* See Tables 5A, 5B, and 5C and the materials and methods portion of the text for definition of N treatment level.

**Corn variety Pioneer 3709 used instead of Pioneer 3780.

APPENDIX B. Response of Selected Parameters at Farmer-Cooperator Sites.

Table B-7. Nitrate-Nitrogen Remaining in the Soil After the Growing Season.

		Sites Receiving Variable Rates of Fertilizer Nitrogen Treatment Level*									
		1		2		3		4		5	
		Depth (cm)									
Site	Year	60	120	60	120	60	120	60	120	60	120
2	1979	219	305	209	334	328	390	291	381	496	612
3	1979	107	172	143	248	146	294	273	651	584	903
4	1979	51	83	46	124	41	125	156	273	291	364
5	1979	28	76	88	182	91	151	131	225	197	323
6	1979	89	136	94	171	143	243	143	340	248	333
7	1979	21	61	64	162	123	246	168	248	334	560
8	1979	47	115	47	122	156	273	228	366	338	488
22	1980	24	51	29	54	18	38	19	59	22	74
24**	1980	12	38	15	42	42	71	59	91	104	134

* Rates 0, 7, and 8 had 120 cm nitrate-N of 33, 41, and 72 kg/ha respectively.

**Corn variety Pioneer 3709 used instead of Pioneer 3780.

		Sites Receiving Set Rates of Fertilizer Nitrogen Nitrogen Treatment Level*									
		1		2		3		4		5	
		Depth (cm)									
Site	Year	60	120	60	120	60	120	60	120	60	120
1	1979	25	54	121	459	112	309	129	458	27	53
11	1979	38	177	98	292	120	339	316	530		
12	1979	57	246	85	257	152	463	372	685		
29	1980	60	167	87	280	244	450	488	775		
30	1980	65	222	139	312	304	640	580	972		

		Sites Repeated in 1979 Nitrogen Treatment Level*									
		1		2		3		4		5	
		Depth (cm)									
Site	Year	60	120	60	120	60	120	60	120	60	120
23	1980	23	42	25	60	33	73	40	135	121	331
27	1980	15	41	22	66	27	104	39	107	52	150
28	1980	20	60	19	54	29	108	50	143	61	201

* See Tables 5A, 5B, and 5C and the materials and methods portion of the text for definition of N treatment level.

APPENDIX C. Nitrate-Nitrogen Sampling Depth and Time Considerations.

Two factors involved in the sampling of fields are to be dealt with in this section. These are vertical distribution of nitrate-N and differences noted in nitrate-N concentration between fall and spring samples.

The models developed employed spring soil samples to a depth of 120 cm for predictive purposes. On a practical scale, soil samples are often taken in the fall. No adjustment for fall sampling is presently made in South Dakota. The researcher-managed area and five farmer cooperator sites were sampled on a plot by plot basis in mid-October of 1979 and again in March of 1980 to a 120 cm depth. This sampling included 140 individual plots. Spring samples consistently exhibited higher nitrate ion concentration than samples from the same plots taken the previous fall. Regression analysis to predict spring nitrate-N content of these plots from fall samples produced the equation:

$$\text{Spring Nitrate-N in kg/ha (120 cm)} = 62 + 1.0 \times \text{Fall Nitrate-N in kg/ha (120 cm)} \quad R^2 = .590$$

Analysis of residuals produced by this equation plotted against the actual total nitrogen measured in the spring indicates that at low nitrate-N levels (< 100 kg/ha) this equation over-predicted actual over-winter mineralization, while at values greater than 100 kg/ha it under-predicted this phenomena.

Residuals plotted against years farmed and irrigated indicates that this equation over predicts mineralization on new sites and under-predicts this value on sites 11 and 12 which had been irrigated for 13

APPENDIX C. Nitrate-Nitrogen Sampling Depth and Time Considerations (Continued).

years.

Definitive conclusions cannot be drawn from this analysis since it involves only one year of data. The winter of 1979-80 was very mild, which may also have exaggerated this factor. It is possible to speculate on some likely causes for these differential over-winter mineralization values. Plots containing high nitrate concentration in the fall of 1979 probably in general produced roots and microbial tissue with higher nitrogen contents than soils that were drawn to low values. It is logical to expect plots containing higher N materials to produce more net mineralization since less immobilization would take place. This logic would explain the systematic deviations noted in plots of residuals versus spring nitrate-N content.

