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CONTENTS

Page

Nitrate in the Environment
J. Les Henry, University of Saskatchewan and Bill Meneley, W.A. Meneley Consultants 1

Spatial Variability of Nitrate-N in Nebraska Corn Fields
Gary Hergert, C.A. Shapiro, F.N. Anderson, R.B. Ferguson, and E.J. Penas, University of Nebraska 15

The Need for Regional Fertilizer Recommendation Guidelines
Dale Leikam, Farmland Industries 26

Soil Fertility Analysis Using Ion Exchange Membranes
J.J. Schoenau, W. Huang, and P. Qian, University of Saskatchewan 32

Evaluation of Chlorophyll Meters for Nitrogen Management
J.S. Schepers, USDA-ARS, R. Follett, Colorado State University, and A. Blaylock, University of Wyoming . . . 40

Economics of Dryland Crop Rotations for Efficient Water and Nitrogen Use
Gary Peterson, and D.G. Westfall, Colorado State University; A.D. Halvorson, USDA-ARS University 47

Long-Term Rotation Effect on Crop Production and Soil Quality
A.M. Johnston and H.H. Janzen, Agriculture Canada Research Station, Lethbridge, Alberta 54

Soil Erosion - Productivity Relationships for Dryland Winter Wheat
John L. Havlin, H. Kok, Kansas State University and W. Wehmueller, USDA-SCS 60

Nutrient Requirements of Canola
Jeff S. Jacobsen, Montana State University; D. Marantz, Cominco Fertilizers; C.A. Grant and L.D. Bailey, Agriculture Canada 66

Soil Fertility and Tillage Management for Sunflower Production in the Great Plains
A.L. Black, USDA-ARS 71

An Overview of Nitrification Inhibitors and Slow Release N Fertilizers.
Merle F. Vigil, USDA-ARS; J.C. Yeomans, University of Manitoba; R.E. Lamond and A.J. Schlegel, Kansas State University 77

The Effects of Nitrogen Fertilizer on Soil
David A. Whitney, L.R. Stone, K.A. Janssen, and J.H. Long, Kansas State University 84

Sulphur Fertilization of Bromegrass in Kansas
Ray E. Lamond, D.A. Whitney, Kansas State University . . 91

Phosphorus Relationships in No-Till Small Grains
Grant D. Jackson, R.K. Berg, G.D. Kushnak, G.R. Carlson, and R.E. Lund, Montana State University 95

Soil Tests for Phosphorus Bioavailability
G.M. Pierzynski, S.J. Thien, and R.G. Myers, Kansas State University 100

Land Tenure Effects on Phosphorus Management
Paul E. Fixen, Potash & Phosphate Institute and A.D. Halvorson, USDA-ARS 106

Planting Date Interaction with Methods of P Application for Wheat
D.H. Sander, University of Nebraska 111

Nitrogen Management in No-Till Corn
G. Carlson, J. Ojiem, R.E. Lamond, and J.L. Havlin, Kansas State University 117

Nitrogen Uptake and Transport Under Varying Moisture Regimes Cropped to Malting Barley
Dennis R. Hengel, W.P. Inskeep, and J.S. Jacobsen, Montana State University 122

Nitrogen Management in Irrigated Ridge-Till Corn
W.B. Gordon, D.A. Whitney, and R.J. Raney, Kansas State University 128

Influence of Simulated Erosion and Subsequent Amendments on Spring Wheat Yield
Frank J. Larney, C.W. Lindwall, and H.H. Janzen, Agriculture Canada, and B.M. Olson, Caledonia Terra Research 134

Relationship Between Soil Quality Criteria and Yield
H. Henry Janzen, F.J. Larney, Agriculture Canada, and B.M. Olson, Caledonia Terra Research 140

An Alternative Crop Rotation for the Eastern Great Plains
William F. Heer, J.L. Havlin, and D.L. Fjell, Kansas State University 147

Landscape Based Variable Rate Fertilization
Jane Elliot and E. de Jong, University of Saskatchewan . 153

Digital Elevation Model Attributes for Predicting Soil Fertility
Kirk L. McEachern, J.S. Jacobsen, G.A. Nielsen, and J.P. Wilson, Montana State University 160

Spatial Variation of Soil Nitrate Within a Continuously Cropped Agricultural Field
E.A. Guertal, R.L. Westerman, and R.K. Boman, Oklahoma State University 165

Enhanced Ammonium Nutrition of Wheat
Bill L. Pan, R.T. Koenig, Washington State University, and Bert Bock, TVA 170

Thirty Years of N and P Fertilization of Irrigated Corn and Grain Sorghum
Alan J. Schlegel, J.L. Havlin, and K. Dhuyvetter, Kansas State University 177

Nitrogen Management for Irrigated Sugarbeets
Alan D. Blaylock, J.G. Lauer, and J.M. Krall, University of Wyoming 188

Phosphorus Fertilization Effects on Winter Wheat Production in Acid Soils
R.K. Boman, R.L. Westerman, G.V. Johnson, and M.E. Jojola, Oklahoma State University 195

Response of Dryland Winter Wheat to Residual P
Ardell D. Halvorson, USDA-ARS and J.L. Havlin, Kansas State University 201

Phosphorus Placement and Rate in Hard Red Winter Wheat in South Dakota
Howard J. Woodard, J. Gerwing, R. Gelderman, South Dakota State University 207

Differing Responses of Popular Spring Wheat Varieties to P Fertilization
Jay Goos, B.E. Johnson, and J. Feuchtenbeiner, North Dakota State University 213

P and K Fertilizer Placement in Alfalfa
Cynthia A. Grant, Agriculture Canada; J.L. Havlin and D.W. Sweeney, Kansas State University; L.D. Bailey and R.G. Simmons, Agriculture Canada 219

Plant Stage and Methods for Assessing Phosphorus Status of Spring Wheat
D. J. Tomasiewicz and G.J. Racz, University of Manitoba 225

A Summary of Chloride Research in the Great Plains
Rick Engel, Montana State University; J.L. Sanders, Potash & Phosphate Institute; and H. Woodard, South Dakota State University 232

Nutrient and Water Management Decisions for High Plains Cotton
Dan Krieg, Texas Tech University 242

NITRATE IN THE ENVIRONMENT

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ABSTRACT

Concern about nitrate contamination of aquifers in other areas has led to questions about the future safety of Western Canadian groundwater supplies. The purpose of this study was to examine the scientific literature on nitrate in the environment and to relate it to possible problems from nitrogen fertilizer use in Western Canada.

Nitrate is not toxic, but nitrite can cause methemoglobin formation which disrupts the oxygen transport system in the blood. In infants and ruminant animals, nitrate can be reduced to nitrite high enough in the digestive tract to be absorbed into the bloodstream.

High nitrate levels in shallow wells in farm yards resulted in infant sickness and death as early as 1945 in Canada and the U.S. The problem wells usually had hundreds of ppm of nitrate and were also bacteriologically contaminated. The contamination was from point sources; usually livestock wastes. Based on the early problems of well contamination and in due consideration of adequate safety factors where health is concerned, the safe level of nitrates was set at 50 ppm . The exception is Britian which uses 100 ppm nitrate as the safe level.

In the past few decades intensive agricultural systems, involving application of fertilizer N at 150+ lbsN/acre annually, or heavy applications of animal or poultry manure have been developed in Britian, Europe and humid or irrigated areas of North America. Where these systems are situated on surface aquifers a gradual increase in the nitrate content of the aquifers has been noted because of non-point contributions. As the nitrate level begins to approach 50 ppm there is concern about the safety of the water supply. There appear to be no documented cases of nitrate related health problems from aquifers with slightly elevated nitrate levels from non-point sources. However, the concern about slightly elevated nitrate levels remains and all possible nitrate sources must be critically examined.

Sources of nitrate can be geologic soil organic matter, animal or human wastes, legumes or fertilizers. Each situation must be examined to determine the relative contribution of the various sources.

To avoid excess fertilizer derived nitrate accumulation, fertilizer rates should not greatly exceed crop removal. Soil testing for nitrate is an important practice to prevent excess fertilization. As well, excess irrigation should be avoided and a crop cover provided during times when precipitation is likely to

exceed evaporation.

INTRODUCTION

Concern about nitrate contamination of aquifers in other areas has led to questions about the future safety of Western Canadian groundwater supplies. The Western Canada Fertilizer Association is conducting a three phase study on groundwater nitrate in Western Canada. This literature review is the first phase of the study. Subsequent phases will document the current groundwater nitrate situation and provide guidelines to prevent problems in the future.

HEALTH ASPECTS OF THE NITRATE QUESTION

Nitrate itself is relatively nontoxic (Magee 1982). When nitrate is reduced to nitrite and absorbed into the blood stream methemoglobinemia can occur. Hemoglobin is capable of transporting oxygen; methemoglobin cannot (Magee 1982).

The fundamental effect of nitrites on oxygen transport have been known for more than 100 years (Gamgee 1868). The first reported problems with nitrate came from the medical administration of nitrate compounds. A review of medical cases has been provided by (Green *et al.* 1981).

Methemoglobinemia is associated mostly with infants. In very young infants a pH greater than 4 is present in the gastric juices in the upper gastrointestinal tract . This allows the reduction of nitrate to nitrite high enough in the digestive tract for it's absorption into the blood stream where the methemoglobin forms (Cornblath and Hartmann 1948).

Excessive nitrate in <u>groundwater</u> has been considered a health problem since Comly (1945) first described methemoglobinemia in babies associated with high nitrate well water in Iowa. The original paper by Comly was quickly followed by similar reports from Saskatchewan (Robertson and Riddell 1949) , Manitoba and Ontario (Medovy *et al.* 1947), Minnesota (Bosch *et al.* 1950), Kansas (Faucett and Miller 1946), California (Shearer *et al.* 1972), Ohio (Waring 1949), Belgium (Ferrant 1946), Israel (Shuval and Gruner 1972), and Namibia (Super *et al.* 1981).

Analysis of water from Iowa wells in 1939 found that 33% of dug wells, 22% of bored wells and 4% of drilled wells contained >10ppm N03-N (Johnson *et al.* 1946). In 1949, a water well survey in Saskatchewan found that 18% of the 2000 wells sampled had 50 or more ppm nitrate(Robertson and Riddell 1949). The common factor was that the wells were in rural areas, usually shallow, hand dug and placed so that contamination from animal or human waste was easily visualized. Thus, nitrate problems in water from rural wells was well established before the nitrogen fertilizer industry was a significant factor in North American agriculture.

A review of the 1940's literature on nitrate contaminated drinking water suggested that 10 ppm of nitrate nitrogen (45 ppm of nitrate) was the permissible level but most cases of methemoglobinemia occurred when the nitrate nitrogen content of the water was in excess of 40 ppm (Walton 1951). The critical level of 10 ppm of nitrate nitrogen has for the most part remained unchanged and is still accepted as the limit in most jurisdictions today. The exception to the 10 ppm N03-N rule appears to be Britian. Since 1972, public water supplies have not been used if they contain more than 100 ppm of nitrate but medical authorities are informed when the nitrate level is above 50 ppm (Croll and Hayes 1988). No cases of methemoglobinemia have been found in the borderline level of 50 to 100 ppm nitrate (Croll and Hayes 1988). In fact, (Croll and Hayes 1988) report that no cases of methemoglobinemia have occurred in the UK since 1972.

Nitrate poisoning of animals from water is not common but it has occurred in Saskatchewan from well water containing 626 ppm N03-N (Campbell *et al.* 1954). More common is nitrate poisoning of ruminants from consumption of feed high in nitrate. An early account of nitrate poisoning was cattle death in Kansas after consumption of com stalks containing 18.8% KNO3 equivalent to 2.6% N03-N (Mayo 1895). A review of all aspects of nitrate accumulation in plants and nitrate poisoning in animals has been provided by Wright and Davison (1964).

GEOLOGIC (NATURAL) NITRATE SOURCES

In arid environments, nitrate compounds can accumulate as a natural phenomenon. The mining of natural sodium nitrate deposits was the beginning of the fertilizer industry in Chile in the mid 1800's (O'Brien 1982).

Natural nitrate deposits have been recorded in the states of Alabama, Arizona, Arkansas, California, Colorado, Idaho, Indiana, Kentucky, Missouri, Montana, Nevada, New Mexico, North Carolina, Ohio, Oregon, Pennsylvania, Tennessee, Texas, Utah, Virginia, Washington, West Virginia and Wyoming (Mansfield and Boardman 1932).

Stevenson found approximately 300 to 400 ppm of fixed ammonium nitrogen in shale samples and approximately 5 to 25 ppm of fixed ammonium nitrogen in granite rocks (Stevenson 1959). Sedimentary rocks are more likely to contain significant nitrate or nitrate precursors than are igneous rocks. A very early account of very high nitrate contents was in salt slicks associated with Cretaceous shales in Utah (Stewart and Peterson 1917).

The geological contribution of nitrate to the San Joaquin Valley has been substantial (Strathouse *et al.* 1980). Elevated nitrate levels at depths from 15 to 60 ft in the eastern Mojave Desert of California were concluded to be Pleistocene relics. (Marrett *et al.* 1990).

In North Dakota and eastern Montana nitrate in lignite beds used as domestic water supplies had its origin in the exchangeable ammonium in associated soft shale beds (Power *et al.* 1974).

Enclaves of high nitrate nitrogen found in weathered till in southern Alberta were a result of nitrification of the exchangeable ammonium which is still present in the unweathered till. (Hendry *et al.* 1984).

NITRATE FROM SOIL ORGANIC MATTER

The classical drain gauge experiments at Rothamsted provided some of the first information on nitrate quantities that might be produced directly from the soil organic matter (Lawes *et al.* 1881). *In the 1870s the water draining from the gauges of unfertilized, bare fallow plots had a nitrate concentration exceeding the limit for potable water under the current European community regulations.*

Under native grass nitrate is seldom present. This has been documented in Saskatchewan by (Doughty *et al.* 1954), (Campbell *et al.* 1975) and (Henry 1975). Only a few ppm of nitrate nitrogen was found under native range conditions to a depth of 9 feet in South Dakota (White and Moore 1972).

Early studies showing high nitrate production by cultivated grassland soils came from Montana (Buckman 1910), Alberta (Newton *et al.* 1939) and Saskatchewan (Larson and Mitchell 1939).

At Swift Current nitrate nitrogen up to 400 lbs per acre was found at the 4 to 10 feet depth of cultivated soils (Doughty *et al.* 1954). The subsoil nitrate was typically present as a "bulge" beneath the crop rooting zone. Subsequent studies at Swift Current (Campbell *et al.* 1984; Campbell *et al.* 1975) suggested that about 20% of the nitrogen initially present in the topsoil had been lost by leaching since it was broken for agriculture. They also determined that the application of fertilizer nitrogen and phosphorus at moderate rates actually reduced nitrate leaching.

Workers in Nebraska started in 1970 with a mixed native prairie sod and instituted three separate tillage treatments on a winter wheat-fallow rotation (Lamb *et al.* 1985). They found that the plough tillage system resulted in leaching of 90 lbs/acre more nitrate nitrogen than with no till or stubble mulch tillage systems. Because they started the experiments from virgin sod, they were able to determine the effects in the first few years of cultivation when large mineralization and large nitrate leaching potential was present.

ANIMAL MANURES

Work in Alberta has shown that manure applied at 30 tons/acre annually for 40 years did not cause an undesirable buildup of nitrogen, phosphorus or soluble salts in the soil (Sommerfeldt *et al.* 1973).

In Eastern Canada liquid dairy manure applied at 800 lbs/acre/year of nitrogen equivalent to a sandy clay loam soil for 5 years resulted in 225-275 lbs of mineral nitrogen/acre (nitrate + ammonium + nitrite) in the 0-4 ft depth (Culley *et al.* 1981).

In California, the quantity of nitrate nitrogen below the root zone was in the order of livestock corrals, pastures used as manure disposal areas and cropland. (Adriano *et al.* 1971). They considered the unsaturated zone above the water table to be the best indicator of the likely eventual contribution of nitrate to the water table.

In an intensively farmed valley containing many concentrated livestock feeding operations in Colorado more than 1000 lbs/acre of nitrate nitrogen was found to a depth of 20 ft beneath feedlots (Stewart *et al.* 1967). While the average value was high the amount of nitrate found under feedlots was extremely variable and they concluded that not much nitrate would reach the water table.

NITROGEN FERTILIZER AND IRRIGATION

In recent decades corn production in the United States has made liberal use of nitrogen fertilizer. This has resulted in numerous publications concerning residual nitrate within or just beneath the rooting zone of com. A cross-section of the many United States experiments with corn include studies in Wisconsin (Olsen *et al.* 1970), Missouri (Linville and Smith 1971), Iowa (Jolley and Pierre 1977), Virginia (Hahne *et al.* 1977), Minnesota (MacGregor *et al.* 1973) and Pennsylvania (Roth and Fox 1990). Most of the work with corn emphasizes the fact that to avoid excess nitrate in the soil profile the amount of nitrogen fertilizer applied should be in balance with crop removal.

An extensive study of soil and subsoil nitrate nitrogen was conducted in Nebraska in the early 1970s (Seim *et al.* 1972). In irrigated medium to fine textured upland soils they found only small accumulations of mineral nitrogen above the water table and most of that was within the rooting range of crops. However, on irrigated sandy lands they found 700 lbs of mineral nitrogen per acre spread throughout the profile above the water table. They concluded that on irrigated sandy lands planted to corn and fertilized with nitrogen that some nitrate had passed through the soil profile to the water table.

Under intensive California agriculture soil samples were obtained to the water table or to the 50ft depth and nitrogen balances determined. The work was summarized in a technical bulletin (Pratt 1972). In summary, these studies have shown that the nitrate concentration of water in the unsaturated zone in open porous soils with nitrogen inputs about 130 lbs N/acre/year can be reasonably estimated by considering the excess nitrogen in the soil calculated as nitrogen input minus crop removal and by the drainage volume. When nitrogen applications were much higher than 130 lbs N/acre/year to porous soils or at lower rates in soils with textural discontinuities denitrification had to be assumed to allow a reasonable nitrogen balance calculation. (Pratt *et al.* 1972)

NITRATE SOIL TEST

One of the earliest reports of the use of the nitrate soil test to predict N uptake by crops was in Montana (Burke 1925). The first major use of the nitrate test came after extensive work with barley in Manitoba (Soper and Huang 1963; Soper *et al.* 1971). *Since the mid 1960s soil testing laboratories in all 3 Canadian Prairie provinces have used the nitrate soil test as the primary tool to make nitrogen fertilizer recommendations.*

Work in Texas showed that even under sub-tropical conditions soil profile nitrate to a depth of 4ft was a very useful indicator of the nitrogen supply to grain sorghum. In Washington State, sweet corn response to nitrogen fertilization could be predicted from soil nitrate (Roberts *et al.* 1980). More recently, work in Wisconsin has shown that soil profile nitrate significantly influenced corn response to applied N (Bundy and Malone 1988).

Despite the widespread evidence supporting the use of the nitrate soil test to improve N fertilizer recommendations, it has not been extensively used in the past, in the main corn states of the United States. However, more recently, the spring soil nitrate test has been researched (Binford *et al.* 1990; Davis and Blackmer 1990; Elhout and Blackmer 1990; Roth and Fox 1990)] and mobile nitrate testing clinics have been established in Michigan (Vitosh *et al.* 1990) and Ontario (Kachanoski 1991).

It is clear that the use of some form of the nitrate soil test to refine N fertilizer recommendations is an important step in improving N fertilizer use efficiency and reducing losses of N to leaching.

NITRATE IN GROUNDWATER

An overview of the groundwater nitrate issue in the U.S. has been provided by (Madison and Brunett 1985) and by (Hallberg 1988). The document by Madison and Brunett reported on 123,656 wells that had been analyzed and 6.4% had N03-N values exceeding 10ppm. The data source used in that study was not a statistical sample but rather a compilation of data from a variety of sources with different original objectives. The United States Environmental Protection Agency (EPA) recently completed a 5 year statistically valid program of sampling wells in 564 community and 783 rural wells (1990 J.Soil Water Cons. pg 613). <u>It showed that only 1.2 % of the community wells and</u> <u>2.4 % of rural wells contain nitrate levels above the 10 N03-N level.</u>

Overview documents in Britian have been provided by (Foster *et al.* 1982) and more recently by (Croll and Hayes 1988). The N03-N values of outcrop portions of major aquifers were typically <10 ppm prior to 1960 and are typically >10 ppm since 1975 (Croll and Hayes 1988). The area of contamination is the area of recharge and the area where well yields are the highest and where, nitrate aside, the water is of highest quality. However, when the aquifers move under clay cover the well yields are reduced, the water becomes anaerobic, troublesome levels of iron and manganese are present, and nitrate levels are low (Croll and Hayes 1988).

Contamination of wells by <u>paint sources</u> such as septic tanks or livestock operations has been documented from Saskatchewan, Manitoba, Ontario, Iowa, Minnesota, Kansas, California, Ohio, Belgium, Israel and Namibia. The reader is referred to the section titled "Health Aspects" for the detailed citations involved. Contaminated wells that were studied in the 1940s and 1950s were highly polluted and were discovered for the most part because of medical problems that had arisen.

Recent publications examine the issue of nitrate content of aquifers over time, and the role of <u>non-point contributions</u> from N fertilizers and spreading of animal manures.

In a recent review of the situation in Iowa (Hallberg 1988) stated *"While septic tanks, chemical spills and poor well construction cause local problems, they are no longer a significant factor. Nitrate problems have become regional in scope, resulting from the widespread application of fertilizer."* The Iowa work included intensive investigations in the Big Spring Basin of northeastern Iowa. The Big Spring Basin is a 103 square mile area with a responsive hydrologic system and one in which discharge can be determined quantitatively. The basin is entirely agricultural, with no industries, landfills or municipal wastes to complicate the picture. In the 1950s and 1960s groundwater nitrate was 3ppm N03-N but by 1983 it was 10.1 ppm. The increase in groundwater nitrate paralled the increase in N fertilizer use associated with increase in per acre rate and an increase in corn acreage (Hallberg 1988) .

In another Iowa study, municipal wells from across the state showed only a slight increase in nitrate from 1950 to 1979 (McDonald and Splinter 1982), and then only for wells less than 30 feet deep. However, the same study showed about 20 ppm nitrate increase in two river systems from the early to late 1970s.

A study in Merrick county, Nebraska showed groundwater N03-N values of about 3 ppm in 1947-51 and about 12 ppm in 1974 (Spalding *et al.* 1978). Where contamination was present the nitrate levels were relatively homogenous, suggesting large diffuse non-point sources. That study concluded that the combination of irrigation and fertilizer N was responsible for the increase in nitrate. A very recent Nebraska study has examined fertilizer rates and found that a large portion of excess N application came from 14% of the area where N rates were <u>$\geq$ 100 lbs N/acre more than the recommended rate</u> (Schepers *et al.* 1991).

Other studies of non-point source aquifer contamination have taken place in Georgia (Beck *et al.* 1985), Delaware (Ritter and Chirnside 1984; Robertson 1979), Wisconsin (Saffigna and Keeney

1977) and Ontario (Hill 1982).

In summary, non-point contamination of aquifers with nitrate from nitrogen fertilizers or spreading of animal manures occurs in humid or irrigated areas where sandy soils are underlain by sand or gravel deposits which form surface, water table aquifers.The agronomy includes the use of high rates of N fertilizers or manures, usually well in excess of crop uptake.

The use of N15 analyses nitrate from water has been suggested as one means to aid in identifying the source. One of the early studies in this regard was that of (Kohl et al. 1971) who reported dN15 for fertilizer to be +3 and for soil N to be +15. On that basis the authors concluded that nitrate added to an Illinois surface water came mostly from fertilizer. Since that time the dN15 values used by (Kohl et al. 1971) for soil (Bremner and Tabatabai 1973) and fertilizer (Freyer and Aly 1974) have both been questioned.

In recent years much more extensive use of the N15 technique has provided some guidelines to aid in its interpretation. Based on papers by (Flipse and Bonner 1985), (Ritter and Chirnside 1984) and (Gormly and Spalding 1979) it can be stated that dN15 values for nitrate derived primarily from fertilizer would be generally <+3.5; while dN15 values of nitrate derived largely from animal manures would be generally >+10. Isotopic fractionation due to denitrification of fertilizer derived nitrates would tend to slightly increase the dN15 value to the +4 to +8 range. Thus, in high organic matter soils, or where denitrification is active it can be difficult to distinguish soil derived nitrate from fertilizer derived nitrate.

Where sandy soils overly sand or gravel water table aquifers, the N15 technique can be used to assist in identifying the nitrate source. This has been done in Nebraska to identify fertilizer as the major contributor (Gormly and Spalding 1979); in Delaware to identify poultry manure as the main contributor (Ritter and Chirnside 1984); in New York to determine that the nitrate source was not animal in origin (Flipse and Bonner 1985), and in British Columbia to identify poultry manure as a major contributor to groundwater nitrate (Kohut *et al.* 1989).

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SPATIAL VARIABILITY OF NITRATE-N IN NEBRASKA CORN FIELDS

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ABSTRACT

Natural and spatial variability of soil nitrate complicates soil sampling. Accurate estimation of the mean nitrate content must be obtained if farmers are to have confidence in deep nitrate testing. The CV of nitrate-N averaged 59% for 43 sites sampled during the fall and spring on a 100 foot grid. Fall soil sampling provided similar results to spring sampling except on sandy soils. Data showed that 12 to 20 cores were required from areas 30 A or less to provide estimates of mean nitrate content that were within ± 20% at confidence levels of 80% and 90%.

INTRODUCTION

Soil sampling has always been an integral part of a profitable fertilizer program. Guidelines for proper soil sampling have been around since the mid 1940's (Cline, 1944). Soil scientists have realized from that time how variable soils could be, so the concept of spatial variability is not new. Past guidelines for soil sampling recognized this variability and suggested dividing fields into different areas based on soil type, color, slope, erosion, drainage, or cropping history. The guidelines always suggested sampling salt spots, terraces, or other problem areas separately. The one statement that summed up soil sampling was " take lots of individual cores for compositing into a single sample and take lots of samples".

Currently there is renewed interest in soil sampling and variable rate fertilizer application (Carr, et. al., 1991; Robert, et. al. 1991; Larsen and Robert, 1991). Farmers have always tried to make fields as uniform as possible, just because it was much easier to do. Farmers have "farmed fields" and not soils. Making a change to "farming by soil" will be a major task because we are changing attitudes that have been around for generations. The technology exists, however, to make the change.

The reason for the renewed interest in variable rate application has come from two areas--improvements in soil sampling research that accommodate spatial variability of nutrients and new computer-controlled equipment that can apply variable fertilizer rates on the go based on computerized soil nutrient maps. Most of the work has been with P and K (Buchholz, 1991; Carr, et. al., 1991; Larsen and Robert, 1991).

Research has shown that grid sampling almost always increases precision compared to random sampling due to the dependence of spatial variables (Peterson and Calvin, 1965). Grid soil sampling is simple. It has been around as a suggested method for years (Peck and Melsted, 1967). A recent advance in soil sampling is the theory of regionalized variables which enables estimation of the spatial dependence of a soil property (Matheron, 1971). The application of statistical techniques from mining geology (geostatistics) have helped provide better estimates of soil properties.

In Nebraska there is a great concern about the influence of nitrogen on groundwater quality. Numerous N control and management areas exist (Hergert, 1987; Ferguson and Peterson, 1991). Excessive N applications and leaching caused by poor irrigation management or excess rainfall have caused substantial increases in groundwater nitrate in several parts of Nebraska (Spaulding, et. al., 1978). The most significant improvement in N recommendations uses deep soil tests for residual nitrate to adjust N recommendations (Hergert, et. al., 1984; Herron, et. al., 1971). Spatial and temporal variability of nitrate-nitrogen in farmer fields needs to be quantified by researchers but has not been thoroughly investigated even though most Universities in the Great Plains strongly recommend deep soil sampling for nitrate. Only limited work has been done on soil nutrient variability in Nebraska during the last 30 years (Hooker, 1976). Because of the emphasis on improved N management, a current look at soil nitrate variability was needed. This was the impetus for this project.

OBJECTIVES

The objectives of this project were to:

1. Determine the variability of nitrate and nitrate distributions within farmer's com fields on selected benchmark soils across the state.

2. Determine seasonal variation in soil nitrate-N levels between fall and spring.

3. Determine the most appropriate number of samples required to estimate the mean nitrate-N value within prescribed confidence limits by classical statistical methods.

4. Utilize geostatistical techniques to determine whether better sampling plans could be developed. Use the grids and geostatistics to develop contour maps to be used in developing variable N rates.

METHODS AND MATERIALS

Farmer's fields from major com production areas across the state were sampled beginning in the fall of 1987. The study was concluded during the spring of 1991. Complete sets of fall versus spring samples were not always taken. Winter precipitation was below normal across most of the state in 1989. Based on the preliminary analysis from the first year sampling, the spring 1989 samples were not taken since the winter of 1989 was an even drier year than 1988. With low precipitation there was little evidence to expect that nitrate levels would have changed significantly. Several sites were sampled during the springs of 1990 and 1991.

Portions of farmer's fields, generally less than 30 acres, were selected by the various principal investigators. Fields were sampled on a grid basis using a 100 foot lag as the standard spacing. Soil samples were taken in 1 foot increments from the soil surface to 4 feet. A Giddings Hydraulic Soil Probe was used at all locations with a core barrel diameter of 2 inches. Individual cores were bagged separately, air dried, ground, and then analyzed for nitrate-nitrogen.

RESULTS AND DISCUSSION

The field sites sampled during this project are listed in Table 1. They included irrigated and dryland sites of sandy and fine textured soils.

Error Checking

With a large number of samples there is a possibility of error. The quality assurance aspect of this project related to field and laboratory analysis included the steps of initially screening the data, checking for missing samples, then sorting and checking for outliers. The top 2% high testing samples and bottom 2% low testing samples of a site were resubmitted to the laboratory for analyses. The rerun nitrate values were compared with the initial values. A plot of the initial versus rerun values (data not shown) gave an excellent correlation ($R^2 = 0.97$) showing that lab variation was not the problem with the apparent outliers. The slope (0.975) indicated that rerun samples generally were lower than initial samples but no consistent pattern was shown. The data confirm the natural large inherent soil variability present in soil nitrate.

Descriptive Statistics

After this step, data were analyzed using the PROC UNIVARIATE procedure in SAS (SAS, 1985). The data analysis included descriptive statistics as well as a check for normality of the frequency distribution. A summary of the descriptive statistics is given in Table 2.

Table 1. Field sites sampled for the Nebraska soil nitrate spatial variability study.

Site	Year	Fall	Sprg	Cooperator	County	Soil	Size-100 feet
1	87-88	y*	y	Marghiem	Scottsblf.	Tripp vfsl**	26 x 5
2	87-88	y	y	Lofing	Scottsblf.	Mitchell sil	6 x 21
3	87-88	y	y	Raun	Wayne	Mdy/Knbc/sicl	10 x 15
4	87-88	y	y	NEREC	Dixon	Nora, Crofton, sil	17 x 8
5	87-88	y	n	Hoffman	Pierce	Thurman-Loup ls	12 x 14
6	87-88	y	y	Fritz	Lincoln	Caruso l	8 x 11
7	87-88	y	y	Johnson	Clay	Hastings sil	12 x 12
8	87-88	y	y	Krull	Clay	Hastings sil	12 x 12
9	87-88	y	n	Thompson	Hall	Wann l	12 x 7
10	87-88	y	y	Speihs	Hall	Wann l	9 x 11
11	87-88	y	y	Henry	Lincoln	Valentine ls	20 x 7
12	87-88	y	y	Wahlgren	Lincoln	Cozad sil	20 x 7
13	87-88	y	y	Schmadke	Lincoln	Uly-Coly sil	9 x 16
14	87-88	y	y	Greeder	Lincoln	Anselmo ls	20 x 7
16	88-89	y	n	WCREC	Lincoln	Cozad-Hord sil	21 x 9
17	88-89	y	n	Peterson	Dixon	Mdy-Thrm sil	14 x 8
18	88-89	y	n	Dahlquist	Cedar	Crofton-Nora sil	14 x 8
19	88-89	y	n	Eakins	Keith	Bayard sl	13 x 8
20	88-89	y	n	Perkins	Scottsblf.	Alice vfsl	18 x 4
21	88-89	y	n	Tripple	Scottsblf.	Keota sil	7 x 5
22	88-89	y	n	Kramer	Logan	Hord sil	14 x 10
23	88-89	y	n	Henry	Lincoln	Valentine s	21 x 7
24	88-89	y	n	Somerhalder	Lincoln	Hord sil	11 x 11
27	89-90	y	y	Betty	Lincoln	Valentine s	14 x 10
28	89-90	y	y	Pickering	Scottsblf.	Tripp vfsl	10 x 7
29	89-90	y	y	Marghiem	Scottsblf.	Tripp vfsl	10 x 7
30	89-90	y	y	Fiericks	Dixon	Crofton sil	12 x 10
31	89-90	y	y	Jacobson	Kearney	Holdrege sil	9 x 12
32	89-90	y	y	Rousey	Lincoln	Caruso l	9 x 11
33	89-90	y	y	Medinger	Butler	Butler sicl	11 x 9
35	89-90	n	y	Bonzak	Hall	O'Neill sal	12 x 12
36	89-90	y	y	Tuttle	Cedar	Moody sicl	12 x 10
37	90-91	y	y	Rousey	Lincoln	Caruso l	9 x 11
38	90-91	y	y	Kinnan 1	Dawson	Cozad sil	21 x 7
39	90-91	y	n	Kinnan 2	Dawson	Hord-Cozad sil	12 x 13
40	90-91	n	y	MARC	Clay	Crete sil	12 x 12
41	90-91	n	y	NEREC	Dixon	Nora, Crofton sil	17 x 8
42	90-91	y	n	Mead Co.	Saunders	Sharpsburg sicl	10 x 10
43	90-91	y	n	Hansen	Saunders	Sharpsburg sicl	10 x 4

*y = yes, n = no

**sil = silt loam; ls = loamy sand; sal = sandy loam; vfsl = very fine sandy loam; sicl = silty clay loam; l = loam; s = sand

The average amount of nitrate found ranged from 20 lbs / A in a 4 ft depth to 676 lbs / A. Overall there was a good indication that farmers have been practicing improved nitrogen management because of the fairly low residual nitrate levels. The very high testing sites (38, 42, and 43) had a history of manure application. Site 40 also had a manure history but did not test high. In most cases the median value was lower than the mean indicating a somewhat skewed, or in many cases, lognormal distribution of the data. Analysis showed that in most instances the data was not distributed normally. The other factor noted from Table 2 is that the coefficient of variation (CV) is very high. This is not unusual for a soil nutrient analyses. The average CV over all fall and spring sites was 59%. The complicating factor of a high CV is that more samples are required to obtain a given accuracy or predictability to be within a given amount of the true mean. The range in individual samples shows that there is a great deal of variability in soil nitrate from point to point in a field and it emphasizes the importance of taking an adequate number of samples.

Fall vs Spring Sampling

A paired comparison of sites that were sampled during both the fall and the spring is shown in Table 3. Very little difference existed in the mean averaged across 21 different sites. The mean and median differed significantly and the CV was somewhat higher for the fall sampling than the spring. This data confirms the fact that in a dry year very little change in soil nitrate is shown. A comparison of the individual values among sites shows a somewhat different picture. Eight of the locations changed very little. Nine of the sites showed an increase and four sites showed a decrease in soil nitrate. The increase in soil nitrate may be attributed to late fall or very early spring mineralization between the two sampling times. The decrease in soil nitrate on the sandy soils (sites 9 and 14) most likely is due to leaching from over-winter precipitation. Losses can also occur on fine textured soil (sites 31 and 38).

For most fine textured soils in Nebraska, the data confirmed that fall sampling is a good estimator of residual nitrate. Taking a sampling in the fall allows farmers to plan their fertilizer program over the winter and gives them a wider time window for fertilizer nitrogen application.

Table 2. Nebraska soil nitrate variability study - nitrate parameters.

Site	Mean	Median	CV	Range Low	Range Hi
	---------------lbs-Nitrate-N in the 0 to 4 foot depth-------				
1F	73.8	57	65%	22	308
1S	78.6	66	55%	30	351
2F	39.0	36	32%	22	103
2S	38.9	34	43%	17	142
3F	39.6	38	37%	15	121
3S	54.7	53	32%	21	119
4F	119.6	88	79%	23	526
4S	117.2	92	70%	21	442
5F	62.2	50	58%	12	236
6F	45.8	39	57%	20	164
6S	53.4	48	39%	22	149
7F	44.4	31	79%	9	206
7S	49.7	42	51%	17	150
8F	15.5	14	60%	6	54
8S	19.9	19	31%	7	39
9F	37.6	35	37%	11	79
10F	50.1	41	74%	9	246
10S	57.9	53	46%	18	179
11F	53.8	51	38%	24	131
11S	36.0	34	36%	17	112
12F	86.3	66	81%	22	422
12S	83.8	65	88%	30	559
13F	78.2	63	73%	13	287
13S	90.6	73	70%	13	398
14F	104.5	96	36%	32	263
14S	49.7	45	42%	14	128
16F	92.7	83	47%	32	409
17F	67.2	56	57%	29	266
18F	95.8	69	76%	17	368
19F	95.6	73	72%	18	300
20F	100.7	69	81%	17	337
21F	90.1	69	60%	28	235
22F	20.8	18	47%	4	76
23F	34.3	31	52%	8	109
24F	23.9	23	55%	7	111
27F	24.0	21	48%	7	70
27S	26.0	25	41%	7	81
28F	97.0	53	95%	53	215
28S	91.0	65	75%	32	412
29F	86.0	42	91%	21	291
29S	102.0	66	75%	27	328
30F	226.0	210	65%	15	937
30S	247.0	206	71%	27	1366
31F	134.0	113	70%	10	350
31S	79.0	66	66%	17	314
32F	74.0	64	48%	38	204
32S	89.0	82	37%	31	205
33F	39.0	37	34%	16	121
33S	41.0	40	29%	20	104
35S	23.0	21	37%	11	85
36F	47.0	44	27%	30	132
36S	42.0	39	32%	3	90
37F	109.0	91	72%	21	617
37S	124.0	112	63%	29	526
38F	280.0	203	84%	43	1308
38S	264.0	186	78%	51	971
39F	148.0	123	72%	19	601
40S	38.0	19	134%	7	357
41S	215.0	175	86%	23	1347
42F	676.0	629	46%	144	1386
43F	159.0	142	54%	46	356
AVG	94.5	77	59%		

Table 3. Comparison of fall versus spring nitrate statistics.

SITE	Fall Mean	Spring Mean	Fall Med	Spring Med	Fall CV	Spring CV	Samples
	----------lbs NO_3/N in 4 feet----------						
1	74	79	57	66	65	55	130
2	39	39	36	35	32	43	120
3	40	55	38	53	37	32	150
4	120	117	88	92	79	70	136
6	46	53	39	48	57	39	88
7	44	50	31	42	79	51	144
8	16	20	14	19	60	31	144
11	54	36	51	34	38	36	140
12	86	84	67	65	81	88	140
13	78	91	63	73	73	70	144
14	105	50	96	45	36	43	140
27	24	26	21	25	48	41	140
28	97	91	53	65	95	75	70
29	86	102	42	66	91	75	63
30	226	247	210	206	65	71	120
31	134	79	113	66	70	66	108
32	74	89	64	82	48	37	99
33	39	41	37	40	34	29	99
36	47	42	44	39	27	32	120
37	109	124	91	112	72	63	99
38	280	264	203	186	84	78	147
	---	---	---	---	---	---	---
AVG	87	85	69	69	60	54	121
RANGE	16-280	20-264	14-210	19-206	27-95	29-88	63-150

Number of Cores Required

A two sample test to determine the number of samples required to estimate the mean nitrate content of a sampling unit within a prescribed confidence interval was developed by Stein (1945). The number of samples required to estimate the mean is calculated by the equation

$$n = \frac{t^2)\ (S^2)}{d^2}$$

where t is the tabulated student t value for the desired alpha level and the degrees of freedom of the initial sample. S is the variance of the initial sample and d is 1/2 of the width of the desired precision. Stein's formula was used with the current data set using a t value based on 80% and 90% confidence limits (α = .2 and α = .1). The value of d was calculated as $\pm$ 10%, to $\pm$ 20% of the mean. The number of samples calculated from the formula for this analyses is given in Table 4.

Table 4. Core number to be within plus or minus 10% or 20% of the mean at alpha levels of 0.1 or 0.2.

Site	Mean lbs N/4'	+10% α = .1	+10% α = .2	+20% α = .1	+20% α = .2
1F	74	113	69	28	17
1S	79	82	50	21	13
2F	39	28	17	7	5
2S	39	49	29	12	7
3F	40	38	23	10	6
3S	55	27	16	7	4
4F	120	168	102	42	26
4S	117	134	81	33	20
5F	62	95	57	24	14
6F	46	87	53	22	13
6S	53	41	25	10	6
7F	44	169	102	42	26
7S	50	69	42	17	11
8F	16	62	37	15	9
8S	20	26	16	6	4
9F	38	38	23	9	6
10F	50	151	91	38	23
10S	58	58	35	15	9
11F	54	38	23	10	6
11S	36	35	21	9	5
12F	86	163	99	41	25
12S	84	207	126	52	31
13F	78	142	87	36	22
13S	91	133	81	33	20
14F	105	36	22	9	5
14S	50	50	30	13	8
16F	93	59	36	15	9
17F	67	89	54	22	14
18F	96	157	95	39	24
19F	96	139	85	35	21
20F	101	183	110	46	28
21F	90	82	49	21	12
22F	21	61	37	15	9
23F	34	74	45	19	11
24F	24	84	51	21	13
25S	112	24	15	6	4
26S	65	23	14	6	4
27F	24	62	38	16	9
27S	26	46	28	12	7
30F	226	116	70	29	18
31F	134	135	81	34	20
31S	79	119	72	30	18
32F	74	63	38	16	10
32S	89	38	23	10	6
33F	39	32	19	8	5
33S	41	23	14	6	4
35S	23	38	23	10	6
36F	47	21	12	5	3
36S	42	29	17	7	4
42F	676	59	35	15	9
43F	159	82	50	21	13
AVG		80	48	20	12

Sampling Design and Nitrate Contour Maps

Geostatistical analysis including Kriged contour maps is just beginning. Preliminary analysis indicates that a sampling interval of 300 to 400 feet may be adequate grid spacing for most fields that are not highly variable. Kriged maps that contain 3 to 4 nitrate ranges seem workable and could be used with existing equipment or newer variable rate equipment. Current mapping programs utilize Kriging, but the underlying theoretical considerations and accuracy is not clear. More investigation of packages (such as Surfer or GS+) needs to be completed to have confidence in this part of the process.

CONCLUSION

This analysis showed that a very large number of samples was required in certain instances. To have a precision of ± 10% of the true mean at an alpha level of .1 on the average requires a great number of samples (80). This number of samples is much larger than any farmer or fertilizer dealer would be willing to take in an average sized field of 30 acres or less. The number of samples required, however, to be within ± 20% of the mean at alpha levels of 0.1 or 0.2 are within the range of practicality (20 to 12). Current sampling recommendations provided by the University of Nebraska suggests 6 to 8 cores from an area of 20 acres or less (Penas et al, 1991). An acceptable procedure in most situations would be to take 12 to 16 cores from an area of 40 acres or less. These general recommendations fall in line with the tabulated values from Table 4. The data point out, however, the range of variability in these samples and the uncertainty in the values when a given number of cores is taken. In most instances soil nitrate levels from farmer samples are only within the range of ± 20% of the mean at a confidence level of 80 to 90%.

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THE NEED FOR REGIONAL FERTILIZER RECOMMENDATION GUIDELINES

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ABSTRACT

Soil testing has long been touted as the single best tool available for aiding in the development of fertility programs. Unfortunately, however, overall farmer acceptance of soil testing is not as great as would be expected and is evidenced by the fact that most fields lack a sound soil test history. Sadly, soil testing suffers from a lack of credibility among the very people it should benefit most. While there are several reasons for this lack of farmer acceptance, the fact that fertilizer recommendation guidelines often abruptly change for no obvious reason when crossing a state line is certainly one. Assuming similar crops, soils, cultural systems and climate, it makes little sense to producers and dealers that recommendation guidelines should vary depending on which side of a political boundary a farm sits. Although it is often assumed that the long-term goals of various state recommendation guidelines are similar, this isn't the case and helps explain some of these differences. Recently, North Dakota, South Dakota and Minnesota developed regional recommendation guidelines for portions of those states that are similar. Several other states are also exploring the possibility developing regional recommendation guidelines for appropriate areas. While there are obstacles to overcome in the development of regional recommendation guidelines - especially if the long-term goals of current state guidelines differ - these efforts promise increased soil testing credibility.

INTRODUCTION

Over the years, much research has dealt with assessing fertility requirements for profitable crop production. As a result, various laboratory procedures (soil tests) have been developed which help predict the likelihood of obtaining a response to specific nutrient applications for specific fields, or portions of fields.

By themselves these soil tests do not provide a specific recommendation. But a sound soil test program, complemented with other information about a specific field/situation, is recognized as essential for developing sound fertility programs. There is little disagreement that comprehensive soil testing programs are essential for optimum profitability and efficiency - at least among trained agronomists. Among farmers, however, a much different story emerges and there is less agreement on the value of soil testing.

While the acceptance of soil testing by farmers varies widely from one geographic region to another, overall, soil testing seems to lack credibility among the very people it should benefit most. While there may be disagreement as to the severity of, and the reasons for, this lack of credibility, few would argue that it exists to some degree. And while there are several reasons for this lack of credibility, the fact that fertilizer recommendation guidelines based on soil testing often vary considerably, and for no obvious reason, is cause for concern for many producers.

DISCUSSION

Historically, fertilizer recommendation guidelines based on soil testing have generally been presented as being the one 'right' recommendation. Skepticism results when soil samples are submitted to different laboratories or institutions and different 'right' recommendations are made.

Often times, this criticism has been used to question the recommendation guidelines made by industry or a particular commercial laboratory. These differences, widely aired in various newsletters and the popular press, have unfortunately added to a distrust of soil testing by some farmers and dealers. However, differences in recommendation guidelines are not limited to comparisons between industry/commercial laboratories and land grant universities - wide differences in recommendation guidelines are observed between bordering land grant universities.

The development of regional recommendation guidelines will not by itself quickly establish better farmer credibility of soil testing. But the total process of universities collectively examining their respective guideline differences with neighboring states would certainly be a step in the right direction.

Nitrogen (N) recommendation guidelines are fairly similar for most states, although the method for deriving the recommendation may vary considerably. There are cases, however, where N recommendation guidelines vary significantly for adjoining states. However, for nutrients such as phosphorus (P) and potassium (K), as well as secondary and micronutrients, recommendation guidelines are often considerably different in comparisons between adjacent states. As a result, it is P and K recommendation guidelines which are most often questioned and suffer the most from a lack of credibility.

Many of these P and K recommendation guideline differences between states are not simply differences in numbers, but are related to differences in the overall, long-term goals of the recommendations (often referred to as 'philosophies'). These differences will be more difficult to rectify when people sit down and attempt to develop a set of regional recommendation guidelines. However, recognizing that there is more than one 'right' long-term goal and agreeing on how to achieve varying fertility program goals may well be the biggest step in establishing credibility for soil testing <u>and</u> the fertility program development process.

Difficulty is also encountered when interpreting P and K soil test values because of differences in the soil test procedures (extractants) and proper sampling depths for adjacent states.

The fact that recommendation guidelines differ for adjacent states, even though the crops, soils, cultural practices and climates are similar, is often deemed unimportant. While this concern is often dismissed with an explanation of differences in climate, soils and cultural practices from state to state - and defended with research information from a given state - many areas have similar soils, climate and cultural practices, but straddle state lines. And the adjacent state also has a solid research base.

Following are a few examples of these differences. The intent is not to infer that one state is 'right' and another 'wrong' since both are supported by research. Nor is it the intent to infer that these are the only states where differences occur. Since all states have a research data base supporting their recommendation guidelines, it is apparent that there must be some differences in how specific soil test values are interpreted and/or what the long-term goals of the recommendation guidelines are.