The previous explanation could be used to justify the higher than predicted values obtained at sites 11 and 12. On examination of plant nitrogen contents of these sites as compared to plant nitrogen contents under the high levels at the other sites included in this analysis, it seems that this may not be the only explanation for the larger amount of over-winter mineralization noted here. As stated in the body of this paper, sites 11 and 12 occupied a backslope position and had historically shown poorer growth due to water stress; therefore, the N content of the plant tissue returned to this soil for the last 13 years may have been relatively high in nitrogen. This factor, combined with the results of the sodium bicarbonate extraction analysis cited in the main

APPENDIX C. Nitrate-Nitrogen Sampling Depth and Time Considerations (Continued).

text may indicate that sites 11 and 12 had higher potential for mineralization. This data certainly cannot be used to draw conclusions but is circumstantial evidence.

Either one or both of the above explanations may be used to justify the differential overwinter mineralization noted. The important fact is that it took place. Perhaps it was only the consequence of one non-typical year. The data suggests that if fall samples are to be used for assessment of nitrogen fertilizer needs, this factor may need more investigation.

Since spring sampling was used for most of this work and previous fall samples were not available for most sites, there is no way of determining if differential over-winter mineralization partially obscured mineralization differences during the growing season and therefore reduced the ability to detect these differences. This possibility should be considered when reviewing the research results.

The other factor that may affect both the models and practical applications of the nitrate test is spatial variability of nitrate. This factor was mentioned in the main text. Since soil sampling involved the compositing of three subsamples per plot and was confined to small areas in a field, horizontal variability cannot be assessed using this data. It was thought that the procedure of dividing samples on the basis of depth would provide insight into vertical variability and the evaluation of total mean nitrate concentration to a 120 cm depth

APPENDIX C. Nitrate-Nitrogen Sampling Depth and Time Considerations (Continued).

based on samples collected at shallower depths. Practical considerations such as time constraints, equipment availability, and the presence of underground cables and pipelines often preclude or at the very least limit the feasibility of collecting samples to a depth of 120 cm.

These data were analyzed in two primary ways. The first deals with the prediction of 60-120 cm nitrates from the concentrations found in the 0-60 cm profile. Regression analysis produced the equation:

Nitrate-N in kg/ha (60-120 cm) = .93 nitrate N in kg/ha (0-60 cm) + 7 kg nitrate-N/ha.

This relationship had an R^2 of 0.772. Residual analysis indicated that substantially more random variation in predictive capability was associated with high nitrate-N concentrations. This, of course, was expected. Systematic under-prediction was associated with high nitrate plots that had received low rates of fertilizer in 1979 and were sampled in the spring of 1980. Nitrate concentration in the surface 60 cm was depleted more than the concentration in the 60-120 cm profile. This factor was mentioned in the main text. Over-prediction of deep nitrates was associated with plots initially low in nitrates that received large amounts of fertilizer nitrogen.

From a practical standpoint it was thought that evaluation of the ability of total nitrate-N measured to a depth of 60 or 90 cm to predict total nitrate N to 120 cm would be of more value than the first analysis procedure. This relationship will possess covariation since the 0-60 or

APPENDIX C. Nitrate-Nitrogen Sampling Depth and Time Considerations (Continued).

0-90 cm nitrate-N concentration is contained on both sides of the equation. These procedures do place more perspective into the ability of shallow samples to predict total nitrate-N in a deeper profile than did the prior analysis.

Regression analysis of all spring samples produced the following equations:

Nitrate N in kg/ha (0-120 cm) = 18 kg of nitrate-N/ha + 1.8 nitrate-N in kg/ha (0-60 cm)
$R^2 = .855$

Nitrate N in kg/ha (0-120 cm) = 7 kg of nitrate-N/ha + 1.2 nitrate-N in kg/ha (0-90 cm)
$R^2 = .977$

Residual analysis, as expected, indicated more random error in these equations at high nitrate-N levels. Substantially more random error was associated with predictions using a 60 cm sampling depth than when the 90 cm samples were used. This was expected. Systematic error was associated with the factors of prior nitrate level and fertilization mentioned before. These errors were reduced by the use of the 90 cm sample as demonstrated by the improvement in R^2 from .855 to .977. The relationships between predicted and actual 120 cm nitrate-N concentrations for 60 and 90 cm samplings are depicted in figures C-1 and C-2, respectively.