The recommendation guidelines presented were developed from the what is believed to be current printed information available from the states. Where a range for the recommendation guidelines or soil test values were presented, a single interpolated value was used. For Kansas, the equations used at the KSU Soil Testing Laboratory were used since the printed material is not current at this time.

Colorado, Kansas and Oklahoma. Walsh, CO, Elkhart, KS and Eva, OK are located in the same general geographic area. Recommendation guidelines from the respective land grant Universities for 50 bu/A dryland, summer-fallow wheat on a medium textured soil with 1.2% organic matter are presented below.

Table 1. Wheat Nitrogen & Phosphorus Recommendation Guidelines (50 Bu/A)

State	Ave. 2 ft. Nitrate N (ppm)	N Rec. (lbs/A)	P Test Procedure	Sample Depth (in.)	P Soil Test (ppm)	Test Category	P_2O_5 Rec. (lbs /A)
Colo.	5	60	AB-DTPA	12	2	L	40
Colo.	10	30	AB-DTPA		8	M-H	0
Kans.	5	50	Bray P-1	6	4	VL	38
Kans.	10	12	Bray P-1		8	L	27
Okla.	5	64	Mehlich III	6	5	VL-L	65
Okla.	10	28	Mehlich III		10	L-M	45

VL-L is at the break between very low and low, L-M is at the break between low and medium and M-H is at the break between medium and high.

Nitrogen guidelines are similar with minor differences. For P, each University provides interpretations for a different P soil test procedure. Even if we assume that the Mehlich III procedure extracts about 20% more P than the Bray P-1 procedure (personal communication, G. Johnson, OSU), differences in P recommendation guidelines between Kansas and Oklahoma are still apparent. Colorado uses the ammonium bicarbonate-DTPA (AB-DTPA) extractant which extracts about on-half as much sodium bicarbonate test - neither of which are interpreted by the adjoining states.

Additionally, Colorado bases P recommendation guidelines on a one foot soil sample. This difference in sampling depth will result in large differences in interpreting the analytical results - even if the same extractant were used.

Nebraska, Missouri and Iowa. Ottoe County Nebraska, Atchison County Missouri and Freemont County Iowa are all in the same geographic area bordering the Missouri River. Assuming a 40 bu/A soybean yield goal and medium subsoil P for Iowa, the recommendation guidelines for these states are presented below.

Table 2. Soybean Phosphorus Recommendation Guidelines (40 Bu/A)

Bray P-1	Ottoe County Nebraska		Atchison County Missouri		Freemont County Iowa	
(ppm)	Interpretation	(lbs P_2O_5/A)	Interpretation	(lbs P_2O_5/A)	Interpretation	(lbs P_2O_5/A)
4	Low	20	V. Low	63	V. Low	87
11	Med.	0	Low	50	Low	62
18	High	0	Med.	45	Med.	44

In this example it is apparent that there are differences in how the same analytical results, using the same procedure, are interpreted by these states. Additionally, P_2O_5 rate recommendation guidelines vary considerably when comparisons of Missouri or Iowa are made with Nebraska. While much of the difference in rate recommendation guidelines may be explained by the long-term goals of the recommended fertility program, it doesn't adequately explain it all. It is more difficult to understand the differences in the interpretation of the analytical results.

Illinois and Wisconsin. McHenry County Illinois and Walworth County Wisconsin are adjoining counties at the Illinois-Wisconsin state line. Both states refine recommendation guidelines based on the subsoil P status and yield goal. Based on parent material (shallow loess over glacial till), the presence of shallow carbonates, high bulk density and slow permeability - Illinois places McHenry county in the "low" subsoil P category. Wisconsin generally places most of Walworth county in the "high" subsoil P category based on relative subsoil P fertility. Based on these subsoil categories, the appropriate state P recommendation guidelines for 140 bu/A corn in these counties are presented below.

Table 3.	Corn Phosphorus Recommendation Guidelines (140 Bu/A)					
Bray P-1 Soil Test (ppm)	Walworth County Wisconsin			McHenry County Illinois		
	Interpretation	Build P_2O_5/A	Total P_2O_5/A	Interpretation	Build P_2O_5/A	Total P_2O_5/A
3	Very Low	15	70	---	99	159
8	Low	10	65	---	76	136
13	Optimum	0	55	---	54	114
20	High	0	25	---	22	82
26	Very High	0	0	---	0	60

Large recommendation guideline differences between these two states are the result of differences in the fundamental assumptions on which the guidelines are based.

Illinois recommendation guideline assumptions are fairly straight forward. In this example, the goal of the P recommendation guidelines is to build soil test P values (over four years) to a level at which P nutrition will not limit crop growth (25 ppm). At soil test values of from 25 to 35 ppm, the amount of fertilizer P removed in the harvested portion of the crop is recommended to maintain the P soil test at a non-limiting level. At P soil tests above 35 ppm, no additional fertilizer P is recommended.

Wisconsin recommendation guidelines are founded on different goals and assumptions. These guidelines are designed is to build 'very low' and 'low' P soil test values to the middle of the 'optimum' range (11-15 ppm) in a five to eight year period. 'Optimum' is defined as the P soil test range at which annual P additions, approximately equal to the amount of P removed with the crop, are needed for optimum economic returns in the year of application. In the 'high' range (16-25 ppm) about one-half the amount of P removed with the crop is required for optimum economic returns in the year of application. No P is recommended for 'very high' soil test values (greater than 25 ppm).

Another major difference between these states, one not as easily explained, is the amount of P_2O_5 required to build soil test P values. For this situation, Illinois assumes 18 pounds of P_2O_5/A is needed to increase soil P tests 1 ppm while and Wisconsin uses a value of 9 pounds of P_2O_5/A to increase soil test values by 1 ppm.

If both sets of guidelines (Illinois and Wisconsin) are presented in the proper context - with appropriate goals and assumptions - and if it is assumed that neither of these guidelines are always 'right' or 'wrong' for a specific farmer/situation - regional recommendation guidelines for this geographic area would increase soil testing/recommendation guideline development credibility.

North Dakota, South Dakota and Minnesota. In the past, North Dakota, South Dakota and Minnesota each had their own set of soil test interpretations and recommendation guidelines - even though large portions of these states were very similar in cropping systems, soils and climate. Recognizing that the development of a set of regional recommendations would be beneficial, these land grant Universities recently coordinated their soil testing programs by developing a unified set of nutrient guidelines for most crops. The geographic area covered by these guidelines are all of North Dakota and South Dakota and the western part of Minnesota.

Since North Dakota relies on the Olsen sodium bicarbonate test and South Dakota and Minnesota rely primarily on the Bray P-1 test, they have agreed on interpretations for both of these tests and developed a single set of recommendation guidelines. While individual states may not use both procedures, producers and dealers using other laboratories will be able to get appropriate interpretations regardless of the procedure used. Equally important, these states have agreed on definitions for the various soil test categories, nitrate N sampling date adjustments, legume crop N credits, secondary and micronutrients, etc. It should be pointed out that this process required compromise on the part of each state in order to benefit the overall good.

As a result of this effort, the entire soil testing/ recommendation development process should enjoy increased credibility in this area. Equally important is possibility of even greater future cooperation and coordination among these states and better utilization of increasingly limited resources. Hopefully, the successful efforts of these states will provide a blueprint for other states willing to develop regional recommendation guidelines.

SUMMARY

While differences between commercial laboratories/industry and university recommendation guidelines have often been the target of criticism, differences are also observed for bordering states with areas of similar soils, climate and cropping practices. Often, these differences relate to the long-term goal of the suggested fertility program since all state universities base their guidelines on a solid research base. In other cases, the differences are not due to long-term goals but to simple numerical differences. Regardless of the reason for these differences, the fact that they occur contributes to a lack of credibility in the soil testing and recommendation development process.

The development of regional recommendation guidelines, definitions and interpretations that span state boundaries would help establish soil testing credibility. However, successful development of regional guidelines would depend on compromise on the part of the states and the realization that there is no one single 'right' recommendation but that fertility goals (and appropriate recommendation guidelines) can vary. North Dakota, South Dakota and Minnesota have already demonstrated that it can be accomplished.

SOIL FERTILITY ANALYSIS USING ION EXCHANGE MEMBRANES

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ABSTRACT

The simultaneous extraction of plant nutrient ions with ion exchange membranes offers many advantages over conventional soil tests. Ion exchange resin extraction is considered a superior assessment of nutrient availability compared to chemical-based soil tests due to the ability of exchange resins to closely simulate the action of plant roots in nutrient absorption and thereby act independently of the soil type. Ion exchange resins in the membrane form offer the additional advantage of providing a rapid simultaneous measurement of nitrogen, phosphorus, sulfur and potassium availability in a soil sample without the need for filtration or complex extracting devices. An extraction procedure highly suitable for a routine soil test lab was developed using anion and cation exchange membranes (ACEM). The study compared the amount of nutrient extracted by ACEM with conventional extractants for P and K (0.5M $NaHCO_3$) and N and S (0.001M $CaCl_2$). ACEM extraction times as short as 15 minutes could be used to predict availability. For 130 soil samples representing a wide range of soil types in Western Canada, the nutrient availability predicted by ACEM was significantly correlated with the conventional methods. Phosphorus uptake by canola plants was more closely correlated with ACEM - extractable P (r^2=0.84) than with 0.5M $NaHCO_3$ - P (r^2=0.70). The ACEM soil test is well suited to routine soil analysis because of low cost and simplicity as well as its consistency over a wide range of soil types.

INTRODUCTION

The phosphate extracted from soil with anion exchange resin has long been considered the best estimate of biologically available P (Amer et al., 1955; Bowman et al., 1978; Sibbesen, 1983; Yang and Jacobsen, 1990). This is attributed to the ability of the exchange resin to closely simulate the action of plant roots. Cation exchange resins have also been used for extraction of available K in soils (Pratt, 1951). Frigenbaum et al. (1981) used the cation exchange resin method to study rates of release of K by different micas, and Martin and Sparks (1983) used resins to examine the kinetics of non-exchangeable K release from soils. The exchange resin technique for measuring the P and K supplying power of the soil is based on movement of phosphate and potassium ions from soil particles to the soil solution, from which they can be adsorbed by the resin. The resin continually removes any ions which come into solution, thus preventing equilibrium of the ions between the solid phase and the solution. Due to this mode of action, resins are thought to be a universal index of relative P and K availability as compared to chemical-based extractions which may be limited in scope due to their ability to remove only specific solid phase nutrient fractions.

Until rccently, most of the reported work with ion exchange resins involved the use of loose beads in extraction, mainly in research applications to estimate the bioavailability of P. A major problem in using loose beads was the difficulty in separation of beads from the soil following the extraction. This problem has been overcome by sewing up the beads in a bag (Sibbesen, 1977; Skogley et al., 1990; Yang et al., 1991). Several recent studies have reported that anion and catin exchange resin beads can be mixed, enclosed in mesh bags and used for simultaneous extraction of plant available nutrient ions (van Raij et al., 1986; Yang et al., 1990 ab; Skogley et al., 1990; Yang et al., 1991). Skogley et al. (1990) report on such a method termed the phytoavailability soil test (PST) which, through extraction for 2-3 days in saturated paste soil samples, will provide simultaneous assessment of P, K and S availability. These workers observed a considerable improvement in the relationship between spring wheat K and S contents and test-predicted availability in the exchange resin extraction compared to conventional soil tests.

The extraction of soil nutrients using ion exchange resins in membrane form was first introduced by Saunders (1964). Saunders (1964) used an anion exchange membrane to extract soil phosphate and showed that its ability to estimate soil P was as good as resins in the bead form. Resin membrane techniques have recently been developed for the extraction of soil P (Saggar et al., 1990; Schoenau and Huang, 1991a). Schoenau and Huang (1991a) have reported that in testing for P, the anion exchange membrane extraction procedure developed was superior to bicarbonate and water extractions due to low cost, simplicity, independence of soil type, and high correlation with plant uptake. Saggar et al. (1990) compared P extracted by shaking soils with resin membranes for 16-17 hours to P extracted by resin beads in bags for a number of New Zealand soils and found that the amounts of P removed by membranes was closely correlated with that extracted by the resin bags. They observed that the bag procedure suffered from the disadvantage that the resin bags often trap fine root and soil particles which can only be removed by washing under pressure as well as problems with wear and tear on sealed edges of the bags.

The use of mixed anion and cation exchange membranes (ACEM) to simultaneously extract plant available nitrate, phosphate, potassium and sulfate has recently been reported by Schoenau and Huang (1991b). Although the number of soils evaluated was limited (8-14 soils), the high correlations between ACEM predicted availability and observed plant uptake of N,P,K and S suggested that the ACEM approach could provide a true multi-element soil test superior to any existing methodologies in routine soil testing. Our next goal became the refinement of the ACEM method for routine soil testing in terms of making it as rapid and simple as possible. We also felt that evaluation and comparison to conventional soil tests on a wider range of soils was required. This paper reports on the results of a study which compares nutrient ion extracted by ACEM under diifferent extraction and elution times to $NaHCO_3$ extractable (Olsen) P and K and 0.001M $CaCl_2$ extractable NO_3-N and SO_4-S in 130

Saskatchewan soils.

MATERIALS AND METHODS

One hundred and thirty surface soil samples from across Saskatchewan were obtained for the study. The soils offered considerable diversity in terms of pH, texture, organic matter content, and available nutrient level. Anion and cation exchange membrane sheets (BDH) were cut into strips of 46 x 10 mm for AEM and 40 x 14 mm for CEM. Exchange membrane strips were washed in 0.5M $NaHCO_3$ and then stored in deionized water prior to use. The exchange membrane extraction method we utilized was similar to that outlined by Schoenau and Huang (1991 ab). A 3 cm^3 scoop of soil transferred to a 125 mL erlenmyer flask and one strip of AEM and one strip of CEM was placed in the flask. Following this, 35 mL of deionized water was added to the flask and the flask placed on a reciprocating shaker. One hour and 15 minute shaking (extraction) times were compared. Following the shaking, the membrane strips were removed from the flask and rinsed with deionized water for about 10 seconds. The strips were then transferred to a clean flask containing 20 mL of 0.5M HCl to elute (remove) the ions from the strip. After 15 minutes the strips were removed from the eluent, washed in $NaHCO_3$ for regeneration, and the nitrate and phosphate concentrations in the HCI eluent determined using routine automated colorimetry (Technicon autoanalyzer). The concentration of K in the eluent was determined using automated flame emission. Sulfate was determined using inductively coupled plasma (ICP) spectrometry. The membrane strips can be re-used over and over. We have used the same strip for as many as 500 extractions with no physical deterioration or loss of effectivecness. The cost of a membrane strip from the supplier is between $0.50 and $1.00.

In the determination of $NaHCO_3$ - extractable P (Olsen P) and K, a 3 cm^3 scoop of soil was shaken with 60 mL of 0.5 M $NaHCO_3$ for 30 minutes on a reciprocating shaker and filtered. Phosphate in the extract was colorimetrically determined by the acid molybdate blue procedure and K was determined using flame emission analysis. Soluble nitrate and sulfate were determined by shaking a 25 cm^3 scoop of soil with 50 mL of 0.001M $CaCl_2$ for 30 minutes. Samples were then filtered and the nitrate and sulfate concentrations determined colorimetrically. The $NaHCO_3$ and $CaCl_2$ extraction are used on a routine basis by the Saskatchewan Soil Testing Laboratory to assess macronutrient availability in farm samples. We also included a recently developed chemical extractant for P known as the modified Kelowna extracting solution (Qian et al., 1991). The modified Kelowna extracting solution is comprised of 0.25N HOAc and 0.015N NH_4F as well as 0.25N NH_4OAc. A soil solution ratio of 1: 10 and a shaking time of 5 minutes was used in the modified Kelowna extraction.

RESULTS AND DISCUSSION

Effect of extraction and elution time

Our first objective was to determine if the extraction (shaking) and elution times in the mixed anion and cation exchange membrane (ACEM) procedure could be reduced below 1 hour. In previous work (Schoenau and Huang, 1991a) we had compared 1 hour, 6 hour, and 16 hour shaking times and found that, although the amounts of P extracted were lower with shorter extraction times, there was no change in the ability of the test to predict P availity to plants. Clearly, if shaking times less than 1 hour could be used without loss of predictive ability, the extraction would be much more suitable for routine soil testing work. We compared 1 hour and 15 minute shaking times for ACEM extractable phosphate, potassium, nitrate and sulfate in 130 soils (Table 1). Studies comparing 15 minute and 1 hour elution times showed that all nutrient ions wcre effectively displaced from the membranes by the HCI in 15 minutes, so a 15 minute elution was adopted.

Table 1. Regression equations for relationships between nutrient extracted by ion exchange membrane in 15 minute versus 1 hour shaking times.

Phosphorus	
$ACEM_{15\,min} = -0.08 + 0.37\ ACEM_{1\,hour}$	$r^2 = 0.96$
Potassium	
$ACEM_{15\,min} = 26 + 0.48\ ACEM_{1\,hour}$	$r^2=0.57$
Nitrate	
$ACEM_{15\,min} = -0.2 + 0.86\ ACEM_{1\,hour}$	$r^2=0.99$
Sulfate	
$ACEM_{15\,min} = 0.3 + 0.60\ ACEM_{1\,hour}$	$r^2=0.97$

For P, we observed that the 15 minute extraction time resulted in extractablc P levels that were about 37% of the values for 1 hour. However, there was no difference in predicted <u>relative</u> P availability in the soils as shown by the high correlation between the 15 minute and 1 hour ACEM P (r^2=0.96). In the case of K, the 15 minute ACEM extraction removed about 50% of that removed in 1 hour extraction. However, the amounts extracted over the two extraction times were not as closely correlated (r^2 =0.57) compared to the other nutrients, likely as a result of different soil K pools measured in short versus longer extraction periods. Over shorter extractions, the K extracted by ACEM would mainly be comprised of soil solution K whereas over longer extraction periods a greater measure of the reserve or exchangeable K may bc included. Stratification of the 130 soils into groups according to texture showed the highest correlations between 15 minute and 1 hour extractions in sandy soils (r^2 = 0.62) and the lowest correlation in soils of high clay content extractions in sandy soils (r^2=0.62) and the lowest correlation in soils of high clay content (r^2= 0.45). The greatest deviation would be expected in soils of high clay content, where the adsorbed K pool is most significant in relation to solution K.

For ACEM extractable nitrate, the 15 minute ACEM removed about 86% of the nitrate removed in the 1 hour extraction. The 15 minute and 1 hour extractions were very closely correlated with minimal scatter (r^2=0.99). The close relationship between 15 minute and 1I hour extraction for nitrate is attributed to the lack of an adsorbed or precipitated pool whose contribution could be affected by extraction time. A similar effect was observed for sulfate, with a close relationship between predicted availability for 15 minute and 1 hour extraction (r^2=0.97).

Relationship between ACEM and conventional soil tests.

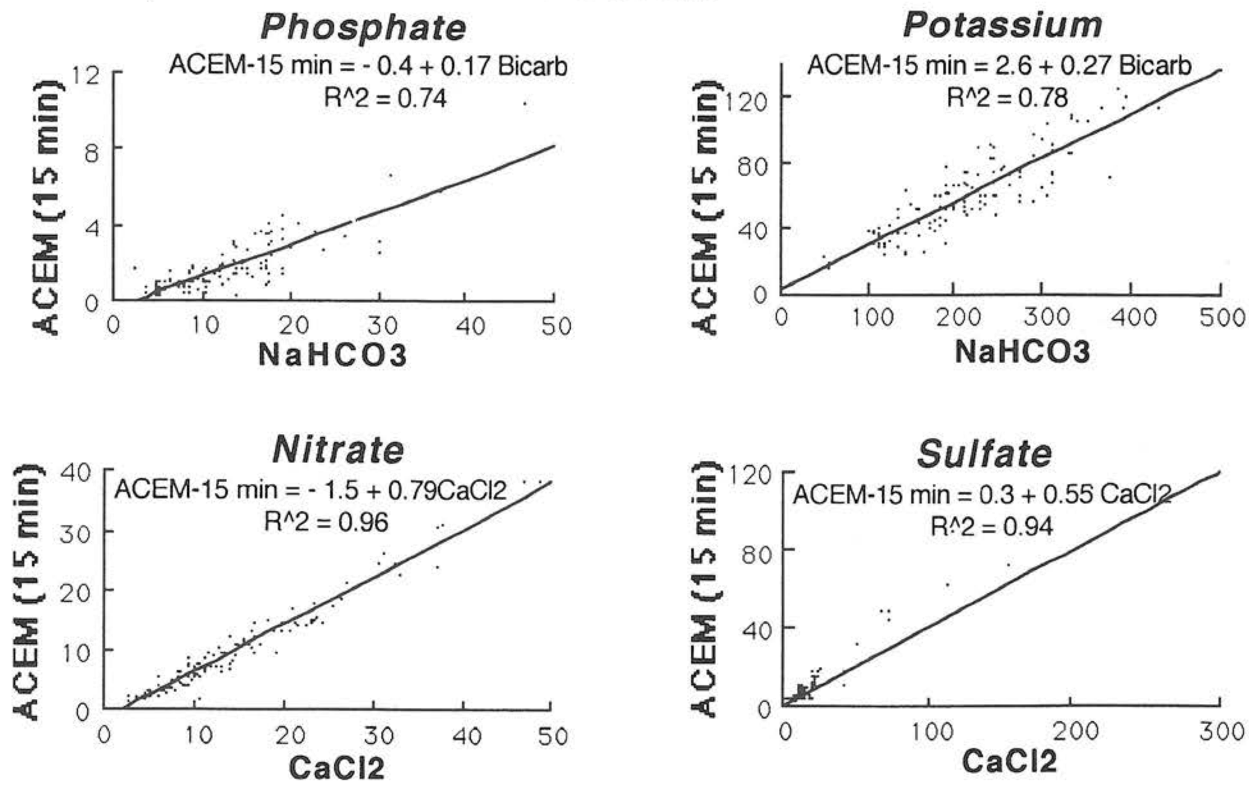

Fig. 1. Relationships between nutrient extracted by ACEM and conventional soil tests.

For the 130 soils tested, we observed a good correlation (r^2=0.74) between ACEM and 0.5 M $NaHCO_3$ P (Fig. 1). Amounts of P extracted by ACEM were about 17 percent of the amounts removed in the Olsen test. An even stronger relationship (r^2= 0.86) was observed between ACEM - P and modified Kelowna - P, with the ACEM extracting about 15 percent of the P removed in the Kelowna test.

Stratification according to soil type showed that for 12 soils of high sand content the relationship between ACEM and Olsen P improved (r^2=0.91) compared to the entire range of soils. For loam and clay soils the relationship was not as strong (r^2=0.76 and 0.73 respectively). The lower degree of correlation between the two extractions as clay content increases likely reflects the difference in mod of action of the two tests and, in particular, that the ACEM includes a lower measure of quantity (solid phase P) than the bicarbonate extraction. Of note are the differences in degree of correlation observed when the 130 soils were stratified into groups on the basis of pH. In the acid soils (pH 5.3 - 6.3) the relationship between ACEM and Olsen P is weak (r^2=0.42), but improves considerably for soils in the neutral (r^2=0.77) and alkaline (r^2=0.88) range. For the acid soils, the relationship between ACEM and modified Kelowna P was strong (r^2=0.78). As well, in the neutral and alkaline soils, the ACEM P was highly correlated with Kelowna P (r^2= 0.91 and 0.87). These results suggest that the Kelowna extraction may be a superior test for P compared to other chemical-based extractions since it is closely correlated to exchange membrane P in all soil types and exchange resins are considered to provide a relative index of nutrient availability that is independent of soil type.

Correlations were determined between P uptake by canola (var. Westar) and soil test predicted availability for 39 of the 130 soils used in this study. The 39 soils were selected so as to provide maximum contrast in P availabiliy and soil characteristics. The ACEM extractable P was more closely correlated with plant P uptake (r^2=0.84) than the Olsen P (r^2=0.70), suggesting that the ACEM provides a better index of relative P availability than the Olsen test.

We observed a reasonably close relationship (r^2=0.78) between the 15 minute ACEM and bicarbonate extractable K for the 130 soils (Fig. 1). When the data were stratified according to soil texture, the strongest correlations between ACEM and bicarbonate K were found to occur in the sandy soils (r^2=0.91). The relationship between the two tests was also good for loam soils (r^2= 0.82). However, in the clay soils, where exchangeable K is large relative to solution K, the relationship between ACEM and bicarbonate K was not nearly as strong (r^2= 0.40). The poor relationship between the two tests in soils of high clay content likely reflects that only the most loosely sorbed K on clay mineral surfaces is removed by ACEM whereas sodium bicarbonate can remove most of the surface - held K.

For nitrate and sulfate, the ACEM and $CaCl_2$ extractions were very closely correlated (r^2=0.96 and 0.94 respectively). A close relationship is expected between the two tests since there is no solid phase pool of ion to be measured. Rather, all the nitrate and sulfate in these soils exists in the soil solution and both tests should be effective at removing all or a consistent portion of this fraction.

CONCLUSIONS

ACEM extraction provides a simple, rapid, simultaneous index of relative P, K, N and S availability in which the mode of extraction closely simulates the action of plant roots. For these reasons, the ACEM extraction is considered to be superior to existing chemical-based soil tests, especially for P and K. Extraction and elution times as short as 15 minutes may be used in ACEM extraction. Evaluation in a routine soil testing laboratory setting has shown that the method is highly suited to routine fertility analyses of field samples and could be easily adopted by any soil testing laboratory. Work is currently underway evaluating the relationship beteen test - predicted availability and nutrient uptake by crops grown on a wide range of western Canadian soils.

ACKNOWLEDGEMENTS

The authors wish to thank ESSO Chemical Canada, Saskatchewan Agriculture Development Fund, and the Saskatchewan Soil Testing Laboratory for support of this research.

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EVALUATION OF CHLOROPHYLL METERS FOR NITROGEN MANAGEMENT

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ABSTRACT

Determining crop N status for the purpose of managing fertilizer applications can be a difficult task. Chlorophyll meters make it possible to quickly and reliably monitor leaf greenness and evaluate the need for additional N fertilizer. Leaf N concentration and chlorophyll meter readings were strongly correlated for corn and wheat. Chlorophyll meter readings were also positively correlated with corn and wheat yields. Cultivar, soil type, water content, and geographic location present challenges to interpretation of chlorophyll meter data. Chlorophyll meter readings were also correlated with petiole nitrate concentrations in sugar beets, but leaf greenness tended to reach an upper limit even at high petiole nitrate concentrations. Protein content of alfalfa was strongly correlated with chlorophyll meter readings. Techniques must be developed and tested to simplify calibration and interpretation of chlorophyll meter data.

OBJECTIVES

Nitrogen management is important to all phases of agriculture, but sometimes for different reasons. Everyone is naturally concerned about the quality of their drinking water and the potential for nitrate contamination, but beyond that producers are concerned because N management can influence profitability and/or the quality of what they grow. Compromises must be reached between environmental and profitability concerns because practices that insure near maximum profits from cereal crops may not effectively use N fertilizer. This is because producers frequently feel that it is necessary to apply "insurance" nitrogen to compensate for possible N losses that could result in lower yields. Even moderate amounts of excess N fertilizer can reduce fertilizer use efficiency by crops and promote the potential for nitrate leaching. The dilemma facing producers is knowing how much N fertilizer is necessary to meet crop needs and when it is necessary to compensate for leaching or denitrification losses caused by excess precipitation or irrigation.

Producers of cereal crops like corn and sorghum are fortunate in some ways because small to moderate amounts of excess N fertilizer usually do not reduce yields, but excess N can result in lodging of some small grains like wheat. Production of noncereal crops frequently requires unique management considerations because excess N availability can decrease the quality of the crop and/or profitability. For example, excess N late in the growing season can reduce yield and sugar content of sugar beets.

The major difficulty in managing N is that fertilizer is usually applied far in advance of harvest and many things can happen to influence N availability during the growing season. Improvements could be made in fertilizer N use efficiency if (1) producers were able to monitor crop N status during the growing season and (2) technologies and procedures were available to correct a nutrient deficiency. Chlorophyll meters offer producers a way to quantify plant greenness, which is related to crop N status, and to program the application of supplemental N fertilizer. Other nutrients such as Zn, Fe, and S are also known to affect crop color and therefore could affect chlorophyll meter readings. Problems associated with multiple nutrient deficiencies can usually be minimized by referencing data to an area with similar fertilizer history but having adequate N fertility. Fertigation and spoke injector techniques make it possible for producers to apply N fertilizer at any time, even to tall growing crops.

The objectives of this paper are to evaluate chlorophyll meters as a N management tool for corn, wheat, sugar beet, and alfalfa production systems.

METHODS

SPAD 502 chlorophyll meters were used to monitor leaf greenness of corn in Nebraska, wheat in Colorado, sugar beets in Wyoming, and alfalfa in Colorado and Nebraska. Chlorophyll meter data from leaves of about 30 different plants were compared with leaf N concentrations of corn, wheat, and alfalfa, petiole nitrate concentration of sugar beets, and yield of corn and wheat.

RESULTS and DISCUSSION

Economic and practical considerations largely dictate producer N management programs. Producer changes are usually slow in coming but are more likely to occur if the financial incentives are substantial and the hassle factor associated with a given practice is minimal. Application of chlorophyll meter technology to agricultural production systems depends on the nature of the problem and instrument limitations. While chlorophyll meters measure leaf greenness, they can not detect luxury consumption or determine which nutrient is responsible for leaf color. This work assumes that N is the nutrient in question and that all other nutrients are adequate or that the interactions with N are minimal. Since the Minolta SPAD 502 chlorophyll meters have only been commercially available for about two years, there have been many questions about how to collect and interpret the data for the various applications.

CORN: Chlorophyll meter data is probably the most abundant for corn of all the crops grown in the Great Plains. This should be expected because much of the corn grown in Nebraska, Kansas, and Colorado is under irrigation, which lends itself to fertigation. The strategy being targeted and developed for irrigated corn production in Nebraska is to use traditional soil testing procedures to make fertilizer recommendations, but to only apply 50 to 75% of the recommended fertilizer N as a preplant, starter, or sidedress application. This approach would allow the crop to utilize N from all available sources first and then permit the addition of N fertilizer in irrigation water as indicated by chlorophyll meter readings.

General questions about application of chlorophyll meter technology deal with how early in the growing season they can be used and how late in the season can a problem be corrected. Answers to these questions are probably not important if one cannot show a good relationship between chlorophyll meter readings and leaf N content or grain yield. All studies to date show that chlorophyll meter readings at silking are strongly correlated with both earleaf N concentration at silking and yield (Figure 1).

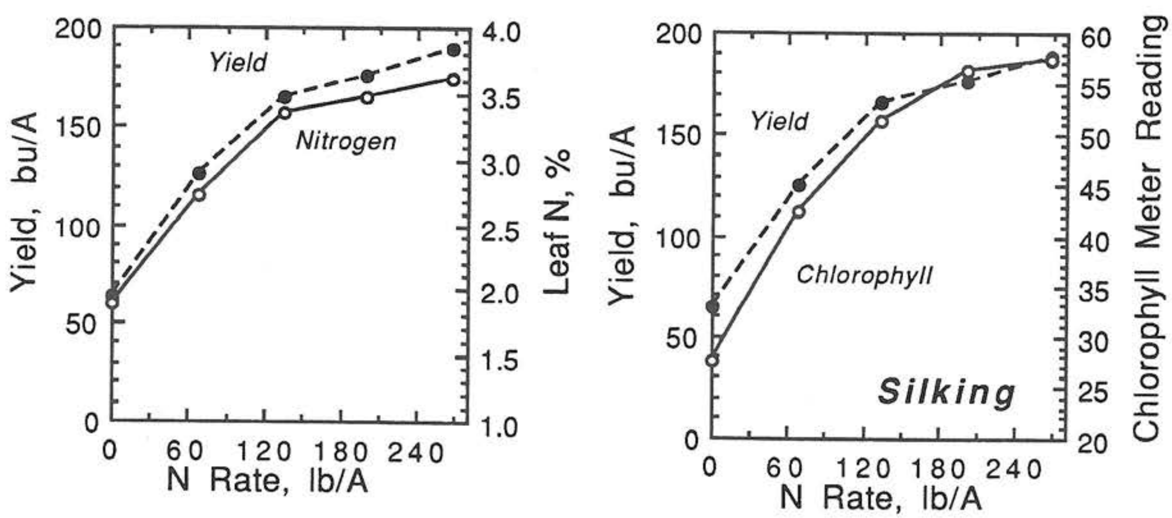

Figure 1. Relationship between corn yields and earleaf chlorophyll meter readings and N concentrations at silking in Nebraska.

The good relationship between chlorophyll meter readings and yield also holds at sidedressing (Figure 2). However, the early season relationship between chlorophyll meter readings and leaf N concentration of the uppermost expanded leaf is not good at high rates of N fertilizer because of luxury consumption.

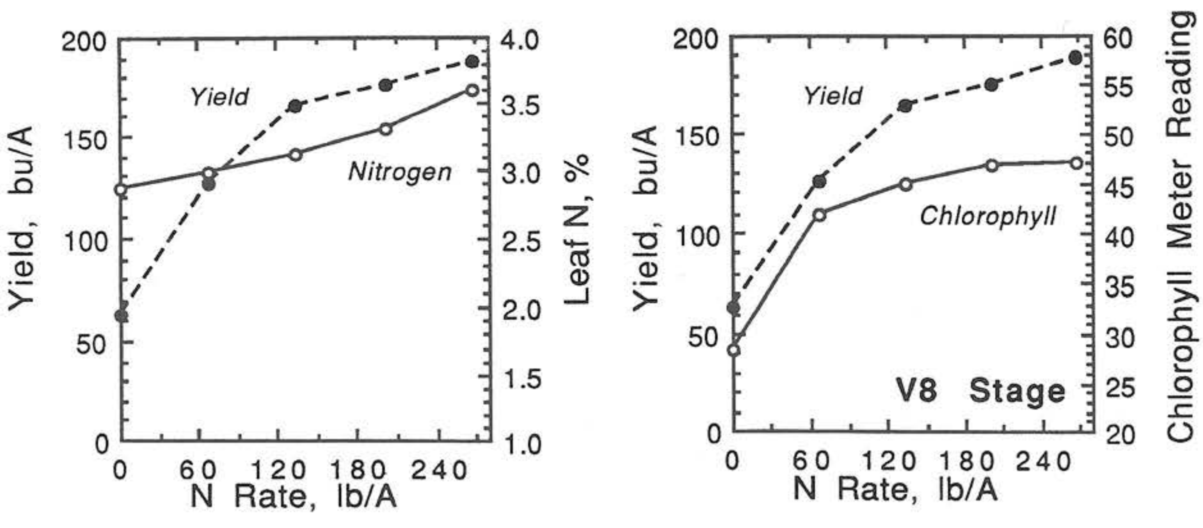

Figure 2. Relationship between corn yield and chlorophyll meter readings and N concentrations of the uppermost expanded leaf at the V8 growth stage.

The strength of the chlorophyll meter approach to N management is that the readings are sensitive in the deficient to adequate range where additional N fertilizer could be used to correct a potential problem. Chlorophyll meters will not tell producers how much excess N fertilizer was applied. Indications of excess N application must be obtained using the postmortem stalk test for nitrate or by sampling the soil for residual N after harvest.

WHEAT: Nitrogen management for winter wheat production presents a challenge for chlorophyll meters because the decision to apply fertilizer is frequently based on data collected in the spring from young plants. In addition, temperatures are cool and soils can be wet so that plant greenness may not be a good reflection of crop N status or of the soils ability to supply N later in the season.

Decisions to fertilizer winter wheat in the spring can be based on soil testing procedures, the determination of leaf N concentration, or perhaps chlorophyll meter technology. Nitrogen rate studies at four Colorado locations showed site specific relationships between chlorophyll meter readings at the late tillering stage (Feekes 5) and grain yields (Figure 3). Based on these data it would be difficult to recommend an optimum chlorophyll meter reading to attain maximum wheat yields. Apparently site specific soil and climatic factors affected leaf greenness at the tillering stage. Normalizing the data for each site relative to an adequately fertilized area (assumed to be the maximum N rate for each study) illustrates that the shape of each response curve remains unchanged. These data suggest that a small adequately fertilized area of the field could probably be used as a reference for the remainder of the field.

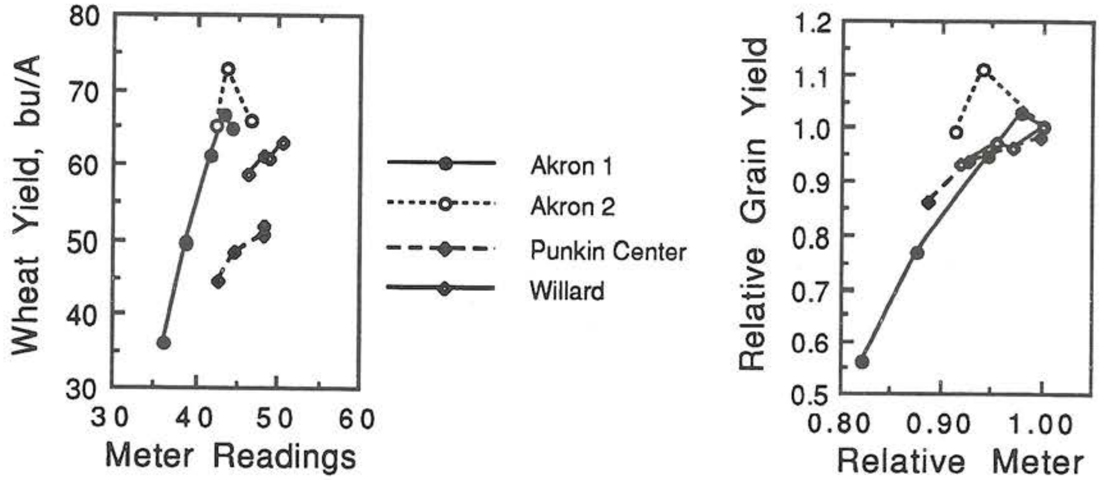

Figure 3. Relationship between chlorophyll meter readings of winter wheat at tillering and grain yields at four Colorado locations.

SUGAR BEET: Chlorophyll meters could have a rather unique application for sugar beet production in that nitrate availability late in the growing season is inversely related to sugar content of the crop. In contrast to corn producers who want to insure adequate N until maturity, sugar beet producers strive to deplete the supply of available N late in the growing season. Producers traditionally monitor the leaf petiole for nitrate-N concentration to estimate when the sugar content will be high enough to begin harvesting. One such guideline indicates that harvesting can be initiated about 6 weeks after the petiole nitrate-N concentration declines to 1000 ppm. Ideally this point would be reached in late August or early September for sugar beet production in western Nebraska, Colorado, Montana, and Wyoming.

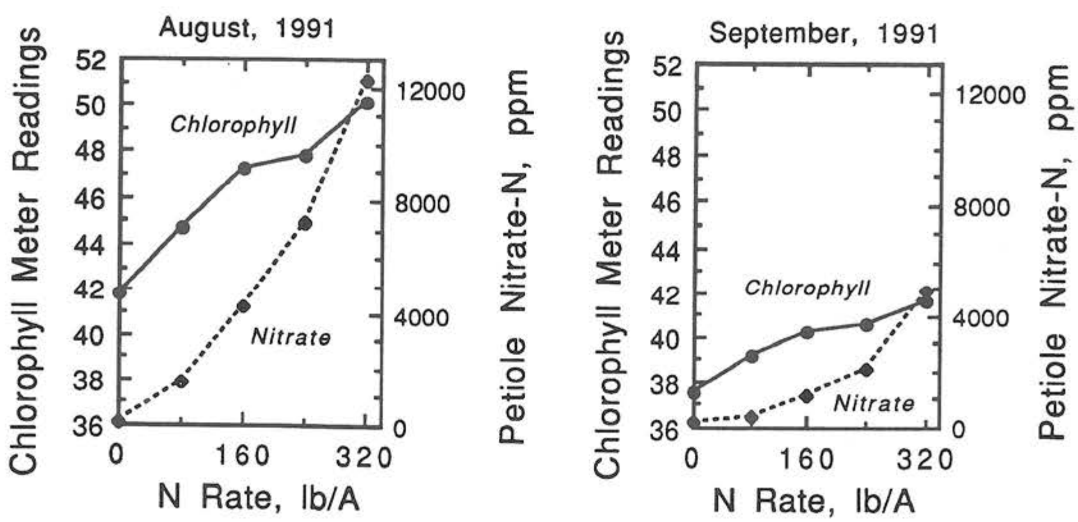

Figure 4. Effect of fertilizer N rate on chlorophyll meter readings and petiole nitrate-N concentrations for sugar beets on two dates.

Chlorophyll meter readings and petiole nitrate-N concentrations in August and September followed similar trends even though the values were lower in September (Figure 4). It should be noted that while petiole nitrate-N concentrations continued to increase beyond the 160 lb N/A fertilizer rate, chlorophyll meter readings tended to reach a plateau.

Prices paid to sugar beet producers depends on factors such as root yield, sucrose concentration, and amount of impurities. Recoverable sucrose integrates some of the above factors and can be used to evaluate chlorophyll meters as a management tool. The petiole nitrate-N concentration of about 1000 ppm corresponds to the peak level of recoverable sugar (Figure 5). This corresponds to a chlorophyll meter reading of 40, however little is known about the cultivar specificity of such a value. Additional research is needed to fully understand and evaluate the merits of chlorophyll meter technology as a management tool for sugar beet production.

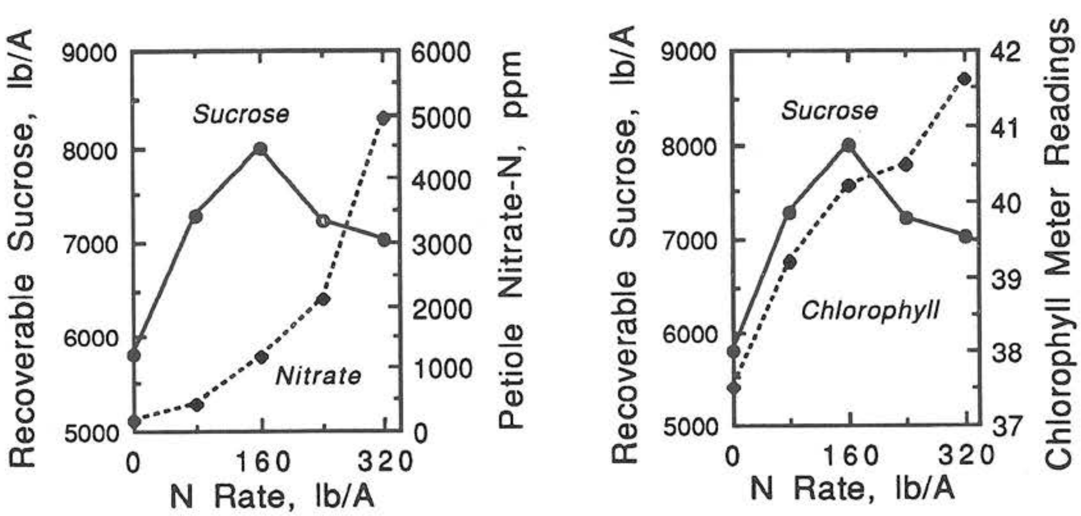

Figure 5. Comparison of recoverable sucrose from sugar beets with chlorophyll meter readings and petiole nitrate-N concentrations in September.

Chlorophyll meter readings and petiole nitrate-N concentrations in August and September followed similar trends even though the values were lower in September (Figure 4). It should be noted that while petiole nitrate-N concentrations continued to increase beyond the 160 lb N/A fertilizer rate, chlorophyll meter readings tended to reach a plateau.

ALFALFA: Since alfalfa is a legume, fertilizer N management is not of concern. However, the value of the crop depends on the protein content, which can be affected by when the alfalfa is harvested. As the crop approaches maturity, the protein content declines while dry matter production increases. Conventional guidelines suggest that harvesting at the 10% bloom stage is a reasonable compromise between dry matter production and protein content. Premium prices for high quality alfalfa hay are enticing some producers to harvest their crop before the 1 0% bloom stage to capitalize on specialized markets. The positive relationship between chlorophyll meter readings and leaf N concentration for corn and wheat offers some possibility that the meters could also be used to monitor alfalfa protein content. Since no adequately fertilized reference area exists in the case of alfalfa production, another method of calibration must be devised.

Calibration of chlorophyll meters for alfalfa production could take at least two different forms. One could simply monitor the crop frequently and over time develop a pattern to attain some minimal protein content while optimizing dry matter production. Another approach would be to monitor two leaf positions on the same plant and develop a harvesting strategy based on a comparison of the two values. Limited evaluations about eight days before bloom showed little difference in chlorophyll meter readings for the upper six leaflets (Figure 6). More extensive monitoring of the the fifth leaf from the top of the plant indicated a positive relationship between leaf N concentration and chlorophyll meter readings. Considerable variation in meter readings was observed between plants, which is attributed to genetic impurities within a given cultivar.

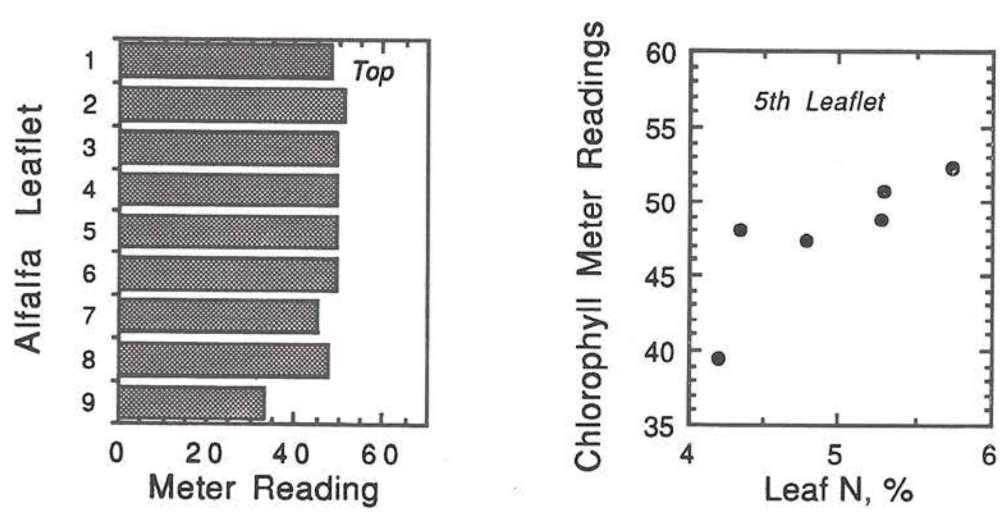

Figure 6. Chlorophyll meter readings for various alfalfa leaflets and the relationship with leaf N concentration of the fifth leaflet eight days before blossom.

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ECONOMICS OF DRYLAND CROP ROTATIONS FOR EFFICIENT WATER AND NITROGEN USE

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ABSTRACT

Conventionally tilled wheat-fallow systems may not be sustainable in the long term. Reducing tillage and maintaining a residue cover on the soil increases water storage, but to attain the maximum increase in water use efficiency (WUE), rotations must be intensified. Switching from wheat-fallow to wheat-corn-fallow and wheat-corn-millet-fallow systems has increased WUE by 60 to 100%. Although these new systems increase input costs by 65%, they result in net income increases of 30%. Compliance with the 1990 farm bill residue requirements can be attained with reduced tillage and extended rotation systems.

INTRODUCTION

The modern Great Plains has a productivity far beyond the dreams of the most optimistic settlers and early scientists that contended with its eccentricities. Populations have boomed and retrenched several times since the late 19th century. Problems in the Plains have been closely linked with its unpredictable climatic conditions. Records show that since 1908 the probability of receiving 75% or less of average annual precipitation at Akron and Burlington CO occurred 20 and 28% of the time, respectively (Greb,1979). Obviously successful management must be able to deal with these extremes.

These erratic precipitation patterns led to the development of summer fallow to stabilize crop yields. Historically, fallowing has meant bare soils with a large erosion potential and very low water use efficiency (WUE). A wheat-fallow system using moldboard plow tillage lost 28 t/A per 24 month period over an eight year period at Alliance NE (Fenster, et al., 1977). Fallow precipitation storage efficiencies generally have been 25% or less since the 1930's and WUE less than 50 to 60 lbs/A/in (Greb, 1979).

Soil organic matter losses from cultivated soils in wheat-fallow systems average over 50% in most Great Plains soils. Fallowing compared to continuous cropping hastened organic matter loss (Haas and Evans, 1957).

Economic instability associated with the irregular weather patterns has been a problem in the Great Plains since the 19th century. Declining farm prices accompanied by rising production costs have complicated the situation in recent years. More than one-half of the land enrolled in the Conservation Reserve Program is found in 396 Great Plains counties (Skold, 1991). Obviously producers are opting for programs that improve economic stability when present practices are not highly profitable.

Water is the primary driver of production in the Great Plains. However, tillage choice can greatly modify the water driver because effective water capture and efficient use are greatly affected by it (Peterson, 1991). For example, fallow precipitation storage efficiencies can vary from less than 15% to as high as 50% depending on tillage system.

Efficient use of stored water and precipitation cannot occur if plants are deficient in N. Past management has caused most soils in the Plains to be N deficient. Nitrogen fertilization is necessary to achieve optimum yields.

Our objective is to discuss current research that addresses the problems enumerated above. Increasing soil cover, decreasing soil stirring, and judicious N fertilization are critical to their solution. The approach involves substitution of herbicides for some or all of the tillage operations usually associated with farming in the Great Plains. The goal of each step is maximizing residue cover during non-crop periods and seedling growth stages. Smika and Wicks (1968) showed 20 years ago that reduced and no-till systems simultaneously improved water storage and reduced potential erosion by increasing cover. Fenster and Peterson (1979) reported significant improvements in water storage efficiency with no-till wheat-fallow, but little overall improvement in grain yield compared to conventional bare fallow farming. Success of a wheat crop in the central Plains is more highly correlated with April through June rainfall than with stored water at seeding. Thus the improved water storage with reduced tillage can only be expected to contribute to wheat grain yield when precipitation in these months is below normal.

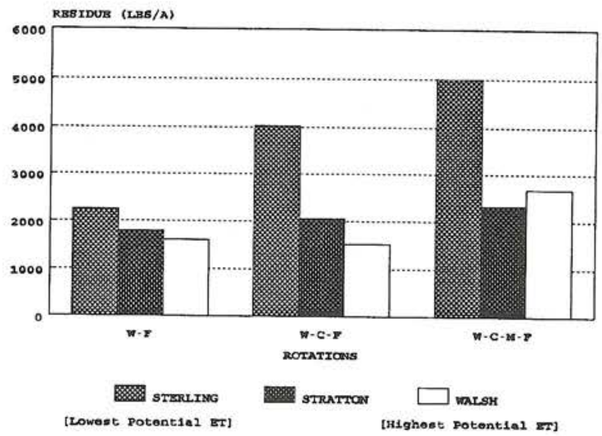
Exploitation of the water savings associated with reduced tillage is being attempted by insertion of more crops into the systems. Summer fallow time is reduced and the additional water is provided to spring planted crops such as corn, grain sorghum and millets. Rotations with two years of crop out of three, three years out of four and even continuous cropping are being researched. New systems are being studied over a range of climates and soils (Peterson, et al., 1991; Halvorson, 1990).

RESULTS

Erosion Potential

Crop residue covers are an effective erosion control device in the Plains (Fenster, et al. 1977). Installation of no-till cropping systems at three eastern Colorado locations greatly reduced erosion potential by increasing residue cover (Fig. 1). The minimum residue present in the most stressful environment, Walsh with high ET, was about 1500 lb/A. This amount of wheat residue provides about 40-50% cover, which in turn should reduce erosion during fallow by 70% compared to bare conditions (Dickey, et al., 1983). A rotation such as wheat-corn-millet-fallow with more crop periods and fewer fallows increased residue weight by 60%, compared to wheat-fallow, resulting in even better potential erosion control.

Figure 1. Crop residue on summit soils at winter wheat seeding in fall 1990 as affected by location (ET regime) and rotation.



Water Use Efficiency

Total production and WUE are dependent on total precipitation and on the effectiveness of that precipitation. Increases in evaporative demand increase potential ET and decrease precipitation effectiveness. Locations at Sterling, Stratton and Walsh CO each have about 16-17 inches of annual precipitation, but range widely in potential ET. Open pan evaporation at Sterling is 42 in/crop season but is 75 in/crop season at Walsh, which indicates the large potential ET gradient between these sites. Increasing rotation intensity has increased grain WUE markedly in all environments (Fig. 2). The wheat-corn-millet-fallow rotation has increased WUE by 100, 60, and 100% compared to wheat-fallow at the Sterling, Stratton and Walsh sites, respectively. Halvorson (1990) found similar relationships at Akron CO plus additional increases in WUE using annual cropping (Fig. 3). Intensifying rotations has increased WUE because it efficiently uses the extra water stored under no-till management.

Figure 2. Annualized grain water use efficiency (WUE) as affected by climatic area and crop rotation.

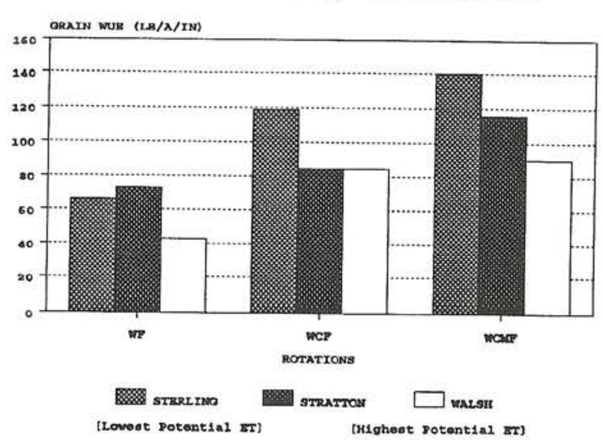
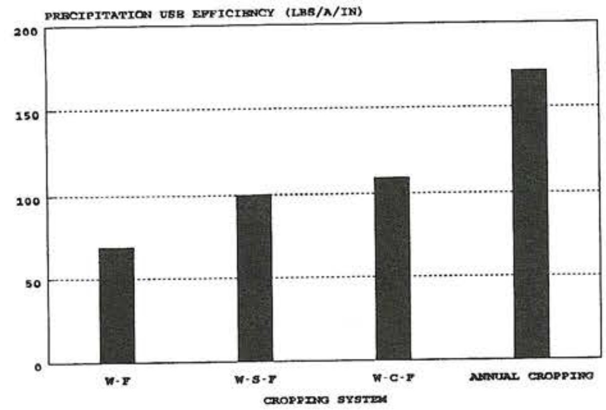


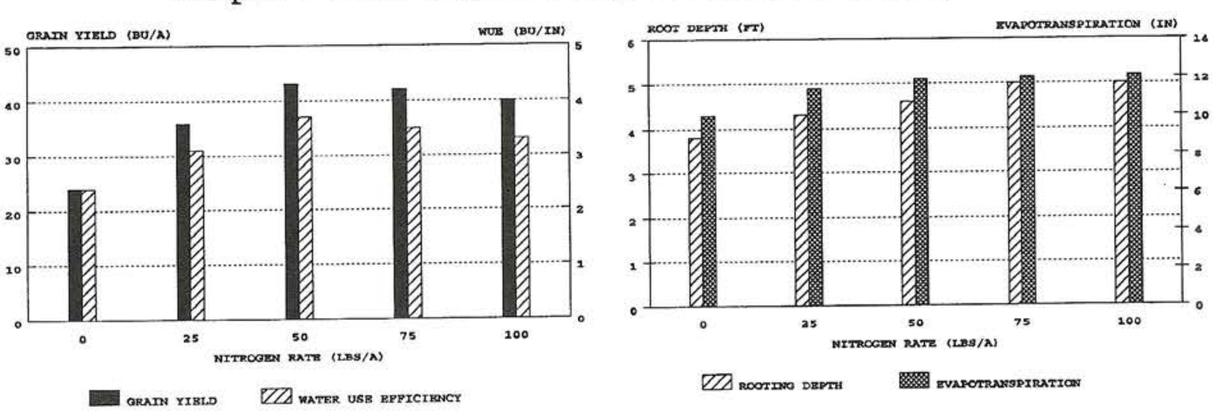
Figure 3. Precipitation use efficiency as affected by cropping system at Akron CO. (Adapted from Halvorson, 1990).



Nitrogen Management

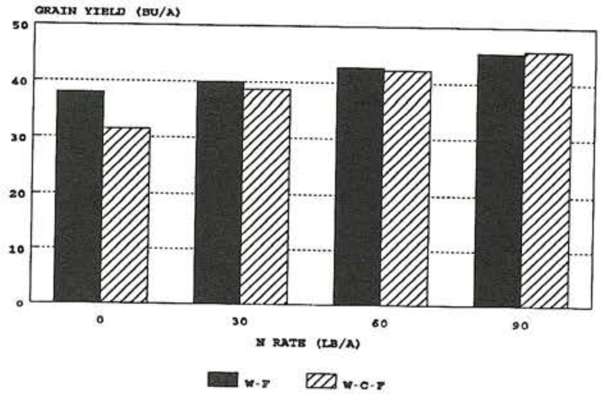
Grain yield and water use efficiency are improved when N deficient soils are fertilized. Nielsen and Halvorson (1991) showed that N fertilization maximized transpiration, but also enhanced root development (Fig. 4). They concluded that, although N fertilization increased transpired water, the exploration of more stored soil water by deeper rooting allowed increases in total production and WUE even in moderately stressed environments.

Figure 4. Grain yield, water use efficiency, root depth and evapotranspiration as affected by N fertilization. Adapted from Nielsen and Halvorson (1991).



Nitrogen response data from Sterling and Stratton CO indicate that more intense rotations like wheat-corn-fallow result in soils that respond more to N fertilization than soils in wheat-fallow systems (Fig.5). The greater N removal in grain in the more intensely cropped rotations increases the need for N fertilization.

Figure 5. Wheat yield response to N fertilization as affected by rotation and N rate at Sterling and Stratton, CO from 1989-91.



Economics of Systems

Wheat yields have either remained stable or increased as rotation intensity increased, in spite of shorter summer fallow periods preceding wheat seeding (Table 1). Corn yields have been equal in the two rotations.

Table 1. Crop yields for 1988-1991 for the Sterling and Stratton sites as affected by crop rotation.

Wheat			Corn		Millet
W-F	W-C-F	W-C-M-F	W-C-F	W-C-M-F	W-C-M-F
Bu/A					
41	41	45	78	78	37

Intensifying rotations increased gross income by 45% using a reasonable price scenario (Table 2). These incomes were annualized to account for varying rotation length and the unproductivity of the fallow year.

Costs of the more intensive rotations, compared to conventionally tilled wheat-fallow, increased by 65% because of added herbicides, more sophisticated planting equipment and increased harvesting cost etc. These costs do not include land cost and overhead. Net income has increased by extending rotation length and decreasing summer fallow. Wheat-corn-fallow, compared to tilled wheat-fallow, increased net income per acre per year by 30%. No-till wheat-fallow decreased net income by 35% compared to tilled wheat-fallow. The wheat-corn-millet-fallow rotation increased net income with millet prices at the long term average. However, proso millet markets are historically volatile compared to wheat, corn and grain sorghum, and the 1991-92 price is now $1.50/Bu compared to the average of $2.80/Bu. Using the lower price wheat-corn-fallow is superior to wheat-corn-millet-fallow by about $9.00/A/Year. Benefits of the longer rotation, such as improvements in weed control and residue cover, may still make it the best choice even when millet prices are low.

Table 2. Annualized gross income, system costs, and net income as affected by crop rotation and tillage system.

Rotation	Gross*	System Costs		Net	
		Tilled	No-till	Tilled	No-till
	------------------$/A/Year-------------------				
W-F	80.22	32.11	49.57	48.11	30.66
W-C-F	117.96	-	54.60	-	63.36
W-C-M-F	117.50	-	51.32	-	66.18

* Wheat @ $4.20/Bu for first 30 bu and $3.13/Bu for balance, Corn @ $2.48/Bu, and Millet @ $2.80/Bu. [Historic average target and farmgate prices for wheat, corn and millet in Colorado since 1980 (Hudson and Fretwell, 1991)]

DISCUSSION

Maintaining residue on the soil surface and decreasing soil stirring improves WUE, decreases erosion potential, and increases total productivity when rotation intensity is increased. The improved productivity leads to increased economic returns to the producer. Proper residue management with reduced tillage permits the addition of spring crops to the rotations and decreases the use of wasteful summer fallow. The combination of reduced soil stirring and greater stover production with increased cropping intensity has allowed soil organic matter levels, both C and N to be increased (Wood, et al. 1991). These changes were evident just four years after establishment of the intensive rotation.

Wheat-fallow, a monoculture system, also has resulted in increased grassy weed problems such as jointed goat grass, downy brome, and volunteer rye. Westra (1990) estimated that these three weeds cost Colorado wheat growers in excess of $20,000,000 annually. Changing to more intensive rotations with more time between wheat crops is probably the only feasible way to eliminate these weed problems, especially jointed goatgrass.

Compliance with the U.S. farm bill also will require a change in present practices. It appears that one way of being in compliance and remaining economically viable is to switch to more intensive crop rotations managed as a no-till or reduced till system.

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LONG-TERM ROTATION EFFECT ON CROP PRODUCTION AND SOIL QUALITY

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ABSTRACT

Grain yield and grain protein response of spring wheat (Triticum aestivum L.) to summerfallow frequency and nutrient amendment were summarized after 36 years on a Dark Brown Chernozemic clay loam soil in southern Alberta. Extending the rotation length beyond the traditional 2-yr fallow-wheat (F-W) rotation increased the yield of wheat on both summerfallow and stubble. Feedlot manure applied to summerfallow in the fallow-wheat-wheat rotation (F+M-W-W) resulted in the highest fallow wheat grain yields under all levels of moisture deficit. Three years of hay in the rotation (F-W-W-H-H-H) increased yield variability and reduced the fallow-wheat yield due to inadequate soil water recharge in this semiarid environment. However, the nutrients released from the decomposing hay roots resulted in the highest grain yield and grain protein of recrop wheat. Total grain production over the 36 years increased as summerfallow frequency decreased and nutrient addition increased. While soil N% continued to decrease in the unamended F-W and F-W-W rotations, an increase was recorded for the fertilized and unfertilized continuous wheat, F+M-W-W, and F-W-W-H-H-H rotations. The results of this study indicate that grain production, grain quality and soil N% can be increased by adoption of extended crop rotations with some form of nutrient amendment.

INTRODUCTION

The semiarid climate characteristic of the Dark Brown soil zone of southern Alberta has resulted in the adoption of cereal rotations with a high frequency of summerfallow. The soil moisture conserved during the 21 month summerfallow period increases spring wheat yield stability (Campbell et al., 1983). However, the dilemma producers face is that the grain yield stability achieved with summerfallow comes at the cost of organic matter depletion (Ridley and Hedlin, 1968; McGill et al., 1988; Janzen, 1987; Campbell et al., 1991a). Soil organic matter losses of 15 to 30% have been reported for the A horizon of Chernozemic soils since settlement of the Canadian prairies 80 to 100 years ago.

The production of legume and grass forages in rotation with cereals has been identified as a means of reducing the decline, or even increasing, soil organic matter and soil nitrogen (Campbell et al., 1976, 1991a). Similar soil quality responses have also been observed with continuous cereal production, particularly when N fertilizer was included (Janzen, 1987; Campbell et al., 1991b). In this paper we will present the 36 year spring wheat grain yield and protein response as influenced by summerfallow frequency and the inclusion of forages, feedlot manure, and fertilizer N.

MATERIALS AND METHODS

Rotation 116 was initiated in 1951 on a Dark Brown Chernozemic clay loam soil (Typic Haploborolls) at the Agriculture Canada Research Station in Lethbridge, Alberta (49°42'N, 112°50'W). The plot area was broken from native sod between 1905 and 1910, and up until 1950 was used for a series of mixed crop rotations that were "lightly" manured every sixth year (Pittman, 1977). The five rotations started in 1951 included continuous wheat (W), fallow-wheat (F-W), fallow-wheat-wheat (F-W-W), fallow+manure-wheat-wheat (F+M-W-W), and fallow-wheat-wheat-hay-hay-hay (F-W-W-H-H-H). The feedlot manure was applied at a rate of 5 tons/a during the summerfallow year, with an estimated nutrient content of 60 lb N/a (Anonymous, 1987). The hay crop, a mixture of alfalfa (Medicago sativa) + crested wheatgrass (Agropyron cristatum), was seeded without a cover crop in the spring of the fourth year. Hay was not harvested in the establishment year and was plowed under in the late fall or early spring following the third year of growth. In 1955 a second continuous wheat rotation was included (W-IF+N). The IF rotation was seeded only if there was 18 to 24 inches of moist soil at seeding in the spring. During the term of this experiment the IF rotation was not seeded in 5 years (1962, 1972, 1976, 1983, and 1988). The rotation was modified in 1980 to include 40 lb/a of fertilizer N, and in 1984 when the rate was increased to 80 lb/a. All rotations were cropped using recommended hard red spring wheat varieties and management practices of the time. Starting in 1984 40 lb/a of P_2O_5 was seed placed with all wheat. Grain protein concentration was determined for wheat harvested after 1977. Daily precipitation and class A pan evaporation data were collected at the Research Stations weather monitoring site (within 1/2 mi). Prior to 1968 evaporation was measured from a buried pan. Yield data presented in this paper will include only the last 36 years, so as to exclude any influence from previous cropping history during the initial years of the experiment.

RESULTS AND DISCUSSION

Spring wheat grain yields on both summerfallow and stubble varied significantly ($P \leq 0.05$) between the rotations when considered on a crop-year basis (Table 1). Increasing rotation length positively influenced the yield of wheat on fallow indicating a crop response to reduced summerfallow frequency. Campbell et al. (1983), working on a Brown Chernozem (Aridic Haploborolls) at Swift Current, reported no difference in fallow-wheat yield between 2-yr and 3-yr rotations. The high yield in the manured rotation reflects the estimated 60 lb N/a added as manure during the summerfallow year, with the influence of the nutrient amendment being greatest under low moisture deficit conditions (Table 1). In those years designated as having either an average or high moisture deficit no significant ($P \geq 0.05$) grain yield advantage was recorded for the manured rotation over the unamended F-W-W. The low fallow-wheat yield in the 6-yr hay rotation is a reflection of the deficiency in soil water associated with a perennial forage.

* Note Adjust All yield to 66% of listed value to correct error 3/3/92

Table 1. Thirty-six year (1956-1991) mean grain yield, CV%, and grain yield response to low, average and high moisture deficit conditions for Rotation 116.

Rotation	Mean Yield/yr (bu/a)†	CV%	Moisture deficit Low‡	Average	High
F-W§	37.5 c¶ (27)	40	45.5 c	38.9 b	31.2 b
F-W-W	40.6 b (29)	40	49.7 b	42.6 a	33.1 a
F+M-W-W	42.9 a (31)	43	54.7 a	43.7 a	34.4 a
F-W-W-H-H-H	38.2 c (26)	50	51.4 b	39.5 b	28.4 c
W	20.3 g (15)	57	23.7 g	22.5 de	16.8 g
F-W-W	22.9 f (17)	50	27.7 f	22.4 e	19.8 ef
F+M-W-W	25.5 e (19)	51	31.6 e	24.7 d	21.7 d
F-W-W-H-H-H	27.1 d (20)	57	35.6 d	28.3 c	20.5 de
W-IF+N	25.0 e (18)	69	31.2 e	28.6 c	18.7 f

† Sample size n=144; 36 years (1956-1991) x 4 reps.

‡ Long-term average moisture deficit (May to July evap-ppt)=425mm Low = <90% (n=44), Average = 90-110% (n=36), High = >110% (n=64) of 425 mm.

§ F-fallow, W-wheat, +M-feedlot manure at 5 tons/a, H-alfalfa/crested wheatgrass hay, IF-continuous wheat seeded if 18 to 24 in of moist soil in spring, N-fertilizer N at 40 lb/a from 1980-1984 and 80 lb/a from 1985-1991.

¶ Values within columns followed by the same letter are not significantly (P≥0.05) different using LSD.

Under low moisture deficit conditions the hay rotation produced fallow-wheat yields which were higher than the 2-yr F-W rotation (Table 1). However, under high moisture deficit conditions fallow-wheat yields were lowest in the hay rotation. This yield variability between years is reflected in the high CV% associated with the hay rotation.

Stubble-wheat yields averaged 61% of wheat on fallow, with yield variability (CV%) higher on stubble (Table 1). The ratio of stubble:fallow wheat yields within rotations was highest at 71% for F-W-W-H-H-H, followed by F+M-W-W at 59%, and F-W-W at 56%. The high CV% recorded for W-IF+N reflects the 5 years when a zero grain yield was recorded due to inadequate spring soil moisture for the crop to be seeded. Stubble-wheat yields were on average highest in the hay rotation, a response which was consistent across all levels of moisture deficit. This stubble-wheat yield response can be attributed to the nutrient supplying power of decomposing hay roots. The yield response to manure observed on summerfallow continued to increase stubble wheat yields over the unamended F-W and W rotations (Table 1).

Grain yields were also determined on the basis of total production per acre over the 36-yr period (Table 2). As with annual production, total production was directly related to summerfallow frequency and nutrient amendment. The W-IF+N rotation produced the highest yield, while the six-year hay rotation showed the lowest production of spring wheat (Table 2).

Table 2. Total grain production for the 36 years (1956-1991), mean annual yield, and precipitation-use efficiency for Rotation 116.

Rotation	Total Production† (bu/a)	% F-W	Mean Yield (bu/a)	PUE‡ (lb/a/in)
F-W	675 d§	100	18.8	73
F-W-W	762 c	113	21.2	82
F+M-W-W	821 b	122	22.8	89
F-W-W-H-H-H	391 e(783)¶	58(116)	10.9(21.8)	42(85)
W	731 d	108	20.3	79
W-IF+N	899 a	133	25.0	97

† Total yield for 36 years (1956-1991); Values adjusted for rotation length.

‡ PUE - precipitation-use efficiency (lb/a/in) calculated as total yield divided by total precipitation received between September 1, 1955 and August 31, 1991.

§ Values within columns followed by the same letter are not significantly (P≥0.05) different using LSD.

¶ Values in brackets represent rotation response excluding the 3 years of hay.

The significantly (P≤0.05) higher total production for the W-IF+N rotation was calculated including the five years of zero grain yield. The manure amended rotation showed significantly (P≤0.05) higher total production than the W rotation, even with 1/3 of the rotation not producing a crop. This response of total production to manure further supports the importance of some form of nutrient addition as a means of optimizing grain production efficiency. A mean annual wheat yield of 25.0 bu/a was recorded for the W-IF+N rotation, identical to the fertilized continuous wheat rotation located in the Dark Brown soil zone in Saskatchewan (Campbell et al., 1990).

Precipitation-use efficiency (PUE) has been suggested as a means of quantifying grain production per unit of precipitation received for different crop rotations (Halvorson, 1990). For the purposes of this paper PUE was calculated using the total grain production and total precipitation received during the 36-year period (Table 2). Rotations which produced the highest total grain yield showed the highest PUE. Nutrient additions, either in the form of fertilizer N, feedlot manure or hay in rotation, increased the efficiency with which precipitation was used to produce spring wheat.

Grain protein concentration and grain N yield values are presented for the period 1978-1991 of the current study (Table 3). Highest grain protein was recorded for fallow-wheat in the hay rotation, followed by stubble-wheat in the same rotation. While the high grain protein response reflects the low fallow-wheat yield in the hay rotation (Table 1), the highest stubble-wheat yields were recorded in this rotation. The F-W rotation had the lowest fallow-wheat protein concentration and the lowest grain yield on fallow. The addition of feedlot manure increased grain protein of wheat on fallow over the F-W or F-W-W rotations.

Table 3. Mean grain protein concentration, grain N yield, estimated total N removal and soil N% for Rotation 116.

Rotation	Grain Protein† (%)		Grain N Yield‡ (lb/a)	Estimated Total N Removal§ (lb/a)	1991 Soil N (%)	
F-<u>W</u>	13.8	de¶	49.7	895	.161	c
F-<u>W</u>-W	14.4	cd	52.8			
F-W-<u>W</u>	13.1	f	30.7	1002	.166	c
F+M-<u>W</u>-W	15.0	bc	59.2			
F+M-W-<u>W</u>	12.9	f	36.8	1152	.183	b
F-<u>W</u>-W-H-H-H	16.2	a	50.4			
F-W-<u>W</u>-H-H-H	15.5	b	38.4	1066	.183	b
W	13.2	ef	29.4	1058	.188	ab
W-IF+N	13.0	f	42.3	1213	.193	a

† Mean grain protein for 14 years (1978-1991).
‡ Mean grain N yield calculated from grain yield x grain protein x .0057 for 14 year period from 1978 to 1991.
§ Estimated total N removal calculated for the period (1956-1991) from grain N yield and adjusted for rotation length.
¶ Values in columns followed by the same letter are not significantly ($P \geq 0.05$) different using LSD.

However, the effect of the manure was short-term, resulting in the lowest stubble-wheat grain protein concentration. Grain N yield response reflected grain yield more than grain protein concentration.

Using the average grain N yield values determined between 1978 and 1991, an estimate of total N removal by wheat with each rotation was calculated for the 36-year period. For the W-IF+N rotation estimated total N removal was calculated using the grain N yield for the W rotation during the period from 1956 to 1979, and grain N yield for the W-IF+N rotation for 1980 to 1991 (the period when N fertilizer was applied). The W-IF+N rotation showed the highest estimated total N removal, 15% higher than the unamended W rotation (Table 3). The feedlot manure amendment also increased total N removal by 15% over the F-W-W rotation. The F-W rotation had the lowest total N removal, a reflection of the low total production of this rotation.

Total soil N% increased with a reduction in fallow frequency and/or nutrient amendment (Table 3). Both the F-W and the F-W-W rotations lowered soil N% below the 0.177% recorded for the F-W rotation in 1954 (Pittman, 1977). Manure addition, hay in the rotation and continuous cereal production all increased soil N% over initial levels. While the unamended W rotation removed 18% more N over the F-W rotation during the 36-yr period, the absence of summerfallow increased soil N% by 17%. The high soil N% recorded for the W-IF+N rotation can partially be attributed to over fertilization during the past 12 years. Using the average grain N yield for the W-IF+N rotation, we would calculate an estimated total N removal of 508 lb N/a, 252 lb N/a less than was applied as fertilizer over the same 12 year period.

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SOIL EROSION-PRODUCTIVITY RELATIONSHIPS FOR DRYLAND WINTER WHEAT

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ABSTRACT

Loss of topsoil by wind and water erosion can reduce the productive capacity of agricultural soils. Erosion-productivity relationships were quantified for dryland winter wheat grown on five Kansas soils over six years. Results indicated that grain yield significantly decreased with decreasing topsoil depth. Grain yield loss per unit decrease in topsoil depth followed the order: ULYSSES = IRWIN > PAWNEE > HARNEY = KENOMA. Topsoil loss influenced soil properties variably between soils. Precipitation, variety, P fertilizer rate, and other crop management factors also influenced yield response to topsoil loss. Further analysis of the database will focus on site specific conditions and management effects on grain yield response to topsoil loss.

INTRODUCTION

In the last decade, soil erosion effects on agricultural sustainability and environmental quality have become a major national concern. The federal government has encouraged research to quantify erosion-productivity relationships and to extend the results to growers, industry, policy makers, and the public. Establishing accurate information on soil erosion effects on productivity, combined with development and transfer of conservation technologies, will sustain agricultural productivity and environmental quality. Therefore, the objectives of this study were to (1) quantify the effect of topsoil loss on winter wheat yield for selected soils, (2) evaluate the influence of topsoil loss on soil chemical properties, and (3) characterize management and precipitation effects on wheat yield response to topsoil loss.

MATERIALS AND METHODS

In 1985, forty field sites were selected on the HARNEY series and twenty sites were selected for the KENOMA series. Additional sites were selected in 1986 for the IRWIN, PAWNEE, and ULYSSES soil series. Pedons located in areas of native vegetation on similar landscape positions to the cultivated counterparts were described and sampled to determine original topsoil thickness for each soil series. Soil chemical and physical properties were determined for each pedon (data not shown). At each site a slightly, moderately, and severely eroded subsite was located based on the erosion class criteria of the National Cooperative Soil Survey and the average topsoil thickness of the pedons in native vegetation (Table 1). The subsites were located on similar slopes and as close together as possible so that management was the same for all subsites.

Surface soil (0-6 in) organic matter (OM), Bray 1-P, NH_4OAc-K, and soil pH were determined at each subsite (Table 2).

All sites were planted to dryland winter wheat by the grower and managed accordingly. Four 44 ft^2 subsamples were hand harvested to determine grain yield at each erosion class subsite. Yield for each subsample was based on the grain weight adjusted for test weight and moisture content. Information on soil and crop management practices used by the grower included wheat variety, seeding rate, planting date, row spacing, harvest date, and N, P, and K fertilizer rate. Annual precipitation data were obtained from the climatological recording station nearest to each site. Precipitation was denoted as the deviation from long-term average annual precipitation.

The data were analyzed using analysis of variance and linear and nonlinear regression procedures. Wheat varieties were considered a class or discrete variable and were grouped into six classes according to similar genetic parentage. Soil series also were used as a class variable. All other variables were considered continuous variables.

Table 1. Topsoil depth used to determine erosion class.

Soil Series/ Classification		Ave. Depth Native sites	Erosion Class Slight	Moderate	Severe
		----------	inches	----------	
Harney	(Typic Argiustoll)	13	10-14	5-9	0-4
Kenoma	(Vertic Argiudoll)	10	8-11	4-7	0-3
Irwin	(Pachic Argiustoll)	10	8-11	4-7	0-3
Pawnee	(Aquic Argiudoll)	10	8-13	4-7	0-3
Ulysses	(Aridic Haplustoll)	11	8-12	4-7	0-3

Table 2. Mean and standard deviation of soil properties.

Soil Type	Soil pH	Bray-1 P*	NH_4OAc-K*	OM
		--------- ppm	---------	%
Harney	6.3 ± 0.6	24 ± 19	548 ± 247	2.2 ± 0.5
Kenoma	6.9 ± 0.7	16 ± 12	197 ± 59	1.9 ± 0.4
Irwin	6.1 ± 0.6	34 ± 24	276 ± 63	2.3 ± 0.4
Pawnee	5.8 ± 0.5	18 ± 7	217 ± 79	2.8 ± 0.6
Ulysses	7.7 ± 0.7	15 ± 4	626 ± 171	1.8 ± 0.5

* 2 x ppm = lb a^{-1}

RESULTS AND DISCUSSION

Grain Yield-Topsoil Depth Relationships

Sampling the same sites over time enables a combined analysis for each soil type over time. The regression analyses indicated that grain yield loss on the ULYSSES and IRWIN soils exhibited similar sensitivity to topsoil loss (1.8 bu a^{-1} $inch^{-1}$), which was more sensitive to topsoil loss than the other three soils (Fig. 1). Alternatively, wheat productivity was the least sensitive on the HARNEY and KENOMA soils at 0.8 bu a^{-1} $inch^{-1}$ of topsoil loss. The PAWNEE soil exhibited intermediate yield sensitivity to topsoil loss (1.2 bu a^{-1} $inch^{-1}$). All linear regression models were significant at the 1% probability level.

Differences between soils in yield sensitivity to topsoil loss are related, in part, to the genetic differences between soils. With the two western Kansas soils, for example, grain production on the ULYSSES soil was twice as sensitive as observed on the HARNEY soil (1.8 vs. 0.8 bu a^{-1} $inch^{-1}$, respectively). Compared to the HARNEY soil, the ULYSSES soil has a shallow surface horizon (< 12 inches) overlaying calcareous, low OM subsoil. Thus, when the ULYSSES topsoil erodes, the exposed subsoil is less productive than the subsoil underneath the HARNEY soil.

Soil Property-Topsoil Depth Relationships

Soil pH decreased with increasing topsoil depth in all soils except the IRWIN soil (Fig. 2). The ULYSSES soil exhibited the greatest sensitivity in soil pH to erosion (-0.11 pH $inch^{-1}$ topsoil loss), compared to the HARNEY soil wherein soil pH decreased only 0.03 pH $inch^{-1}$ topsoil loss. Bray 1-P significantly increased with increasing topsoil depth in the ULYSSES and KENOMA soils; however, Bray 1-P was not affected by topsoil loss in the IRWIN, PAWNEE, and HARNEY soils (Fig. 2). NH_4OAc-K significantly decreased with increasing topsoil depth in the KENOMA and PAWNEE soils; however NH_4OAc-K increased with increasing topsoil depth in the ULYSSES soil (Fig. 2). Topsoil loss in the HARNEY and IRWIN soils did not significantly affect NH_4OAc-K. Soil OM significantly increased with increasing topsoil depth in all soils except the PAWNEE (Fig. 2). The 'ln' transformation of TS depth improved the relationship between TS and OM compared to a linear TS term (data not shown).

Significant soil property-erosion relationships infer that changes in soil properties with topsoil loss also are significantly related to yield loss. For example, as TS decreased, OM content decreases, thus, OM content was significantly correlated to grain yield (data not shown). Although these soil property-yield relationships are important, changes in soil properties are not always related to yield loss even though topsoil depth is related to yield loss. Other factors like rainfall and crop management interact to influence yield response to topsoil loss. Multiple regression analysis for the rainfall and crop management effects on grain yield for the HARNEY soil was performed for the 1985, 1986,

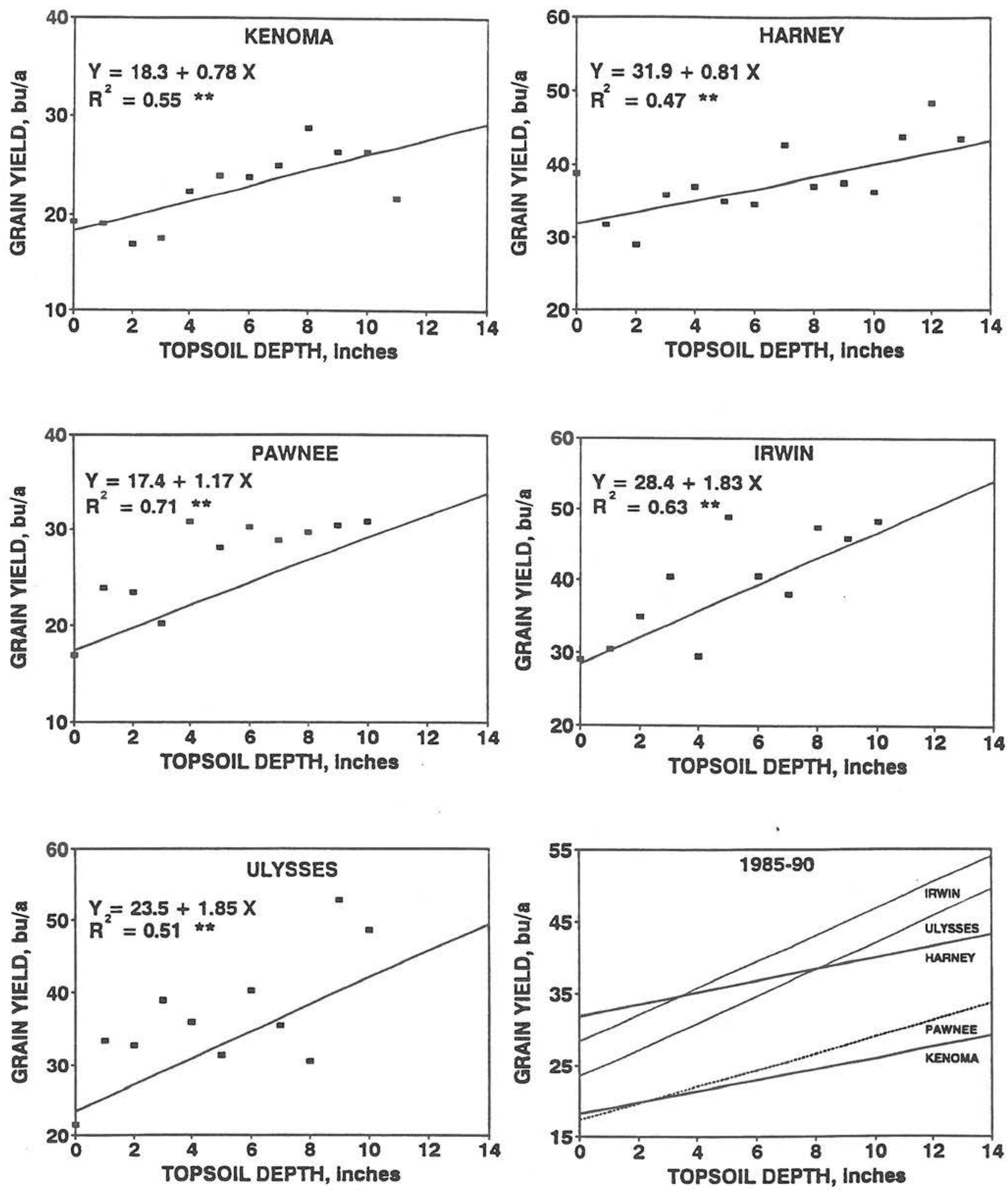
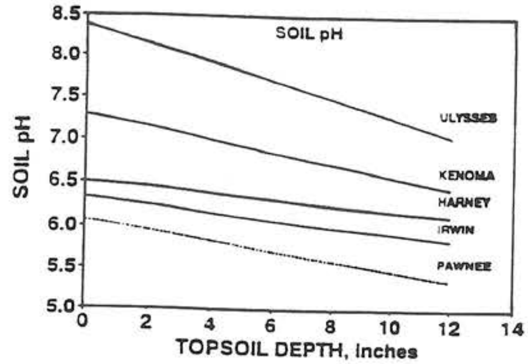


Figure 1. Relationship between wheat grain yield and topsoil depth for each soil averaged over years.



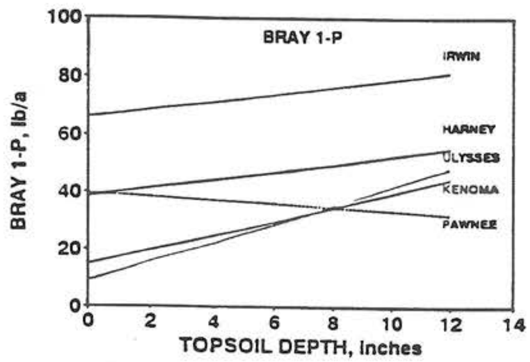
ULYSSES: $Y = 8.37 - 0.11X$ $R^2 = 0.86^{**}$

KENOMA: $Y = 7.28 - 0.07X$ $R^2 = 0.24^{*}$

HARNEY: $Y = 6.50 - 0.03X$ $R^2 = 0.28^{*}$

IRWIN: $Y = 6.32 - 0.04X$ $R^2 = 0.12$ ns

PAWNEE: $Y = 6.07 - 0.06X$ $R^2 = 0.44^{*}$



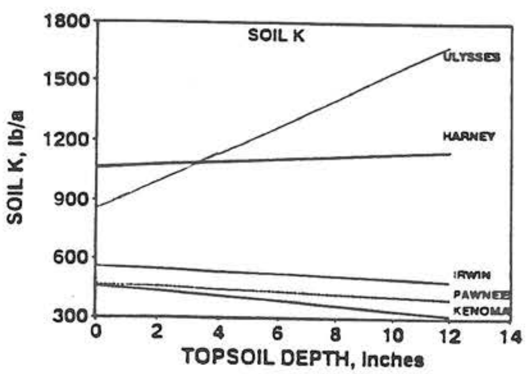
IRWIN: $Y = 65.9 + 1.3X$ $R^2 = 0.02$ ns

HARNEY: $Y = 38.7 + 1.4X$ $R^2 = 0.10$ ns

ULYSSES: $Y = 9.1 + 3.3X$ $R^2 = 0.46^{**}$

KENOMA: $Y = 14.7 + 2.5X$ $R^2 = 0.41^{*}$

PAWNEE: $Y = 39.5 - 0.6X$ $R^2 = 0.18$ ns



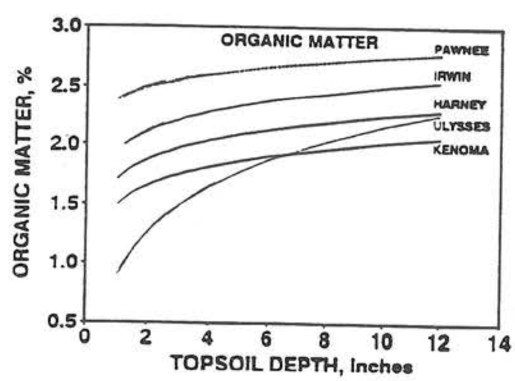
ULYSSES: $Y = 857 + 69X$ $R^2 = 0.65^{**}$

HARNEY: $Y = 1066 + 7X$ $R^2 = 0.05$ ns

IRWIN: $Y = 559 - 6X$ $R^2 = 0.05$ ns

PAWNEE: $Y = 467 - 6X$ $R^2 = 0.35^{*}$

KENOMA: $Y = 456 - 12X$ $R^2 = 0.48^{**}$



PAWNEE: $Y = 2.38 + 0.16 \ln X$ $R^2 = 0.03$ ns

IRWIN: $Y = 1.93 + 0.25 \ln X$ $R^2 = 0.41^{*}$

HARNEY: $Y = 1.70 + 0.24 \ln X$ $R^2 = 0.30^{*}$

ULYSSES: $Y = 0.85 + 0.57 \ln X$ $R^2 = 0.63^{**}$

KENOMA: $Y = 1.49 + 0.23 \ln X$ $R^2 = 0.30^{*}$

Figure 2. Relationship between selected soil properties and topsoil depth for each soil.

and 1990 data (Table 3). Too few sites in 1987 and 1988 did not enable analysis for these years. The results showed that variety and rainfall significantly influenced grain yield response to topsoil loss in each year. Below average annual rainfall increased the negative affects of soil erosion on yield. Alternatively, when rainfall was average or above, topsoil loss did not reduce yield to the same extent as under low rainfall. The significant variety effect illustrates that proper variety selection can reduce the influence of soil loss on yield. Although, Bray 1-P was not significantly influenced by topsoil loss in the HARNEY soil (Fig. 2), P fertilizer rate significantly influenced yield response to topsoil loss. Planting date also was a significant factor in 1985 and 1986. If wheat is planted too early or too late, topsoil loss exhibited a greater effect on productivity. Obviously, many of the crop management and soil factors interact and their relationships to yield loss are complex. Detailed analysis of these interactions will be conducted over the next year.

Table 3. Statistical significance of the relationships between management factors and wheat yield for the HARNEY soil.

Crop Factor	1985	1986	1990
Observations	37	13	17
Variety	*	*	-
Precipitation	*	*	**
Planting Date	(*)	(*)	NS
Planting Rate	NS	*	*
Row Spacing	NS	-	-
N Rate	NS	*	NS
P Rate	**	**	(*)

NS = Not Significant, ** = 1%, * = 5%, (*) = 10%, - = only 1 level

SUMMARY

Preliminary analysis of the erosion-productivity data for five soils from 1985 to 1990 shows that wheat yields significantly decrease with increasing topsoil loss. Wheat yield response to erosion varied between soil series in the order ULYSSES = IRWIN > PAWNEE > HARNEY = KENOMA. Loss of topsoil influenced soil properties variably between soils. In general, OM and Bray 1-P decreased with topsoil depth, whereas soil pH and K increased with decreasing topsoil depth (except for K in the ULYSSES soil). Precipitation significantly influenced yield response to topsoil depth on the HARNEY soil as we would expect. Variety, P fertilizer rate, and other management factors also influenced yield response to erosion. This report represents only a preliminary analysis which will continue over the next year to further quantify the influence of erosion on dryland crop yields in Kansas and to elucidate effects of site specific conditions and/or management on grain yield response to topsoil loss.

NUTRIENT REQUIREMENTS OF CANOLA

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Canola is receiving new attention as a potential crop for Great Plains cropping systems. Canola produces a seed high in edible oils with desirable fatty acid composition. Canola is very responsive to optimum management strategies, particularly fertilizer management (Grant and Bailey, 1990). With a limited amount of fertilizer correlation and calibration information available in the United States, soil scientists and agronomists have initially utilized Canadian and other research to make nutrient recommendations. This review paper highlights some of the published research as well as recent information generated in the Northern Great Plains.

Canola responds dramatically to nitrogen (N) and sulfur (S) applications and to a lesser extent, phosphorus (P) and potassium (K). Table 1 illustrates canola response to N, P and S fertilizer in Montana (Jackson and Welty, personnel communication). The magnitude of the response is dependent upon soil test levels,

Table 1. Canola fertilizer trial at Conrad and Kalispell, MT (1991).

Conrad		Kalispell	
Rate (lbs/a)	Yield (lbs/a)	Rate (lbs/a)	Yield (lbs/a)
$N-P_2O_5-K_2O-S$		$N-P_2O_5-K_2O-S$	
0-0-0-0	743	0-0-0-0	1477
100-0-0-0	2007	50-60-0-0	1821
100-45-0-0	2018	100-60-0-0	1725
100-45-0-20	2059	150-60-0-0	1729
150-30-0-0	2205	100-60-50-0	1740
150-60-0-0	2488	100-60-0-20	2086

yield potential related to available water, agronomic management level and pest control. Canola yields can be predicted based on plant available water (PAW), soil water and growing season precipitation, from the following equation: Canola yield (bu/a) = 2.75 bu/a*(total PAW - 4). Generally speaking, canola requires more N, P and S and less K than small grains. Irrigated trials in

Powell, Wyoming indicate the tremendous capacity for N response averaged across P rates and Global and Westar cultivars (Blaylock, personnel communication).

Table 2. Canola response to N applications at Powell, WY (1991).

N rate (lbs/a)	Yield (lbs/a)	Oil (%)	Oil yield (lbs/a)
0	1056	42.1	447
100	1498	41.9	629
200	1747	41.3	724
300	2012	39.8	802

Canadian research has shown that a 40 bu/a (2,000 lbs/a) yield will remove 120 lbs N/a, 80 lbs P_2O_5, 95 lbs K_2O and 21 lbs S/a. Available N and S (residual and fertilizer) should be in the ratio of approximately 7:1 for optimal yields. The actual amount of fertilizer P required may, however, be less, since canola is more efficient in utilizing P from the soil as it acidifies the rhizosphere, solubilizes P and increases overall availability. Canola also has the ability to proliferate roots in fertilizer bands, thereby increasing fertilizer uptake efficiency. Increases in canola yield have also been reported on a limited basis with micronutrient applications.

Nitrogen

Nitrogen increases yield by accelerating growth and development as shown by increases in stem length, number of flowering branches, total plant weight, leaf area index and number and weight of pods and seeds (Allen and Morgan, 1972). Crop yield and protein increased with N rates in excess of 180 lbs N/a when soil test levels were low (Bailey, 1990; Nuttall et al., 1987; Soper, 1971). Whole plant tissue levels of N at flowering should be between 2.5-4% N, with levels below 2% deficient and levels above 5% excessive (Manitoba Soil Testing Laboratory).

Henry and MacDonald (1978) in Saskatchewan demonstrated that 0.9 lbs/a of fertilizer N would increase seed yield of canola by 1.14 lbs/a under dryland conditions and 4.23 lbs/a under irrigated conditions based on coefficients in the regression analysis. Yield increased with rates up to 150 lbs N/a when soil test N was 30 lbs/a in the top 2 feet. Excessive applications of N can reduce both yield and quality due to lodging problems, delayed maturity and subsequent harvest difficulties. High N additions consistently decrease oil content by increasing the pod development period causing an extended ripening period with immature seeds containing lower oil content (Table 2). Protein content increases with increasing levels of N applied.