This analysis included spring samplings from all farmer sites and the researcher managed area for both years. Since systematic variations were associated with sites that were repeated in 1979, it was felt

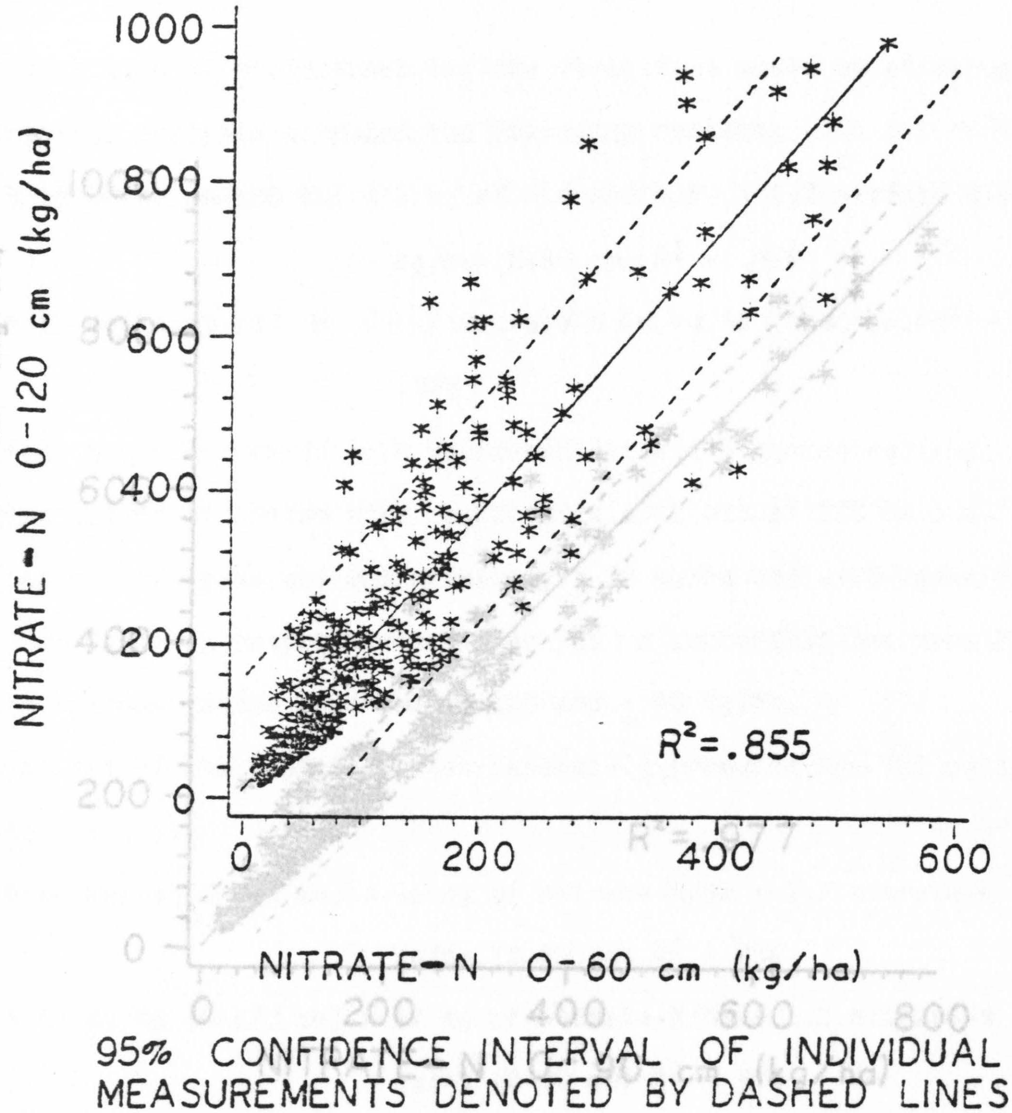

Figure C-1: Relationship Between Total Nitrate-N Sampled to a Depth of 60 cm and Total Nitrate-N Sampled to a Depth of 120 cm.