Canola is extremely sensitive to N placed with the seed. Nyborg (1961) showed in pot studies that canola was more sensitive

Don't put NO3 w/ seed

to ammonium nitrate placed with the seed compared to oats, barley and wheat, but was less sensitive than flax. He indicated that 10 lbs/a of N placed with the seed could seriously reduce canola stands with dry soil conditions. Seedling emergence and seed yield were improved by applying N one inch below the seed (Table 3).

Nutall et al. (1989) found no significant difference between fall and spring broadcast applications of N for canola grown in Saskatchewan over a six year period. The presence or absence of a response was, however, directly related to climate and its relationship to the N cycle. Work in Manitoba indicated that, on a relative basis, spring banded N>spring broadcast>fall banded>fall broadcast by 120, 100, 93 and 82%, respectively. Source of N does not influence the response or N efficiency under field conditions, provided the agronomic practices are properly implemented.

Table 3. Yield and number of canola plants following ammonium nitrate placement (Nyborg and Hennig, 1969).

Rate (lbs/a)	Placement	Yield (lbs/a)	Number (plt/ft)
0	Row	436a*	13a
0	Below row	463a	13a
15	Row	401a	4a
15	Below row	446a	12b
30	Row	321a	1a
30	Below row	508b	13b

*In each column at each rate of fertilizer, values are significantly different when not followed by the same letter.

Phosphorus

Phosphorus is rapidly taken up in the early stages of growth and continues until late growth stages (Kalra and Soper, 1968). Canola response was limited when the Olsen-P extractable level was greater than 10 ppm (Soper, 1971). Maximum responses for canola are attained at lower rates of applied P compared to wheat, corn or barley (Sheppard and Bates, 1980; Ukrainetz et al., 1975). Phosphorus fertilization has increased (Bailey and Grant, 1990) or decreased oil concentration (Henry and Schappert, 1971). Phosphorus applications hasten crop maturity, particularly in short growing season areas, and positively affect crop yield and quality. Phosphorus tissue levels from the whole plant at flowering should be between 0.25-0.5%, with levels below 0.15% deficient and levels above 0.8% excessive (Manitoba Soil Testing Laboratory).

Placement of P in bands with or near the seed in low to medium testing soils is more efficiently utilized (Soper and Kalra, 1969; Bailey and Grant, 1990). Phosphorus applications greater than 18 lbs P/a applied directly in the seed row reduced seedling emergence. Yield was greater with a one inch spacing below and/or to the side (Bailey and Grant, 1990; Nyborg and Hennig, 1969). Bailey and Grant (1990) reported a significant increase with a band application of P compared to a broadcast and incorporate treatment. Band application of 13 lbs P/a away from the seed led to a 60% increase in P accumulation 21 days after emergence compared to a broadcast and incorporate treatment at 22 lbs P/a rate at an equivalent grain yield.

Potassium

Canola response to K fertilizer applications have not been frequent or great in magnitude. A thorough review of the subject is presented by Bailey and Soper (1985). Although canola biomass required large amounts of K, the actual amount of K removed in the seed is quite small. Canadian research indicates that canola would respond to applications of 22 to 44 lbs K/a on soils with exchangeable K levels below 35 to 100 ppm.

Sulfur

Canola normally responds to application of 20 to 30 lbs S/a if sulfate-S soil test levels of less than 30 lbs/a. Tissue analysis of less than 0.2% at flowering is considered low, 0.2-0.25% marginal and greater than 1% excessive (Manitoba Soil Testing Laboratory). In Manitoba, yield increases of up to 600 lbs/a have been reported with application of 30 lbs S/a (Ukrainetz et al., 1975). Excessive rates of applied S have been reported to decrease oil content.

Micronutrients

Micronutrient deficiencies are not common. Boron and zinc yield and quality responses have been reported in the literature on a limited basis.

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P_2O_5 w/seed stand loss data

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Black sunflower

may-sept

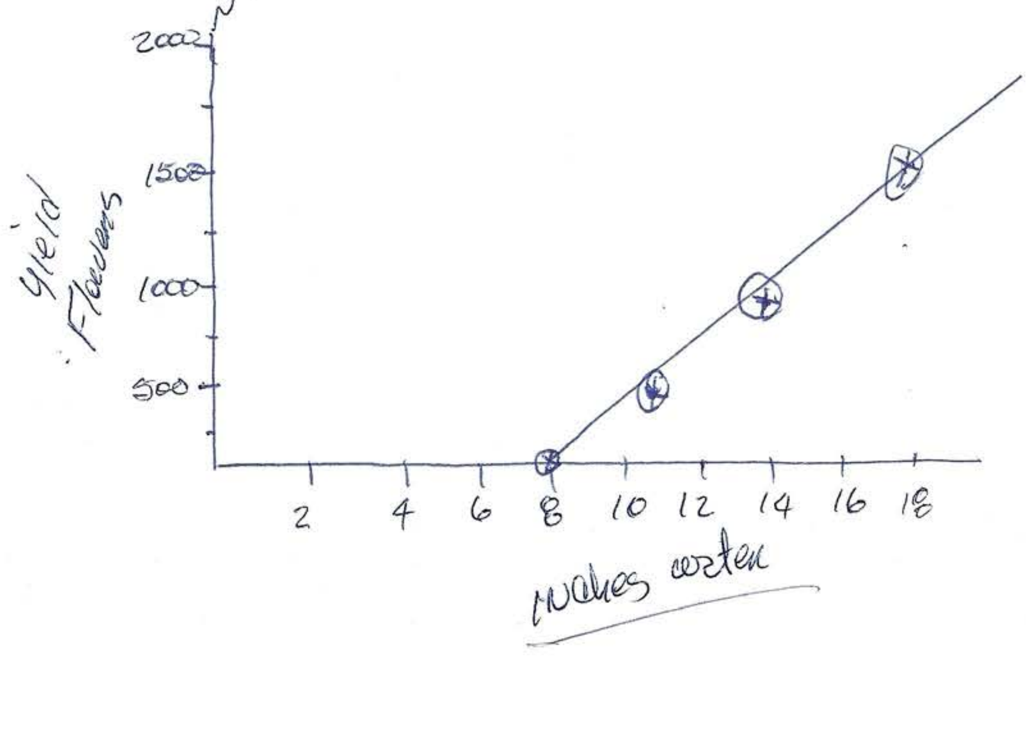
8" to get 1st # of seed

10-11" w/ 500#

14" w/ 1000#

18" w/ 2000#

Need to start w/ 4-5" of stored water + 7-8" Rain.



SOIL FERTILITY AND TILLAGE MANAGEMENT FOR SUNFLOWER PRODUCTION IN THE GREAT PLAINS

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ABSTRACT

Improved conservation tillage-production systems and more crop diversity in rotations are needed in the Great Plains to break disease, insect and weed cycles, reduce herbicide use for pest control, and protect the soil from erosion. An undercutter-minimum tillage system for sunflower production in a spring wheat-winter wheat-sunflower rotation has been developed to provide 30 to 60% crop residue cover after sunflower planting. When growing season precipitation (May through September) was greater than 10.7 inches in 1985, 1986 and 1987, minimum-till and no-till produced sunflower yields equal to conventional-till averaging 2110, 2120, and 2200 lb/ac, respectively, with 90 lb fertilizer N/ac. In 1988 and 1989 when growing season precipitation was less than 7.7 inches, seed yields averaged 840 and 610 lb/ac, respectively, with 30 or 60 lb fertilizer N/ac. In 1990, the third year of successive drought with 7.5 inches of growing season precipitation, seed yields averaged 540 lbs/ac with no-till and 150 lbs/ac or less for conventional- or minimum-till. No subsoil available water was present in the 2 to 6-foot soil depth at planting in 1989 and 1990. Over the six year period, seed yields were improved about 100 lb/ac/yr using minimum- or no-till systems compared to conventional-till and N-fertilization with 60 or 90 lbs N/ac increased seed yields and additional 100 lbs/ac, or more, in all tillage systems compared to the 30 lbs N/ac annual application.

The purpose of this report is to provide a 6-year summary of sunflower production in an ongoing conservation tillage-cropping systems research project for increasing precipitation-use efficiency in an annual cropping system compared to spring wheat-fallow.

MATERIALS AND METHODS

Our field research is conducted on a 63-acre site on a Williams loam (fine-loamy, mixed, Typic Argiborolls at the USDA-ARS and Area IV SCD Research Farm near the Northern Great Plains Research Laboratory, Mandan, ND. The experimental variables in three replications are all combinations of (1) two cropping sequences: spring wheat-fallow and spring wheat-winter wheat-sunflower (main blocks 450 x 250 ft.); (2) three conservation tillage treatments: conventional-, minimum- and no-tillage (main plots, 150 x 250 ft.); (3) three fertilizer N rates: 0, 20, and 40 lbs N/ac for crop-fallow and 30, 60, and 90 lbs N/ac for the continuous cropping (subplots, 150 x 80 ft.); and (4) two cultivars, standard (check) and current "best" (sub-subplots, 75 x 80 ft.).

The soil fertility variable in this study is N rates. Fertilizer P (0-46-0) was uniformly applied at a onetime high rate (46 lb P/A) at the beginning of the study to maintain available P at an adequate level. All N rates are broadcast in the spring ahead of planting for each spring-planted crop and as a topdressing in late April for winter wheat using ammonium nitrate (34-0-0) as the source of N.

Based on the quantity of crop residue present at harvest, our tillage treatments are defined in terms of post-planting target crop residue maintenance levels as follows: conventional tillage, 30% or less crop residue on the soil surface; minimum tillage, 30 to 60% residue cover; and no-till, 60% or greater crop residue cover. We do not have a fixed pattern or number of tillage and/or spray operations but rather a system of tillage, tillage plus spray, or spray-only options as may be required for weed control and for providing post-planting target residue levels at planting.

In our rotation, fall weed control on the winter wheat stubble (or spring wheat in years when winterkill occurred in 1985 and 1989 in conventional- and minimum-till) is accomplished with Roundup1 applications with or without 2,4-D. The stubble is left erect overwinter in all three tillage treatments to trap snow and enhance soil water storage from snowmelt.

In the spring, the tillage treatments preceding sunflower planting operations for each tillage system are as follows: (1) Conventional tillage treatment consists of using the undercutter (32-inch sweeps) with a granular herbicide applicator mounted on the front to apply Treflan GR-10 granules1 at 0.9 to 1.0 lbs ai/ac (now Sonolan G-10 granules1 at a rate of 0.8 to 0.9 lbs ai/ac) and to accomplish the first incorporation in mid-April each year. This is followed by a tandem disk operation about May 15 to accomplish the second incorporation just before planting the sunflowers; (2) The minimum-tillage treatment consists of using the undercutter with granular application in mid-April for the first incorporation. The second incorporation is accomplished with the undercutter about May 15, avoiding the same tillage pattern of the first undercutter operation. It is critical that depth of undercutting (tillage) be kept as shallow as possible (about a 2-inch depth), that speed be controlled at 4 to 5 mph, and that the period between the time of application (first incorporation) and the second undercutter operation be about three weeks to allow precipitation and soil water adequate time to activate the herbicide granules; (3) The no-tillage treatment consists of a fall-spray application (late October) of Surflan at a rate of 1.25 lbs ai/ac and a spring burndown spray application of Roundup just before sunflower planting.

[1]Mention of any product trademark in this paper does not imply endorsement of the product by USDA, Agricultural Research Service.

In all years, sunflowers were planted May 15-23 using an 800 IHC Cyclo-seeder, unit-row, no-till planter (36-inch row spacing) for all three tillage treatments. This is a precision planting unit capable of cutting through large quantities of wheat straw (up to 4,000 lbs/ac) and establishing uniform plant populations across tillage treatments. Annual sunflower populations have varied from 19,000 to 21,000 plants/acre from 23,000 planted viable seeds/acre. In no year, have we found a significant difference in plant populations among tillage treatments.

Soil samples have been collected by 1-foot increments to a depth of 5-feet just prior to planting and after harvest each year since 1985 for soil water and nitrate-nitrogen determinations.

RESULTS AND DISCUSSION

Growing season precipitation (May through September) for the years 1985, 1986, 1987, 1988, 1989, and 1990 was 10.4, 14.4, 15.0, 7.6, 6.3 and 7.5 inches, respectively. The long-term average precipitation (1941-1990) for May-Sept growing season precipitation is 11.5 inches. In 1988, 1989, and 1990 precipitation from July through September, corresponding to early bloom through seed filling development stages was below normal totaling 3.1, 3.6, and 4.3 inches, respectively. There was no available soil water present in the 2 to 6-foot depth in 1989 and 1990.

Tillage system and rate of N applied significantly influenced sunflower yields each year but there was no difference in seed yields between early- and mid-class maturity cultivars. Therefore, only seed yields of the early-maturity class cultivars are shown in Table 1 for the 6-year period.

Applications of 60 or 90 lb fertilizer N/ac increased sunflower seed yields in all three tillage systems in 1985, 1986, 1987, and 1988. These same N rates increased seed yields about 100 lbs/ac more in minimum- and no-till systems than the conventional tillage treatment. Seed yields with minimum- and no-till in 1989 were 300 to 400 lbs/ac more than conventional-till system, and in 1990 seed yields averaged over 300 lbs/ac more on no-till then the other two systems. No seed yield responses to fertilizer N were measured in 1989 and 1990 because of relatively high residual N-fertilizer carry-over as indicated by soil test.

Soil NO3-N accumulations after 3 years of drought (fall 1990) in the spring wheat-winter wheat-sunflower cropping system averaged 108, 184, and 290 lb N/ac to the 5-foot depth over all crops for annual applications of 30, 60, and 90 lb fertilizer N/ac, respectively, since 1984 (Table 2). However, NO3-N accumulation after 6 years for conventional-, minimum-, and no-tillage systems averaged 231, 200, and 145 lb N/ac, respectively, over all crops. Tillage treatment influences on soil NO3-N accumulations were inversely related to grain yield trends with yields of conventional-till <minimum-till <no-till. There was no major influence of crop grown in 1990 on NO3-N accumulation, because all

Table 1. Seed Yields of Sunflower as Influenced by Tillage System and Rate of Fertilizer N Applied.

Year	N applied	Sunflower Seed Yields			
		Conv. Till	Min. Till	No-Till	Avg (N rates)
	lb N/ac	- - - - - - - - - - lbs/ac - - - - - - - - - -			
1985	30	1950	2050	2060	2020
	60	2110	2250	2130	2160
	90	2230	2260	2370	2290
	Avg (tillage)	2100	2190	2190	2160
1986	30	1760	1670	1480	1640
	60	1840	2020	1720	1860
	90	2080	2100	2120	2100
	Avg (tillage)	1890	1930	1770	1860
1987	30	1760	1920	1740	1810
	60	1960	1980	2130	1960
	90	2020	2000	2100	2040
	Avg (tillage)	1910	1970	1990	1940
1988	30	710	820	790	770
	60	840	940	900	890
	90	830	1040	1050	970
	Avg (tillage)	790	930	910	880
1989	30	390	780	660	610
	60	360	840	600	600
	90	210	450	750	470
	Avg (tillage)	320	680	670	560
1990	30	180	20	410	200
	60	150	30	540	240
	90	30	40	540	200
	Avg (tillage)	120	30	500	210
All Years (Avg.)	30	1130	1210	1190	1180
	60	1210	1340	1340	1300
	90	1230	1320	1490	1360
	Avg (tillage)	1190	1290	1340	1280

Table 2. Soil NO3-N accumulation (fall-1990 as influenced by 3 drought years, tillage/cropping system, and fertilizer-N rates.

Cropping System	Crop Grown in 1990	N-Added	Tillage System: Conv-Till	Tillage System: Min-Till	Tillage System: No-till	Avg (N-rates)
		lb/ac	-Soil NO3-N to 5-foot depth- lb/ac			
Annual	Sp.W.*	30	156	93	51	100
		60	292	207	119	206
		90	368	273	191	277
		Avg (Tillage)	272	191	120	194
Annual	W.Wh.*	30	129	117	85	121
		60	179	134	129	147
		90	363	289	245	299
		Avg (Tillage)	224	180	150	189
Annual	Sun*	30	101	174	31	102
		60	176	210	208	198
		90	317	304	260	294
		Avg (Tillage)	198	229	166	198

*Sp.W. = Spring wheat; W.Wh. = Winter wheat; and Sun = Sunflowers.

three crops had cycled the same number of times in each rotation block during the 3-year drought. In other words, NO3-N accumulations were influenced by the 3-year drought, rate of fertilizer N applied, and tillage system rather than by the crop grown.

Soil NO3-N contents to 5-feet at seeding and after harvest were used to measure soil NO3-N plus fertilizer-N use by sunflower in 1986, 1987, and 1988 (Figure 1). Sunflower seed yields for each N rate (30, 60, or 90 lb N/ac) and for each tillage system (conv-, min, and no-till) were plotted against soil NO3-N and fertilizer-N disappearance from seeding to harvest. This shows that 100 lb N/ac, used from soil-plus fertilizer-N sources, produced about 2000 lbs of seed/ac. Sunflower N needs versus yields levels based on total above ground plant N uptake have been previously published in Fertiliizer Guides (SAES) and are in agreement with our soil based assessment of N-use by sunflower to reach various yield levels.

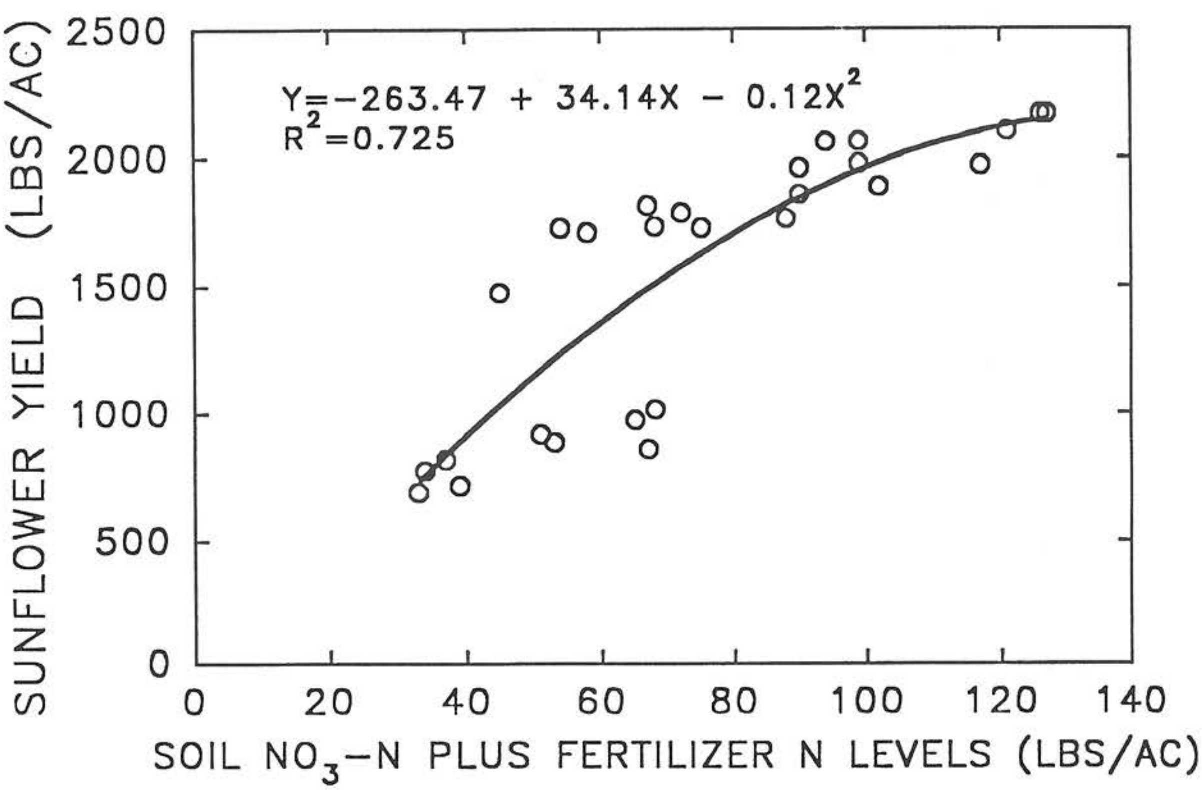

Fig. 1. Relationship of Sunflower Seed Yield to Soil NO_3-N Plus Fertilizer-N Used (1986, 1987, and 1988).

AN OVERVIEW OF NITRIFICATION INHIBITORS AND SLOW RELEASE FERTILIZERS

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ABSTRACT

Sources of nitrogen (N) and methods of placement that synchronize soil N availability with the period of maximum crop N uptake should increase N use efficiency and reduce N loss. A review of the lit-erature and recent research indicates that nitrification inhibitors and slow release fertilizers maintain ammoniacal N in the ammonium (NH_4) form longer than conventional fertilizers, but results are inconsistent with respect to increasing crop yields. Yield increas-es from studies with ammonium thiosulfate (ATS) in Kansas look pro-mising but need further study. Results from studies with large urea pellets have shown increases in plant tissue N, but yield increases have not been consistent. Studies with polyolefin coated urea indi-cate these N sources release N slowly for up to 120 days but are expensive and have not been tested in the Great Plains. This review will examine recent research where both nitrification inhibitors and slow release fertilizers have been evaluated.

INTRODUCTION

Attempts to maximize N availability with crop N demand include the application of N with nitrification inhibitors, urease inhibitors or protective coatings that slowly release inorganic N from the fertilizer. The strategy for using inhibitors and slow release fertilizers is to maintain ammoniacal N as NH_4-N during periods of low crop N demand with a subsequent maximum release of both NH_4-N and NO_3-N during the period of rapid N accumulation by the crop. If much nitrification of fertilizer N occurs during periods of low crop N demand (which may go hand in hand with periods of high rain-fall) the fertilizer NO_3-N will be lost from the root zone through leaching and/or denitrification. These losses reduce N fertilizer use efficiency and can potentially degrade groundwater.

The simplest scheme to maintain fertilizer N as NH_4-N for a longer period is to apply ammoniacal N fertilizers (urea, anhydrous ammonia) in concentrated zones (banded, point injected, or in large urea pellets). In the immediate zone of fertilizer application the pH of the soil reaches values near 9 which is toxic to nitrifiers therefore limiting the conversion of NH_4-N to NO_3-N. In addition the practice minimizes the exposure of fertilizer N to the soil micro-flora (including nitrifiers) and/or crop residues and should theoretically minimize both immobilization and nitrification.

Desirable characteristics for nitrification inhibitors include: no adverse affects on other beneficial soil organisms, higher plants, or animals, in amounts used to inhibit N transformations; easy to apply, stable in storage; not readily inactivated by soil constituents; and economical to use. Inhibition must be of practical duration.

Both natural organic and synthetically produced inhibitors have been studied. In general the natural organics are less effective then synthetically produced chemicals. Of the chemical inhibitors available carbon disulfide, dicyandiamide (DCD), nitrapyrin, etridiazole, and acetylene have been shown to consistently inhibit nitrification in field and laboratory soils. Research in North Dakota (Goos 1985a; 1985b) indicates ammonium thiosulfate (ATS) inhibits both nitrification and urea hydrolysis. Bronson et al. (1991) reported no increases in wheat yield but measured significant increases in fertilizer N immobilization, when DCD was applied broadcast with urea solution. In that study enhanced N immobilization by DCD treatment the first year resulted in a subsequent remineralization of immobilized fertilizer N the second year. Bronson using ^{15}N reported a significant increase in N uptake of first year fertilizer N by a subsequent years crop with DCD treatment. Ferguson et al. (1991) reported greater NH_4-N vs NO_3-N in the zone of fertilizer application 10 days prior to corn anthesis when nitrapyrin was applied with anhydrous ammonia early in the spring. As with the study of Bronson, Ferguson (1991) reported greater N immobilization with nitrapyrin.

A summary of published literature from Missouri, Minnesota, Kansas, and Nebraska indicates chemical inhibitors seldom increase yield (Hergert and Weise. In Illinois, Hoeft (1984) reported an average yield decrease of 1% for spring applied nitrification inhibitors and an average 5% increase for fall applied nitrification inhibitors. Blackmer and Sanchez (1988) showed a positive yield response to nitrapyrin at only 2 of 12 site years. The objectives of the following review of studies is to report on some of the recent applied research conducted in eastern and western Kansas, Nebraska, and Japan dealing with nitrification inhibitors and slow release fertilizers.

MATERIALS AND METHODS

The DCD, calcium carbide study was initiated the spring of 1990 on a Hall Silt Loam at the Management Systems Evaluation Area (MSEA) near Shelton, Nebraska and continued in 1991. Large 1.7g urea pellets were placed 4 inch deep and 4 inch away from rows of V1 stage corn (1990) and V3 stage corn (1991) at 8 inch intervals along the row. Nine treatment combinations of large urea pellets with and without the two nitrification inhibitors DCD (DCD encapsulated in the large urea pellet) and acetylene (applied as wax coated Calcium carbide) were applied at 3 rates of 36, 71, or 107 lbs N/acre. Conventionally banded urea and a check (no fertilizer applied) were also included in the experiment. Microplots within larger field plots were established at all treatment combinations for the 36 and 107 lb N/acre rates. These received ^{15}N labeled urea to allow for the estimation of fertilizer N recovery and plant N derived from fertilizer. Inorganic N levels in the zone of fertilizer application were monitored 7, 32, 43, and 96 days after fertilizer application by taking a 4 inch diameter core directly over previously flagged fertilizer placement zones at the 0-6 and 6-12 inch depths. Grain yields and N uptake data were measured.

The Kansas DCD research was conducted at the Southwest Kansas Research and Extension Center near Tribune. Experimental design was a split plot with combinations of method (broad-cast vs dribbled UAN) and N rates of UAN solution (0, 80, 120, and 160 lb N/acre) as main plots. Subplots were rates of DCD (0, 1.5, and 3% of total N as DCD N). All treatments were applied after planting corn. Soil samples (0-6 and 6-12 inches) and plant biomass samples were collected 3 and 6 weeks after treatment application. Plants were analyzed for total N; soils for inorganic N. The materials and methods for the ATS studies of Lamond et al. (1986, 1987, 1988) can be found in the Kansas fertilizer reports of progress 1986 through 1988. In those studies calcium sulfate was used to balance sulfur additions made by adding 10% ATS volume/volume (v/v) to UAN.

RESULTS AND DISCUSSION

Research in Kansas with ATS has given mixed results (Tables 1 and 2). While measured yields are sometimes higher with ATS additions the differences are not always statistically significant. Data of Fox and Piekielek (1987) was similar, they reported a significant increase in ear leaf N with ATS addition but found no yield increase. Since the addition of ATS to UAN at 10 % v/v is relatively inexpensive further investigations to elucidate the potential yield response to ATS are probably worthwhile.

Table 1. Effect of UAN with and without 10% v/v ATS on bromegrass in Kansas (Lamond et al.,1987 and 1988).

Year	N rate	ATS	Forage yield	Tissue N
	lbs/acre		lbs/acre	%
1987	60	no	6170	1.72
	60	yes	6530	1.67
	120	no	7140	2.10
	120	yes	7150	1.97
LSD(0.05)			920	0.17
1988	60	no	3819	1.73
	60	yes	3929	1.72
	120	no	4764	2.07
	120	yes	4629	2.06
LSD(0.05)			718	0.20

Table 2. Effect of broadcast UAN with and without ATS on no-till sorghum in Kansas (Lamond et al. 1986 and 1987).

Year	N rate	ATS	Yield	Tissue N
	lbs/acre		bu/acre	%
1986	50	no	98	2.06
	50	yes	103	2.17
	100	no	120	2.52
	100	yes	134	2.68
LSD(0.05)			14	NS
1987	50	no	93	1.97
	50	yes	99	1.91
	100	no	122	2.29
	100	yes	114	2.16
LSD(0.05)			NS	NS

Both yield increases (Amberger, 1989) and yield decreases (Reeves and Touchton, 1986) have been reported with the use of DCD. Reeves and Touchton (1986) reported a phytotoxic affect at levels greater than 10% N as DCD. Studies conducted at the Southwest Kansas Research and Extension Center (Tribune) indicate no increase in corn yields due to additions of DCD at 1.5 and 3% (Table 3). In that study, the 3% DCD treatment maintained 16% of the inorganic N in the soil as NH_4-N 3 weeks after application whereas only 10% NH_4-N was measured in the 0% DCD treatment.

Table 3. Effect of DCD rate on grain yield and ear leaf N, A Schelegel (1991).

DCD rate	Grain yield	ear leaf N
-%-	-bu/acre-	-%-
0.0	154	1.88
1.5	146	1.89
3.0	152	1.88
LSD(0.05)	NS	NS

At Nebraska, DCD encapsulated in large urea pellets maintained a greater percentage of N as NH_4-N up to 36 days after fertilizer application (Fig 1.). In 1990 no yield responses were observed to either DCD, calcium carbide, or N (Table 4). An excess of 38 inches of water containing 30 ppm NO_3-N was applied to the field. We estimated that 350 lbs N/acre was added in the irrigation water. So it is not surprising N responses were not observed. In 1991 the study was moved to another site where a significant response to N was mea-sured (Table 4). However, even at this site the application of DCD or calcium carbide did not increase yields. In 1991, a significant increase in yield was measured with large urea pellets without inhibitor as compared to conventionally banded urea, DCD encapsulated with the large pellet, and calcium carbide application with large urea pellets (Table 4 and 5). In 1991 the inhibitor treatments may have been applied late enough (V3 stage) to have reduced the amount of NO_3-N available to the crop during peak N demand. Whereas the dissolution, hydrolysis and subsequent nitrification of NH_4-N from the large urea tablets without inhibitor may have been just rapid enough to match crop N demand resulting in the higher yields.

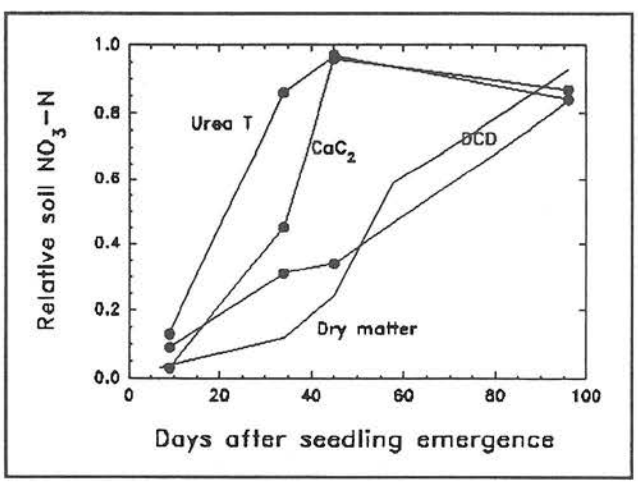

Fig. 1. The percentage of total inorganic N as NO_3-N in the fertilized zone vs days after emergence (Shelton, NE, 1990).

In Kansas with cool season grasses, large urea granules significantly increased tissue N concentration in 5 of 6 studies when top dressed in early spring but didn't increase forage yields when compared with conventional urea fertilizer. In those studies the peak N demand for cool season grasses lasts about 30-35 days from mid-April to mid-May. The slower dissolution and subsequent hydrolysis of the large pellets may have been just slow enough to have missed the peak demand period. Higher plant tissue N with larger urea granules was the result of luxury consumption late in the spring at or near harvest in mid-May.

Table 4. Effect of calcium carbide, DCD, and large urea pellets on irrigated corn Shelton Nebraska. From M.F. Vigil, J.F. Power, J.S. Schepers, and D.D. Francis.

	-------- Grain yields --------	
Treatment	1990	1991
DCD	195(2.0)†	170(8.3)
CaC_2	195(1.5)	169(7.2)
Urea Tablet	191(1.7)	178(7.9)
Urea Banded	196(1.9)	169(9.0)
N rate		
0	197(2.1)	149(9.9)
36	195(1.5)	160(6.3)
71	194(2.4)	183(7.6)
107	193(1.6)	171(5.9)

† Values in parenthesis are the standard error of the mean.

Table 5. Single degree of freedom orthogonal comparisons (planned F test) for the DCD-calcium carbide study at Shelton Nebraska in 1991.

Contrast		Mean square	F value	Pr > F
Check	vs 72 lb N rate	3543.1	21.7	0.0001
Inhibitor	vs none	240.3	1.5	0.2334
Banded urea	vs precision placement	82.2	0.5	0.4830
36 lb N rate	vs 71 and 107 lb N rate	2883.1	17.6	0.0002
36 lb N rate	vs 71 lb N rate	3843.5	23.5	0.0001
71 lb N rate	vs 107 lb N rate	960.3	5.9	0.0206
71 lb N rate	vs 36 and 107 Lb N rate	2882.0	17.6	0.0002
Urea tablets	vs others treatments w/o check	727.2	4.4	0.0420
Urea tablets 71 lb N rate	vs others at 71 lb N rate	541.4	3.3	0.0772

Fujita et al. (1990) reported on the use of polyolefin coated urea. They reported polyolefin coated urea released N slow enough to match the N demand of field corn for up to 126 days after application. They reported that 80 % of the N in the fertilizer was released by 126 days. These N sources might be useful in areas with high spring rainfall. However, they could have a detrimental effect similar to those reported for nitrification inhibitors by releasing N too slowly during the period of peak N demand.

Barking up the wrong tree ?

There is plenty of credible literature indicating inhibitors inhibit nitrification and slow release fertilizers release inorganic N slower than conventional fertilizers. This doesn't insure higher crop yields or economic benefits. They are not a miracle product. These products have their greatest potential in areas with high spring rainfall and high leaching potential. To be used effectively accurate fertilizer recommendations, and an appreciation of synchronizing the release to match crop N demand is critical.

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THE EFFECTS OF NITROGEN FERTILIZER ON SOIL

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Nitrogen (N) fertilizer use increased greatly through the decade of the 70's and then remained relatively constant through the 80's. In Kansas, the tonnage of actual N applied in 1984 was 9.5 times that applied in 1958. For the period July 1987 through June 1988, of the total commercial N applied in Kansas; 59, 18, 11, and 3% was applied as anhydrous ammonia, urea-ammonium nitrate solution, urea, and ammonium nitrate, respectively. In 1960, only 18% of the N applied as commercial fertilizer was applied as anhydrous ammonia. The marked increase in N use has generated many questions about possible negative affects of N fertilization on soil chemical and physical properties. Additionally, concerns are often raised on long-term use of anhydrous ammonia.

Nitrogen source comparisons have been made on many short-term experiments with the majority of the studies showing little or no difference among N sources when properly applied. Few long-term N source comparison studies exist for comparing N source affect on soil physical and chemical properties, but such studies have been conducted in Kansas. During a 20-year period (1969 through 1988), four N fertilizer sources (anhydrous ammonia, ammonium nitrate, urea, and urea-ammonium nitrate solution [UAN]) were applied annually to field plots at three Kansas locations (Manhattan, Ottawa, and Powhattan [two field sites]). The soil types are Smolan silty clay loam, Woodson silt loam, and Grundy silty clay loam at Manhattan, Ottawa, and Powhattan, respectively.

During the 20 years, corn was grown on one Powhattan site and grain sorghum was grown on the other Powhattan site and at Ottawa. At Manhattan, the crop grown varied among grain sorghum, winter wheat, and soybean during the 20 years. The four N sources were applied in the spring of each year, starting in 1969 at an annual rate of 200 lbs N/acre. At Powhattan, the rate was changed to 150 lbs N/acre starting in 1973. At Ottawa, the rate was changed to 100 lbs N/acre starting in 1980. In addition to the N source applications, during 1969 through 1978 at Powhattan; totals of 94 lbs N/acre, 113 lbs P/acre, and 17 lbs K/acre were applied as starter fertilizer to the corn site and totals of 67 lbs N/acre, 89 lbs P/acre, and 35 lbs K/acre were applied as starter fertilizer to the sorghum site. At Ottawa, 21 lbs P/acre were applied to all plots in 1980. A no-N check plot was included at each of the four field locations. Except for the starter fertilizer at Powhattan, and the P application at Ottawa, the check treatment received no fertilizer. Nitrogen source applications were continued annually through the spring of 1988.

These field plots have provided test sites for evaluating soil physical and chemical properties as influenced by nitrogen fertilizer source. In the fall of 1978, soil samples from these plots were collected and several soil physical and chemical properties were evaluated. The evaluation of soil properties after 10 years of fertilizer N source treatments was the subject of an Extension Facts Sheet. In October of 1988 we again sampled the field plots and then determined the status of selected soil physical and chemical properties after the 20 years of N source treatments. Two soil layers were sampled, the 2.5- to 5.5-inch and the 8.5- to 11.5-inch layers. Our examination of the difference in soil properties between N fertilized plots and the no-N check, and among the four N source treatments, is the subject of this Facts Sheet.

SOIL CHEMICAL PROPERTIES

Chemical analyses for the two soil layers sampled are reported by treatment in Table 1. Statistical contrasts show no significant difference (0.05 probability level) among the four N sources in any of the chemical properties in either soil layer. In the upper soil layer, N fertilized plots compared with the no N check had reduced pH, available P, and exchangeable Ca, Mg, and Na; and increased nitrate-nitrogen, ammonium-nitrogen, and DTPA-extractable Fe, Cu, and Mn. In the lower soil layer, N fertilized plots compared with the no-N check had reduced pH and exchangeable Na, and increased nitrate-nitrogen.

Treatments receiving N were significantly lower in pH than the no-N check. Fertilizers that either contain ammonium (NH_4^+) or convert to ammonium have an acid-forming nature because of the release of hydrogen (H^+) during the nitrification of NH_4^+ to nitrate (NO_3^-). The data support this in that all four nitrogen sources reduced pH (more acid) compared with the no-N check and there was no significant difference in pH among the four N sources. Acid conditions produced by continued use of acid- forming fertilizers (as these four are) can be corrected by liming. The increase in concentration of DTPA-extractable micronutrients Fe, Cu, and Mn associated with a decrease in pH (more acid conditions) is consistent with expected trends. We found no significant difference in Zn concentration. With soil acidification, the concentrations of exchangeable Ca, Mg, and Na are expected to decrease. Exchangeable K was not significantly influenced by treatment.

SOIL PHYSICAL PROPERTIES

Results from the analysis of soil physical properties across all locations are summarized in Table 2. As with the chemical properties of Table 1, statistical contrasts show no significant difference among the four N sources in any of the physical properties in either soil layer (Table 2).

If nitrogen source has an influence on soil compaction, then different compaction levels in treated plots would be indicated by differences in clod density. Clod density values presented in Table 2 show no effect from treatments in either soil layer. The clod density method usually gives larger density values than do other (bulk density) methods. A primary reason is that the clod method does not take the interclod air spaces into account. Therefore, these clod density values are expected to be greater than bulk density values for the same soils. But, the clod density values enable a comparison of compaction levels among treatments. In that comparison we found no evidence of different compaction levels among treatments.

The size distribution of water-stable aggregates can be expressed as a single value by determining the geometric mean diameter (GMD) of the aggregates. The larger the GMD, the greater the proportion of large water-stable aggregates. In results summarized in Table 2, N fertilized plots had significantly larger GMD values in the upper layer and significantly lower GMD values in the lower layer. We have no evidence to explain this seemingly contradictory finding for the two soil layers. There were, however, no differences among N sources for either layer.

If chemical dispersion of clay and clay migration occur from nitrogen source application, then nitrogen source should influence soil physical properties such as clay content, water content at low soil water potentials, and soil compactibility. From an analysis of particle-size distribution, there was no significant difference in clay content of either soil layer due to N source. Soil water content at low water potentials is directly related to particle surface area. (The -1.5 MPa soil water potential value is normally considered to be the potential corresponding to the permanent wilting point condition.) If dispersion of clay and clay migration had occurred in treated plots, one would expect the water content at -1.5 MPa of water potential to be different. Our results show no significant difference in water content among the four N sources or between N treated and the no-N check.

Even though the clod density data of Table 2 indicated no real difference in density due to treatment, it was possible that differences in potential for compaction existed but were not evident due to proper soil and tillage management. If dispersion of clay and clay migration are influenced by N source, then N sources should exhibit different potentials for soil compaction. To evaluate the potential for compaction, we determined soil compactibility with a standard, constant-load technique (data presented in Figure 1). As soil water content increases from air-dry, water films provide lubrication between soil particles, which allows the particles to slip and form a closer packing (increased density) when a load is applied. As water is added to soil, the amount of water occupying soil pore space increases, and the pore spaces occupied by water are not able to receive soil particles during load application. The lubrication and pore-filling influences of water are present at all levels of water content; lubrication, however, is of greater importance when the soil is relatively dry and pore-filling of greater importance when the soil is relatively wet. When the "lubrication effect" is increasing more rapidly than the "pore-filling effect", there is an increase in dry bulk density with increased water content. When the "lubrication effect" is increasing less rapidly than the "pore-filling effect", there is a decrease in dry bulk density with increased water content. The change from an increasing to a decreasing dry bulk density pattern with increased water content often occurs near the "field capacity" water content value. In practice, farming operations occur to the left of the maximum bulk density value. At soil water contents where field operations are possible, the potential for compaction increases as water content increases. In this study, if dispersion and migration of clay had occurred, the compactibility analysis would have shown an influence of treatment on maximum bulk density and optimum water content for compaction. The maximum bulk density and optimum water content for compaction values were taken from statistical regression curves for the data of Figure 1 and are summarized in Table 2. No significant treatment effect was found for data on maximum bulk density and optimum water content for compaction.

Grain yields were taken at the Ottawa and Powhattan locations. During the years 1985 through 1988, plots receiving fertilizer N yielded significantly more grain (overall average of 77.6 bushels per acre) than the no-N check (average of 36.6 bushels per acre). There was no significant difference in grain yield among the four N sources.

SUMMARY AND CONCLUSIONS

Our results show no significant difference in any chemical or physical property among the four nitrogen sources (anhydrous ammonia, ammonium nitrate, urea, urea-ammonium nitrate solution). The primary influence of 20 years of nitrogen fertilization has been on soil acidification and the associated nutrient availabilities, and on increased concentrations in the soil of nitrate-nitrogen and ammonium-nitrogen.

Table 1. **Chemical properties, as influenced by nitrogen source, of disturbed soil samples taken from two layers in field plots.**

Nitrogen source	pH	Organic matter	CEC	Avail. P	Exchangeable				DTPA-extractable					
					K	Ca	Mg	Na	Zn	Fe	Cu	Mn	NO_3^--N	NH_4^+-N
		$g\ kg^{-1}$	$cmol_c kg^{-1}$	mg kg^{-1}										
2.5- to 5.5-inch soil layer														
1. Check (no N)	6.2	20.4	23.3	38	220	2,949	548	25	1.23	52.8	1.63	14.8	4.0	5.0
2. Anhydrous ammonia	5.2	18.4	22.7	27	217	2,601	459	15	1.20	75.9	1.99	39.8	26.6	8.7
3. Ammonium nitrate	5.2	22.7	21.7	26	220	2,443	432	14	1.11	70.4	2.14	44.3	20.9	11.2
4. Urea	5.1	22.8	22.7	24	210	2,566	478	15	1.07	75.7	2.12	51.2	30.8	11.5
5. UAN solution	5.2	20.4	22.2	28	204	2,494	425	15	1.02	77.8	1.89	38.0	20.2	8.4
Contrasts[a]														
Check (no N) vs. fertilized (1 vs. 2,3,4,5)	**	NS	NS	**	NS	**	**	**	NS	**	**	**	**	**
Combinations of fertilized (2 vs. 3 vs. 4 vs. 5)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
8.5- to 11.5-inch soil layer														
1. Check (no N)	6.4	15.2	32.6	8	210	3,893	822	71	0.48	44.7	1.94	8.9	1.4	4.7
2. Anhydrous ammonia	6.0	12.8	31.6	6	199	3,823	733	40	0.36	49.4	1.90	10.4	13.0	4.8
3. Ammonium nitrate	6.2	14.9	34.0	6	208	4,060	815	41	0.42	43.1	1.93	7.4	9.3	5.1
4. Urea	6.0	15.4	32.6	6	212	3,666	719	42	0.38	45.4	1.99	15.6	10.1	5.9
5. UAN solution	6.2	14.1	31.0	5	209	3,949	808	40	0.33	39.0	1.80	7.1	9.0	4.8
Contrasts[a]														
Check (no N) vs. fertilized (1 vs. 2,3,4,5)	*	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	**	NS
Combinations of fertilized (2 vs. 3 vs. 4 vs. 5)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a]Orthogonal contrasts were not different at the 0.05 probability level (NS), were different at the 0.05 probability level (*), or were different at the 0.01 probability level (**).

NOTE: To convert from SI units, perform these multiplications: g $kg^{-1} \times 0.1$ = percent, $cmol_c kg^{-1} \times 1$ = milliequivalents per 100 grams, and mg $kg^{-1} \times 1$ = parts per million.

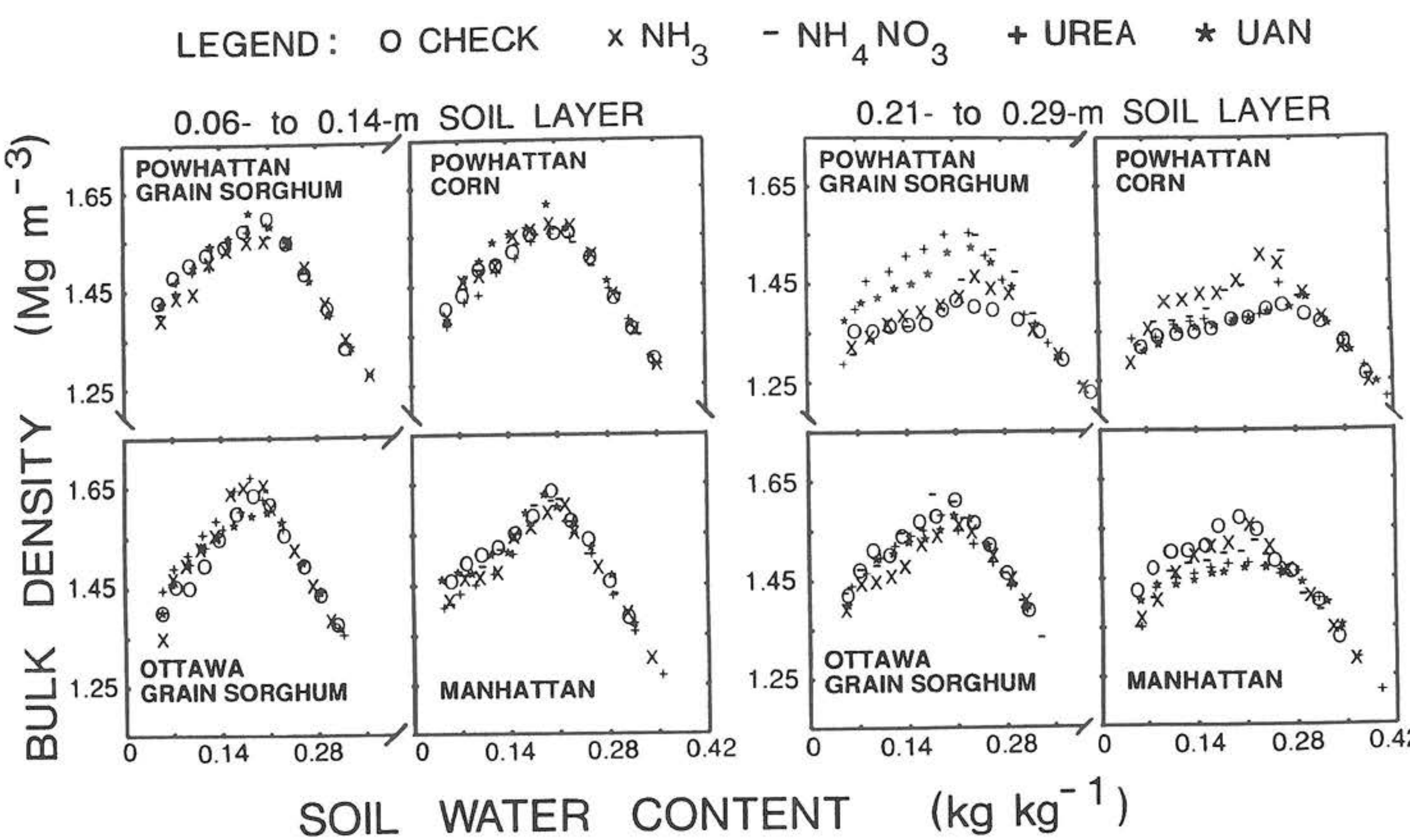
Table 2. **Physical properties, as infuenced by nitrogen source, of disturbed soil samples taken from two layers in field plots.**

Nitrogen source	Compactibility analysis: Maximum bulk density	Compactibility analysis: Optimum water content for compaction	Clod density	Water content at -1.5 MPa potential	Particle-size distribution: Sand (0.05-2 mm)	Particle-size distribution: Coarse silt (0.02-0.05 mm)	Particle-size distribution: Fine silt (0.002-0.02 mm)	Particle-size distribution: Clay <0.002 mm)	Geometric mean diameter
	$Mg\ m^{-3}$	$kg\ kg^{-1}$	$Mg\ m^{-3}$	$kg\ kg^{-1}$	$g\ kg^{-1}$				mm
2.5- to 5.5-inch soil layer									
1. Check (no N)	1.60	0.190	1.50	0.125	113	260	338	290	0.95
2. Anhydrous ammonia	1.59	0.193	1.45	0.126	95	213	398	295	1.48
3. Ammonium nitrate	1.59	0.189	1.46	0.127	85	253	368	295	1.50
4. Urea	1.58	0.196	1.46	0.125	103	215	395	288	1.75
5. UAN solution	1.60	0.190	1.49	0.127	108	255	343	295	1.57
Contrasts[a]									
Check (no N) vs. fertilized (1 vs. 2,3,4,5)	NS	NS	NS	NS	NS	NS	NS	NS	**
Combinations of fertilized (2 vs. 3 vs. 4 vs. 5)	NS	NS	NS	NS	NS	NS	NS	NS	NS
8.5- to 11.5-inch soil layer									
1. Check (no N)	1.49	0.220	1.67	0.188	75	180	330	415	1.35
2. Anhydrous ammonia	1.51	0.216	1.66	0.189	70	183	330	418	0.90
3. Ammonium nitrate	1.52	0.217	1.65	0.191	58	215	308	420	0.98
4. Urea	1.50	0.219	1.68	0.192	60	175	338	428	0.94
5. UAN solution	1.49	0.232	1.67	0.187	80	173	328	420	1.02
Contrasts[a]									
Check (no N) vs. fertilized (1 vs. 2,3,4,5)	NS	NS	NS	NS	NS	NS	NS	NS	**
Combinations of fertilized (2 vs. 3 vs. 4 vs. 5)	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a]Orthogonal contrasts were not different at the 0.05 probability level (NS), or were different at the 0.01 probability level (**).