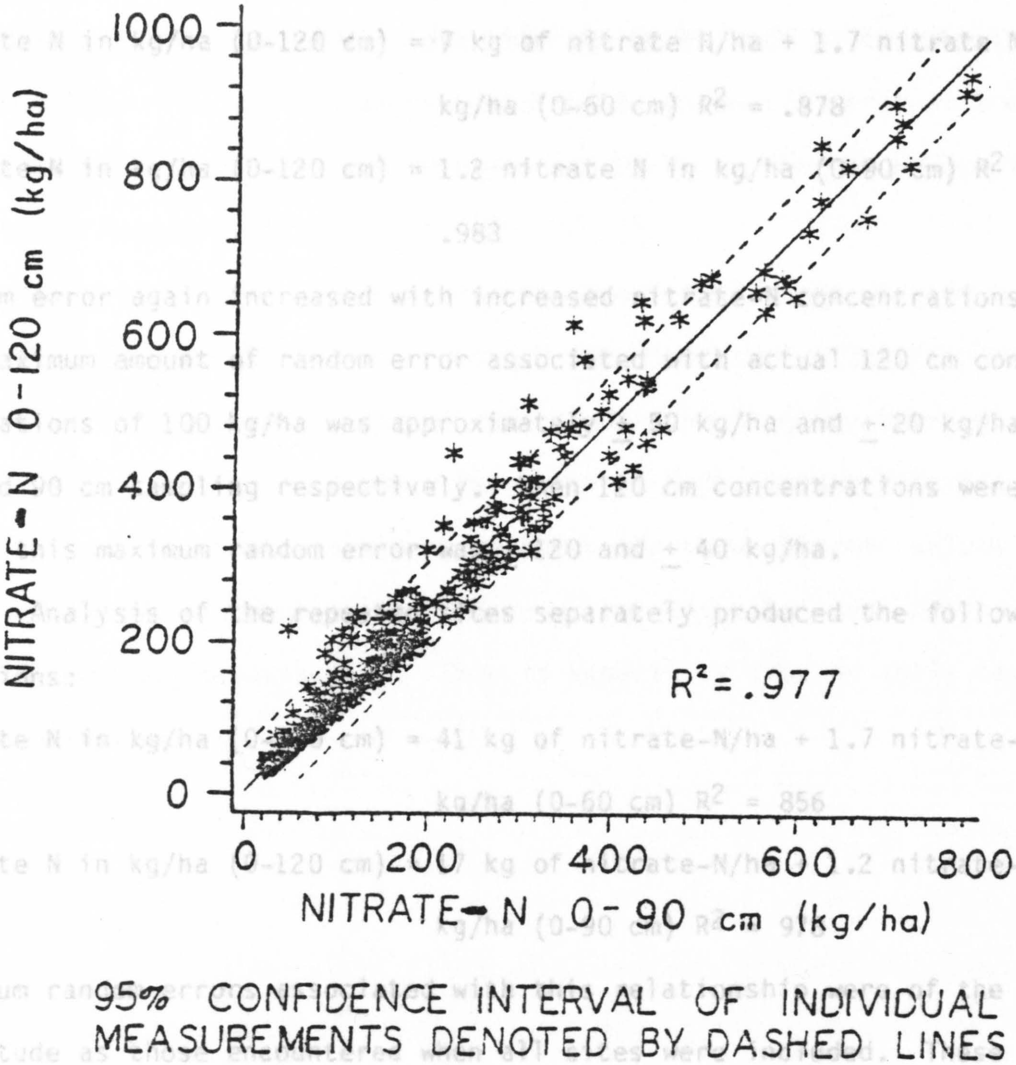

Figure C-2: Relationship between Total Nitrate-N Sampled to a Depth of 90 cm and Total Nitrate-N Sampled to a Depth of 120 cm.