NOTE: To convert from SI units, perform these multiplications: $Mg\ m^{-3} \times 62.4$ = lbs per ft^3, MPa × 9.90 = atmospheres, kg × 2.20 = pounds, $g\ kg^{-1} \times 0.1$ = percent, and mm X 0.0394 = inches.

Figure 1. **Bulk density versus water content during compaction of soil from the 2.5- to 5.5-inch (0.06- to 0.14-m) and the 8.5- to 11.5-inch (0.21- to 0.29-m) soil layers with five treatments and four locations.**



SULPHUR FERTILIZATION OF BROMEGRASS IN KANSAS

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ABSTRACT

Field research was conducted from 1987-1991 at three locations in eastern Kansas to evaluate the effects of sulphur (S) rates (0, 15, 30 lb/ac) and sources (ammonium thiosulfate [ATS], ammonium sulfate [AS]) on forage production and quality of smooth bromegrass (Bromus inermis L.). Nitrogen was balanced at 120 lb/ac using ammonium nitrate during February each year. All fertilizer treatments were surface broadcast. Sulphur fertilization consistently and significantly increased bromegrass forage yields and forage S concentrations, but had little effect on forage protein levels. Averaged across 9 site-years, S increased bromegrass forage yields by nearly 600 lb/ac/yr, and 15 lb S/ac was adequate.

INTRODUCTION

Several million acres of introduced cool-season grasses, primarily smooth bromegrass and tall fescue, are used for haying or grazing or both in Kansas. For optimum production, these grasses require fairly intensive management, including application of nitrogen and sometimes phosphorus (P) and/or potassium (K).

Sulphur (S) is an essential nutrient for plants and animals; thus, S fertilization has the potential to benefit forage growth and animal performance by improving forage quality. Studies conducted in the early 1970's (Lamond, 1975) indicated a possible need for supplemental S on cool-season forages in eastern Kansas. Responses to S in these studies varied with year, possibly related to soil temperature and mineralization release of S from organic matter.

Because of the importance of cool-season grasses in Kansas and the indication that these forages may respond to S fertilization, this research was established to evaluate the effects of S rates and sources on smooth bromegrass forage production and quality.

MATERIALS AND METHODS

Studies evaluating S rates (0, 15, 30 lb/ac) and S sources (ammonium thiosulfate [ATS]), ammonium sulfate [AS]) were conducted at three sites in eastern Kansas on established smooth bromegrass from 1987 through 1991. Table 1 summarizes site information.

Table 1. Summary of site information

County	Years	Grass	Soil Test Values, 0-6 in. pH	OM	P	K	S
Riley	87-91	Brome	6.1	3.4	47	210	7
Greenwood	88-90	Brome	6.3	3.2	16	185	9
Brown	91	Brome	5.6	4.0	18	205	5

Nitrogen (N) was balanced on all treatments at 120 lb/ac on the bromegrass using ammonium nitrate. All fertilizer treatments were surface broadcast during February each year. Forage was harvested (late May-early June); yields were determined; and subsamples were retained for moisture, N, and S determinations. Forage yields are reported at 12.5% moisture. For forage N analysis, forage samples were digested with sulfuric acid and hydrogen peroxide followed by N determination on a Technicon Auto Analyzer. For S analysis, samples were digested with nitric-perchloric acid followed by turbidimetric S determination on a Technicon Auto Analyzer.

RESULTS AND DISCUSSION

Bromegrass

Sulphur fertilization resulted in consistent and, in most years, significant increases in brome forage production at all sites (Table 2). Forage yields were increased by S fertilization in 8 of 9 site years. Averaged over years and locations, S fertilization has increased forage production by nearly 600 lb/ac (Table 3). Differences between the 15 and 30 lb/ac S rates were nonsignificant, and 15 lb S/ac appears to be enough to meet plant needs. Both sources of S performed equally well.

Sulphur fertilization had no effect on bromegrass forage protein levels at normal harvest time (late May). However, the addition of S did significantly increase forage S concentrations. Table 3 summarizes the effects of S on brome forage yields, protein levels, and S concentrations.

In 1990 (Riley County), dramatic visual responses to applied S became apparent in early April. Results of forage analyses from samples taken early (April 24) showed that S did increase forage protein levels and greatly increased forage S concentrations (Table 4). By harvest a month later, however, these differences had largely disappeared.

Table 2. Effects of sulphur fertilization on bromegrass forage yields.

S Rate	S Source	Riley Co. 1987	Riley Co. 1988	Riley Co. 1989	Riley Co. 1990	Riley Co. 1991	Greenwood Co. 1988	Greenwood Co. 1989	Greenwood Co. 1990	Brown Co. 1991
lb/ac		lb/ac								
0	---	6230	4090	2990	8280	5200	5410	3910	5930	7150
15	ATS	6800	4160	3480	9040	5700	6010	4190	7090	8060
30	ATS	6890	4100	3260	9270	5860	5690	4160	6750	7790
15	AS	6480	4480	3570	8770	5790	5810	3950	7220	8070
30	AS	7240	4080	3230	9250	6010	5700	4360	7120	7970
LSD (.05)		570	NS	NS	680	NS	NS	NS	NS	590
LSD (.10)		---	NS	440	---	510	320	330	960	---

Table 3. Effects of sulphur fertilization on bromegrass forage production and quality.

Treatment	Forage, 9-Year Average Yield	Protein	S
	lb/ac	%	%
S Rate 0	5470	10.6	.08
lb/ac 15	6030	10.6	.11
30	6040	10.6	.12
S ATS	6020	10.6	.11
Source AS	6060	10.6	.12
F Test			
Rate (R)	+	NS	*
Source (S)	NS	NS	NS
R X S	NS	NS	NS

*,+ indicate significance at 0.05 and 0.10 levels of probability, respectively.

Table 4. Effects of sulphur fertilization on early-season forage quality.

S Rate	S Source	Riley County, 1990 Protein	S
lb/ac		-------- %	-------
0	---	19.8	.08
15	ATS	21.8	.19
30	ATS	22.2	.22
15	AS	23.3	.21
30	AS	22.6	.24
LSD (0.05)		NS	.06
LSD (0.10)		2.1	---

SUMMARY

Overall results from this research indicate consistent and significant increases in bromegrass forage yield and forage S concentration with S fertilization. Addition of 15 lb S/ac was adequate. Sulphur fertilization had minimal effect on bromegrass protein levels. With current S, hay, and beef prices, increases in forage production with S fertilization are economically viable. Producers who place heavy demands on their brome should give particular consideration to S.

In S-responsive situations, both ATS and AS appear to be viable S fertilizer alternatives.

REFERENCES CITED

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PHOSPHORUS RELATIONSHIPS IN NO-TILL SMALL GRAINS

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ABSTRACT

Phosphorus (P) fertilizer practices for no-till small grain production require refinement with the advent of no-till planters capable of banding fertilizer below the seed. This research determined P response relative to the Olsen P soil test, compared P fertilizer placements with the seed and banded below and to the side of the seed, and evaluated rates from 0 to 50 lbs P_2O_5 as ammonium phosphate (11-52-0) for no-till small grain production. Seven spring barley, 11 spring wheat, and six winter wheat locations in Central and Northcentral Montana were evaluated between 1986 and 1990. Grain yield, above-ground crop yield, plant P conc. at maturity, and P uptake were measured. Results for individual experiments were analyzed by ANOVA. The data combined across all experiments were analyzed by a paired t-test, Cate-Nelson graphical method, and linear multiple regression. According to ANOVA one winter wheat location had a significant yield response to P, and P conc. was increased significantly at one spring barley and spring wheat location. Phosphorus uptake data were all nonsignificant. Both the ANOVA and paired t-test were used to analyze the P placement data and were all nonsignificant. Slopes of grain yield response (grain yield for each P rate minus the grain yield without P), P conc., and P uptake versus P rate were analyzed with the t-test; none of the P response slopes were greater than zero. The P responses by individual crop were regressed against P rate, Olsen P soil test, available soil water at planting, and pH. Phosphorus rate was not a significant factor in any of the equations. Significant and useful predictive equations for grain yield response could not be generated; however, equations predicting P conc. and P uptake were developed. The Cate-Nelson graphical analysis was unsuccessful in estimating an Olsen P soil test critical level. All attempts failed to relate grain yield or grain yield response to the Olsen P soil test and/or P rate. Grain growers should apply a maintenance level of P fertilizer, about 10 to 20 lbs P_2O_5/ac either banded below or with the seed, when producing small grains no-till.

INTRODUCTION

No-till cropping systems are the "ultimate" in protecting cultivated soils from wind and water erosion. Montana grain growers are adopting no-till planting methods because of recent advances in implement technology, price reductions in preplant contact herbicides, and the residue requirements of the 1985 Farm Bill. Commercial equipment capable of planting and fertilizing in heavy residue and harvest implements that distribute stover rather than windrowing have eliminated early problems of no-till small grain production. No-till increases the frequency of annual cropping in flexible cropping systems; therefore, adjustments in fertilizer recommendations are necessary. The objectives of this research were to (1) determine phosphorus (P) response relative to the sodium bicarbonate extractable P soil test, and (2) compare P fertilizer placement bands with the seed and below and to the side of the seed (deep-band) for no-till small grains grown in Central and Northcentral Montana.

MATERIALS AND METHODS

Field experiments involving P fertilizer placement and rate on no-till spring barley, spring wheat, and winter wheat were planted on land previously cropped with small grains located near Moccasin, Conrad, and Havre, Montana from 1986 to 1990. Experimental site characteristics of soil series, mean grain yield, Olsen P soil test, pH, growing season precipitation, and available soil water at the beginning of the growing season are summarized in Table 1.

Table 1. Research site characteristics of no-till small grain phosphorus studies. 1986-1990.

Loc. No.	Year	Soil Series	Mean Grain Yield	Olsen P Soil Test	pH	Growing Season Precip.	Avail. Soil Water
			bu/ac	ppm		in.	in.
		Spring Barley					
1	1986	Phillips loam	50	16	8.0	4.3	7.0
2	1986	Tamaneen clay loam	78	20	7.7	8.2	7.0
3	1987	Scobey clay loam	71	26	7.6	5.5	7.0
4	1987	Phillips loam	53	16	8.0	4.6	7.0
5	1987	Kevin clay loam	31	13	8.1	4.0	2.5
6	1989	Phillips clay loam	16	29	7.5	9.6	2.5
7	1989	Kevin clay loam	42	13	8.0	6.9	7.0
		Spring Wheat					
8	1986	Tamaneen clay loam	57	22	7.1	10.1	7.0
9	1986	Tamaneen clay loam	51	21	7.7	8.2	7.0
10	1986	Scobey clay loam	43	25	7.3	5.8	7.0
11	1986	Phillips clay loam	39	20	8.0	4.3	7.0
12	1987	Kevin clay loam	20	13	8.1	4.0	2.5
13	1987	Scobey clay loam	38	26	7.6	5.5	7.0
14	1987	Scobey clay loam	37	26	7.6	5.5	7.0
15	1987	Marias silty clay	20	26	8.0	2.9	7.0
16	1989	Tamaneen clay loam	34	25	7.8	10.2	3.5
17	1989	Kevin clay loam	36	13	8.0	6.9	7.0
18	1989	Phillips clay loam	15	29	7.5	9.6	4.0
		Winter Wheat					
19	1987	Phillips clay loam	38	16	8.0	4.6	7.0
20	1988	Tamaneen clay loam	35	16	8.0	8.5	3.5
21	1989	Tamaneen clay loam	38	17	8.0	10.1	3.5
22	1990	Tamaneen clay loam	43	38	7.3	6.5	5.0
23	1990	Scobey clay loam	42	37	7.3	5.1	5.0
24	1990	Phillips clay loam	21	12	7.4	3.9	3.0

Treatments of 0, 15, and 30 lbs P_2O_5/ac with the seed and a deep-band treatment of 30 lb P_2O_5/ac were applied at sites 1, 2, 9-11, and 19. Zero and 53 lbs P_2O_5/ac with the seed and a deep-band were applied at site 8. At locations 14 and 15, P_2O_5 treatments were 0, 15, 30, and 50 lbs/ac applied with the seed and the deep-band treatment at the 15 lb/ac rate. Field plot design of these sites was RCB with three replications. A factorial field plot design with P rates, two placements, and three replications was used on the remaining locations. Phosphorus treatments 0, 15, 30, and 45 lbs P_2O_5/ac with the seed and in a deep-band were applied at sites 3-5, 12, and 13. Sites 6, 7, 16-18, and 20-24 were similar except P rates were 0, 10, 20, 30, 40, and 50 lbs P_2O_5/ac. Total crop yield at maturity, grain yield, and P conc. of the whole plant at maturity were measured, and P uptake calculated from the total yield and P conc.

Three no-till planters having fertilizer placement capabilities were used. A Haybuster 8000 planter with coulters and a 12 in. row space was adapted for plot work and used at locations 8, 16, and 20-22. This planter used point-hoe openers with the fertilizer band placed about 1.5 in below and between two seed rows spaced three in apart. Also with these locations, all treatments received 90 lbs nitrogen (N)/ac placed in the deep-band. At locations 7, 14, 15, and 17, a custom built planter with double-disc openers placed seed in the 6- by 14-in paired row configuration with fertilizer placed between and 2 in below each pair of rows for subsurface treatments. A USDA III double disc planter with a 5- by 15-in row arrangement was used at the remaining locations in a manner similar to the custom built double disc planter. The sites using the double disc planters received 80 lbs of N/ac placed in the deep-band. Glyphosate was used for preplant vegetation control, with bromoxynil, MCPA, and diclofop used as postemergent herbicides when needed. Clark was used as the spring barley cultivar. Spring wheat cultivars were Newana at site 8, Glenman at sites 9-11, Rambo at 14 and 15, and Lew at all remaining locations. Winter wheat cultivars included Redwin at location 19 and Tiber at locations 20-24. Seeding rate for all experiments was 20 seeds/ft^2.

Individual experiments were statistically analyzed using ANOV with mean separation by LSD. To determine if an overall P response occurred, all possible slopes (including both placement methods) of grain yield response, P conc., and P uptake versus P rate were tested against zero with the t-test. To determine the overall effect of P placement on grain yield response, P conc., and P uptake, all possible P placement pairs were tested with the sign and t-test. The Cate-Nelson graphical method was used to define the Olsen P soil test critical level. Linear multiple regression using appriopriate P with the seed data from each crop and location were utilized to relate dependant variables grain yield, grain yield response, P conc., and P uptake with independent variables P rate, Olsen P soil test (ST), pH, and available soil water (SW). Independent variables were included if significant at p level < 0.05.

RESULTS AND DISCUSSION

Using ANOVA (Table 2.) only site no. 19 had a significant grain yield response to P, sites 3 and 17 had a significant P conc. increase due to P, and all P uptake data were non-significant.

Table 2. Analysis of variance summary of grain yield, P conc., and P uptake of the no-till small grain P studies conducted in Central and Northcentral Montana. 1986-90.

Loc.	----Grain Yield----		--P Concentration--		------P Uptake-----	
No.	P Rate	P Placement	P Rate	P Placement	P Rate	P Placement
			Spring Barley			
1	NS	NS	NS	NS	NS	NS
2	NS	NS	NS	NS	NS	NS
3	NS	NS	0.02	NS	ND	ND
4	NS	NS	NS	NS	NS	NS
5	NS	NS	NS	NS	NS	NS
6	NS	NS	NS	NS	NS	NS
7	NS	NS	NS	NS	NS	NS
			Spring Wheat			
8	NS	NS	ND	ND	ND	ND
9	NS	NS	NS	NS	NS	NS
10	NS	NS	NS	NS	ND	ND
11	NS	NS	NS	NS	NS	NS
12	NS	NS	NS	NS	NS	NS
13	NS	NS	NS	NS	NS	NS
14	NS	NS	NS	NS	NS	NS
15	NS	NS	NS	NS	NS	NS
16	NS	NS	NS	NS	NS	NS
17	NS	NS	0.04	NS	ND	ND
18	NS	NS	NS	NS	NS.	NS
			Winter Wheat			
19	0.05	NS	NS	NS	NS	NS
20	NS	NS	NS	NS	NS	NS
21	NS	NS	NS	NS	NS	NS
22	NS	NS	NS	NS	NS	NS
23	NS	NS	NS	NS	NS	NS
24	NS	NS	NS	NS	NS	NS

ND = Not determined. NS = Not significant at $p < 0.05$.

In spring barley, grain yields ranged from 15 (loc. 6) to 81 bu/ac (loc. 2), P conc. varied from 0.15 (loc. 3) to 0.31 % (loc. 6), P uptake fluctuated from 5.9 (loc. 7) to 15.0 lbs P/ac (loc. 1). Spring wheat yields ranged from 61 (loc. 8) to 14 bu/ac (loc. 18), P conc. from 0.25 (loc. 16) to 0.15 % (loc. 12), and P uptake from 12.8 (loc. 11) to 4.2 lbs P/ac (loc. 12). Winter wheat yields fluctuated from 20 (loc. 24) to 49 bu/ac (loc. 23), P conc. from 0.07 (loc. 23) to 0.20 % (loc. 19), and P uptake from 3.1 (loc. 24) to 12. lbs P/ac (loc. 22). The ANOVA analysis for P placement (grain yield, P conc., and P uptake) were non-significant for all locations. The P placement data was pooled by crop and all crops together for paired-t analysis and sign which were both non-significant. All possible P response data (P with the seed and in the deep band) were used to calculate slopes of grain yield response, P conc., and P uptake versus P rate. These slopes from each crop and all crops combined together were tested against zero using the paired t-test. All t-tests were non-significant. Results from the Cate-Nelson graphical analysis were non-significant implying that any soil test could be the critical level or all soils tested had adequate P levels.

Results of the linear multiple regression analysis are shown in Table 3. Significant equations predicting grain yield and significant and meaningful equations predicting grain yield response could not be generated. Note that P rate was not included in any of the equations, only SW and pH were significant dependant variables in equation 3, and the positive sign for ST in equation 6. Equations were developed for estimating P conc. and P uptake. However, many of the signs were unexpected such as the negative ST in equation 4, the positive pH signs in equations 1, 7, and 8, and the positive SW sign in equation 2.

Attempts to relate no-till small grain yield and yield response to Olsen P soil test and P rate were unsuccessful. In order to maintain available soil P levels, grain growers should consider fertilizing with P at approximately the same rate as estimated crop removal, 10 to 20 lbs P_2O_5/ac.

Table 3. Multiple regression equations expressing grain yield response, P conc., and P uptake of no-till small grains as a function of P rate, P soil test, pH, and available soil water. 1986-1990.

Equation		R^2
	Spring Barley	
1. Y_2 =	$-0.61 + 0.0060ST - 0.0097SW + 0.096pH$	0.33^{*}
2. Y_3 =	$8.61 + 0.656SW$	0.46^{**}
	Spring Wheat	
3. Y_1 =	$39.34 + 0.758SW - 5.668pH$	0.46^{**}
4. Y_2 =	$0.35 - 0.0024ST - 0.0171SW$	0.65^{**}
5. Y_2 =	$0.27 - 0.0134SW$	0.51^{**}
	Winter Wheat	
6. Y_1 =	$-2.68 + 0.118ST$	0.20^{*}
7. Y_2 =	$-0.99 + 0.0028ST + 0.139pH$	0.84^{**}
8. Y_3 =	$-45.77 + 0.273ST + 6.200pH$	0.80^{**}

All regression coefficients significant $p < 0.05$.
Y_1 = Grain yield response, bu/ac.
Y_2 = P concentration at maturity, %.
Y_3 = P uptake at maturity, lb P/ac.
ST = Olsen P soil test, ppm.
SW = Available soil water in 4 ft. of soil, in.
pH = Soil pH in plow layer.
* Regression equation significant $p < 0.05$.
** Regression equation significant $p < 0.0005$.

SOIL TESTS FOR PHOSPHORUS BIOAVAILABILITY

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ABSTRACT

With increased concern for the environment and efficient use of resources, there is renewed interest in assessing the relative contribution of various soil P pools to plant available P. The purpose of this experiment was to evaluate two novel methods of measuring soil P bioavailability. Iron-oxide coated filter paper was used as a P sink in one procedure. The second procedure measures P release after incubation with a C and N containing substrate analogous to root exudates. Both procedures responded to P removal via cropping. Soils incubated with the C and N substrate consistently had higher bioavailable P as compared to paired samples incubated without the substrate. Further investigations with the soil P bioavailability indices are warranted.

INTRODUCTION

Several key questions are associated with the general topic of P bioavailability in soils. First, can an accurate assessment of the total amount of plant-available P in soils be made and what are the desorption kinetics of that pool? What contributions do organic P forms make? A more thorough understanding of P bioavailability could ultimately lead to increases in P use efficiency and a decline in the problems associated with excessive P additions to soils. There exists a need for a generalized procedure to assess the total amount of P that could be desorbed, dissolved or mineralized from a soil and the rate at which that P becomes available for plant growth. The available P indices in use today (e.g. Bray P1, Olsen's, etc.) meet this need to a limited extent. However, the extractants are more an indicator of intensity, since the soil comes to a "steady-state" condition with the extract, and are poor indicators of capacity (Kuo, 1990). They provide no information on kinetics or potentially mineralizable P. Organic P constitutes a significant portion of the total soil P, ranging from 15 to 80% (Stevenson, 1982), but quite normally 30 to 50% in most soils (Paul and Clark, 1989).

Two novel methods for assessing soil P bioavailability will be presented. The first utilizes iron-oxide impregnated filter paper as a P sink and is an adaptation of the procedure presented by van der Zee et al. (1987). The second procedure measures changes in labile P forms after induced microbial activity places a high demand on biologically-available P (Thien and Myers, 1992). The purpose of this experiment was to evaluate the two methods for assessing P bioavailability.

MATERIALS AND METHODS

A P drawdown study conducted under greenhouse conditions provided the soil samples. Five crops of a sorghum-sudangrass hybrid were grown on four soils (Eudora silt loam, Bray P1 P=150 ppm; Eudora silt loam - manure amended, Bray P1 P=190 ppm; Tully silty clay loam, Bray P1 P=28 ppm; Judson silt loam, Bray P1 P=107 ppm). Three crops have been grown on a fifth soil (Crete silty clay loam, Bray P1 P=42 ppm). Four replications were used. Tops and roots were collected at each harvest along with representative soil samples.

Iron-oxide impregnated filter paper is made by soaking Whatman #541 filter papers (2.8 in diameter) in a 10% $FeCl_3$ solution and then treating them with 7 M NH_4OH. The P desorption experiments are run by weighing soil into an 8 oz. glass bottle and adding 3 filter disks and 4 oz. of 0.01 M $CaCl_2$. The bottles are placed horizontally on a reciprocating shaker. Duplicate bottles are destructively sampled at t=1, 2, 3, 6, 8, 12, 24, 48, and 72 hours. The P is removed from the papers by several extractions with 0.4 M H_2SO_4. Standard colorimetric P analysis techniques are employed. The data is fit to:

$$P_d = P_{ib}(1 - e^{-kt})$$

where P_d is the amount of P desorbed (ppm) at time t, P_{ib} is the maximum amount of P that can be desorbed (ppm), k is the rate constant (h^{-1}) and t is time (hours).

Soil samples were also evaluated for bioavailable P according to Thien and Myers (1992). Twin soil samples are mixed with a glucose and nitrogen solution, simulating rhizosphere conditions, and incubated for 7 days (bioactive). Olsen's bicarbonate extraction before and after $K_2S_2O_8$ digestion allows determination of inorganic and inorganic plus organic P on one sample. The other is treated with hexanol to lyse microbial cells and then extracted with bicarbonate to determine inorganic plus microbial biomass P. A second set of samples is incubated without glucose and nitrogen (not bioactive). The term bioavailable P is the sum of inorganic, organic and microbial biomass P.

RESULTS AND DISCUSSION

The influence of cropping on the values of P_{ib} and k is shown in Tables 1 and 2. The intial values of P_{ib} were higher than the initial Bray extractable P levels for all samples, indicating that a larger pool of available P was being measured by the iron-oxide coated paper than by the Bray extractant. All samples had a lower P_{ib} value after harvest #5 as compared to the respective initial values. The Tully, Judson and Crete samples exhibited steady or declining P_{ib} for harvests #1 to #4. The two Eudora samples had steady to increasing P_{ib} values, however, for harvests #1 to #4. The reason for this is not known at this time. Similar results were obtained with bioavailable P for the Eudora sample (Table 3).

Table 1. The effects of cropping on the value of P_{ib}.

		------- Harvest No. -------					
Sample	Initial	1	2	3	4	5	95% C.L., H5
	ppm						
Eudora	201	257	308	278	251	174	163-186
Eudora (manure)	246	253	312	225	308	167	155-179
Tully	65	60	nd[#]	nd	nd	nd	-[@]
Judson	148	132	133	110	115	99	88-110
Crete	79	65	58	52	-	-	45-58

[#]not detectable; [@]not available.

Table 2. The effects of cropping on the value of k.

		------- Harvest No. --------					
Sample	Initial	1	2	3	4	5	95% C.L., H5
	h^{-1}						
Eudora	0.38	0.36	0.89	0.60	1.04	0.50	0.35-0.65
Eudora (manure)	0.31	0.43	1.00	1.74	0.84	0.29	0.21-0.37
Tully	0.43	0.71	-[#]	-	-	-	-
Judson	0.34	0.59	0.43	0.24	0.69	0.16	0.10-0.22
Crete	0.22	0.44	0.62	0.10	-	-	0.06-0.13

[#]not available.

Initial values of k were all less than 0.5 h^{-1}. Each sample experienced an increase in k with cropping at some point at or before harvest #4 and then a decline in k at harvest #5. The value of k represents the relative rate at which the pool of available P desorbs. If the trend that is evident when comparing harvest #5 to harvest #4 continues, the data would suggest that the pool of available P is slow to desorb after extensive cropping.

The parameters of interest determined with the iron-oxide coated filter paper procedure primarily reflect the pool or inorganic P remaining after each harvest. Changes in bioavailable P as measured by the procedure of Thien and Myers (1992) may allow an assessment of changes in organic P pools.

The conversion of P_o to P_i in soils is primarily microbially mediated (Paul and Clark, 1989). The most direct influence of soil microorganisms occurs in the rhizosphere, or microbially active zone near roots. Thus we have developed an extraction scheme that utilizes enhanced microbial activity to form biological sinks for soil P (Myers and Thien, 1992). Measuring the total P available to these microbes generates a bioavailable P index, or a measure of P availability from all forms. Table 3 shows changes in the bioavailable P index over 5 harvests intended to show changes in the availability of different P pools. The data show a bioavailable pool consistently larger than predicted by preincubation chemical extraction (Olsen's test). For the bioactive Tully soil (where microbes have been stimulated to mimic rhizosphere conditions), the bioavailable P ranged from 55-76 ppm compared to an Olsen test value range of 10-18 ppm P. The Tully soil had been under prairie vegetation, had received no prior P fertilization, and would have been characterized as requiring P fertilization. The bioactive test, however, reveals that pools of P unavailable to the chemical extractant were available to the soil microbes. In reality, the P supplying rating of this soil was greater than the chemical extractant predicted. This same effect is noted in the other soils, but seems to diminish as the original P level in the soil increases. It must be emphasized that these data are in the preliminary stages of interpretation and will continue to be evaluated as this experiment is continued.

Table 3. Changes in phosphorus pools during a five-harvest drawdown period. A bioactive soil has had the microbial population stimulated with carbon and nitrogen. Bioavailable P is the sum of inorganic, organic, and microbial phosphorus. All values are in ppm.

		Pre-incubation		Incubated							
				Not Bioactive				BioActive			
Soil	Harvest	Pi	Po	Pi	Po	Pm	BioAv	Pi	Po	Pm	BioAv
Eudora	0	80	7	75	8	0	**84**	42	38	33	**112**
	1	105	6	107	1	1	**109**	86	14	34	**134**
	2	90	2	95	2	2	**98**	73	20	11	**103**
	3	83	7	78	7	42	**127**	59	16	31	**106**
	4	73	8	66	4	41	**111**	45	17	32	**94**
	5	66	7	63	6	24	**93**	79	15	39	**132**
Eudora plus manure	0	110	7	113	3	4	**120**	92	19	52	**163**
	1	106	4	107	3	3	**113**	87	21	26	**134**
	2	91	4	93	4	10	**108**	70	20	7	**97**
	3	81	9	80	7	7	**94**	57	17	14	**88**
	4	71	7	67	6	14	**87**	47	20	28	**95**
	5	66	8	62	6	20	**89**	77	16	42	**135**
Judson	0	64	11	58	8	5	**71**	47	35	25	**107**
	1	49	10	46	9	5	**59**	54	24	10	**88**
	2	46	12	43	10	3	**55**	31	27	46	**104**
	3	39	11	34	9	6	**49**	26	35	27	**88**
	4	35	10	30	9	4	**43**	25	26	24	**75**
	5	35	12	33	9	5	**46**	21	26	45	**92**
Tully	0	17	16	16	13	19	**48**	6	26	35	**68**
	1	18	15	16	14	12	**42**	10	25	38	**73**
	2	16	16	13	13	14	**41**	7	30	40	**76**
	3	12	15	11	11	17	**39**	5	26	23	**55**
	4	10	15	8	11	14	**33**	7	24	32	**63**
	5	10	15	10	11	11	**32**	7	21	41	**70**

Pi = Inorganic P Po = Organic P Pm = Microbial P BioAv = Bioavailable P
Values are means of six replications

CONCLUSIONS

The principle of trying to identify the most readily labile pools of P is shared in many extraction approaches, including the filter paper procedure. In general, the iron-oxide coated filter paper procedure consistently responded to P removal when the initial pool or inorganic P was less than 150 ppm. The incubation procedure assumes that stimulating microbes to accumulate P from the most labile inorganic and organic pools approximates their activites under rhizosphere conditions and that, in turn, rhizosphere conditions will eventually determine net P availability to the plant. Using microbial capture of labile P has provided a bioavailable P index that includes both inorganic and organic sources of P. The indices generated by both procedures will next be used to correlate crop growth and response to P fertility. Such indices have potential value in understanding P cycling and proper fertilizer management.

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LAND TENURE EFFECTS ON PHOSPHORUS MANAGEMENT

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ABSTRACT

A long-term approach to P management is needed due to the residual effects of P additions and the uncertainty of annual rate and response predictions. Soil test calibration data from the northern Great Plains were used to define the relationship between Olsen soil test P level and average relative spring wheat yield. A spreadsheet computer program was developed that uses the calibration function to estimate the optimum soil test P level for wheat based on 7 inputs, including land tenure and yield potential. For a 50 bu/A yield potential, optimum soil test P levels varied from 17 lb/A to 36 lb/A for tenures of 2 and 10 years respectively. Soil test interpretations, based on a long-term approach, that include factors such as land tenure have the potential to increase the profitability of wheat production in the Great Plains.

INTRODUCTION

Economic evaluation of P management decisions is often clouded by the substantial residual value of P additions. Only a fraction of the P applied in any one year is used by the crop in that year. In most soils, the majority of applied P remains in the soil in forms that are available for future uptake. Just as costs of installing tile drainage or irrigation do not need to be recovered in one year, the cost of fertilizer P does not need to be recovered in one year. In many cases, the residual P response is equal to or greater than the first-year response. Thus, the optimum P rate cannot be determined by simply evaluating yield response the year of application.

A second complicating factor for P economics is that P soil tests are indices reflecting the average relative yield or probability of response at a given soil test level and frequently do not accurately predict the rate of P necessary to give a certain yield in any given season. Figure 1 (after Halvorson, 1986) summarizes several long-term spring wheat studies from the northern Great Plains and is typical of P calibration data. At a 20 lb/A (10 ppm) soil test, relative yield varies from 70% to 100%. Response variability at a given soil test P level should not be surprising.

Numerous factors other than soil test P level influence supplemental P needs of a given crop in a given growing season and on a given soil type. Variability in P response among years and the residual effects of P fertilization suggest that P economics should be viewed in the long term and that land tenure is an important factor in making P management decisions.

All commonly accepted P fertilizer recommendation systems maintain soil tests at some level whether intentionally or incidentally from rates recommended for various yield goals. However, systems vary in the rate at which soil tests are increased and also in the extent of the increase. The most critical question in the long term is: At what level should soil tests be maintained?

The objective of this study was to develop an approach to soil test interpretation that focused on the long term with adjustments for land tenure.

MATERIAL AND METHODS

The data set used in this study is the continuous cropping set reported by Halvorson (1986) and graphed in Figure 1. It was selected because it includes information from several long term experiments conducted in the major spring wheat production region. The equation shown in Figure 1 was used to relate soil test level to long-term average relative yield and was selected using the TableCurve statistical software from Jandel. Model selection criteria were r2, lack of pattern in residuals, simplicity, and having a derivative with a direct X solution. Since model predictions slightly exceeded 100% at soil test levels greater than 51 lb/A, the function y=100% was used above 51 lb/A. The error mean square for the model was 0.00626 (df=107) with an F of 122.2.

A Lotus spreadsheet was developed that calculates the ratio of the average value of an additional unit yield increase to the amortized cost of an additional unit of soil test P increase. The target or optimum soil test P level that the individual grower should maintain was calculated as the level at which the ratio defined above is equal to the acceptable marginal rate of substitution input by the user (defined below). The program requires the following inputs:

1. Acceptable marginal rate of substitution - the minimum return per dollar invested acceptable to the individual. A value of 1.00 will cause the program to estimate the level where the last dollar spent increases crop value by one dollar. A value of 1.50 would return $1.50 on the last dollar spent.

2. Annual interest rate or opportunity cost - the actual interest rate if capital is borrowed or an opportunity cost for alternative use of the cash at a similar risk level.

3. Land tenure - the period of time the grower will be farming the field. Since in most soils residual P should not be depleted if removed nutrients are replaced, expected time of ownership or operation in most cases substitutes for the life expectancy of the capital investment in the amortization process.

4. Fertilizer P_2O_5 required to increase soil test level one unit - typically 8 to 12 lb P_2O_5 are required to increase the Olsen P by 1 lb/A.

5. Fertilizer cost - average weighted cost of the fertilizer over the land tenure period.

6. Net crop price - average price of the crop over the land tenure period minus the cost of maintenance P per bushel.

7. Yield potential - the average yield over the land tenure period if P was not yield limiting. The yield potential is used to determine the economic value of a percentage change in relative yield. This is not the same as the yield goal as used in most soil testing programs.

RESULTS AND DISCUSSION

Table 1 shows the effect of yield potential on the relationship between soil test level and bu/A lost from P deficiency. We have commonly viewed a relative yield of 95% as essentially the same as maximum yield. However, a real long term average yield reduction of 5% from P deficiency can be of substantial economic importance to a grower because increasing soil test P levels is relatively inexpensive.

Table 1. Average spring wheat yield loss from P deficiency at various soil test levels based on the calibration data set reported by Halvorson (USDA).

Olsen P	Relative yield	Average Yield		
		30	50	70
lb/A	%		bu/A lost	
10	78.0	6.6	11.0	15.4
20	90.4	2.9	4.8	6.7
30	95.4	1.4	2.3	3.2
40	98.2	0.5	0.9	1.3
50	99.9	0.0	0.1	0.1

Yield potential and land tenure have dramatic effects on the optimum soil test P level (Figure 2). The three curves represent 30, 50 and 70 bu/A yield potentials. As land tenure increases, optimum soil test P level increases. Land operated on a short-term lease has a lower optimum P level than land that is owned and likely to stay in the family for decades. Also, a farmer who is an excellent manager in a higher rainfall area will have a higher optimum soil test P level than a grower that has a lower yield potential.

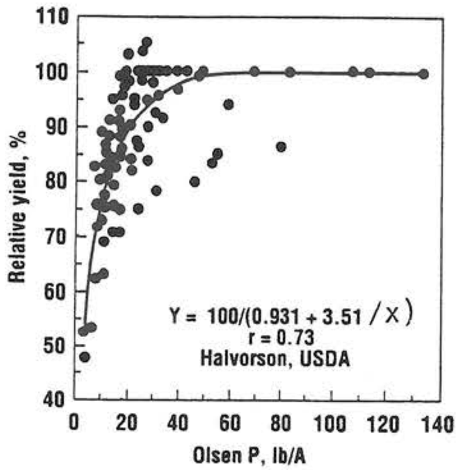

Figure 1. Spring wheat response to soil test P level in the northern Great Plains.

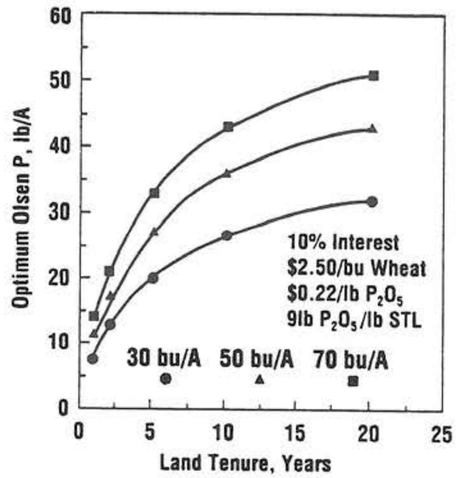

Figure 2. Land tenure affects optimum Olsen P level for wheat.

Fertilizer price, crop value, and interest rates also influence optimum P levels but not as much as yield potential and land tenure. For example, increasing net wheat price from \$2.50 to \$3.50/bu increases optimum soil test P level by only 5 to 8 lb/A. When one considers that these should be long-term average prices or rates rather than current market conditions, the effect of these factors on optimum soil test P levels is dampened further.

Soils differ in the amount of P required to change soil test P levels. Soil test P levels are typically easier to change on coarse textured sandy soils than on medium or fine textured soils. Some low pH and some high pH soils fix applied P readily and increasing soil test P levels is more costly, decreasing the optimum level. This assumes such soils have the same P yield response relationships as normal soils.

When a long-term basis is used in making P rate decisions, the focus should be on soil test P level. Therefore, the first step in determining optimum P fertilizer rate is determination of optimum soil test P level considering the factors discussed earlier. Then, a P rate-soil test level relationship needs to be used that maintains soil test P levels at the optimum point. In other words, if the current soil test P level is less than the optimum, the fertilizer P rate should be greater than the quantity of P removed by the crop to allow soil test P levels to increase. If the current soil test P level exceeds the optimum, the P rate should be less than P removal which will allow soil test P levels to decline to the optimum point. A detailed example of one approach to determining optimum P rates with various placement methods is offered by Fixen and Halvorson (1991).

Researchers in Saskatchewan have compared one-time broadcast applications to annual seed-placed P and to various combinations of broadcast and seed-placed P over a 5-year period (Wagar et al., 1986). At low P rates, seed placement appeared to have a slight advantage over broadcast application, however, at optimum rates, broadcast application produced higher yields over the 5-year period even though the initial soil test P level was very low. The most effective treatment was where an initial broadcast application was made that elevated soil test levels followed by small annual applications applied with the seed. Such data suggest that regardless of placement methods, it is important to maintain an optimum soil test level to experience the full yield potential of the system.

Similar effects are being measured in an ongoing Colorado study on no-till winter wheat (A.D. Halvorson & J.L. Havlin, Personal communication). Cumulative response to seed-placed P leveled off at about 100 lb/A P_2O_5 and produced a total response of 14 bu/A over 3 years. The broadcast treatments continued to increase yield to rates exceeding 200 lb/A P_2O_5 and produced a total response over 3 years of 28 bu/A, twice that of the seed-placed treatments. As in the Saskatchewan study, there was a decided advantage to correcting soil test levels quickly. These studies and others indicate that a soil testing at its optimum level will often have a higher yield potential than one testing low even though P fertilizer is applied. Land tenure is critical to determining that optimum.

SUMMARY

A long-term approach to P management is needed due to the residual effects of P additions and the uncertainty of annual P rate and response predictions. Land tenure and yield potential are important factors when a long-term approach is used. Refinement of soil test P interpretation programs to include these parameters will likely increase the profitability of wheat production in the Great Plains and improve the credibility of P soil testing and the resulting P recommendations. Computer spreadsheet programs can be easily developed to aid in this refinement.

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PLANTING DATE INTERACTIONS WITH METHOD OF P APPLICATION FOR WHEAT

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ABSTRACT

Seed and knifed P (dual placement) have generally performed similarly when averaged over several years. However, P method performance can vary considerably between years and locations. Three winter wheat experiments were established on low available P soils in southeast Nebraska to study the effect of date of seeding on seed and knifed P (dual placement) performance. Three rates of P (11, 22, and 33 kg P ha^{-1}) were seed and knife applied on three seeding dates in 1987. Results indicated that the effectiveness of knifed P decreased as date of seeding is delayed compared to seed applied P. The difference in performance between the two methods of P application is probably related to the probability of root access to the fertilizer P in the fall. Root access to fertilizer P in the fall influences the number of tillers developed in the fall which determine head numbers at harvest and final grain yield. Therefore if seeding date is delayed, fertilizer P should be applied with the seed for maximum effectiveness.

OBJECTIVE

To determine if seeding date of winter wheat affects the performance of seed versus knifed P (dual placement) methods of P application.

INTRODUCTION

Recent studies in Nebraska have indicated that method of P application can greatly affect P fertilizer efficiency as well as the amount of profit wheat producers can obtain from applying P. Sander et al (1990) reported that seed and knife application resulted in fertilizer P efficiencies of between 35 and 40% compared to only 5 percent for broadcast P applications on a low available P Pawnee clay loam in eastern Nebraska. Fiedler et al. (1989) showed that on low P soils, seed application on winter wheat resulted in twice the profit from applied P compared to broadcast and that maximum profits from P fertilization occurred when seed applied P was applied at about the same rate of application as broadcast P. This finding was contrary to the usual P recommendation of reducing the P rate in half when seed applied compared to broadcast. Research has also shown that knifed P (dual placement) and seed applied P perform basically the same even on different soils and areas of Nebraska although seed application tended to be superior to knife on glacial till derived soils in Nebraska compared to loess derived soils at the same soil test levels (Sander et al. 1991).

Research indicates that while knifed and seed applied P usually provide similar results, results can vary from year to year. Reasons for such variability are not well understood but it is often assumed that variability in method of P application is related to when the roots reach the fertilizer band and the availability of P in the band area during the fall when numbers of seed bearing tillers are believed to be determined. Since knifed P is further from the seed, any factor that affects root growth in the fall would limit fall P uptake and therefore possibly influence performance of the two banding methods. Therefore three experiments were established in 1987 to study the effect of date of seeding on the performance of seed and knife methods of P application.

METHODS AND MATERIALS

Three experiments were established in the fall of 1987 on low available P soils in Gage (1 location) and Saline County (2 locations) Nebraska. Soil P levels (Bray and Kurtz No. 1) were as follows for the 0-10, 10-20, and 20-30 cm depths, respectively: Location 88-2 (Wymore sic) 9.4, 4.6, and 4.6 mg kg^{-1}; Location 88-6 (Eroded Crete Sicl) 9.9, 3.5, and 1.0 mg kg^{-1}; Location 88-7 (Crete sicl) 6.8, 3.0, and 1.2 mg kg^{-1}.

Experimental design involved three seeding dates, two P application methods (knife-dual placed N and P, and seed application) with 3 P rates (11, 22 and 33 kg P ha^{-1}) and a check plot. All plots received N as ammonia to equal a total of 80 kg N ha^{-1} which included the N in 10-15-0 (N-P-K) liquid ammonium polyphosphate, which was the P source. Knife spacing was 30-cm applied to a depth of 15-cm one week prior to the first wheat seeding. Seed applied P was placed directly with the seed. Sixty-seven kg ha^{-1} of Brule wheat was seeded in 30-cm spacing with a hoe type drill.

Plots were 2.4 meters wide by 12 meters long with 0.3 meters between wheat rows. Grain and straw yields were determined from two rows 3 meters in length. Stem counts were made from 60 cm of row. Seed counts and seed weights were determined from 10 heads selected at random.

RESULTS AND DISCUSSION

Grain and straw yields were increased by applied P at all three locations (Table 1). Seed application increased yield significantly more than the knife application when averaged across dates of seeding and rates of application. However, method of P application performance was significantly affected by the planting date and P application rates. Delaying the seeding date from

Table 1. Effect of date of planting of winter wheat on P method of application performance. Southeast Nebraska. 1988.

Variable	Gage Co. (88-2) Grain	Gage Co. (88-2) Straw	Saline Co. (88-6) Grain	Saline Co. (88-6) Straw	Saline Co. (88-7) Grain	Saline Co. (88-7) Straw
	Mg ha^{-1}					
P Rate-Kg ha^{-1}						
0	2.96	2.92	3.60	3.26	3.15	3.23
11	3.24	3.32	3.75	3.55	3.70	3.71
22	3.61	3.63	4.12	3.96	3.87	3.87
33	3.57	3.52	4.09	3.97	3.93	3.97
Date 9-22-87	3.60	3.84	4.12	4.25	4.06	4.30
10- 6-87	3.81	3.75	4.10	3.76	3.89	3.80
10-19-87	3.03	2.90	3.75	3.49	3.55	3.45
Method						
Knife	3.31	3.34	3.80	3.73	3.71	3.78
Seed	3.65	3.64	4.17	3.92	3.96	3.92
Analysis of Variance						
Date (D)	.02	.02	NS	NS	.04	.05
Method (M)	.01	.01	.01	.07	.10	NS
Rate (R)	.09	.01	.07	.10	NS	NS
D x M	NS	NS	.01	NS	.02	.11
D x R	NS	.05	NS	.02	NS	NS
M x R	.09	.09	NS	NS	NS	NS
D x M x R	NS	NS	.01	.02	.04	.01

Delaying the seeding date from September 22 to October 19 decreased grain yield 26% where no P was applied (for two locations that had significant method x date interactions), compared to only 13% where P was applied (Table 2). While the three locations did not react the same (significant L x D x M and L x D x R interactions), results indicate that seed application was more effective than knife at later seeding dates (Table 3 and Fig. 1). At more nearly optimum seeding dates, knifing P was equal to seed application in terms of grain yield and P uptake performance which is similar to most reported data (Sander et al. 1991). Increasing the P rate tended to prevent yield depression when knifed but had little effect when seed applied. In addition, higher knife rates of P application were more effective in maintaining yield than when seed applied as seeding date was delayed.