APPENDIX C. Nitrate-Nitrogen Sampling Depth and Time Considerations (Continued).

analysis involving sites included for the first time would be of value. This regression analysis produced the following results:

Nitrate N in kg/ha (0-120 cm) = 7 kg of nitrate N/ha + 1.7 nitrate N in kg/ha (0-60 cm) R^2 = .878

Nitrate N in kg/ha (0-120 cm) = 1.2 nitrate N in kg/ha (0-90 cm) R^2 = .983

Random error again increased with increased nitrate-N concentrations. The maximum amount of random error associated with actual 120 cm concentrations of 100 kg/ha was approximately ± 50 kg/ha and ± 20 kg/ha for 60 and 90 cm sampling respectively. When 120 cm concentrations were 200 kg/ha this maximum random error was ± 120 and ± 40 kg/ha.

Analysis of the repeated sites separately produced the following equations:

Nitrate N in kg/ha (0-120 cm) = 41 kg of nitrate-N/ha + 1.7 nitrate-N in kg/ha (0-60 cm) R^2 = 856

Nitrate N in kg/ha (0-120 cm) = 17 kg of nitrate-N/ha + 1.2 nitrate-N in kg/ha (0-90 cm) R^2 = 978

Maximum random errors associated with this relationship were of the same magnitude as those encountered when all sites were included. These values were on the order of ± 55 kg/ha and ± 34 kg/ha when 100 kg of total nitrate-N/ha was present and ± 134 and ± 70 kg/ha when 200 kg of nitrate-N/ha was present for the 60 and 90 cm sampling depths, respectively. The equations developed on these repeated sites systematically.

APPENDIX C. Nitrate-Nitrogen Sampling Depth and Time Considerations (Continued).

over-predicted nitrate-N concentration on plots that contained less than 150 kg of nitrate-N/ha to 120 cm when 60 cm sampling was used and where total nitrate-N to 120 cm was less than 100 kg/ha when 90 cm sampling was employed. The maximum magnitude of this systematic error at the 100 kg/ha nitrate-N level was 50 kg/ha and 15 kg/ha for the 60 and 90 cm samplings, respectively.

These data were presented for the benefit of those wishing to adapt the concepts outlined in this paper to practical situations. The results of this analysis indicate that deeper sampling may have value in special situations such as where reduction of high nitrate-N levels in soils is involved. The excellent relationship shown between values obtained by shallow samples and 120 cm values indicates that deep sampling may not be necessary. This is especially true on soils testing low in nitrates.

APPENDIX D. Reducing Extractant Volumes and Flask Size for Sodium Bicarbonate Extraction of Surface Soil Samples.

Extraction of soil organic components with a dilute (0.01 M) sodium bicarbonate solution was cited in the main text as a possible method of evaluating a soil's potential for mineralization. This procedure was originally developed by MacLean (1967) and later modified by Fox and Piekelek (1972). The original procedure of MacLean employed 5 grams of soil sample extracted with 100 ml of a .01 M $NaHCO_3$ solution by shaking in 250 ml flasks for 15 minutes at 120 cycles per minute. Following filtration the extract was submitted to standard digestion and distillation steps followed by determination of ammonium content of the distillate by nesslerization. These procedures are too laborious and time consuming to be of value for routine soil analysis.

Fox and Piekelek (1972) adapted the procedure to include direct analysis of the extract following filtration by using ultra violet spectroscopy. This eliminates the need for titration, distillation, and nesslerization of the distillate. They used a wavelength of 260 nm for their analysis. Absorbance in this wavelength is associated with the $\pi \rightarrow \pi^*$ transition in conjugated hydrocarbons (Banwell, 1966) and therefore does not measure nitrogen content but rather assesses the concentration of the organic materials in this extract. Jenkinson (1968) cited the ability of this test to assess "glucose type" materials.

Although the field research methods were not precise enough to indicate measurable differences in net mineralization, it was felt analysis using the techniques of Fox and Piekelek would provide insight

APPENDIX D. Reducing Extractant Volumes and Flask Size for Sodium Bicarbonate Extraction of Surface Soil Samples (Continued).

into the differences that exist in the amount of easily oxidizable organic materials present in these soils as affected by past management.