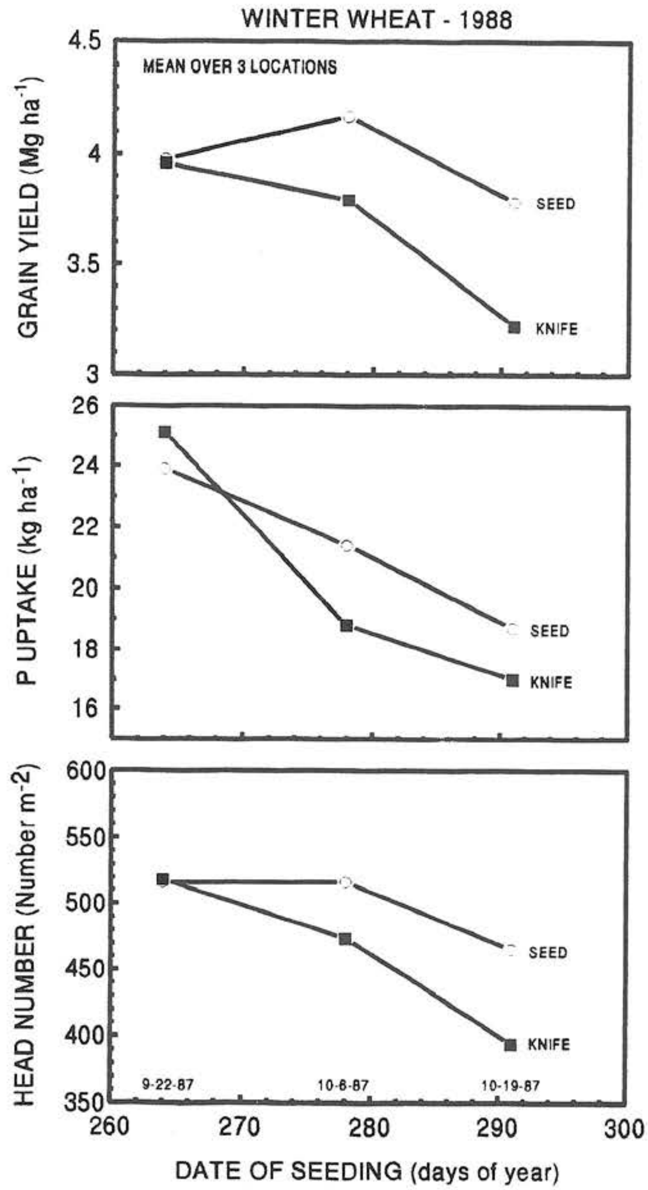

Fig. 1. Effect of date of seeding winter wheat on the performance of seed and knife methods of P application on grain yield, P uptake, and head numbers. Mean over three locations S.E. Nebraska 1988.

Table 2. Interaction means of grain yield showing how method of P application performance is influenced by both rate of P application and date of seeding. Southeast NE, 1988.

Seeding Date	P Rate	Location (88-7) Knife	(88-7) Seed	(88-6) Knife	(88-6) Seed	(88-2) Knife	(88-2) Seed
Day of the year	kg ha^{-1}	Grain Yield - Mg ha^{-1}					
264 (9-22-87)	0	3.85		3.81		3.20	
	11	4.11	3.84	4.31	3.77	3.11	3.92
	22	3.77	4.24	4.58	3.77	3.81	3.76
	33	4.51	3.91	3.77	4.45	3.28	3.77
278 (10-6-87)	0	3.24		3.66		3.20	
	11	3.64	3.77	3.91	3.91	3.29	3.78
	22	3.71	4.11	3.64	4.65	4.06	4.11
	33	3.91	4.18	4.04	4.51	3.47	4.10
291 (10-19-87)	0	2.34		3.34		2.48	
	11	2.90	3.91	2.36	4.18	2.40	3.13
	22	3.71	3.71	3.97	4.18	2.90	2.98
33	33	3.10	3.97	3.50	4.24	3.40	3.34

Table 3. Analysis of variance over all three locations in 1988.

Variable	Grain Yield	P Uptake	Head Number
	---------- Probability of > F	-------------	
Location (L)	NS	NS	NS
Date (D)	NS	.09	.12
L*D	NS	NS	NS
Method (M)	.01	.12	.01
Rate (R)	.01	.01	.11
L*M	NS	NS	NS
L*R	NS	NS	NS
D*M	.01	.08	.01
D*R	NS	NS	NS
M*R	NS	NS	.02
L*D*M	.08	NS	NS
L*M*R	NS	NS	.02
D*M*R	.09	NS	.01
L*D*M*R	.06	.01	.01

It has been shown that the primary yield component affected by applied P on low P soils is the number of heads produced which is a direct function of fall tillering. As date of seeding was delayed, head numbers were significantly decreased (Table 3 and Fig 1). Applying P with the seed was more effective than knife application in maintaining head number as the seeding date was delayed. It appears that early P uptake in the fall is a major factor affecting fall tillering. Seed application provided easy access to fertilizer P while knifing placed P a maximum of 15 cm from the seed row and from 10-15 cm deeper in the soil than seed application.

The data indicates that root growth to the knifed P band may be very important for performance of knifed P for winter wheat. Delayed seeding may result in poor root interception of the knifed P band which limits knifed P effectiveness. If seeding dates are delayed past the optimum date, P fertilizers should be applied with the seed for maximum effectiveness.

LITERATURE

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NITROGEN MANAGEMENT IN NO-TILL CORN

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ABSTRACT

Nitrogen (N) fertilizer in no till cropping systems may be subject to considerable losses if not applied properly. Experiments were conducted to evaluate the effects of N rate and method of application on corn grain yield, fertilizer N recovery, and residual profile N after harvest. Broadcast, knife, and point injection placement methods were used at N rates of 75 and 150 lbs N/a. Grain yield and percent N were lower with broadcast N than with knifed and point-injected treatments. Apparent nitrogen recovery (ANR) also was greater with the subsurface methods compared to broadcast N, while ANR decreased with increasing N rate except for the broadcast treatment. Residual profile N for the broadcast treatments was higher in 1989 and lower in 1990 than knife and point-injection treatments. Placement effects on total profile N after harvest are primarily related to differences in total rainfall and distribution between the two years. The results of this study suggest that efficient fertilizer N management in no-till cropping systems requires N placement below the soil surface.

INTRODUCTION

Increasing adoption of conservation tillage practices has increased concerns about N efficiency of unincorporated broadcast applied N. Under high residue systems, surface application of fertilizer N is subject to immobilization, denitrification, and volatilization losses, which can reduce crop recovery of fertilizer N. Thus, N fertilizer placement below the soil surface is essential for maximizing recovery of fertilizer N. Leaching of residual inorganic N left in the profile after harvest also may contribute to groundwater contamination. Therefore, the objectives of the study were to evaluate the relationships between yield, percent recovery of N, and residual profile N when managed by different N fertilizer application methods and rates.

MATERIALS AND METHODS

The Riley County, KS. site had been in continuous no-till grain sorghum from 1982 through 1988. In 1989 the experiment was planted to no-till corn using the same treatments as the previous sorghum study. Pioneer 3379 was planted at 22,000 seeds/a with a John Deere Max-Emerge II no-till planter on April 12, 1989 and 1990, and on April 24, 1991. Residue at the time of planting in 1989, 1990, and 1991 was estimated at 4500, 5500, and 5500 lbs/a, respectively. Nitrogen rates of 75 and 150 lbs/a were applied as urea ammonium nitrate (UAN; 28-0-0) just prior to planting. The N placement methods included surface broadcast, knifed (6-7 inches deep on 20 inch centers), and point injection (4-5 inches deep on 20 inch centers). The point injection applicator was developed at

Iowa State University and is commercially available.

Weed control consisted of a split treatment of Bicep. No cultivation was required during the growing season. Counter was also applied in-furrow during planting to control insects. Total biomass yield and N content were determined by sampling the whole plant at physiological maturity. The grain was hand-harvested and grain samples also were analyzed for N. The N analyses of soil and plant samples in 1991 have not been completed and therefore is not presented.

RESULTS AND DISCUSSION

Grain yields in 1989 were below average due to the below average rainfall during the growing season (Table 1, Fig. 1). Even with the low precipitation, significant responses to N rate and placement were observed. Knife placement produced significantly higher grain yield and grain N than any other placement method in 1989. Grain yields for 1990 were greater than in 1989, probably due to higher rainfall in 1990 (Fig. 1). Significant grain yield response to N rate was observed in 1990. Although N placement did not significantly affect grain yield, grain N concentration was significantly increased with N rate and placement (subsurface N > surface N). Despite water stress from June until physiological maturity, a significant grain yield response to N was observed in 1991. Knife and point injection placement of N produced significantly higher corn grain yields than broadcast application.

Table 1. Nitrogen management for no-till corn in Riley Co., KS.

N Rate	N Placement	1989 Grain Yield	1989 Grain N	1990 Grain Yield	1990 Grain N	1991 Grain Yield	1991 Grain N
lb/a		bu/ac	%	bu/ac	%	bu/ac	%
0	--	16	0.87	46	0.78	30	0.99
75	BC	49	1.06	90	1.02	60	0.96
150	BC	69	1.08	101	1.18	94	1.27
75	PI	47	1.00	98	1.18	91	1.41
150	PI	72	1.23	113	1.47	92	1.52
75	KN	67	1.16	95	1.10	82	1.05
150	KN	86	1.36	113	1.33	96	1.23
LSD (0.05)		19	0.12	15	0.13	17	0.20
Mean Values:							
N Rate	75	52	1.04	92	1.09	78	1.14
lb/a	150	73	1.19	108	1.28	94	1.34
LSD (0.05)		9	0.07	8	0.07	9	0.04
Method of	BC	59	1.07	95	1.10	77	1.12
Appln.	PI	60	1.12	105	1.33	92	1.47
	KN	76	1.26	104	1.22	89	1.14
LSD (0.05)		13	0.10	NS	0.09	11	0.04

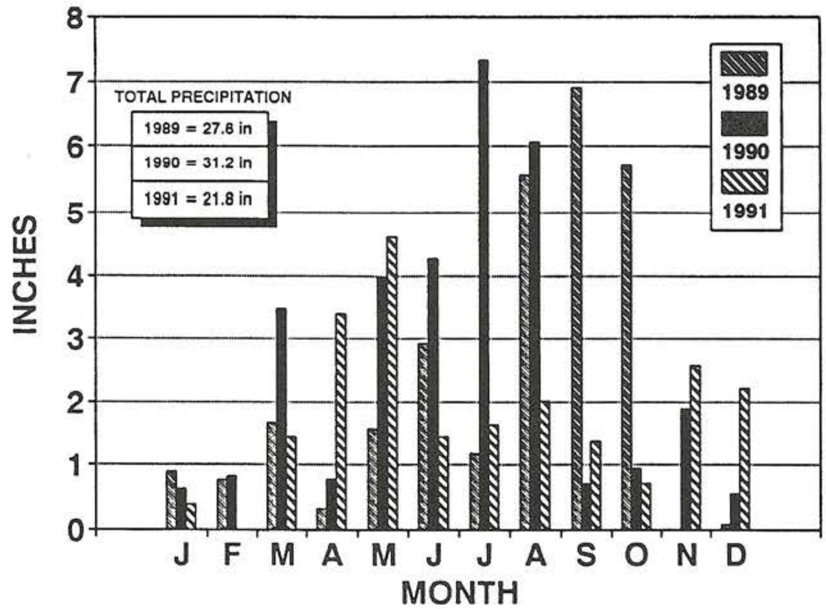

Figure 1. 1989 to 1991 precipitation at the Riley Co. site.

When grain yield is reduced by limited rainfall, fertilizer N recovery is reduced which increases residual profile N content after harvest, compared to a year with adequate moisture (Table 2). In 1989, total profile N after harvest was slightly higher in the broadcast treatments than in the knife or point-injection treatments (Table 2; Fig. 2). Rainfall was very limiting during the early growing season, which probably reduced fertilizer N movement through the residue into the soil. In August and September, when above normal rainfall was received, the plant already had reached physiological maturity and, thus, recovery of fertilizer N was reduced compared to 1990. In early 1990, rain incorporated the broadcast N during the early growth period when plant N accumulation was very high. The above-normal moisture condition enhanced N immobilization and denitrification losses, which reduced total profile N with broadcast N compared to subsurface N placement in 1990 compared to 1989 (Table 2; Fig. 2).

Total profile N after harvest and ANR appear to be inversely related. A higher ANR does not necessarily mean a lower total profile N when comparing treatment differences within the same year. In 1990, for example, ANR with broadcast N averaged 65% compared to an average 79% with point-injected and knifed N; however, average total profile N for broadcast N was 4.1 lb/a, which was ten times less than with point-injection and knife treatments (ave. 46 lb/a). The difference between N placement methods was probably due to greater immobilization, denitrification, and volatilization of broadcast N compared to subsurface N placement.

Table 2. Effects of N rate and placement on apparent N recovery (ANR) and total inorganic profile N after harvest.

N rate	Profile N 1989	Profile N 1990	ANR 1989	ANR 1990
lbs N/a	---lbs./a-5 ft---		---------%---------	
CHECK	73.0	1.5	0	0
75 BC	97.8	4.3	38	60
150 BC	107.8	3.9	52	69
75 KN	96.2	42.5	78	80
150 KN	94.0	45.2	70	76
75 PI	81.4	40.7	64	83
150 PI	90.4	55.9	56	75
LSD (.05)	13.2	9.6	20	14
CV (%)	35.4	50.2	21	12
MEAN VALUES:				
N rate (lbs N/a)				
75	91.8	29.2	60	74
150	97.4	35.0	59	73
LSD .05	NS	2.0	9	6
N Placement				
BC	102.8	4.1	45	65
PI	85.9	48.3	60	79
KN	95.1	43.9	74	78
LSD .05	NS	2.8	13	10

BC = broadcast KN = knife PI = point-injection

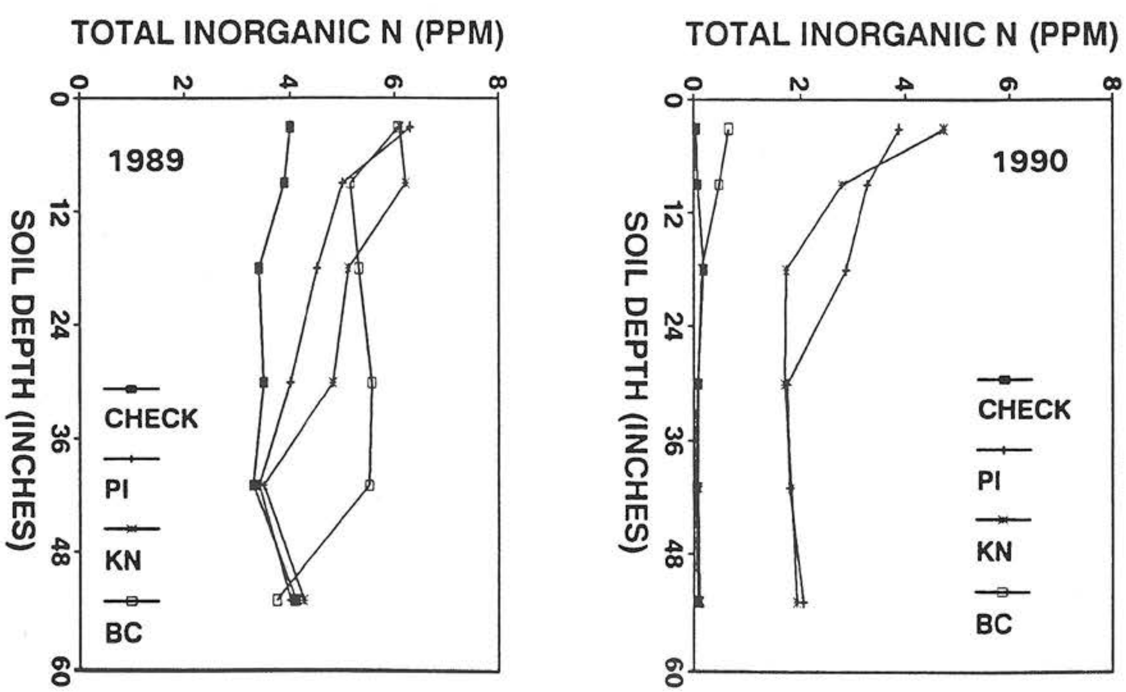

Figure 2. Distribution of inorganic N in the profile after harvest in 1989 and 1990.

SUMMARY

In general, results from this experiment suggest that N placement below the soil surface, away from previous crop residue, increases grain yield, grain N concentration, and ANR. When grain yield is reduced by limited rainfall, fertilizer N recovery is reduced which causes higher residual profile N content after harvest. In a dry year, broadcast N resulted in slightly greater residual profile N after harvest than subsurface applied N. In a wet year, profile N with surface applied N was less than subsurface applied N, probably because of increased immobilization and denitrification losses with surface applied N. This experiment will be continued for several more years to quantify the effects of N management on fertilizer N recovery.

NITROGEN UPTAKE AND TRANSPORT UNDER VARYING MOISTURE REGIMES CROPPED TO MALTING BARLEY

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ABSTRACT

Over-application of nitrogen (N) fertilizer increases agricultural production costs and may contribute to nitrate contamination of groundwater systems. A two-year study was conducted to determine N fertilizer and soil N distribution through the soil profile and efficiency of plant nitrogen uptake under varying moisture regimes. Soil and plant samples were collected seven times throughout the growing season from four different irrigation treatments on a site cropped to 'Klages' malt barley. Under dryland conditions, over-application of N resulted in high residual levels of NO_3-N in the soil profile. Fall and spring moisture recharge could result in movement of the residual NO_3-N into the groundwater system. Proper irrigation management combined with an optimum N fertilizer rate did not contribute to significant NO_3-N movement through the soil profile.

INTRODUCTION

The fate and transport of N fertilizers in agricultural production systems is an important consideration for developing best management practices which minimze impacts on water quality. Under irrigated conditions, the highly mobile NO_3^- ion may move out of the root zone prior to significant plant uptake. Nitrogen moving out of the root zone would not be available for uptake and could potentially move into shallow groundwater systems. Under dryland conditions, applied fertilizer N or mineralized N which is not utilized by the crop may be available for transport out of the root zone during the subsequent fallow season. The objectives of this study were to: (i) determine the distribution of applied fertilizer and soil N as a function of time and soil depth under varying moisture regimes cropped to malting barley, (ii) determine the efficiency of plant uptake of applied fertilizer N under varying moisture regimes, and (iii) evaluate the potential contribution of applied N to water quality problems under varying moisture regimes.

MATERIALS AND METHODS

A field study was conducted in 1990 and 1991 at a site 25 miles west of Bozeman, MT on a Brocko silt loam (coarse-silty, mixed, Borollic Calciorthid). The Brocko silt loam has a deep, well-drained profile and the soils in this area are very uniform. The soil surface has a pH of 8.3 and an organic matter content of 1.6%. This paper will describe experimental methods and results for the 1991 field season, however, methods and results from the 1990 field season closely parallel those of the 1991 season.

Initial soil samples taken just prior to seeding indicated that the soil profile (0-48 in) contained 25 lbs/acre NO_3-N. Nitrogen was uniformly applied at a rate of 150 lbs N per acre using monoamomnium phosphate and ammonium nitrate (78.5 lbs NH_4-N, 71.5 lbs NO_3-N) to a 100 ft by 200 ft field area. The sum of profile N and fertilizer N applied met the requirement for a 100 bu/acre yield goal which is typical for malting barley under irrigated conditions. Olsen-P levels averaged 15 ppm and were optimum for this yield goal. Four moisture treatments were established perpendicular to a line source irrigation system, using 10 ft by 20 ft plots, with 3 replications per moisture treatment. Total moisture (irrigation plus precipitation) applied from seeding to harvest was 16.8, 14.1, 9.5 and 4.6 inches for the high, medium, low and dryland moisture treatments, respectively (Table 1). 'Klages' malting barley was seeded at a rate of 80 lbs/acre on 24 May 91. Irrigation treatments commenced on June 10th and were continued on roughly 7 day intervals until the start of inflorescence (Table 1). Soil samples were taken seven times throughout the growing season to establish N distribution as a function of soil depth (0-6, 6-12, 12-24, 24-48 inches) and time. Whole plant samples were taken at the same time along with plant density counts to obtain N uptake. Soil samples were extracted using 1M KCl and analyzed for NO_3-N and NH_4-N using automated colorimetry (Henriksen and Selmer-Olsen, 1970). Whole plant samples were analyzed for dry weight and total Kjeldahl N (TKN) using sulfuric acid digestion (Bremner and Mulvaney, 1982).

Table 1. Irrigation and precipitation dates for the 1991 field season.

Plant Time†	growth stage‡	Irrigation (inches) High	Medium	Low	Dryland	Precipitation (inches)§
12	Three leaf (3.0)	0.62	0.50	0.23	0.01	1.38
20	Mid-tiller (4.8)	2.16	1.63	0.79	0.05	0.04
26	First node (6.0)	2.47	1.80	0.71	0.10	0.16
33	Flag leaf (7.0)	1.76	1.51	0.99	0.02	0.32
47	Boot (9.2)	2.18	1.78	1.02	0.01	0.16
53	Spikelet (10.2)	3.37	2.66	1.61	0.21	0.00
112	Kernel (16.0)	0.00	0.00	0.00	0.00	2.13
	Total moisture	12.56	9.88	5.35	0.40	4.19

† Days after plant emergence.
‡ Plant growth stage (Haun, 1973).
§ Precipitation received by all four moisture regimes.

Soil NO_3-N distribution as a function of soil depth throughout the growing season shows the dynamics of NO_3^- movement and plant uptake under the four moisture regimes (Fig. 5). The rate of NO_3-N movement through the soil profile was directly related to the amount of moisture applied. For example, significant amounts of NO_3-N appeared in the 6-12 in and 12-24 in depths after 21 and 27 days of crop emergence under the high moisture regime. However, in the low moisture regime, much of the profile NO_3-N remained in the 0-6 in depth until 27-34 days after emergence and very little moved into depths below 12 in. Under dryland conditions, the majority of 1991 applied N remained in the 0-6 in depth; NO_3-N values in the 12-24 in and 24-48 in depths represent residual NO_3-N from the previous year.

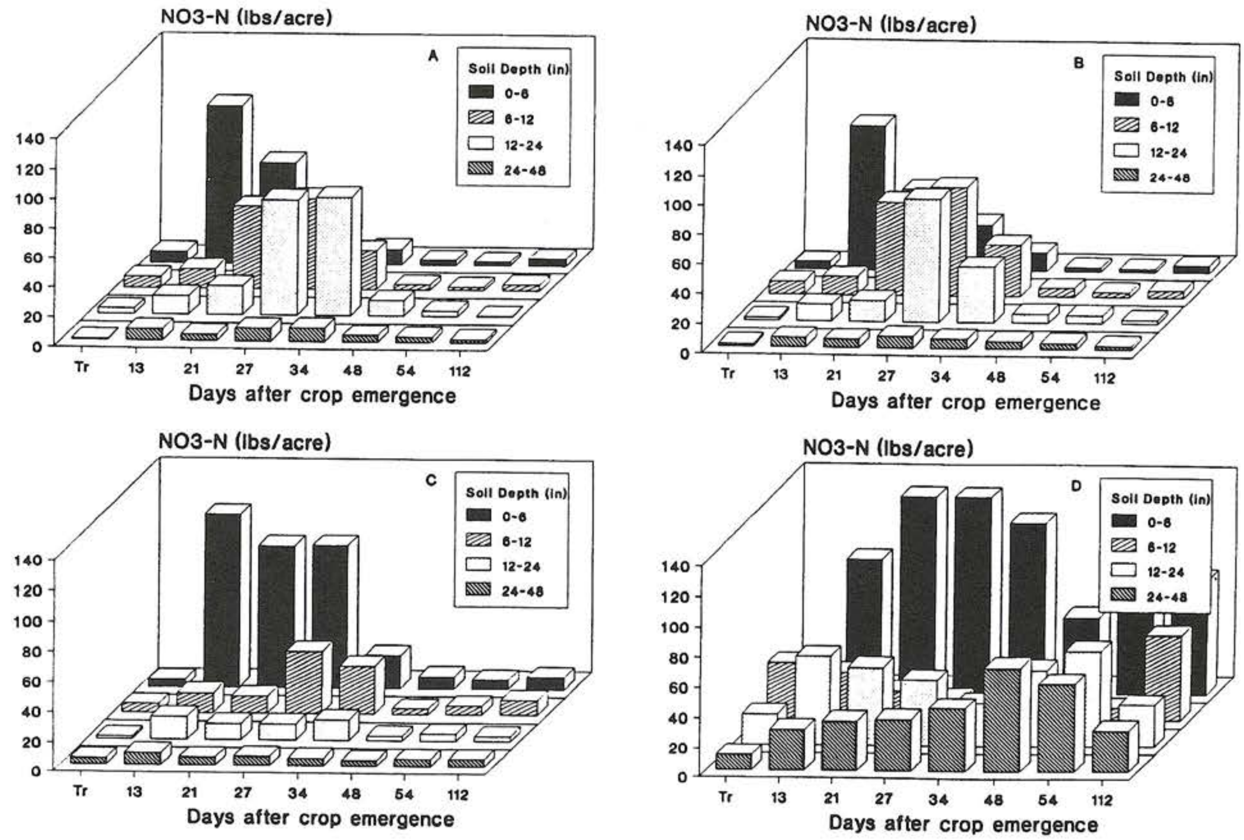

Fig. 5. Soil NO_3-N distribution as a function of time and soil depth for the high (A), medium (B), low (C) and dryland (D) moisture regimes.

We initially expected greater NO_3-N movement out of the rooting zone for the high moisture regime; however, by the time the NO_3-N peak reached the 12-24 in depth (e.g. at 27-34 days after emergence) plant uptake was at its maximum rate and prevented NO_3-N from moving lower in the profile. Interestingly, with the exception of dryland conditions, all other water regimes provided enough plant available water for efficient utilization of soil profile N, without significant movement out of the profile.

of applied N under limited moisture conditions. Although the applied N would have been considered high for the expected yield goal under dryland conditions, lower uptake efficiency under conditions of limited moisture underscores the importance of managing N applications in accordance with expected plant water availability and subsequent yield potentials. Furthermore, under fallow management systems, poor utilization of N during the cropping season may leave significant amounts of N in the soil profile which may be subject to transport out of the root zone in the subsequent fallow year.

Table 2. Plant N uptake efficiency ratio (plant N/available N).

Moisture	Days after crop emergence						
regime	13	21	27	34	48	54	112
High	.03	.06	.10	.26	.78	.72	.76
Medium	.03	.05	.08	.28	.68	.79	.76
Low	.02	.06	.08	.30	.73	.73	.62
Dryland	.01	.04	.06	.19	.23	.29	.15

Soil Nitrogen Distribution

Soil samples analyzed throughout the growing season at four depths indicated that NO_3-N was the predominant inorganic N fraction. The amount of NH_4-N was measurable but generally remained below 50 lbs/acre in the 48 in soil profile. Soil profile NO_3-N declined significantly (approximmately six lbs NO_3-N/acre/day) in the low, medium and high moisture regimes from 27 to 48 days after barley emergence (first node to initial boot stages) (Fig. 4). This is consistent with the observed period of maximum plant uptake (Fig. 3), and indicates that the majority of soil NO_3-N losses from the soil profile were due to plant uptake, even under the high moisture regime. Soil profile NO_3-N remained high under dryland conditions consistent with the lower plant N uptake rates.

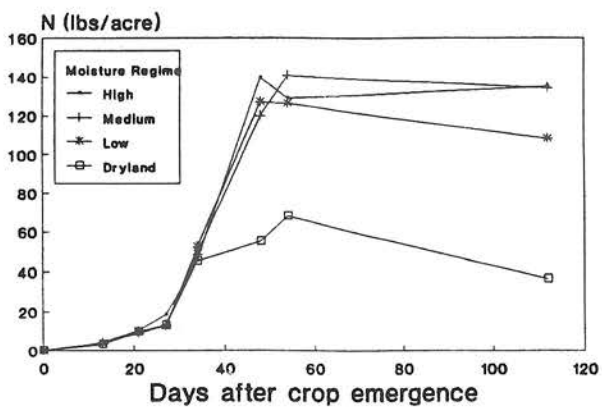

Fig. 3. Changes in plant N uptake during the growing season.

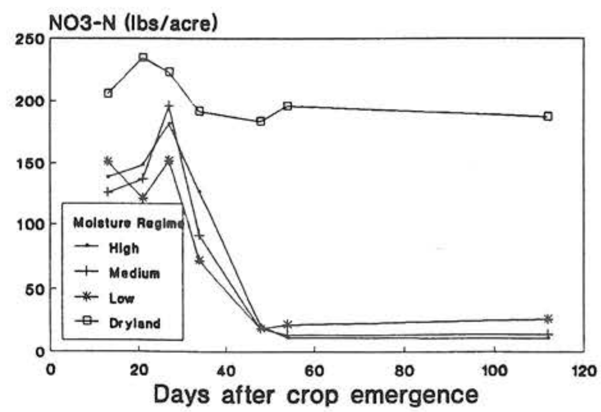

Fig. 4. Changes in NO_3-N content in the soil profile during the growing season.

RESULTS AND DISCUSSION

Plant/Nitrogen Relationships

Barley dry matter production throughout the growing season increased with increasing moisture application (data not shown). Grain yield ranged from 3.6 bu/acre in the dryland treatment to 83.5 bu/acre in the highest moisture treatment (Fig. 1). Total Kjeldahl N (TKN) contents of plant tissue samples ranged from approximately 6% at the first tiller growth stage to 1.2% at harvest. Total Kjeldahl N values were significantly higher under dryland conditions than other moisture treatments from the start of the boot stage (48 days after emergence) to harvest (112 days after emergence) (Fig. 2). Nitrogen uptake (lbs/acre) over the growing season was similar for barley grown under the low, medium, and high moisture regimes. However, by 48 days after emergence (initial boot stage), N uptake under dryland conditions dropped considerably and was significantly lower than the other moisture treatments for the remainder of the growing season (Fig. 3).

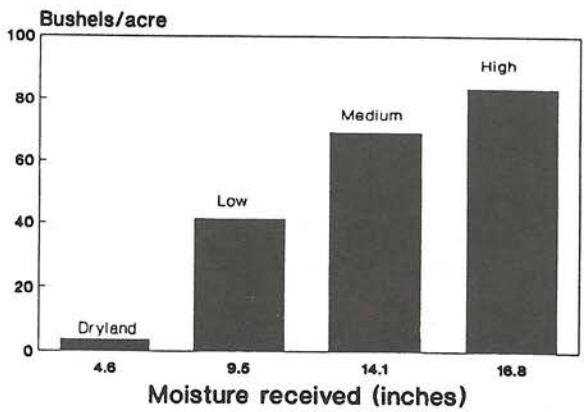

Fig. 1. Barley yield as a function of the amount of moisture received (irrigation and precipitation).

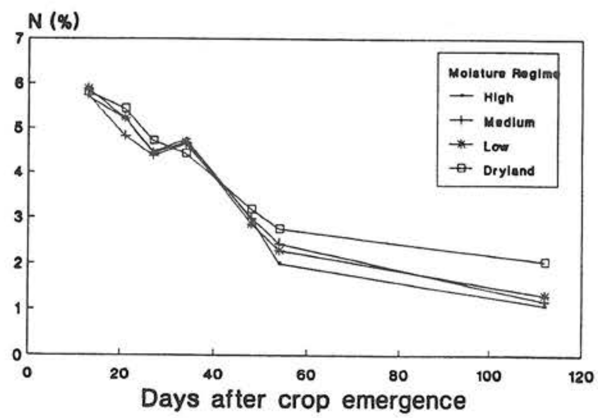

Fig. 2. Changes in plant N content during the field season for four moisture regimes.

The highest rate of plant N uptake occurred between the mid-tiller (27 days after emergence) and initial boot stage (48 days) of plant development. The high, medium, low, and dryland treatments had respective plant N uptake rates of 5.8, 5.1, 5.4, and 2.0 lbs/acre/day between mid-tiller and initial boot.

Plant uptake of N was also expressed as an efficiency ratio of N uptake/N inputs (Table 2). This data shows that under moisture conditions ranging from 9-17 inches over the course of the growing season efficiency ratios plateaued at approximately 0.75 by the boot stage (48-54 days after emergence). Under dryland conditions efficiency ratios peaked at only 0.29, indicating poor utilization

We also calculated a N balance based on measured inputs of soil N (residual profile N + applied N) and measured profile N and plant N uptake. Despite the fact that N losses such as denitrification, immobilization, volatilization, drainage, and/or root N uptake were not measured, 80% of the total nitrogen within the system was accounted for at all sampling points. This indicates that: (i) mineralized N from organic fractions was either small or was accounted for via measurement of both NO_3-N and NH_4-N, (ii) N losses through denitrification, drainage or volatilization were minimal under these environmental conditions, and (iii) that our soil and plant sampling techniques adequately characterized the fate of applied and residual N under these growing conditions.

SUMMARY

With proper irrigation management, application of fertilizer N at the expected yield goal did not contribute to significant NO_3-N movement through the soil profile into potential groundwater systems. However, under dryland conditions, over-application of N above the expected yield goal resulted in residual profile NO_3-N which may move deeper in the soil profile during fall and spring moisture recharge. Furthermore, fallow cycles which follow a season of poor soil profile N utilization may be a source of NO_3-N movement out of the rooting zone.

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NITROGEN MANAGEMENT IN IRRIGATED RIDGE-TILLED CORN

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ABSTRACT

Field tests were conducted during 1987-1991 on a Crete silt loam soil at Scandia, Kansas to evaluate effects of nitrogen (N) application methods and timing [anhydrous ammonia (AA) preplant, knife injected; 28% urea-ammonium nitrate solution (UAN) preplant surface broadcast, knife injected,or surface-band dribbled, and split applications of surface band-dribble and knife injected UAN] and N rates [0, 50 100 and 200 lb/acre] on ridged-tilled corn. When averaged over the 5 year period, grain yields of the UAN broadcast and surface band dribbled treatments were significatly less than the yields achieved with the other 4 application methods. Surface band-dribbled UAN was proven to be no more effective than surface broacasting. Split applications of surface band-dribbled UAN were as effective as knife injecting. Split knife applications did not inprove yields over applying all N preplant, knife injected. Yields obtained by knife injecting UAN were equal to knife injected AA. Corn grain N content (1990-1991) followed the same trends as grain yield. In no year of the experiment was there a significant application method x N rate interaction. Higher N rates did not compensate for inefficient application systems. Regression analysis showed maximum grain yield was acheived with 160 lb/acre N. In both 1990 and 1991 residual spring soil nitrate N content was higher in plots receiving annual applications of 200 lb/acre N than in plots receiving 50 or 100 lb/acre N. In 1991 plots that received knife injected N at the 200 lb/acre N rate were much higher in NO_3-N content than plots in which N was surface applied.

OBJECTIVES

The use of conservation tillage methods, including ridge-tillage, have increased dramatically in recent years. The large amounts of residue left on the soil surface in the ridge-tillage system can cause loss of N fertilizers. These residues tend to stimulate immobilization of mineral N in the surface soil (Kitur et al., 1984). NO_3-N may be suject to leaching due to improved pore continuity in reduced tillage soils (McMahon and Thomas, 1976) and greater denitrification losses can occur because of higher moisture and increased carbon content associated with high surface residues (Rice and Smith, 1982). Volatilization of NH_3-N can also be a significant loss mechanism (Keller and Mengel, 1986).

Several application methods and timings have been investigated for applying N fertilizers to reduced tillage corn. In some studies, dribbling UAN in narrow bands has produced higher grain yields than than surface broadcasting (Touchton and Hargrove, 1982). Injecting N below the soil surface has proven to be a highly efficient way of applying urea containing fertilizers (Bandel et al., 1984). Relatively few studies have included comparisons of anhydrous ammonia with injected UAN. This study was initiated in order to assess the effectiveness of N rates and preplant broadcast, knife injected, dribbled UAN applications, knife injected AA and split UAN applications on yield, grain N content, and residual soil inorganic N content.

MATERIALS AND METHODS

This furrow irrigated experiment was conducted at the Irrigation Experiment field, located near Scandia, Kansas on a Crete silt loam soil (Panchic Argiustoll, fine, montmorillinific, mesic) during the period 1987-1991. The experimental design was a two factor randomized complete block, replicated 4 times. Ridges were built by cultivation during the 1986 growing season and maintained in the same places throughout the experiment. The test included four preplant N application methods (all N from anhydrous ammonia (AA) knife injected, between the old rows; all N from 28% urea-ammonium nitrate solution (UAN) broadcast on the soil surface; and all UAN surface band-dribbled to the side of the old rows on 30 inch centers. Two split N application systems were also evaluated (UAN band-dribbled and UAN knife injected). In the split application systems, 1/2 of the N was applied preplant and 1/2 was applied when the corn was 15-20 inches tall. All application methods were evaluated at N rates of 50, 100 and 200 lb/acre (0 N check plots were also included).

Preplant N applications were made 10-14 days prior to planting. Injected AA and UAN materials were applied six inches below the soil surface, midway between the rows. Broadcast UAN treatments were applied using flat fan spray nozzles at 15 inch centers on a boom set 20 inches above the soil surface. Dribbled treatments were applied to the soil surface at the base of the ridge (30 inch centers) using sprayer mounted metering orifices and drop tubes. Corn was planted in the first week of May each year. Plant populations averaged 25,500 plants/acre.

In 1990 and 1991 corn grain samples were taken at harvest and analized for N content. Soil samples were taken to a depth of 24 inches in April before N application and analized for NH_4-N and NO_3-N. The amounts of NH_4-N and NO_3-N in the soil profile were calculated using the assuption that 1 acre of soil, 6 inches deep weighes 1,800,000 lbs.

RESULTS AND DISCUSSION

When averaged over the five year period, grain yields were significantly lower in the UAN preplant broadcast and dribble treatments than in the other 4 application systems (Table 1.). Spliting applications of dribble applied UAN did improve grain yields. Applying 1/2 of the total N near the time of maximum corn uptake made the dribble system as efficient as the knife injected treatment. Split application of knife injected UAN did not improve yields over applying all N preplant on this medium textured soil.

Only in 1 year (1990) was the preplant broadcast treatment as effective as the knife injection methods. Rainfall was received within 4 hours of fertilizer application in 1990, thus minimizing N loss. Grain yields in the preplant AA knife system and the UAN knife system were similiar in each of the 5 years of the test. No difficulty was encountered in injecting the AA into the corn residue. In general AA is a cheaper N source than UAN and its use would lower the farmers cost of production.

There was no significant interaction between application method and N rate in any year on the experiment. Applying more N did not improve yields in the preplant broadcast or dribble systems. When averaged over all application systems, regression analysis showed that maximum grain yield was achieved with 160 lb/acre N ($Y=94.36+.915X-0.029X^2$, $R^2=.95$). Applying 140 lb/acre N would result in 98% of the maximium yield.

Grain N content followed the same general trends as the grain yield (Table 2). When averaged over N rates, grain N content was lower in the UAN broadcast and dribble treatments than in the other 4 application systems. Split dribble-band applications resulted in higher grain N content than a single dribble application. Split applications of knife applied N did not improve grain N content over applying all UAN preplant. There was no interaction between application method and N rate. The grain N content in the broadcast and dribble treatment was lower at all N rates than in the other 4 systems.

Inorganic N content (NH_4-N+NO_3-N) in a 24 inch soil profile is shown in Figure 1. In 1990 the AA system had a significantly greater ammount of NH_4-N than the other systems because of the large carry over at the 200 lb/acre N rate. NO_3-N in 1990 was affected by N rate alone. Residual nitrates increased as N rate increased. In 1991 both NH_4-N and NO_3-N were affected by an interaction between application method and N rate. In all three knife injected systems total inorganic N content was higher than in the surface applied systems. This may indicate that there was a higher loss of N in the surface applied treatments in 1990 than in 1991. As previously stated, rainfall was received shortly after N application in 1990. Large ammounts of residual inorganic N accumulated when N rates in excess of crop needs were applied over a number of years.

Table 1. Effect of application method and N rate on corn grain yield, 1987-1991. Scandia.

Application Method	N-Rate	1987	1988	1989	1990	1991	Avg.
	lb/a	bu/a					
Check	0	112	70	79	116	91	94
AA Preplant	50	135	129	135	149	124	134
Knife	100	160	162	179	180	149	166
	200	168	163	181	180	157	170
UAN Preplant	50	129	122	120	156	110	127
Broadcast	100	129	144	163	172	139	149
	200	131	145	173	177	143	154
UAN Preplant	50	145	128	151	156	125	141
Knife	100	156	149	174	168	148	159
	200	173	161	181	180	152	169
UAN Preplant	50	122	125	134	133	110	125
Dribble	100	142	150	170	163	136	152
	200	153	155	173	176	138	156
UAN Split	50	153	133	146	147	135	143
Knife	100	159	146	173	165	142	157
	200	162	160	179	182	144	165
UAN Split	50	147	124	134	149	126	137
Dribble	100	152	144	167	166	144	154
	200	155	152	169	173	152	160
CV %		6.3	6.9	9.7	6.9	9.5	8.0

<u>Means</u>

	1987	1988	1989	1990	1991	Avg.
Application Method						
AA; Preplant, Knife	154	151	165	169	144	157
UAN; Preplant, Broadcast	130	137	152	168	130	143
UAN; Preplant, Knife	158	146	168	168	142	156
UAN; Preplant, Dribble	135	143	159	157	128	145
UAN; Split, Knife	157	146	167	165	140	155
UAN; Split, Dribble	151	140	156	163	141	150
LSD .05	7.5	8.2	12.8	NS	10.7	4.4
N-Rate						
50	139	127	137	148	122	135
100	149	149	171	169	143	156
200	155	156	176	178	148	163
LSD .05	5.3	5.8	9.0	6.7	7.6	3.1

Table 2. Corn grain nitrogen content as affected by N application method (averaged over N rates), 1990-1991. Scandia.

Application Method	1990	Year 1991	Average
		%	
0 N check	1.24	1.27	1.25
AA; Preplant, Knife	1.36 A	1.42 A	1.39 A
UAN; Preplant, Broadcast	1.30 B	1.35 B	1.32 B
UAN; Preplant, Knife	1.35 A	1.42 A	1.39 A
UAN; Preplant, Dribble	1.31 B	1.35 B	1.33 B
UAN; Split, Knife	1.34 A	1.43 A	1.37 A
UAN; Split, Dribble	1.34 A	1.39 AB	1.37 A

Means followed by the same letter are not different at the .05 level.

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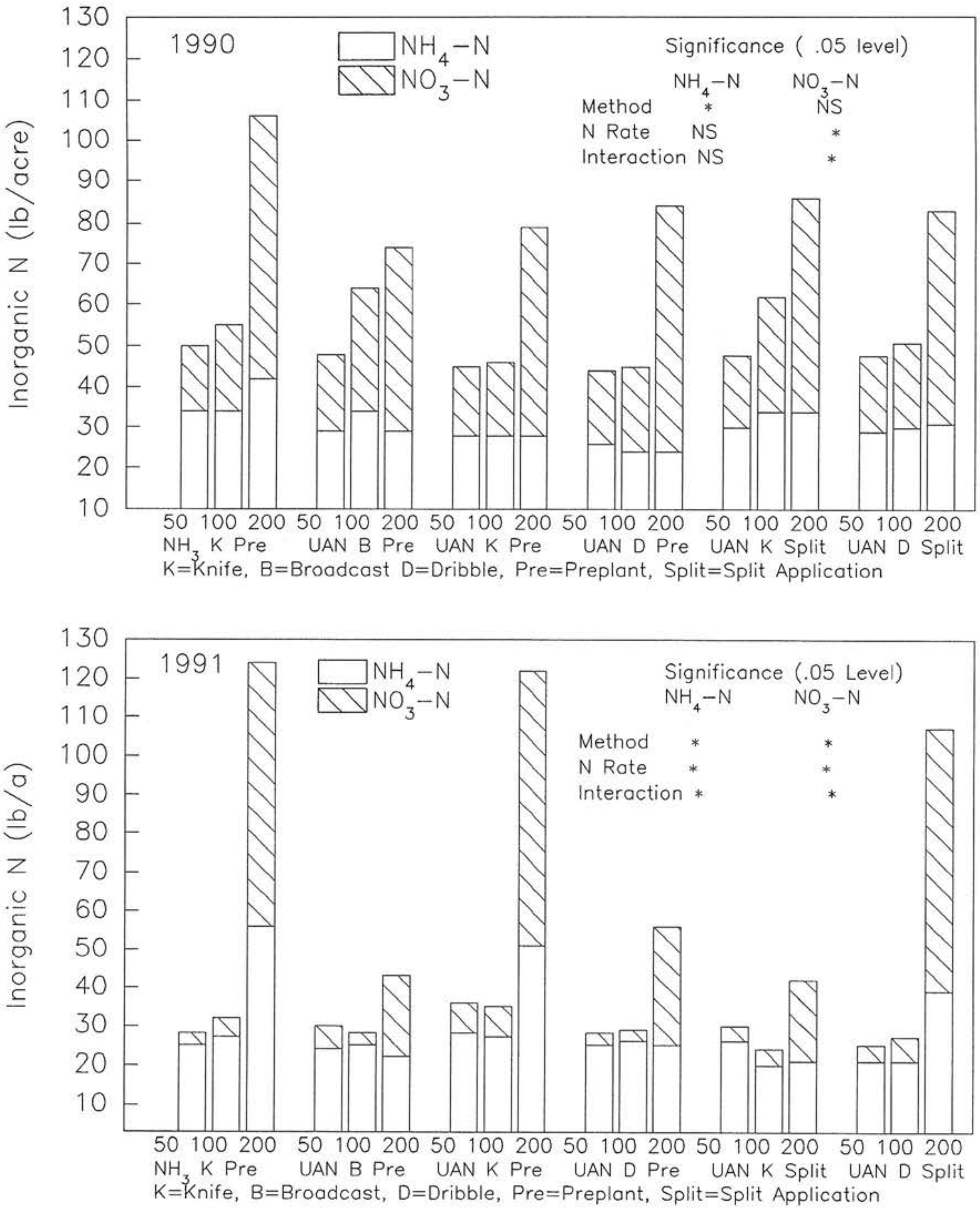

Figure 1. Soil inorganic N content (NH_4-N + NO_3-N), to a depth of 24 inches, as affected by N application method and N rate, 1990 and 1991.

INFLUENCE OF SIMULATED EROSION AND SUBSEQUENT AMENDMENTS ON SPRING WHEAT YIELD

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ABSTRACT

Wind erosion is a major soil degradation phenomenon on the Canadian prairies but its effects on soil productivity are not well quantified. Amendments aimed at restoring productivity to eroded soils also need examination in terms of their immediacy and longevity as compensators for soil loss. In the spring of 1990, incremental depths of soil (0, 5, 10, 15 and 20 cm) were removed with an excavator, to simulate wind erosion at three sites (two dryland and one irrigated) in southern Alberta. Three amendatory treatments (high rate of N plus P fertilizer, re-application of 5 cm of topsoil, or 50 Mg/ha of feedlot manure) and a check were superimposed on each of the desurfaced treatments. Highly significant relationships were found between the depth of desurfacing and subsequent spring wheat grain and straw N and P concentrations and total N and P yields, showing that simulated erosion drastically reduced soil and crop productivity. Feedlot manure proved to be the best amendment for restoring productivity to the artificially eroded surfaces, with N plus P fertilizer being the worst. Treatment effects at the irrigated site followed the same trend as the dryland site illustrating that topsoil loss cannot be compensated by adequate soil moisture.