The use of their techniques on the large number of surface soil samples involved in the study provided some logistical problems. The large amount of extracting solution used and the limitation in the number of samples that could be simultaneously placed on a mechanical shaker with 250 ml flasks precluded the use of their techniques for this purpose.

A laboratory study was initiated to investigate the possibility of reducing extractant volume and flask size. Three flask size-extracting solution volume combinations were used. These were 250 ml flasks with 100 ml of extracting solution, 125 ml flasks with 50 ml of extracting solution and 50 ml flasks (in shaking racks) with 20 ml of extracting solution. Five grams of soil were used in all cases.

Three soil samples were selected for this procedure. They were chosen to reflect a range in organic matter content by using soils from different depths. A surface soil (0-15 cm), a soil from the 15-30 cm depth, and a deep sample (60-90 cm) from the researcher managed area were used.

Application of the original techniques of Fox to these samples produced absorbance values on the order of .57, .33 and .13 for the three depths. Beer's law calculations indicated that reductions in extracting volumes from 100 ml to 50 and 20 ml would produce absorbances

APPENDIX D. Reducing Extractant Volumes and Flask Size for Sodium Bicarbonate Extraction of Surface Soil Samples (Continued).

beyond the range most desirable (.2 to .6) for analysis purposes if extraction efficiency was not reduced substantially. Since the values associated with the surface sample using the original technique were near the top end of this range, it was decided to dilute the extract prior to analysis when reduced extracting volumes were used. Dilutions of 1:1 and 1:2 of extract and sodium bicarbonate solution were used for the 50 ml and 20 ml extracting solution procedures respectively.

Four replicates of 5 g of each soil sample were assigned to flasks of each size at random. This procedure was repeated on each of two days using different operators.

The flasks were simultaneously shaken at 120 OPM for 15 minutes. The suspensions were filtered through #5 Whatman filters (cloudy filtrate was re-filtered). A 10 ml aliquot of filtrate was pipetted to test tubes followed by dilution with 10 and 20 ml of the .01 M sodium bicarbonate solution for the extracts from the 125 ml and 50 ml flasks respectively.

The absorbance of these samples was measured at 260 nm in matched sprasil quartz cells with a pathlength of 1.0 cm using a Bausch and Lomb spectronic 2000 spectrophotometer. Sodium bicarbonate solution was employed as the blank in this double beam instrument.

Correlations of .993 and .994 were achieved between the absorbance values obtained by the original procedure and those employing 125 ml and 50 ml flasks respectively (R^2 = .987 and .988). The excellent

APPENDIX D. Reducing Extractant Volumes and Flask Size for Sodium Bicarbonate Extraction of Surface Soil Samples (Continued).

results obtained with the small flasks made further examination of the results from the samples in the 125 ml flasks unnecessary. The regression equation describing the relationship between absorbance values using the original procedure and the 50 ml flasks was: Absorbance (250 ml flasks) = -.027 + 1.36 Absorbance (50 ml flasks) (See Table D-1). Correlation between operators was .998.

The modified procedure produced surface soil sample absorbances on the order of .4 which is in the desirable range for analysis purposes.

The procedure utilizing the small flasks was refined further by placing the soil suspension into centrifuge tubes following shaking. These were centrifuged at 3150 rpm for 45 seconds. A 10 ml aliquot of the supernatant liquid was combined with 20 ml of sodium bicarbonate solution prior to filtering. This procedure facilitated filtration substantially and did not affect absorbance values. (A regression of three soil samples replicated four times using these two methods produced the equation: $Y = 0.001 + 1.00$ ($R^2 = .996$), where Y represents absorbances from extracts employing the centrifuge. The last procedure was the method used to obtain the absorbance values reported in the main text.

The modified procedures reported here should greatly facilitate the practical application of sodium bicarbonate extraction techniques if future research indicates that such a test would be valuable for

APPENDIX D. Reducing Extractant Volumes and Flask Size for Sodium Bicarbonate Extraction of Surface Soil Samples (Continued).

inclusion in routine soil testing analysis.