INTRODUCTION

The impact of wind erosion on soil quality leads to a reduction in soil productivity and hence crop yield. However, its effects on soil productivity are difficult to quantify. Topsoil depth is recognized as a major parameter in determining soil quality and productivity. Characterizing erosion-topsoil depth-soil productivity relationships is a vital step in assessing the true on-farm costs and benefits of conservation tillage and erosion control programs. If we could adequately assess the effect of loss of topsoil depth (i.e. erosion) on soil productivity we could move part of the way towards providing meaningful costs of soil erosion as well as assessing the economic benefits in switching from conventional to conservation tillage.

One approach aimed at quantifying erosion effects on productivity is to simulate the erosion process by desurfacing or 'scalping', whereby incremental depths of topsoil are mechanically removed and subsequent effects on soil productivity are monitored (Dormaar et al., 1986; Tanaka and Aase, 1989). Levels of amendments necessary to restore original productivity may also be studied.

The objective of this study was to assess the effects of simulated erosion and subsequent amendments on soil and crop productivity. This paper reports on these objectives in terms of grain and straw N and P concentrations and total N and P yields.

METHODS

The sites were selected for desurfacing in spring 1990. Criteria for selection included uniformity of Ap horizon depth and topography. Although three sites were included in this study, only two will be discussed here. Both are Dark Brown Chernozemic silty clay loams located at the Agriculture Canada Research Station at Lethbridge, one under dryland management and one irrigated.

Five main desurfacing treatments or cuts (12 X 10 m plots) were established at each site by carefully removing 5, 10, 15 or 20 cm of topsoil using an excavator with a grading bucket and leaving a check (0 cm removed).

On each of the main treatments four sub-treatments (3 X 10 m sub-plots) were super-imposed (three amendatory and one check). The amendatory sub-treatments were: an optimum rate of N and P fertilizer (75 kg/ha N, 50 kg/ha P_2O_5), re-application of 5 cm of topsoil, or 50 Mg/ha (dry weight) of feedlot manure. Fertilizer N and P rates were doubled at the irrigated site. The 5 cm of topsoil re-applied was that saved from the 0-5 cm layer during the desurfacing operation. The feedlot manure had a moisture content of 33% (w/w) and contained 19% total C and 2.2% total N.

All plots were replicated 4 times in a randomized complete block design (5 cuts X 4 amendments X 4 replicates = 80 plots). All treatments were seeded to spring wheat (*Triticum aestivum* L., cv. Lancer) with a hoe drill at recommended seeding rates. The irrigated site received 17.5 cm of water during the growing season to ensure that root zone soil moisture was not a limiting factor.

Yield data are based on six 5 m row lengths hand-harvested from each sub-plot. Grain and straw N and P concentrations were determined by the sulphuric acid-hydrogen peroxide single digestion method of Thomas et al. (1967) and measured using a Technicon II autoanalyzer. Total N and P yields were obtained by multiplying total dry matter production (grain plus straw) times concentration.

RESULTS AND DISCUSSION

Grain N concentration increased with depth of topsoil removal on the check sub-treatments at the dryland site, from 26.3 g/kg on the 0-cm cut check treatment to 33.1 g/kg on the 20-cm cut-check treatment (Fig. 1a). This was contrary to the findings of Dormaar et al. (1986), Tanaka (1990) and Tanaka and Aase (1989) who reported decreased grain N concentrations with increased soil removal. There was also an increase in grain N concentration on the fertilizer sub-treatments from 26.7 g/kg on the 5-cm cut to 30.4 g/kg on the 20-cm cut. Grain N concentrations generally

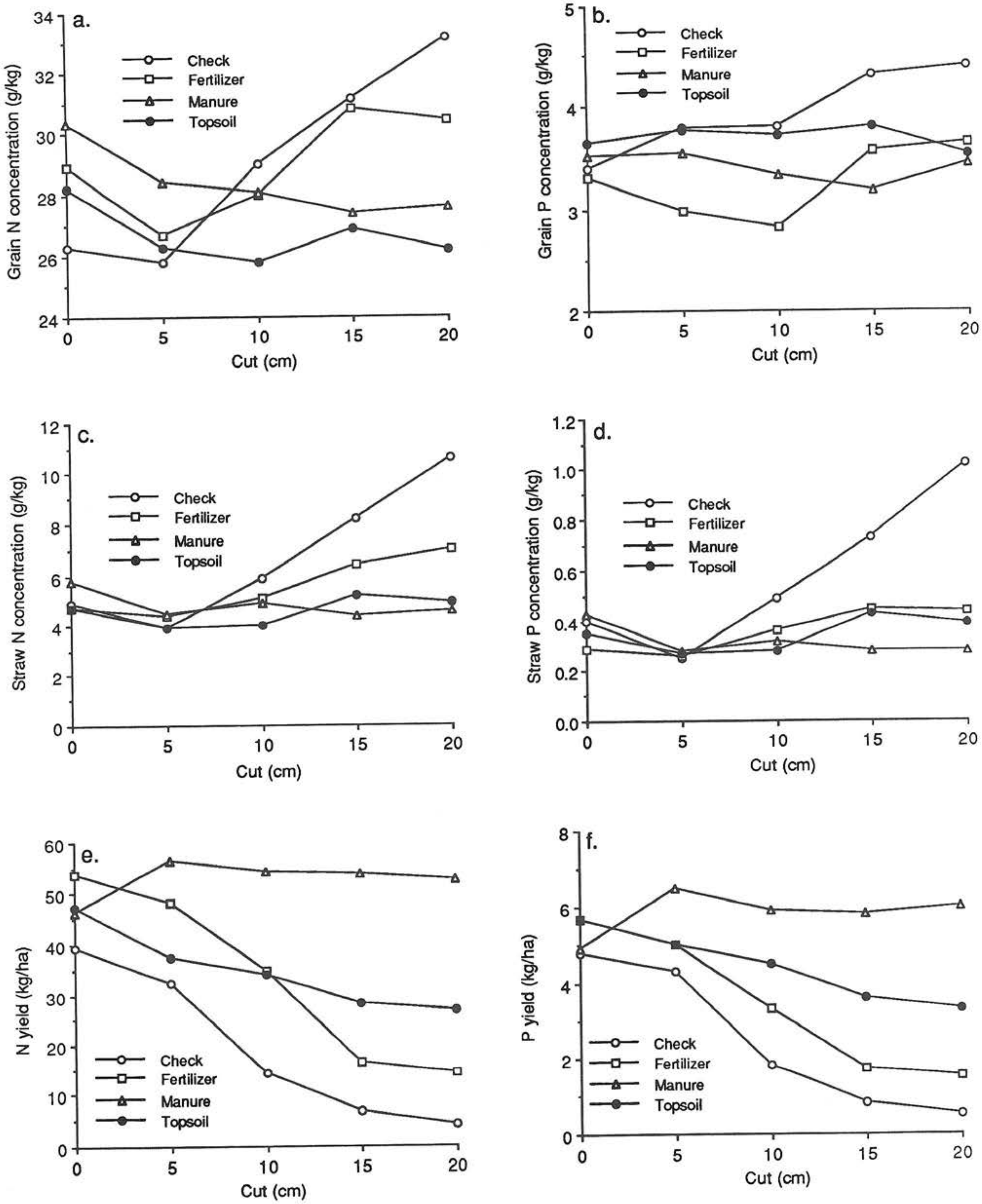

Figure 1. Effect of topsoil removal and amendments on grain N concentration (a), grain P concentration (b), straw N concentration (c), straw P concentration (d), total N yield (e), and total P yield (f) at the Lethbridge dryland site in 1990.

decreased or stayed constant with depth of topsoil removal on the feedlot manure and 5 cm topsoil addition sub-treatments. Grain P concentration followed similar trends, also increasing with depth of soil removal on the check sub-treatment: from 3.4 g/kg on the 0-cm cut-check to 4.4 g/kg on the 20-cm cut check (Fig. 1b). However, grain P concentration did not vary much with depth of cut when amendments of feedlot manure and topsoil were added.

Straw N and P concentrations also increased with depth of topsoil removal below 5 cm on the check sub-treatments: from 3.9 g/kg N on the 5 cm cut to 10.6 g/kg on the 20-cm cut and from 0.25 g/kg P on the 5 cm cut to 1.02 g/kg on the 20-cm cut (Figs. 1c, 1d). There was also a trend of increased straw N concentration with depth of topsoil removal on the fertilizer sub-treatment (Fig. 1c). Straw N and P concentrations on the feedlot manure and 5 cm topsoil addition sub-treatments were generally constant with depth of topsoil removal.

Total N and P yields on the check treatments illustrate the effect of artificial erosion on soil productivity when no attempt is made to restore it (Figs. 1e, 1f). As depth of desurfacing increased then total N and P yields decreased drastically. There were 10-fold yield differences in both total N and total P between the 0-cm cut-check and the 20-cm cut-check. Overall, feedlot manure proved best at restoring productivity followed by topsoil addition and lastly N and P fertilizer application. N and P yields were relatively constant irrespective of depth of topsoil removed on the feedlot manure sub-treatment.

The increases in grain and straw N and P concentrations with depth of topsoil removal on the check treatments can be explained by the large dry matter yield decrease which accompanied incremental topsoil removal (Larney et al., 1991). Dry matter accumulation was supressed more than N and P assimilation on these treatments, resulting in the effective concentration of these nutrients in the plant tissues. The results suggest that N and P were non-limiting to the crop on the deeper cuts since there was no decline in their concentration with depth of topsoil removal.

Grain and straw N concentrations and straw P concentration on the 5-cm cut were lower than on the 0-cm cut on all sub-treatments at dryland site (Figs. 1a, 1c, 1d). Higher organic matter content (2.13%) on the 0-cm cut probably had more nitrogenous materials than on the 5-cm cut (1.72%) which could have increased N mineralization during the season, increasing the quantity of available N and resulting in greater grain and straw N concentrations.

Grain N and P concentrations, straw N and P concentrations and total N and P yields showed remarkably similar trends at the irrigated site (Figs. 2a-f). Concentrations of grain N and grain and straw P showed an increase with depth of desurfacing on the check sub-treatments again attributed to the large decline in dry matter yields on these treatments.

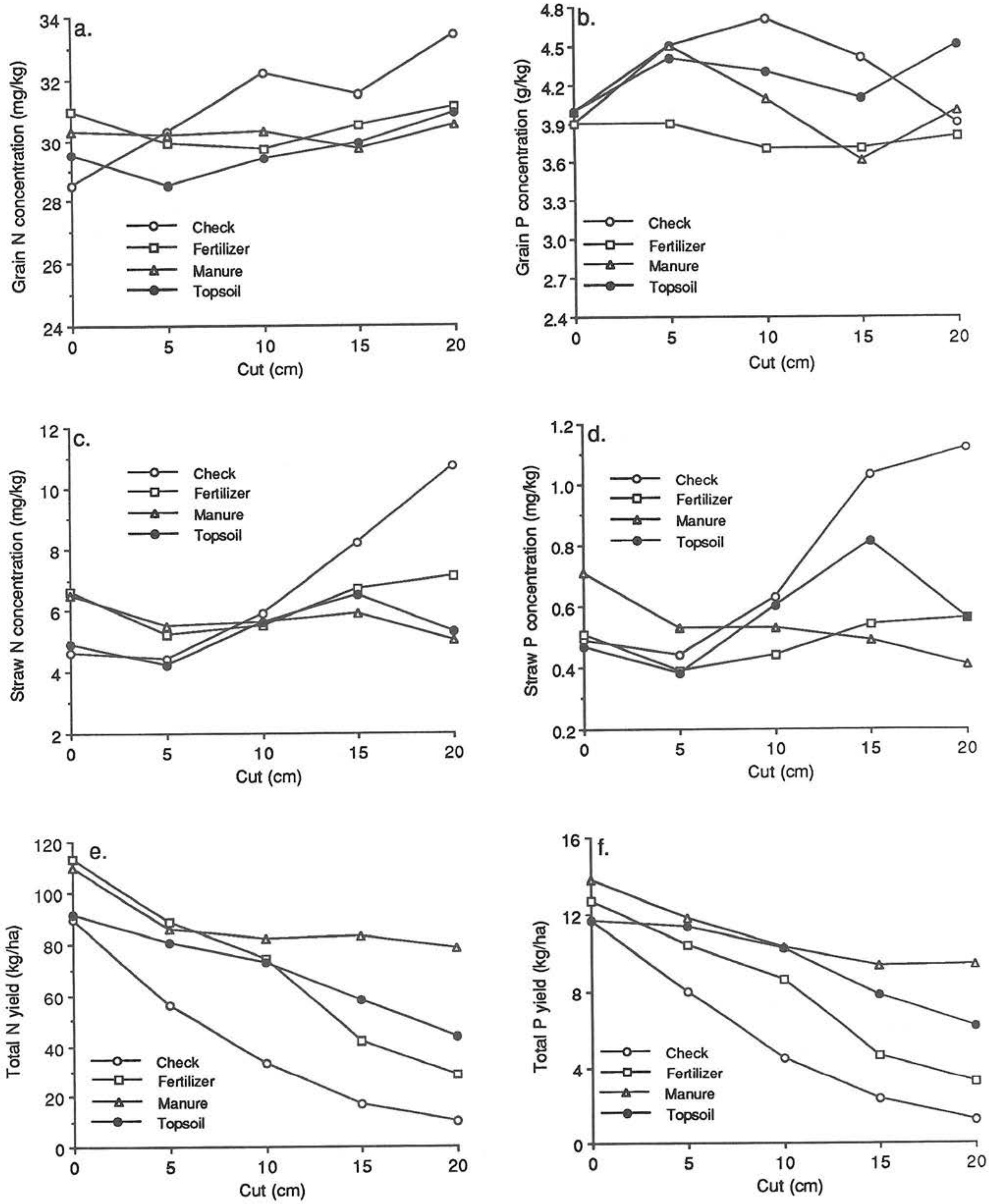

Figure 2. Effect of topsoil removal and amendments on grain N concentration (a), grain P concentration (b), straw N concentration (c), straw P concentration (d), total N yield (e), and total P yield (f) at the Lethbridge irrigated site in 1990.

The only notable change in trend between the two sites occurred with grain P where its concentration decreased with desurfacing below 10-cm depth on the check sub-treatment (Fig. 2b).

Removing moisture stress as a yield-limiting factor through irrigation did not compensate for the loss of topsoil even with the application of 150 kg/ha of N and 100 kg/ha of P_2O_5. In fact an overall greater loss of productivity (79.3 kg/ha of N yield) occurred on the irrigated site (0-cm cut-check vs. 20-cm cut-check; Fig. 2e) than on the dryland site (35.2 kg/ha N; Fig. 1e).

In conclusion, topsoil removal drastically reduced soil and crop productivity in terms of dry matter production on the check treatments where no effort was made to restore productivity. This strong overriding factor led to increases in N and P levels in both grain and straw simply due to concentration of these nutrients in the very small of amounts of dry matter that was produced. Concentrations of N and P varied much less with depth of desurfacing where feedlot manure and topsoil addition were used as amendments because they compensated to some extent in restoring dry matter yields, hence diluting N and P concentrations on the deeper cuts. From these results it would seem that N and P are non-limiting nutrients on the deeper cuts. Further investigations will include micronutrient analysis which may elucidate the reasons for poor crop productivity on artificially eroded surface.

ACKNOWLEDGEMENTS

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RELATIONSHIP BETWEEN SOIL QUALITY CRITERIA AND YIELD

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ABSTRACT

There is growing concern over the deterioration of soil productivity, yet the specific soil factors that dictate productivity have not been adequately defined. The objective of this study is to evaluate an alterative approach for defining the relationship between soil quality and productivity. This approach involves deposition of diverse soils at a common location and quantifying the quality/productivity relationships. Two sites, one irrigated and one dryland, were established by removing surface soil and relocating 36 diverse soils in a randomized complete design with three replicates. Yield data from the first year demonstrated consistent and highly significant differences in productivity among soils; differences between least and most productive soils were as high as three-fold. Linear correlation analyses identified significant positive relationships of soil organic C, total N, N and P fertility, and microbial N with soil productivity. Carbonate concentration and pH were negatively correlated with productivity. Nonlinear regression suggested that the relationship between organic C and productivity was best described by a linear plateau model. These preliminary findings confirm the importance of soil quality in governing productivity, and suggest that the experimental approach adopted may have some utility in defining the soil quality criteria.

INTRODUCTION

A fundamental element of sustainable agriculture is the preservation or regeneration of soil productivity. Because all forms of agricultural production ultimately depend on the capacity of soils to support plant growth, deterioration in soil productivity inevitably jeopardizes agricultural output.

Soil productivity refers to the capacity of a soil to sustain crop growth and generate crop yields (Canadian Society of Soil Science 1976; Soil Science Society of America 1984). This capacity is governed by a large number of factors as summarized in Equation [1].

$$P_S = f(Q_S, Q_L, I_E) \qquad [1]$$

where: P_S = soil productivity, Q_S = soil quality,
Q_L = landscape quality, and I_E = energy inputs

In this conceptual relationship, Q_S represents intrinsic soil properties such as organic matter content, organic matter quality, pH, and texture; Q_L represents extrinsic factors such as precipitation, temperature, topography, and hydrology; and I_E denotes inputs such as fertilizers, irrigation, and tillage events which mitigate deficiencies in Q_S or Q_L

Of the three groups of variables in Equation [1], the contribution of soil quality to productivity is least understood. Considerable research effort has been expended in determining the influence of various management practices on indices of soil quality. For example, the effects of tillage, crop rotation, fertilizer application, and organic amendments on soil organic matter content have been well-documented. But the influence of resulting organic matter losses or gains on subsequent soil productivity has not been definitively quantified. Without a quantitative understanding of the relationship between soil quality and soil productivity, any attempts to sustain productivity by optimizing soil quality factors may be haphazard or even misdirected.

The long-term objective of the work described here is to identify and characterize the soil quality factors which dictate soil productivity under conditions in southern Alberta. The specific aim of this paper is to outline one approach for addressing this objective and to illustrate its potential application using preliminary results.

MATERIALS AND METHODS

Approach

The relationship between soil quality and productivity can be quantified by defining P_S as function of Q_S under conditions where Q_L and I_E are held constant (Equation 1). This function can be described using a number of approaches. One common method is to sample a number of points in a landscape and correlate yield with the specific parameters of interest. While this approach has generated useful information, it does not necessarily establish causality because of the confounding effect of nonuniform Q_L variables. For example, depressional areas may accumulate more organic matter and exhibit higher yields than will elevated areas. As a result, regression analysis may reveal a strong correlation between yield and organic matter, but this relationship does not necessarily indicate that increased yields were attributable to higher organic matter (in fact, higher yields resulting from increased moisture may themselves be the cause of higher organic matter).

An alternative approach is to artificially introduce variability in soil quality by deposition of diverse soils on a common subsoil at the same location, and subsequently defining yield as a function of quality factors. In this approach, Q_L is uniform or spatially random, thus eliminating confounding effects inherent to the former approach. Furthermore, it permits evaluation of a much broader range of soil characteristics because soils from divergent cropping histories can be included at a common site.

The effects of Q_L and Q_S are almost certainly interactive; for example, optimum Q_S under and conditions will be very different from those under humid conditions. As a result, the P_S/Q_S relationship described at any given site will be specific to the prevalent set of Q_L factors. The objective of this alternative approach is not to identify the 'best' soil in its original location, but to define the soil properties that maximize soil productivity in a given Q_L regime. The approach simply addresses the question: Given our ability to modify soil characteristics by manipulation of agronomic variables, and given the constraints imposed by Q_L factors, what suite of soil characteristics should we seek to engender in the soil to maximize productivity? This approach focuses on the surface soil because, in many cases, it is this layer that is most influential in dictating productivity and most subject to agronomic manipulation.

Experimental design

The experimental design adopted to assess the feasibility of the approach described included 36 soils deposited at each of two sites in a randomized complete block design with three replicates. Both sites, one irrigated and one dryland, are located at the Agriculture Canada Research Station in Lethbridge, Alberta. Two fertilizer sub-plots (with and without N fertilizer) were established within each soil treatment. This design yielded a total of 108 main plots (216 sub-plots) at each of the two sites.

Establishment procedures

Two level sites were selected with uniform soil characteristics. The soil profile at both sites was typical of a Dark Brown Chernozem (Typic Boroll) with a thin B horizon. The topsoil layer was removed from within appropriately sized areas using an excavator with a grading bucket. This machine permitted accurate removal of the topsoil with minimal disruption or compaction of the subsoil layers.

After removal of the topsoil, the exposed subsoil was subjected to a shallow tillage using disk harrows to roughen the interface between subsoil and subsequently deposited soil. Soils were then placed over this exposed subsoil in a grid pattern in plots measuring 6 m by 5 m. Mass of soil deposited in each plot was approximately 7.2 tonne and depth after settling was approximately 18 cm. Individual plots were laid down using wooden forms as borders to ensure distinct transitions between adjacent soils.

Of the 36 soil deposited at each site, 2 were subsoils (B and C horizons) obtained from an adjacent area. All other soils were surface soils (A_h or A_p) selected to represent a broad diversity of characteristics. Approximately half were obtained from existing long-term experiments at the Lethbridge Research Station, some of which date back to 1910. Soils were obtained from treatments varying in crop rotation, organic amendments, tillage practices, simulated erosion, and irrigation regime. Most of the remaining soils were donated by producers within a 100 km radius of the experimental sites and included 'organically' managed soil, wind-blown soil accumulated along fencelines, uncultivated grassland soil, and soil from various agroecological regions.

Both sites were established in the summer and fall of 1990. In May of the following year, ammonium nitrate was broadcast onto designated subplots at a rate of 60 and 100 kg N ha^{-1} at the dryland and irrigated sites, respectively. The entire plot area and surrounding buffer zones was then seeded to spring wheat (*Triticum aestivum* var. 'Lancer') using a hoe drill with 18 cm row spacing. Phosphorus was applied with the seed at a rate of 40 kg P_2O_5 ha^{-1}. Water was applied to the irrigated site as needed to minimize water stress using a sprinkler irrigation system.

Plant heights were measured after heading. The wheat was harvested by manually sampling all above-ground material in 0.89 m X 5 m areas within each sub-plot. After threshing, grain and straw were dried and subsequently weighed for determination of dry matter yields.

Analytical procedures

Surface soil samples from all of the main plots (108 at each of two sites) were air-dried and ground to pass a 2 mm sieve. The samples were then analyzed for total carbon (Carlo Erba CNS analyzer), total nitrogen (Carlo Erba CNS analyzer), carbonate (gas chromatography following addition of acid), KCl-extractable ammonium and nitrate, 0.5 M sodium bicarbonate-extractable phosphate, and texture (pipette method). Fresh soil samples obtained from the sub-plots at the irrigated site receiving no N fertilizer were also analyzed for microbial biomass N concentration using a fumigation-extraction technique.

RESULTS

Dryland site

Grain and total dry matter yield was significantly affected by soil but not by N fertilizer application (Table 1). When pooled across fertilizer treatments, grain yields ranged from 1.2 to 4.0 tonne ha^{-1} and total dry matter yields ranged from 2.6 to 9.4 tonne ha^{-1} . Lowest yields were observed in the two subsurface soils. When these two soils were excluded, grain yields still ranged from 2.5 to 4.0 tonne ha^{-1} and total dry matter yields ranged from 5.4 to 9.4 tonne ha^{-1}.

Grain yield, total dry matter yield, and plant height were positively correlated with concentrations of organic C, total N, extractable nitrate, and bicarbonate-extractable P (Table 2). Soil carbonate concentration and pH, however, were negatively correlated with yield.

Table 1. Summary of analysis of variance to determine the effects of soil, N fertilizer, and their interaction on grain yield, dry matter yield, and plant height at two sites. Seven soils (2 in the irrigated site and 5 in the dryland site) were excluded because of weeds, disease , or poor emergence.

source	dryland site			irrigated site		
	grain	total	height	grain	total	height
soil (S)	***†	***	***	***	***	***
N fertilizer (F)	ns	ns	ns	*	***	*
S X F	ns	ns	ns	**	*	*
CV	9%	9%	3%	13%	12%	6%

† ns = not significant; '*', '**', and '***' indicate significance at P=0.05, 0.01, and 0.001, respectively.

Irrigated site

Wheat yields at the irrigated site also showed large differences across soils (Table 1). In addition, yields were significantly affected by N fertilizer application and the interaction of fertilizer and soil. In sub-plots receiving no N fertilizer, grain yields ranged from 1.2 to 3.7 tonne ha^{-1} and total dry matter yields ranged from 2.7 to 10.1 tonne ha^{-1}. When the two subsurface soils were excluded, grain and dry matter yields ranged from 1.9 to 3.7 tonne ha^{-1} and 4.6 to 10.1 tonne ha^{-1}, respectively. In N-fertilized plots, range of grain and total dry matter yields were 2.1 to 3.9 tonne ha^{-1} and 5.2 to 10.9 tonne ha^{-1}, respectively.

Correlations between productivity and soil quality indices were similar to those observed under dryland (Table 2). The relationship between soil quality and productivity at this site may have been obscured somewhat by serious crop lodging in some of the treatments, particularly in the N-fertilized sub-plots.

Table 2. Correlation coefficients (r) for the linear relationship between soil properties and total dry matter yield at the dryland and irrigated sites in 1991. Seven soils (2 in the irrigated site and 5 in the dryland site) were excluded from the analyses because of weeds, disease, or poor emergence).

parameter	dryland site	irrigated site	
		-N	+N
organic C	0.39	0.40	0.34
organic N	0.43	0.42	0.33
microbial N	n.d.†	0.38	n.d.
extractable NO_3	0.63	0.45	0.27
available P	0.49	0.24	n.s.
CO_3	-0.58	-0.56	-0.44
pH	-0.40	-0.31	-0.28
surface soil moisture	0.25	n.d.	n.d.
plant density	n.s.	n.s.	n.s.
sand	n.s.	-0.27	-0.21
silt	n.s.	0.37	0.25
clay	n.s.	n.s.	n.s.

† n.d. = not determined, n.s. = not significant at P=0.05

DISCUSSION

The results confirm the profound influence of soil quality characteristics on soil productivity as measured by wheat growth. Under dryland conditions, yield in the most productive soil was approximately three times that in the least productive soil. Even under conditions of adequate moisture and fertility at the irrigated site, differences between lowest and highest yielding plots were approximately 2-fold. The latter observation suggests that deficiencies in soil quality can not necessarily be circumvented by addition of fertilizers or water.

The identification and characterization of specific quality factors responsible for the large differences in productivity remains in preliminary stages. Correlation analysis provides evidence that differences in productivity may be partially linked to positive effects of organic matter fractions and to negative influences of carbonates. Linear correlation techniques, however, may not accurately describe the soil quality/productivity relationships. For example, more detailed analysis of the relationship between yield and organic C concentration indicated that it could be effectively described by a linear plateau model fitted by non-linear regression (Fig. 1). This technique suggested that yields increased with increasing organic C concentration up to approximately 2.0% and then remained constant with further increases in organic C. This linear plateau model accounted for a much higher proportion of variability than observed in the linear model.

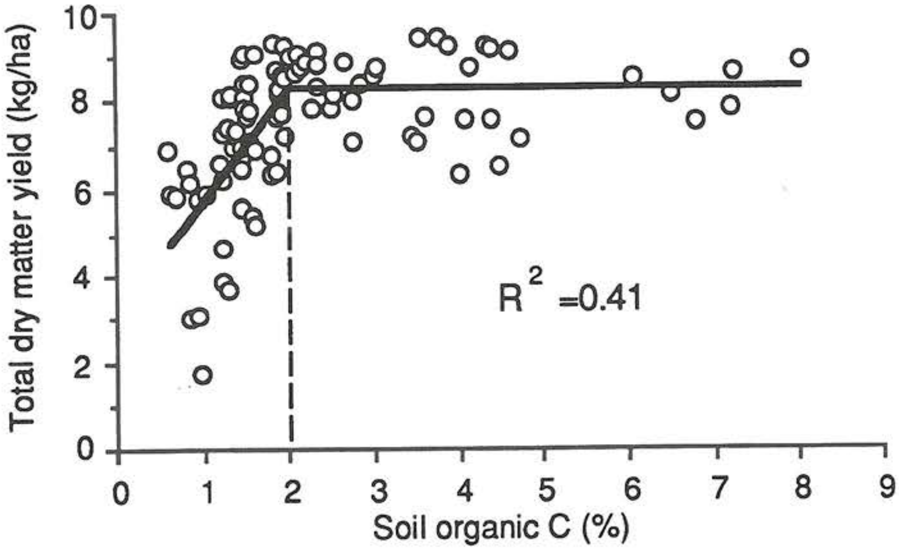

Figure 1. Preliminary evaluation of the relationship between productivity and soil organic C from yields in 1991 under dryland conditions. (Five soils excluded because of weeds, disease, or poor emergence).

The results represent only the first year in a long-term field study. Consequently, they may be subject to some errors arising from residual effects of deposition procedures, weed problems, or minor disease infestations. More detailed evaluation of the relationships between soil quality and productivity will be undertaken in subsequent years. Major emphasis in future research will be accorded to the influence of biochemical and biological parameters on soil productivity.

A supplementary objective of the experiment is to determine the nature and rate of changes in soil properties following relocation of the soils. This component of the study may have particular relevance in view of expected changes in global climates.

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1.72 × %C = %OM

AN ALTERNATIVE CROP ROTATION FOR THE EASTERN GREAT PLAINS

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ABSTRACT

Research was initiated at the KSU South Central Experiment Field to determine the effectiveness of Nitrogen fertilizer when using early planted short season corn in a corn-winter wheat-grain sorghum rotation under dryland conditions. Nitrogen rates of 0, 25, 50, 75, 100, 125 Lb ac^{-1} were used. Crop response to N varied by year. Yield increases occurred with increased N in the crop produced under the most favorable climatic conditions. Significant grain N differences occurred with apparent nitrogen recovery (ANR) being the highest in the favorable years. Initial results indicate that corn can replace the fallow portion of a wheat-grain sorghum-fallow rotation in the South Central Kansas region. However, there is the potential for the loss of the wheat crop after corn in years when fall and winter moisture is limited. This loss has not occurred where continuous winter wheat is produced under the same nitrogen rates used in the rotation.

INTRODUCTION

In South Central Kansas continuous hard red winter wheat and winter wheat-grain sorghum-fallow are the predominate cropping systems. The summer-fallow period following sorghum is required because the sorghum crop is harvested in late fall, after the optimum planting date for wheat in this region. Average annual rainfall is only 29 in yr^{-1}, with 60 to 70% occurring between March and August. Therefore, soil moisture is often not sufficient for optimum wheat growth in the fall if planted after sorghum (7).

Short season dryland corn (Zea mays L.) matures 30 to 60 days earlier than sorghum, which would allow for more timely planting of wheat. However, corn is not commonly grown because of the limited rainfall and soil moisture present under the conventional tillage. Successful production of a wheat-sorghum-corn rotation would require soil water conservation strategies that would increase soil moisture.

No-tillage systems often increase soil moisture by increasing infiltration and decreasing evaporation (4,7). Higher no-tillage grain yields associated with increased soil water have not always been observed (4,5,6). Winter wheat rotated with sorghum and corn would provide improved weed control through additional herbicide options and reduced disease incidence by interrupting disease cycles.

Fertilizer nitrogen requirement for many crops is often greater under no-tillage than conventional tillage (3,8). Increased immobilization and denitrification of inorganic soil N and decreased mineralization of organic soil N have been related to the increased N requirements under no-tillage (8). The few N response studies reported for no-till dryland corn in the Great Plains have shown highly variable responses, which were related to variance in growing season precipitation, method of application, and soil profile N content at planting (1,2).

The objectives of this study were to 1) evaluate the production potential of no-tillage dryland wheat-grain sorghum-corn rotation and 2) quantify the fertilizer N response for each crop in the rotation.

MATERIALS AND METHODS

The research was conducted from 1987 to 1990 at the KSU South Central Experiment Field, Hutchinson. Soil was an Ost loam (fine, loamy, mixed, thermic Udic Argiustolls). The site had been in wheat the previous two years. The research was replicated five times using a randomized block design with a split plot arrangement. The main plot was crop (corn, wheat, and sorghum) and the subplot six N levels (0, 25, 50, 75, 100, and 125 Lb ac^{-1}. Nitrogen treatments were broadcast applied as NH_4NO_3 prior to planting. All crops were produced each year of the study and planting dates are shown in Table 1. Plots were harvested at maturity to determine grain yield, moisture, and test weight. Grain N was determined by autoanalysis of H_2SO_4-H_2O_2 digestion of grain subsamples. Apparent Nitrogen Recovery (ANR) was calculated using the following formula:

$$ANR = [(Y_N - Y_{No})/N]*100$$

where N = Nitrogen rate applied, Y_N = grain N (lb/ac) at given N rate and Y_{No} = grain N (lb/ac) at N=0.

TABLE 1. PLANTING DATES FOR EACH CROP AND YEAR.

Crop	Planting Date 1987	1988	1989
Corn	4/18 (108)*	4/8 (99)	4/5 (95)
Wheat	10/2 (275)	10/4 (278)	10/11 (284)
Sorghum	5/22 (142)	6/8 (160)	6/21 (172)

* Julian dates in ( ).

RESULTS AND DISCUSSION

Corn grain yields increased with increasing N in all years of the study (Table 2). Lack of significant yield increases with higher N rates in 1987 reflect the presence of high residual N in the soil at the start of the study (soil test data not reported) and the ideal growing season precipitation (Fig. 1). As the residual soil N was removed by the cropping sequence, the higher N rates produced corn yields which were significantly larger than the control or the 25 Lb ac^{-1} N rates (Table 2). Corn yields in 1989 (Table 2) reflect more timely precipitation (Fig. 1) and cooler growing season temperatures compared to previous years. Insufficient precipitation during the fall and winter of 1989-90 resulted in a lack of soil moisture recharge. This lack of soil moisture coupled with the hot dry conditions in May through July of 1990 were less than ideal for grain formation in corn. Therefore, the corn crop was harvested for silage and the yields reported in tons per acre on a dry matter basis. A favorable growing season for grain sorghum (moist and warm) in 1988 produced an excellent crop with no significant yield differences for the sorghum crop in the rotation sequence (Table 4). These ideal conditions for sorghum however were not ideal for corn and thus the corn yields in 1988 were suppressed compared to 1987 and 1989 (Table 2). Wheat yield increases with increasing N rate were observed in 1988 and 1990 (Table 3). The extremely dry conditions from planting (Table 1) through early May of 1989 (Fig 1) caused the complete loss of the wheat crop in the rotation. In the years 1988 and 1990 (Fig. 1) where timely precipitation occurred in both germination and spring regrowth periods, wheat yields following corn were comparable to wheat following wheat. Nitrogen application significantly increased grain N contents in all crops (Tables 2,3,4).

Table 2. Effects of nitrogen rate on **CORN** in a corn-wheat-sorghum rotation. Hutchinson.

	Yield				1988 Grain	
N Rate	1987	1988	1989	1990	N	ANR*
lb/ac	-- BU ac^{-1} --			T ac^{-1}	--- % ---	
0	62	37	60	2.3	1.4	----
25	63	45	65	2.4	1.5	26.6
50	66	49	78	2.5	1.6	24.5
75	65	48	94	2.3	1.6	16.1
100	68	50	96	2.2	1.6	15.8
125	71	54	100	2.5	1.6	15.8
$LSD_{0.1}$	NS	7	12	NS	0.1	NS
CV (%)	13	14	14	4	7	57

* Apparent Nitrogen Recovery

Table 3. Effects of nitrogen rate on **WHEAT** in a corn-wheat-sorghum rotation. Hutchinson.

N Rate	Yield 1988	Yield 1990	Grain N 1988	Grain N 1990	ANR* 1988	ANR* 1990
lb/ac	- BU/AC -		---------- %	----------		
0	9	21	2.7	2.1	----	----
25	13	31	2.7	2.0	34.1	46.3
50	17	43	2.9	1.9	30.5	47.4
75	19	53	3.0	2.0	24.8	50.4
100	17	54	3.0	2.1	17.3	41.0
125	19	55	3.0	2.2	15.9	37.7
$LSD_{0.1}$	5	4	0.1	NS	12	9.7
CV (%)	27	8	4	4	46	24

* Apparent Nitrogen Recovery for Grain

Table 4. Effects of nitrogen rate on **GRAIN SORGHUM** in a corn-wheat-sorghum rotation. Hutchinson.

N Rate	Yield 1987	Yield 1988	Yield 1989	Yield 1990	Grain N 1988	Grain N 1990	ANR* 1988**	ANR* 1990
lb/ac	----- BU/AC -----				---------- %	----------		
0	50	82	66	29	1.3	2.1	----	----
25	57	82	61	36	1.4	2.2	20.3	76.3
50	69	80	69	35	1.4	2.3	16.0	21.2
75	73	83	71	39	1.4	2.2	10.6	26.2
100	75	81	72	35	1.6	2.2	15.5	10.8
125	76	80	74	36	1.6	2.2	12.2	8.7
$LSD_{0.1}$	10	NS	6	5	0.1	0.1	9.4	8.5
CV (%)	14	7	8	14	6	5	53	31

* Apparent Nitrogen Recovery for Grain.
** Four replications used in AVOVA.

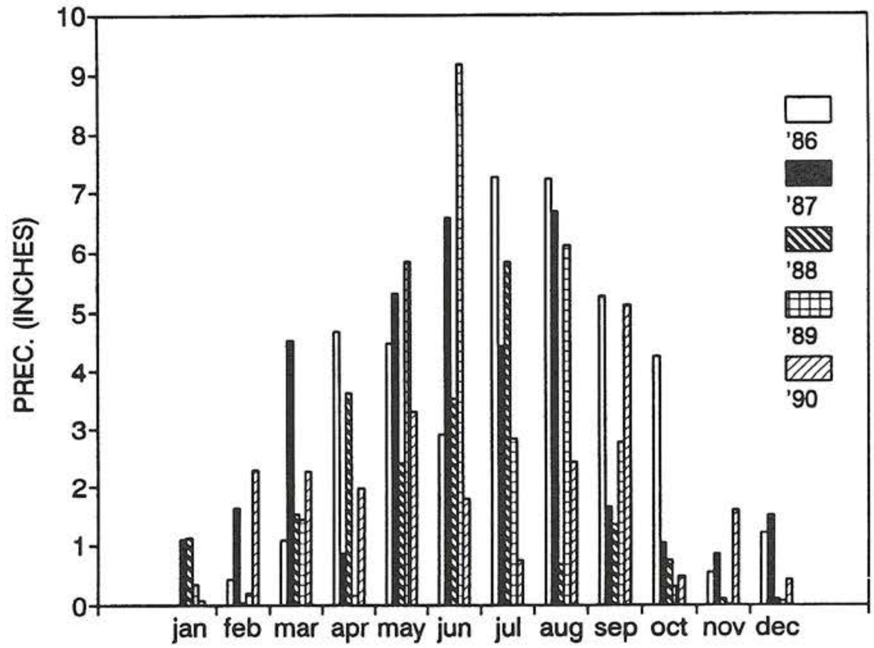

Figure 1. 1986 - 1990 Precipitation, Hutchinson, KS

It therefore appears that corn can replace the fallow portion of a wheat-grain sorghum-fallow rotation in the Eastern Great Plains region of the US and that N response in this region is affected by timely precipitation. However, there is the potential for the loss of the wheat crop after corn in years when fall and winter moisture is limited and in dry years, the corn may have to be utilized as a forage/silage crop.

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LANDSCAPE-BASED VARIABLE RATE FERTILIZATION

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ABSTRACT

Fertilizer responses were measured on management units determined by landscape analysis. Yield variability was greatest at the sites which had been broken in the early 1900s. Yields tended to be higher on footslope and level complexes than on shoulder complexes. Shoulders also exhibited slightly different fertilizer responses than footslope complexes.

INTRODUCTION

Crop yield varies within the landscape: knolls which are generally drier and infertile yield less than footslopes which receive runoff water and additional nutrients in soil eroded from higher elevations. Such differences make variable rate fertilization an attractive management option.

From the standpoint of soil conservation, additional fertilizer could be applied to knolls to improve crop growth and reduce the potential for further erosion (Hamm 1985). However if water is the yield-limiting factor on knolls, the extra fertilizer may be redundant. From an economic standpoint, resources should be concentrated on the lower slope positions where yield potential is greatest (Kachanoski et al. 1985).

This research was undertaken to clarify the effect of fertilizer addition on yield on different parts of the landscape. The objectives were to identify easily recognizable landscape units which could be fertilized uniformly and to establish fertilizer responses within each of the units.

MATERIALS AND METHODS

Yield experiments were carried out at three sites with strongly rolling topography near Saskatoon, Saskatchewan in 1991. The Cutbank site was located on a Dark Brown Chernozem (Typic Boroll) classified as a Weyburn loam (Ellis et al. 1970). The land at the site was broken in the early 1900s and for the past 20 years a two-year wheat-fallow rotation had been in place. The other two sites were located one mile apart on a Black Chernozem (Udic Boroll) classified as an Oxbow loam (Mitchell et al. 1962). The Kresse site was broken around 1910 and had recently been cropped to canola, wheat, and barley with summerfallow every third or fourth year. The Termuende site had been continuously cropped to wheat or barley since it was broken in 1977. In 1990 a wheat crop had been grown on summerfallow at the Kresse site and barley was grown at the Termuende site.

Spring wheat was grown on all the sites: var. Neepawa at Cutbank and var. Laura at Kresse and Termuende. Fertilizer treatments were seeded in strips 1.87 m wide (one seeder width) and 500m long so that each treatment was applied on all elements of the landscape. Treatments were randomly allocated to the strips. At each site there were nine fertilizer treatments which combined three rates of nitrogen and phosphorus fertilizer (0, 20, and 40 kg/ha of N as ammonium nitrate and 0, 20, and 40 kg/ha of P_2O_5 as ammonium phosphate). Where N was applied as ammonium phosphate, the rate of ammonium nitrate was correspondingly reduced and two extra check strips with 4 and 8 kg/ha N were included for comparison with the N:0 P:20 and N:0 P:40 strips respectively.

Prior to seeding soil samples were taken at 0-15, 15-30, 30-60, 60-90 and 90-120 cm depth every 10m along the N:0 P:0 and the N:40 P:40 strips. These samples were used to determine profile moisture at seeding, nitrate-N (Keeney and Nelson 1982), bicarbonate extractable P (Olsen and Sommers 1982), and Cesium content (de Jong et al. 1982). The distribution of Cs in the landscape is an indicator of soil redistribution which has occured since 1961. A horizon depth and depth to $CaCO_3$ were recorded at the sampling positions. Topographic surveys were used to obtain elevation data for the area of the plots at a 5 m grid spacing. Temperature and precipitation were measured at each site. Harvest yield samples were taken every 10 m along each fertilizer strip. Both total (grain and straw) and grain yield were recorded.

RESULTS AND DISCUSSION

Identification of Landform Complexes

The elevation data was used to determine the downslope and cross-slope curvature at each yield sampling position. The sampling positions were then assigned to a landform element using the classification developed by Pennock et al. (1987). Five landscape elements were identified on each of the three study sites: diverging and converging shoulders and footslopes and level elements. Although these landform elements could be easily recognized in the field, their distribution was too complex to be considered as a pattern for the application of different fertilizer rates.

A more useful classification was achieved by grouping the landform elements using a progressive smoothing proceedure. The five landform elements were reduced to three landform element complexes: shoulder, footslope, and level complexes. Level complexes could occur either in depressions or on top of knolls. Depending on its neighbours a landform element could be assigned to any of the complexes (ie. a converging shoulder element could be found in a footslope complex). The landform element complexes are visually identifiable and are sufficiently large to be field management units. A significant amount of the land area fell into each landform element complex (LFC) at each site. Nearly half of the land area at the Kresse site was in level complexes, while shoulder complexes dominated at the Cutbank site, and at the Termuende site there was not a dominant complex.

Variation in Soil Properties between Landforms

Differences in soil properties between the landform element complexes are shown in Table 1. Significant differences in soil properties between landscape elements were found at all three sites. There were significant differences between the LECs for all properties except spring profile moisture at the Cutbank site, nitrate and depth to $CaCO_3$ did not vary significantly between LEC at the Kresse site, and at the Termuende site cesium was the only soil property which varied significantly between LECs. The lack of significant differences in soil properties between LECs at Termuende reflects the relatively recent breaking of the land and the continous cropping system that has been in place since the land was brought into production. Long-term crop production, summer-fallow, and soil erosion have strengthened the differences in soil properties across the landscape at the other two sites.

Table 1. Mean values for the soil properties on the landform element complexes at the three sites.

Soil Property	LFC	Cutbank	Kresse	Termuende
Nitrate	Shoulder	6.3 a	6.9	8.4
kgN/ha	Footslope	8.1 b	9.7	11.6
0-60 cm	Level	8.3 b	9.1	11.1
Phosphorus	Shoulder	17.0 a	47.4 a	68.6
kgP/ha	Footslope	27.2 a	116.0 b	94.9
0-60 cm	Level	44.5 b	80.9 ab	67.3
Profile	Shoulder	32.2	25.5 a	24.8
Moisture	Footslope	30.6	27.6 ab	27.4
cm	Level	31.5	28.6 b	24.8
A horizon	Shoulder	5.3 a	10.2 a	15.2
Thickness	Footslope	11.7 b	18.0 b	16.1
cm	Level	8.3 b	18.1 b	16.2
Depth to	Shoulder	7.3 a	9.9	36.8
$CaCO_3$	Footslope	38.0 b	26.5	46.3
cm	Level	16.5 a	17.2	42.6
Cs conc.	Shoulder	7.0 a	-	10.0 a
Bq/kg	Footslope	9.8 b	-	13.2 b
0-15 cm	Level	10.9 b	-	11.9 ab

Values for all of the soil properties were generally higher on the footslope and level complexes than on the shoulder complexes, with most of the significant differences being between shoulder and footslope complexes. Differences between footslope and level complexes tended to be slight and were only significant for P and depth to $CaCO_3$ at the Cutbank site. The P level was greater on the level complex than the footslope complex but $CaCO_3$ was found deeper in the profile on the footslope complex.

Yield Variability in the Landscape

Differences in total and grain yield between landscape element complexes on the control strips are shown in Table 2. The only significant differences in grain yield were found at the Cutbank site where footslope and level complexes significantly outyielded shoulder complexes. At the Kresse and Termuende sites moisture stress resulted in very low grain yields and harvest indices, and masked the effect of landscape position on yield. Soil moisture in the spring was very low on the stubble fields (Table 1) and although exceptional precipitation in May and June (171 mm) gave rise to substantial dry matter production, hot dry weather in July and August resulted in low grain yields. At the Kresse site significantly higher total yields were measured on footslope and level complexes than on the shoulder complexes. The absence of significant differences in total yield at Termuende reflected the uniformity of soil properties at the site.

Table 2. Average yields for the unfertilized strips on the landform element complexes at the three sites.

	LEC	Cutbank	Kresse	Termuende
Grain Yield kg/ha	Shoulder	1641 a	1496	1297
	Footslope	2097 b	1531	1252
	Level	1911 ab	1519	1284
Total Yield kg/ha	Shoulder	3692 a	3464 a	3884
	Footslope	4942 b	4317 b	3971
	Level	4310 b	4393 b	4019

Fertilizer Responses on the Landform Units

Fertilizer responses for the two landform element complexes which showed the greatest contrast are shown in Figure 1. Grain yield is plotted for the Cutbank site but total yields were used for the Kresse and Termuende sites to avoid the leveling effect of late season moisture stress on grain yield.