Figures D-1, D-2, and D-3 show the absorbance spectra over the range from 200 to 300 nm for the surface soil extract using the original method of Fox and Piekelek, for the sodium bicarbonate extractant versus a water blank and for a 1 ppm nitrate solution, respectively. Analysis of a 100 ppm nitrate solution indicated that no error in absorbance would be expected from nitrate at 260 mm.

Table D-1. Absorbance of sodium bicarbonate extracts of soil using various flask size-extracting volume combinations.

Soil	Rep	Flask Size 250 ml	125 ml	50 ml
		Operator 1 - D. Beck 2/28/82		
1	1	.572	.438	.436
	2	.557	.421	.418
	3	.546	.428	.423
	4	.548	.430	.431
2	1	.358	.260	.252
	2	.334	.249	.241
	3	.320	.266	.262
	4	.318	.263	.253
3	1	.126	.100	.121
	2	.127	.115	.120
	3	.125	.111	.115
	4	.135	.106	.115
		Operator 2 - B. Bauer 3/1/82		
1	1	.566	.431	.427
	2	.547	.418	.419
	3	.544	.426	.424
	4	.543	.430	.437
2	1	.351	.256	.246
	2	.329	.218	.271
	3	.320	.256	.243
	4	.322	.262	.253
3	1	.128	.101	.121
	2	.127	.115	.120
	3	.123	.111	.114
	4	.132	.110	.115

Absorbance (250 ml flask) = -.027 + 1.36 Absorbance (50 ml flask)

R^2 = .988

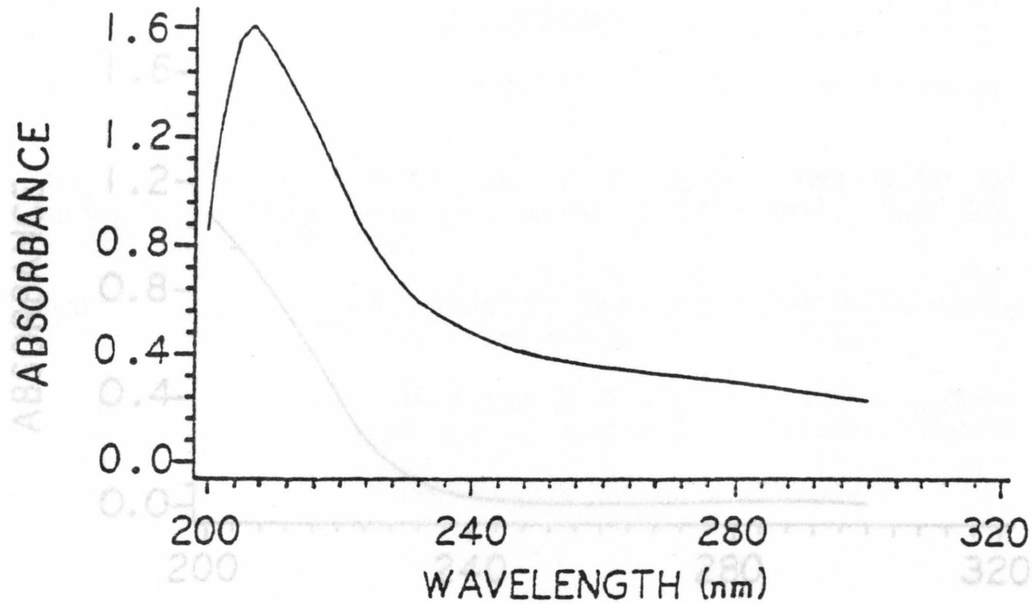

Figure D-1: Absorbance Spectrum of a Sodium Bicarbonate Extract of Surface Soil.

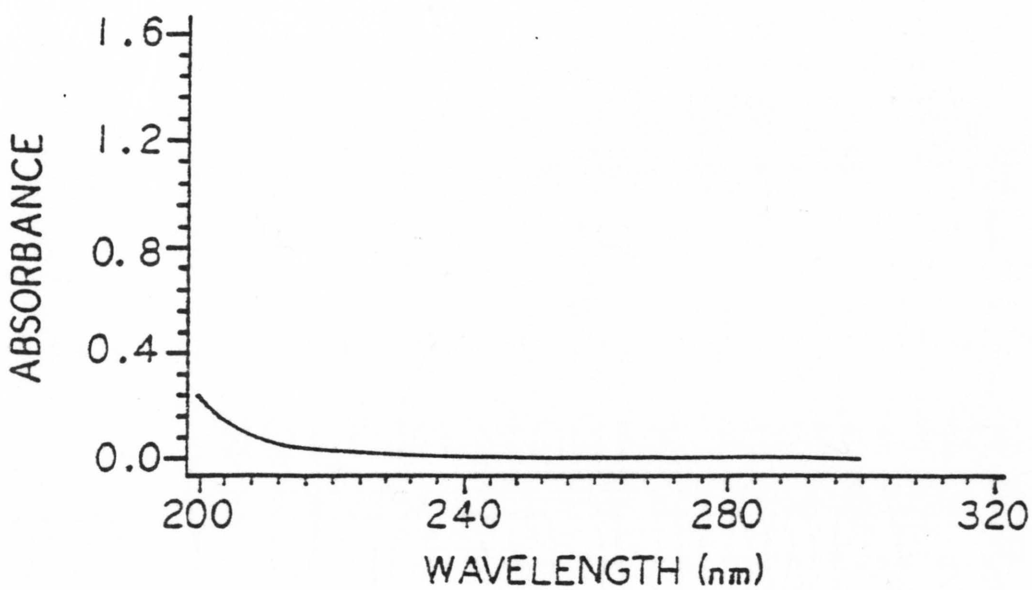

Figure D-2: Absorbance Spectrum of 0.01 M Sodium Bicarbonate Solution.

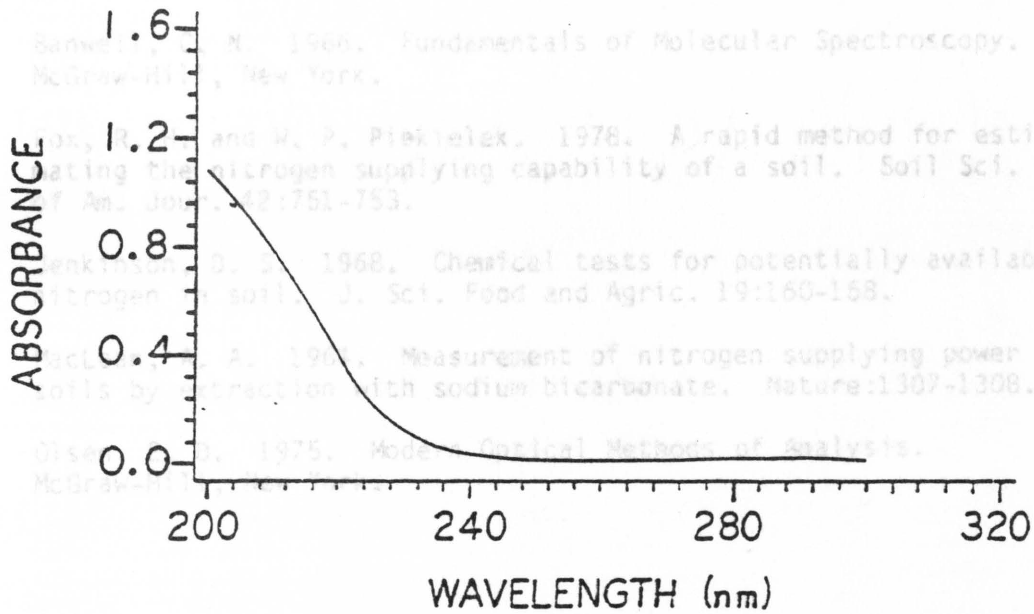

Figure D-3: Absorbance Spectrum of a 1 ppm N (as nitrate) Solution.

CITED LITERATURE

1. Banwell, C. N. 1966. Fundamentals of Molecular Spectroscopy. McGraw-Hill, New York.

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

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

4. MacLean, A. A. 1964. Measurement of nitrogen supplying power of soils by extraction with sodium bicarbonate. Nature:1307-1308.

5. Olsen, E. D. 1975. Modern Optical Methods of Analysis. McGraw-Hill, New York.