There was a significant response in yield to most of the fertilizer treatments at the Cutbank site. On the shoulder complexes 20 kg/ha of N or P did not produce a significant response if the other nutrient was missing. Only the N:20 P:0 treatment failed produce a yield response on the footslope complexes. The

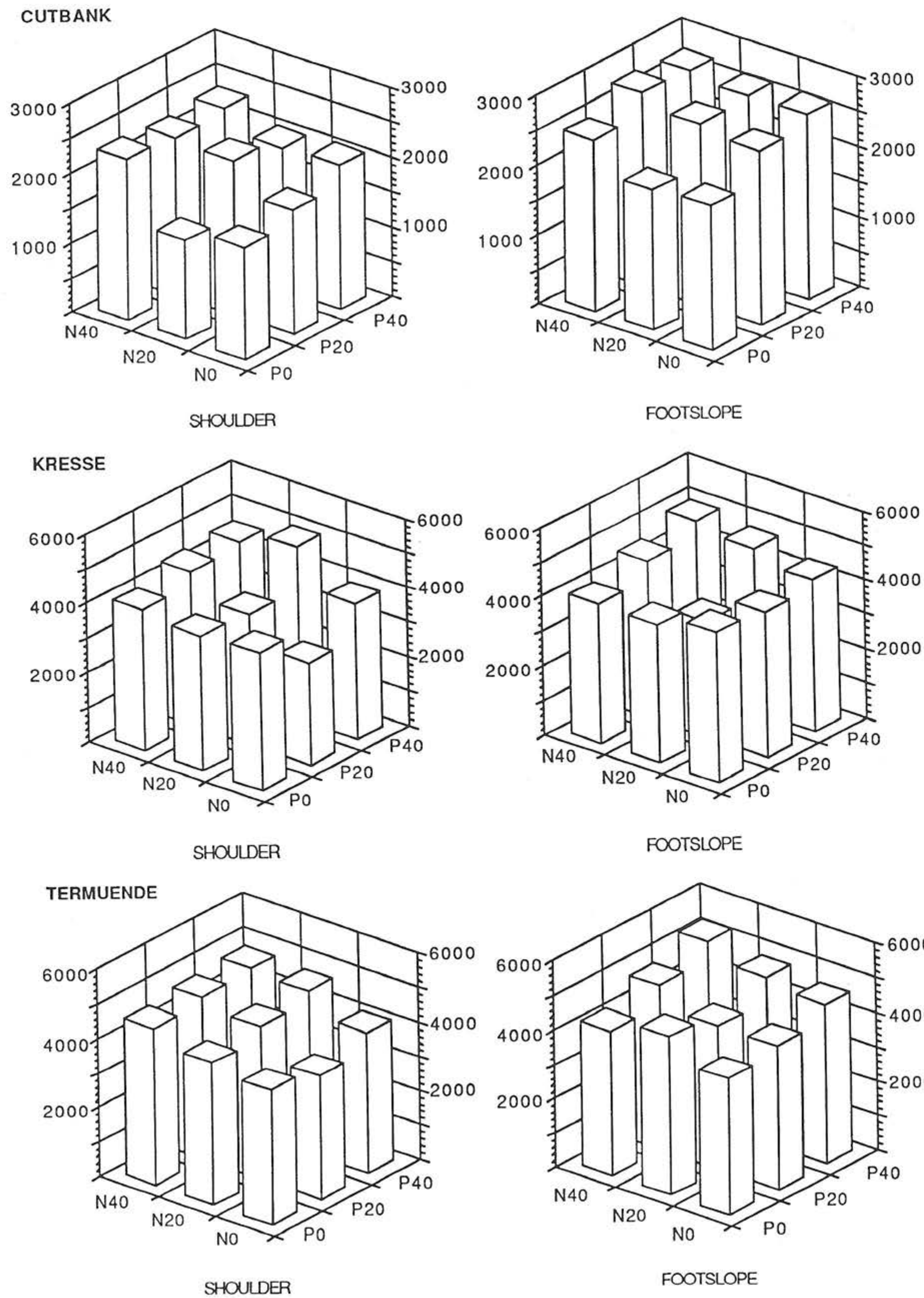

Figure 1. Yield reponses on shoulder and footslope complexes. (all units in kg/ha).

shoulder complexes responded more strongly to N fertilizer than the footslopes but the effect of P was greatest on the footslope complexes although responses were good throughout the landscape.

At the Kresse site, fertilizer responses were generally better on the footslope complexes than the shoulder complexes. On all three landform element complexes the only treatments which significantly increased total yield above that on the check strips were N:40 P:40, N:40 P:20 and N:20 P:40.

There were no significant differences in total yield due to fertilizer addition at the Tremuende site. Trends in total yield were similar on all landscape element complexes but P responses appeared stronger on the footslopes than the shoulders.

CONCLUSIONS

Landform element complexes are a useful tool for subdividing a field into management units as they seem group soils with similar properties. The benefits of variable rate fertilization were more apparent on the Cutbank and Kresse sites where there was greater variability in soil properties. Results were inconclusive but shoulders appear to benefit more if both nitrogen and phosphorus fertilizers are applied whilst yield responses (especially to phosphorus) appear to be greatest on footslope complexes.

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DIGITAL ELEVATION MODEL ATTRIBUTES FOR PREDICTING SOIL FERTILITY

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ABSTRACT

The development of a field-scale geographic information system (GIS) for fertility management will depend on development of sufficiently precise soil fertility maps. Traditional soil sampling techniques for fertility management are inadequate for precise, within field management of soil fertility. The use of a digital elevation model (DEM) in combination with a soil map may be a strategy to improve on traditional sampling schemes. The objective of this paper is to determine if DEM attributes are related to pH, NO_3-N, P, K, and organic matter. The DEM attributes for profile curvature, plan curvature, wetness index and slope were developed for a 5280' by 330' crop strip near Power, MT. Regression was used to compare these values to values for NO_3-N, P, K, pH and organic matter from 93 sample points in the strip. The soil fertility values were also analyzed with ANOVA using SCS soil mapping units as independent variables. Slope had the most significant relationship to the soil variables compared to the other DEM attributes. Preliminary results indicate that the soils map more accurately portrays the variability in soil fertility compared to DEM attributes.

INTRODUCTION

Geographic information systems are currently being used to investigate numerous natural resource issues primarily at small scales. Large scale agronomic applications have not been attempted. A field-scale GIS (FSGIS) would capture any economic and environmental benefits of farming soils according to their individual needs. The implementation of a FSGIS would be a powerful tool for implementing the "Farming Soils, Not Fields" concept (Carr, 1991). The development of a FSGIS for fertility management would depend on sufficiently precise soil fertility maps. A traditional composite soil sample representing a "field average" will mask any fertility differences within the field and is inadequate for differential fertilizer application. To facilitate the intensive sampling needed for a FSGIS, we are investigating the integration of landscape attributes into a SCS soil survey map using a DEM. A DEM is an electronic, three dimensional representation of the terrain. Landscape attributes obtainable from a DEM which may relate to soil fertility include slope, profile (down-slope) curvature, plan (across-slope) curvature and relative wetness indices. These attributes have been related to water movement and soil productivity, and may help to describe concentrations of NO_3-N, P, K, pH and organic matter.

OBJECTIVE

The objective of this work is to determine if DEM attributes or SCS soil mapping units can be related to residual levels of NO_3-N, P, K, in addition to pH and organic matter.

METHODS

Study Area

The study area (5280' by 330') is a winter wheat/fallow strip near Power, MT dominated by silty clay loam and silty clay textured soils derived from Colorado Shale. The area was glaciated during the late Pleistocene, but no glacial till remains. The soils vary mainly in depth to a paralithic contact, gypsum and salts. The topography is typical of till plains with two small drainage ways at the north end of the strip and large, gently sloping planar areas in the south intersected by a short, moderately sloping area.

Permanent sample points (93) were established on a 100 by 165 foot grid. This configuration gave three transects separated by 100 feet that ran the length of the strip. Sample points were sampled pre- and post-harvest (Aug 1990 and 1991) in 0-6, 6-12, 12-24 inch increments. Nitrate-N was analyzed at all depths in 1990 and 1991 while P, K, pH and organic matter were analyzed at the first depth in 1990 only. Winter wheat yield data were collected on 4 by 165 foot plots (0.015 acre) with a Hegge plot combine. The plots coincided with the permanent sample points and were replicated twice. Test weights were determined for each sample. Yield and test weight data are not reported.

Digital Elevation Model

Elevation data were collected around the edge of the strip using a pair of Trimble 4000-ST global positioning system (GPS) receivers. These data were interpolated to a square, 61 ft grid using algorithms described by Moore et al (1988). Results of this study are preliminary, since the data are interpolated across the study area and further GPS derived elevation data are being collected within the study strip. The interpolated 61 ft elevation data were next entered into Moores' TAPES-grid (Topographic Analysis Programs for the Environmental Sciences) DEM (Moore et al. 1988; Moore and Nieber, 1987) to produce plan curvature (Plan-c), profile curvature (Prof-c), slope and specific catchment area attributes for each 3716 ft^2 cell in the study area. The specific catchment area (As) is the area draining to a cell divided by the width of that cell. A wetness index (WI) is derived from As for each cell by: WI = ln(As/tan slope).

Database Development

The standard SCS soils map of the study area and DEM attributes were analyzed in ARC/INFO using standard GIS techniques. The values for prof-c, plan-c, WI and slope were imported from the DEM into a grid containing 568 cells which represented the study area. A point-in-polygon overlay of a map of the 93 sample points and the grid was performed to determine which cells the sample points were in. The DEM attributes for each cell containing a sample point and the values for NO_3-N, P, K, pH and organic matter for each sample point were extracted from ARC/INFO for further analysis. Regression analysis was performed on these data using MSUSTAT (Lund, 1987) with the DEM attributes as the independent variable.

The SCS soil mapping units were also used to group the fertility data. The data were grouped by soil mapping unit and by individual polygon. Analysis of variance was performed on both data sets using MSUSTAT.

RESULTS AND DISCUSSION

The DEM attribute values reflect the subtle topography of the study area (Table 1). There are no extreme values for any of the attributes. The low values of Prof-c and Plan-c indicate the gradual changes in the land surface. The WI values are indices relative only to the total area analyzed with the DEM. Larger indices indicate those cells in the study area having low slope and large drainage areas relative to other cells in the study area. The slope values further reflect the gentle topography with a maximum value of 7.5%.

Table 1. Summary statistics for the digital elevation model attributes profile curvature (Prof-c), plan curvature (Plan-c), wetness index and slope.

Attribute	Minimum	Maximum	Mean
Prof-c (degree/yd)	-0.07	0.14	-.0014
Plan-c (degree/yd)	-0.11	0.11	0.005
Wetness index	4.2	10.0	6.4
Slope (%)	0	7.5	2.2

Results from the regression model for the soil variables compared to the DEM attributes indicate that slope had the greatest predictive capability (Table 2).

Table 2. Summary regression analysis results for soil fertility variables and DEM attributes.

	Prof-c	Plan-c	Wetness index	Slope
Nitrate depth (in)				
0-6	*[+]	NS	NS	*
6-12	NS	NS	NS	*
12-24	NS	NS	NS	*
0-24	NS	NS	NS	*
Phosphorus	NS	NS	*	NS
Potassium	**	NS	NS	*
pH	*	NS	NS	NS
Organic matter	NS	NS	NS	NS

[+] *, **, NS Significant at P= 0.05, 0.01 probability levels and not significant, respectively.

However, the data exhibited a large degree of variability for all attributes and the overall predictive capability is low. Slope was significant for all NO_3-N depths and K. Prof-c was significant for the 0-6" NO_3-N values, K and pH. Wetness index was significant for P only and plan-c was not significant for any soil variable.

Analysis of variance for the individual mapping unit polygons indicate significant differences for some soil variables between mapping units (Table 3). All units, but one, had significant differences for at least one soil variable, with none having significant differences for all variables. These differences were not consistent by either polygon or soil variable. Mapping units 170 and 70 did not exhibit the same variability from one unit to a similar unit. Unit 170 is a complex of three contrasting soils and the variability between the units can be expected. The results of this analysis indicate that soil units in the study area behave differently and may respond to variable management. When grouped by mapping unit and not by polygon alone the data resulted in even fewer significant differences than the data presented.

SUMMARY

Preliminary results suggest that soil units more realistically reflect fertility differences than the DEM attributes alone. Of the DEM attributes, slope had the most significant relationship to the soil variables. Further work with these data is being completed to determine if the incorporation of the DEM attributes into the soils map will improve the predictive capability of the soils map for fertility management.

Table 3. Summary analysis of variance results for soil fertility variables and soil mapping units.

	Soil mapping unit polygon ID					
	80	45	70	170	70	170
Nitrate depth (in)						
0-6	**[+]	NS	NS	***	*	NS
6-12	NS	NS	NS	***	**	*
12-24	NS	NS	NS	***	*	NS
0-24	NS	NS	NS	***	*	NS
Phosphorus	NS	NS	NS	***	NS	NS
Potassium	**	NS	NS	NS	**	*
pH	**	***	NS	NS	**	***
Organic matter	*	NS	NS	***	NS	NS

[+] *, **, ***, NS Significant at P= 0.05, 0.01 and 0.001 probability levels and not significant, respectively.

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SPATIAL VARIATION OF SOIL NITRATE WITHIN A CONTINUOUSLY CROPPED AGRICULTURAL FIELD

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ABSTRACT

An 7.4 acre field which had been cropped to continuous wheat was sampled in order to examine the spatial variability of soil nitrate across an agricultural field. In an effort to characterize the horizontal spatial variability of soil nitrate semivariograms were created from both surface and subsurface soil cores; a total sampled depth of 4.00-ft. These horizontal semivariograms were produced at six depths: 0-6, 6-12, 12-18, 18-24, 24-36 and 36-48 inches. Actual measured nitrate values varied widely, ranging from a low of 22 lbs/A (0-6 inch depth) in the NW corner of the field to a high of 140 lbs/A in the SE section of the field. This variation was evident in all the sampled depths. Omnidirectional semivariograms at all depths were fit to a Gaussian model, providing information about the sill and range of each soil depth. Directional semivariograms demonstrated strong directional ansiotropies, as both the sill and range varied with direction across the field. Results indicate that, while strong spatial relationships for soil nitrate are present, a reevaluation of the data set for the presence of trends may be necessary.

OBJECTIVES

1. Determine the usefulness of geostatistical techniques for the characterization of the spatial variability of soil nitrate.

2. Examine the changes in spatial variability of soil nitrate that occur with depth in a field that has been cropped to continuous wheat.

METHODS AND MATERIALS

The chosen experimental site was a uniform field located in north central Oklahoma that had been cropped to continuous wheat for a period of at least ten years. The soil type was a Pond Creek silt loam (fine-silty, mixed, mesic Pachic Argiustoll). Total sampled area measured 7.41 acres, sampling every 82 feet in a square grid across the site. A smaller grid was centered in this large grid, and samples were removed every 16.4 feet within the small grid. A total of 63 and 36 points were sampled from the large and small grids, respectively.

Each grid point was sampled with a Giddings hydraulic soil probe to a depth of 4 feet. The cores were sectioned into 6 or 12 inch increments for the 0-24 and 24-48 inch lengths, respectively. Soil nitrate values were determined colormetrically, using a Lachat Flow Injection Analyzer.

Geostatistical analysis was performed using the GEOEAS computer program, a public domain software program from the USEPA. Semivariograms were calculated both omnidirectionally and directionally, and models were visually fit to these semivariograms. Chosen models will be used in subsequent kriging procedures.

RESULTS AND DISCUSSION

Table 1 provides summary statistics for soil nitrate at the six chosen depths. At all depths the maximum value was much larger than the mean value, signaling the presence of outlying high values. The presence of erratic values was further illustrated in both the coefficient of variation (ratio of the standard deviation to the mean) and the skew. A coefficient of variation that is higher than 1.0 may signal a data set that contains erratic values, which may have an impact on final estimates.

Table 1. Summary statistics for soil nitrate as measured at six soil depths.

Depth	Mean	Max	Min	C.V.	Skew
--in--	--------lb/A-----------				
0-6	48	140	22	.35	2.0
6-12	19	67	7	.55	2.8
12-18	8	63	2	1.2	4.2
18-24	6	57	1	1.3	4.0
24-36	5	31	1	1.1	2.7
36-48	5	32	1	1.3	3.2

Figure 1. illustrates the location of higher soil nitrate values within the sampled site. High values in the 0-6 inch soil increment were located in the SE corner of the field, and this region of elevated values continued for the entire 4 foot sampling depth.

Topographically, there are few on-site explanations for the wide range in soil nitrate values across the field. The site is level, with a slight downward slope (<2.0%) in the southwest direction. The region which contained higher nitrate readings was neither an elevated nor depressional portion of the landscape.

Omnidirectional semivariograms considered every direction across the field, providing a general representation of the spatial variability of nitrate. Initially, models were fit to these omnidirectional semivariograms, creating 'average' estimates of the range, sill and nugget effect. The nugget is that portion of the variance attributable to pure random error, the sill is the region where the semivariogram may level, and the range is that distance at which samples are no longer spatially related to each other.

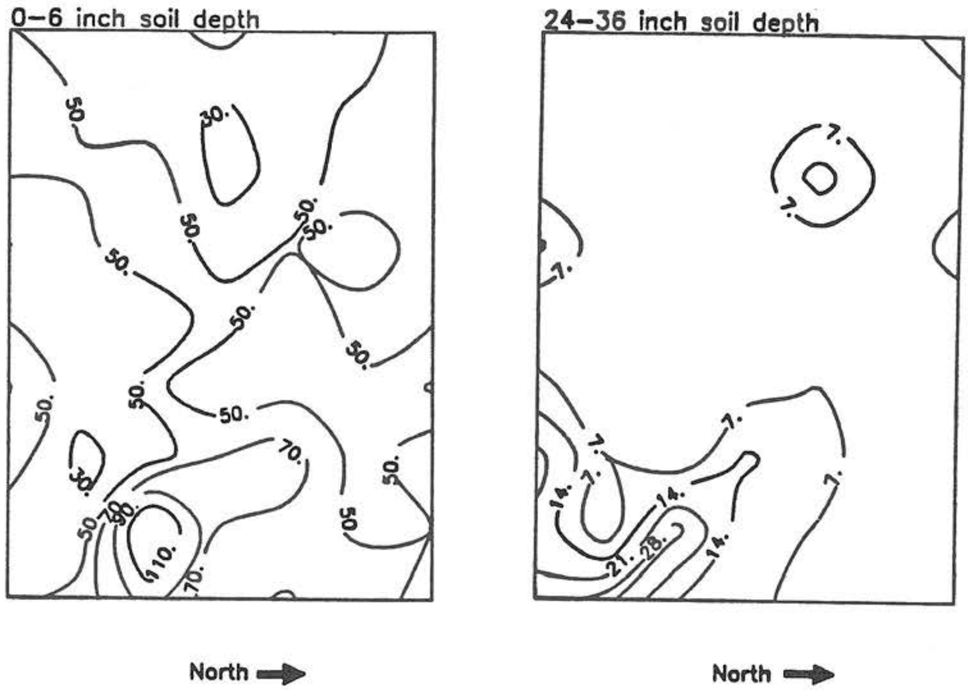

Fig. 1. Soil Nitrate Content (lb/A) at Two Soil Depths

Examples of created omnidirectional semivariograms are shown in Figure 2. A Gaussian model was fit to both these semivariograms, as occurred with almost all the remaining soil depths. A Gaussian model is characterized by a parabolic shape at the origin, and the sill is reached asymptotically. The sills shown in Figure 2 are approximately 300 $(lb/A)^2$ and 30 $(lb/A)^2$ for the 0-6 and 24-36 inch depths, respectively. The distance at which samples are no longer related to each other (the range) is 250 ft, for both omnidirectional semivariograms. Once samples are more than 250 ft apart they are no longer spatially related.

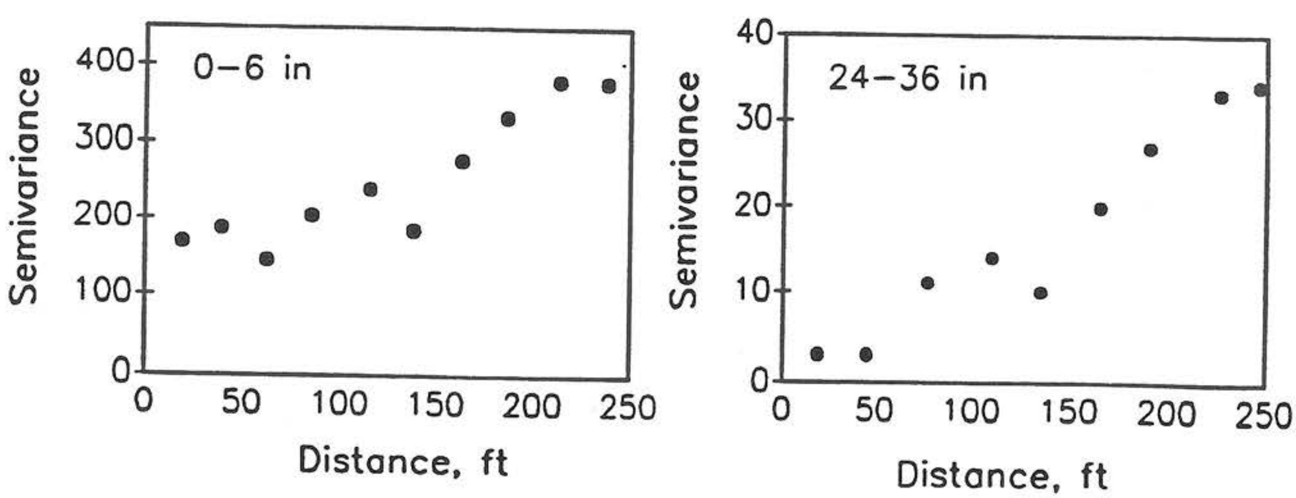

Fig. 2. Omnidirectional Semivariograms

Figures 3 and 4 provide examples of directional semivariograms, in which the spatial variation of nitrate in a given geographic direction is characterized. For example, Figure 3(N) considers all those points lying in the northern direction within a 22.5° angular tolerance. Directional semivariograms pinpoint the presence of anisotropy, which occurs when the spatial variability is not the same in every direction.

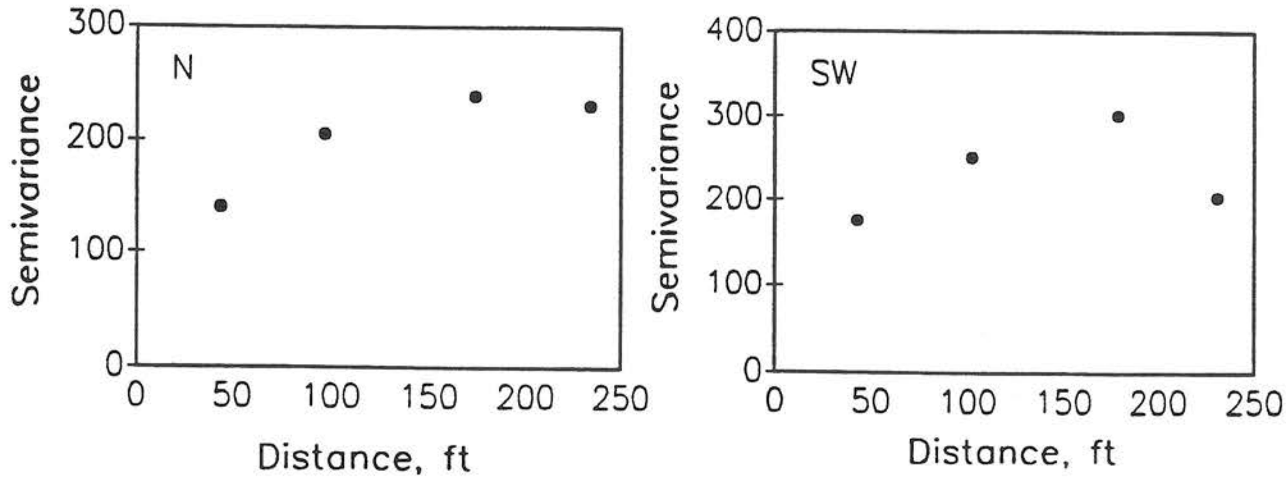

Fig. 3. Directional Semivariograms, 0-6 inch soil depth.

The directional semivariograms for soil nitrate exhibited anisotropies at all soil depths, and the direction of anisotropy changed with depth. At the soil surface (0-6 inch) soil nitrate values were most related to each other moving directly north across the field (Fig. 3). The range in this direction was 225-ft, as compared to the shorter range of 175-ft in the southwest direction. In contrast to all the other created semivariograms these two curves were fit to a spherical model, often considered to be a classical curve for describing spatial variability.

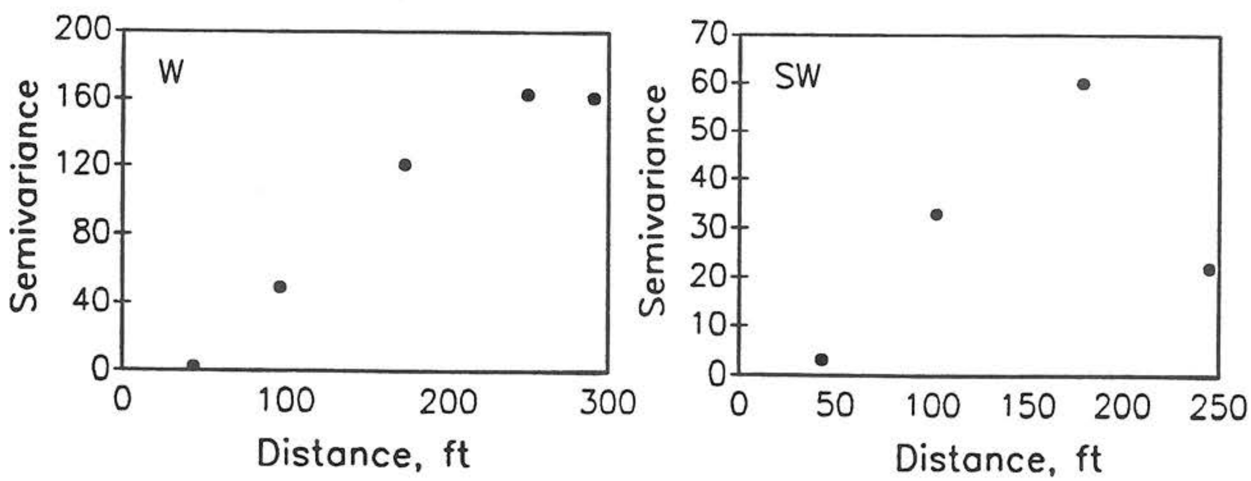

Fig. 4. Directional Semivariograms, 18-20 inch soil depth.

The direction of greatest continuity switched at the 18-24 inch depth, moving west across the field (Fig. 4). The direction with least continuity was to the southwest, demonstrated by a semivariogram with a shorter range and a less continuous semivariogram. The direction of greatest continuity would again change at the 24-36 inch depth, moving northwest across the sampled site.

The semivariogram pictured in soil depth 18-24 inch (West) was also the typical shape found in semivariograms created at the 24-36 and 36-48 inch soil depths. While this shape can indicate a continuous phenomena near the origin, it may also signal the presence of trends in the data set. Additional clues to the presence of a non-stationary data set may include the lack of a detectable nugget effect and a gently parabolic concave shape near the origin. The semivariogram shown in 18-24 inch (West) contained both of these characteristics, as did most of the semivariograms at the deeper soil depths. A reevaluation of the data sets for the presence of linear trend is the next step of this research.

The elimination of any linear trend will improve the description of spatial variability, and the model fit. An improved model fit will provide accurate estimation of unknown values during the kriging procedure. Kriging is the estimation of unknown values, a process that depends upon the validity of the model(s) fit to the experimental semivariograms.

This data set represents an intensely sampled area, with a small grid designed to help reduce the nugget effect (random variance). While this data collection design can demonstrate the benefit of geostatistics for characterizing spatial variability, it may be more important to prove that the same results can be obtained through a smaller, less intensive sampling pattern. A grid design, while simpler to evaluate, may not be as informative as an irregular sampling scheme which may concentrate samples in areas of interest.

ENHANCED AMMONIUM NUTRITION OF WHEAT

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ABSTRACT

Enhanced ammonium supply (EAS), elevated soil ammonium (NH_4) levels, can increase wheat growth by minimizing soil N leaching and enhancing N availability, or by optimizing NH_4 nutrition of the plant. Experiments were conducted between 1988 and 1991 to determine the effects of N source and N management on spring wheat yields in field environments. Inconsistent spring wheat tillering and yield differences due to N source were observed in dryland experiments, probably due to overriding moisture limitations. Nevertheless, elevated soil NH_4 levels were able to be sustained with urea and nitrification inhibitor up to anthesis. Tiller and yield responses to EAS were observed in an irrigated experiment in 1991. Grain yields averaged 41 bu a^{-1} in the spring wheat grown with calcium nitrate applied at planting, while all other N sources containing urea with or without a nitrification inhibitor averaged 62 bu a^{-1}. These differences corresponded to parallel differences in tiller number at the 6-leaf stage and head number at maturity. Greater leaching of the nitrate (NO_3) source may have partially accounted for the yield difference; however, while increasing N rate from 89 to 178 lb NO_3-N a^{-1} increased N uptake, it had no effect on dry matter accumulation or tillering at the 6-leaf stage. This implies N uptake from the NO_3 nitrate source was not limiting growth and tillering, and that NH_4 nutrition was partially responsible for these differences.

INTRODUCTION

Optimizing NH_4 nutrition of field-grown wheat requires consideration of several soil and plant factors, as reviewed by Bock (1986). Ammonium distribution in the rooting zone is a primary concern. Since NH_4 is less mobile than NO_3, it has been suggested that NH_4 requires a broad distribution throughout the soil profile to ensure adequate delivery to plant roots (Bock, 1987). More recently, the observations of enhanced tiller responses (Camberato and Bock, 1990) implies that early exposure of roots to EAS conditions may be most critical in initiating the physiological response. Banding the NH_4 source close to the early developing root systems may be adequate to elicit the response; however, maintaining large concentrations of NH_4 has potential problems with regard to NH_4 toxicity (Bock, 1986). Thus, a compromise must be found in which the placement of the N source provides adequate N positional availability while maintaining elevated NH_4 levels.

Tiller and grain head density are often correlated to final grain yield, such as in conservation tillage systems (Huggins and Pan, 1988). Management strategies for improving plant tillering may provide a method for overcoming this type of yield limitation.

OBJECTIVES

The objectives of the field experiments described herein were to 1) determine whether elevated soil NH_4 levels could be maintained through tiller development in spring wheat, 2) determine whether the maintenance of fertilizer N in the NH_4 form stimulates tiller development, and grain yield of hard red spring wheat, and 3) identify soil conditions conducive to eliciting the EAS response.

MATERIALS AND METHODS

In 1988, a factorial combination of N sources and rates was evaluated in conventional (1988-1) and conservation (1988-2) tillage systems near Pullman, WA, on a Palouse silt loam soil (fine-silty, mixed, mesic Pachic Ultic Haploxeroll) soil. The N sources were calcium nitrate (CN) with and without a nitrification inhibitor (NI, Nitrapyrin) (CN+NI and CN-NI), urea-N with a NI (U+NI), and 50% urea-N:50% CN with a NI (UCN+NI). Nitrogen was banded 4" beneath the soil surface at rates of 100, 150, and 200 lb N a^{-1}. The hard red spring wheat cultivar 'WB906R' was seeded at the rate of 100 lb a^{-1} with 12" row spacing. The seed was placed 2" beneath the soil surface and 2" above the fertilizer band. Tillers $plant^{-1}$, dry matter production and dry matter partitioning were determined at the 5-6 leaf stage, anthesis and maturity. Soil NO_3 and NH_4 levels were determined at each sampling.

In 1989, two experiments were established near Pullman, WA. Experiment 1989-1 evaluated a combination of N sources, rates and tillage. This experiment was similar to the 1988 studies except that CN-NI was replaced with a urea-N without a NI (U-NI) N source. The 1989-2 experiment evaluated the same N sources, but combined these with two N placements and four cultivars. The N sources were applied at a rate of 150 lb a^{-1} in either compact or diffuse bands in the soil. The banded N was placed 5" beneath the soil surface. Diffuse N placement was achieved by surface banding of the N source, followed by rotary tilling of the surface soil to a depth of 6". The hard red spring wheat cultivars '906R', 'Spillman' and 'Len', and the spring barley cultivar 'Steptoe', were seeded at the rate of 100 lb a^{-1} with 8" row spacing. Soil and plant samples were collected at the 5-leaf stage and anthesis, and additional plant samples were collected at maturity. Tillers $plant^{-1}$, dry matter production and dry matter partitioning were determined on the plant samples and NO_3 and NH_4 determined on the soil samples.

In 1990 and 1991, irrigated experiments were conducted near Lind, WA, on a Shano silt loam (coarse-silty, mixed, mesic Andic Mollic Camborthid) soil. The same combination of N sources, rates and placements was evaluated in each year. Four N sources (CN-NI, UCN+NI, U-NI and U+NI) were applied at rates of 89, 124 and 178 lb N a^{-1}. The NI Nitrapyrin was applied at rates of 0.5, 0.75 and 1.0 qt a^{-1} with increasing N rates, respectively, in the +NI treatments. The diffuse- and compact-band placements were accomplished in a similar manner as in the 1989-2 experiment. The hard red spring wheat cultivar 'Len' was seeded at the rate of 60 lb a^{-1} with 8" row spacing. Plant and soil sampling procedures were similar to earlier experiments. In 1990, 2" irrigation water was applied three times during the growing season, commencing after the first sampling. In 1991, weekly applications of 2" irrigation water began at the 3-leaf stage and continued through anthesis.

RESULTS AND DISCUSSION

Soil N forms. Compared to the CN+NI, CN-NI and U-NI treatments, application of U+NI resulted in substantially elevated soil NH_4 levels through the 6-leaf stage of plant growth. This trend was supported by the experiments conducted in all years; however, data from only two experiments are presented here (Table 1). Soil samples collected at anthesis showed that soil NH_4 levels remained 4 to 8 times higher in treatments combining NH_4 with a NI (data not presented). Nitrification inhibitor effectiveness was similar between the diffuse and compact band N placements (data not presented).

Table 1. Effect of N source on soil NO_3 and NH_4 levels at the 0-12" depth and the 6-leaf stage of plant growth[1].

		N SOURCE			
EXPERIMENT	N FORM	CN-NI	CN+/U-[2]	UCN+NI	U+NI
		----------- ppm soil N -----------			
1988-1	NO_3-N	48	65	3	21
	NH_4-N	19	15	42	100
1990	NO_3-N	61	21	27	6
	NH_4-N	7	18	40	48

[1]Intermediate N rate: 150 lb a^{-1} in 1988-1; 138 lb a^{-1} in 1990. Compact band N placement.
[2]CN+NI N source in 1988-1; U-NI N source in 1990.

Differences in the upper profile distribution of the N forms were apparent at the 6-leaf stage of plant growth in all experiments (data not presented). Nitrate-N tended to redistribute following application, whereas the NH_4-N remained near the point of application. In 1988, over 90 % of the applied NO_3 remained in the top 12", rather evenly distributed between the upper and lower 6". In the 1991 irrigated experiment, the differential movement of N sources was greater than previous years. By the 6-leaf stage of plant growth, the majority of NO_3-N had leached to the 12-24" depth, while the NH_4 remained at the 0-12" depth.

These data show that nitrification can effectively be inhibited, and elevated NH_4 levels can be maintained throughout the 6-leaf stage of growth and up to anthesis, in two soils of eastern and central Washington.

<u>Tillering and yield responses to N source.</u> Nitrogen source had no significant effect on plant development, dry matter accumulation or grain yields in either of the 1988 experiments; however, higher grain protein levels did result from the UCN+NI mixture than either the CN+NI or U+NI N sources in experiment 1988-1 (data not presented).

Nitrogen source had no significant effect on plant growth in experiment 1989-1; however, N source did affect the number of headed tillers $plant^{-1}$ and grain production in experiment 1989-2 (Table 2). The UCN+NI mixture increased the number of heads $area^{-1}$ by 17 and 18 percent and grain yield by 21 and 23 percent above the CN-NI and U-NI N sources, respectively, with the diffuse band placement. Grain yield with U+NI exceeded that of UCN+NI by 18% with the compact band N placement (Table 2). Furthermore, the increase in grain yield in the 1989-2 experiment was due primarily to an increase in the number of heads $area^{-1}$, as weight $head^{-1}$ was not affected by N source (data not presented).

Table 2. Effects of N source and placement on grain yield in the 1989-2 experiment.[1]

	N PLACEMENT	
N SOURCE	DIFFUSE BAND	COMPACT BAND
	----------grain yield, g m^{-1}	---------
CN-NI	512	565
UCN+NI	619	503
U-NI	505	530
U+NI	493	592
	$LSD_{.05}$: 86	

[1]Data averaged over all cultivars.

The number of T1 and T2 tillers $plant^{-1}$ was significantly lower with the U+NI than with the remaining N sources in 1990 (data not presented). Nitrogen source did not significantly affect the remaining plant parameters or grain yield. Late seeding and low moisture availability in 1990 resulted in overall poor crop performance. Over the first three years, plant stress induced by water limitation may have negated the growth-promoting response to EAS.

In the 1991 irrigated experiment, CN-NI resulted in fewer tillers than with the remaining N sources by the 6-leaf stage (Table 3). Similar effects were also apparent with dry matter production at the 6-leaf stage, and tillering and dry matter production at anthesis (data not presented). Compared with the CN-NI treatment, the remaining N sources yielded approximately 50% more grain at harvest (Table 4).

Table 3. Effects of N source, N rate and N placement on the tillering of 'Len' hard red spring wheat at the 6-leaf stage of growth (1991 experiment).

N PLACEMENT SOURCE[1]	N	N RATE (lb a^{-1}) 89	134	178
		------------ tillers $plant^{-1}$		-----------
COMPACT BAND	CN-	2.51	2.32	2.33
	UCN+	2.81	3.05	3.43
	U-	3.61	3.34	2.95
	U+	2.08	2.82	2.50
DIFFUSE BAND	CN-	1.81	1.88	2.20
	UCN+	3.37	2.79	3.23
	U-	3.37	3.28	3.05
	U+	2.32	3.60	3.68

[1]The N source x N rate and N source x N placement interactions are significant at the 5% and 1% levels, respectively. $LSD_{0.05}$ between N sources for the same or different N rate and placement: 0.90.

Table 4. Effects of N source and rate on grain yield of 'Len' hard red spring wheat in the 1991 experiment.[1]

N SOURCE	N RATE (lb a^{-1}) 89	134	178	MEANS
	--------------	grain yield, bu a^{-1}		--------------
CN-NI	37	46	39	41
UCN+NI	58	67	64	63
U-NI	51	60	74	62
U+NI	53	60	69	60
				$LSD_{0.05}$: 8
MEANS	50	58	62	
		$LSD_{0.05}$: 6		

[1]Data averaged over diffuse and compact band N placements.

Differences in the profile distribution of NO_3 and NH_4 sources in this experiment may have contributed to the observed N source effects. A total of 4" irrigation water was applied, in two equal increments, between planting and the first soil sampling at the 6-leaf stage. This sampling indicated that some downward movement of NO_3 had occurred. However, irrigation commenced at the three-leaf stage of plant growth. It is likely that the N sources were present at equal depths until that time. Furthermore, the first irrigation probably did not move NO_3 the total distance determined in the first soil sampling. Roots were observed in soil samples down to a 24" depth at the 6-leaf stage. Therefore, the N forms were positionally available to plant roots at least through the 4-leaf stage of growth. The magnitude of the early tillering response (Table 3) suggests that the N sources were having a large effect on plant growth. The effect of N source was likely apparent prior to leaching of NO_3 (prior to the 3-4 leaf stage).

Perhaps the best evidence that argues against the N availability explanation for the tiller response to N source is found in the shoot N concentration data (Table 5). Whereas N concentration in the shoots at the 6-leaf stage increased with increasing rate of CN, shoot dry matter (data not shown) and tillering (Table 3) was not affected. Therefore N availability from the CN source and resulting N uptake were not limiting factors in tiller production and shoot dry matter accumulation through the 6-leaf stage. Higher shoot N concentrations were obtained with the urea N sources than with all CN (Table 5).

Table 5. Effects of N source and rate on plant tissue N concentration at the 6-leaf stage of growth (1991 experiment).[1]

N SOURCE	N RATE (lb a^{-1}) 89	134	178	MEANS
	------------ % N in shoot ------------			
CN-NI	2.56	2.86	3.17	2.86
UCN+NI	3.90	3.98	3.92	3.93
U-NI	3.63	4.07	3.97	3.89
U+NI	3.92	4.52	4.67	4.37
				$LSD_{0.05}$: 0.18
MEANS	3.50	3.86	3.93	
	$LSD_{0.05}$: 0.38			

[1]Data averaged over diffuse and compact band N placements.

Early tillering differences paralleled head number at maturity, thus contributing to final grain yield differences among N sources. In addition, kernel weight and kernel number were also lower with CN relative to all other sources. These latter yield component effects may have been partly due to lower positional NO_3-N availability from late season leaching.

In summary, crop responsiveness to EAS may require high yielding conditions, as obtained in 1991. Greater tiller production with NH_4 sources were observed by the 6-leaf stage. A lack of dry matter and tiller responses to increasing NO_3 rates, despite increased N uptake, suggests enhanced ammonium nutrition was required to obtain greater dry matter accumulation and tiller production, as observed with the urea sources.

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THIRTY YEARS OF NITROGEN AND PHOSPHORUS FERTILIZATION OF IRRIGATED CORN AND GRAIN SORGHUM

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ABSTRACT

Nitrogen and phosphorus fertilizer were applied for 30 years to corn and grain sorghum grown in monoculture under irrigation in western KS. The objectives of the study were to evaluate the effect of long term fertilization on grain production, soil chemical properties, and production economics. Grain yields of irrigated corn and grain sorghum are increased by N and P applications. The economic optimal N rate is about 155 lb N/acre for irrigated corn and about 135 lb N/acre for irrigated sorghum based on current economics. The optimal N rate is fairly constant across yield potential. The addition of fertilizer P at 40 lb P_2O_5/acre is sufficient to maintain soil P levels for sorghum but a higher rate is needed for corn. Nitrate accumulation in the soil profile is greater with sorghum than corn at equal N rates reflecting the greater yield and N removal by corn. Application of P with N decreased nitrate accumulation, emphasizing the importance of a balanced fertility program. Application of N in excess of that needed for crop growth, reduced net income and increased nitrate accumulation and leaching below the active crop root zone.

OBJECTIVES

The initial objectives of this research were to determine the optimum N rate for corn and grain sorghum grown under flood irrigation and to determine whether fertilizer P or K was needed for maximum production. No response to K fertilization has been observed and it will not be discussed in this report. Since these studies have been conducted for over 30 years, additional objectives are to determine the long term effects of N and P fertilization on chemical content of the surface soil (particularly P) , nitrate accumulation in the soil profile, and nitrate movement below crop root zones.

MATERIALS AND METHODS

Nitrogen and phosphorus fertilizers were applied annually since 1961 to irrigated corn and grain sorghum grown on a Ulysses silt loam (Aridic Haplustoll) . The experiment was conducted at the Tribune Unit, Southwest Kansas Research-Extension Center. Initial chemical properties of the surface soil (0-6 inch) were 17 ppm P (Bray-1) , 1.4% organic matter, and pH of 7.9. A complete factorial of six N rates (0, 40, 80, 120, 160, and 200 lb N/acre) as NH_4NO_3 and two P rates (0 and 40 lb P_2O_5/acre) as triple super phosphate was arranged in a randomized complete block design replicated five times. Fertilizers were broadcast by hand in early spring and incorporated prior to planting. Corn and grain sorghum were grown in adjacent areas. Plot size was 12 by 60 ft for corn and 10 by 60 ft for grain sorghum. Both studies were furrow irrigated during the growing season to meet evapotranspiration demand. After physiological maturity, the center two rows of each plot were machine harvested (hand harvested prior to 1984). Grain yield was adjusted to 15.5% moisture for corn and 12.5% for grain sorghum. Periodically during the study, surface soil samples (0-6 inch) were collected and analyzed for Bray-1 P. . After harvest in 1990, soil samples to a depth of 10 ft were collected and analyzed for NO_3-N by extraction with 1M KCl and colorimetric analysis.

Economic analyses were based on estimated yield response curves to determine net revenue, cost of production per bushel, and optimal economic N rate for corn and sorghum. The P rate for all analyses was 40 lb P_2O_5/acre. The yield response curve for corn is a function of N rate (linear and quadratic) and a time variable. Sorghum yield is a function of N rate (linear and quadratic) without a time variable. Since yields varied from year to year, the dataset was also partitioned by yield potential (low, medium and high) based on annual average yields. optimal economic N rates were determined for each yield potential. The cost/price assumptions used were N cost of $0.15/lb, corn price of $2.50/bu, sorghum price of $2.25/bu, fixed cost for corn of $200/acre and fixed cost for sorghum of $120/acre. The fixed costs included all production expenses other than N cost.

RESULTS AND DISCUSSION

Corn yields averaged over 31 years were increased by N rates up to 160 lb N/acre (Table 1) . Although no yield response to P was observed during the first five years of the study, since then the yield response to P has steadily increased. Phosphorus fertilizer, across all N rates, increased corn yields 24 bu/acre over 31 years, 37 bu/acre over the past 10 years, and 73 bu/acre in 1991. When P was applied with adequate N in 1991, corn yields were over 100 bu/acre greater. In general, corn yields tended to increase during the study, possibly due to improvement in corn hybrids. However, when N was applied without P, yields tended to decrease with time corresponding to an increased P deficiency.

Sorghum yields increased with increased N rates, particularly with the first increment of N. Similar to corn, sorghum yield response to P fertilizer was first observed after about five years and has steadily increased since then. When averaged across N rates, P increased sorghum yields 12 bu/acre over 31 years, 18 bu/acre over the past 10 years, and 24 bu/acre in 1991. For both corn and sorghum, P applied without N did not increase grain yield. The yield potential of sorghum was about 25% less than corn.

Soil P levels reduced rapidly when no fertilizer P was applied from about 18 ppm Bray-1 P initially to less than 10 ppm after about 5 years and then stabilized at this lower level for both corn and sorghum (Figs. 1 and 2). At low N rates, soil P was increased by application of P fertilizer to both corn and sorghum. However, at higher N rates on sorghum, application of P (40 lb P_2O_5/acre)

Table 1. Effect of nitrogen and phosphorus on yield of irrigated grain sorghum and corn, Tribune, KS.

N rate	P_2O_5 rate	Sorghum 1991	Sorghum 1982-1991	Sorghum 1961-1991	Corn 1991	Corn 1982-1991	Corn 1961-1991
lb/acre		- - - - - - - -	- bu/acre§ -	- - - - - - - -			
0	0	67	72	72	64	82	70
	40	59	72	73	78	87	73
40	0	91	87	93	82	109	107
	40	121	109	107	119	131	119
80	0	100	95	105	82	115	121
	40	138	111	114	158	150	143
120	0	97	91	103	90	114	124
	40	135	115	118	180	166	159
160	0	109	93	103	89	120	131
	40	134	118	121	206	177	169
200	0	110	97	105	92	119	132
	40	134	117	121	196	173	166
MEANS							
Nitrogen							
0 lb/acre		66	73	73	73	86	73
40		112	101	102	106	124	115
80		125	107	112	129	139	136
120		123	107	114	156	151	148
160		125	108	114	166	155	155
200		130	111	116	164	155	155
LSD .05		10	4	3	10	8	4
Phosphorus							
0 lb/acre		96	89	97	83	110	114
40120		107	109	156	147	138	
LSD .05		7	3	2	8	5	3

§ Grain sorghum yields adjusted to 12.5% moisture and corn yields adjusted to 15.5% moisture.

only maintained soil P levels, indicating P removal was about equal to P additions. With corn, soil P levels tended to decline slightly even with application of P, indicating that P removal by corn exceeded that supplied by fertilizer P.

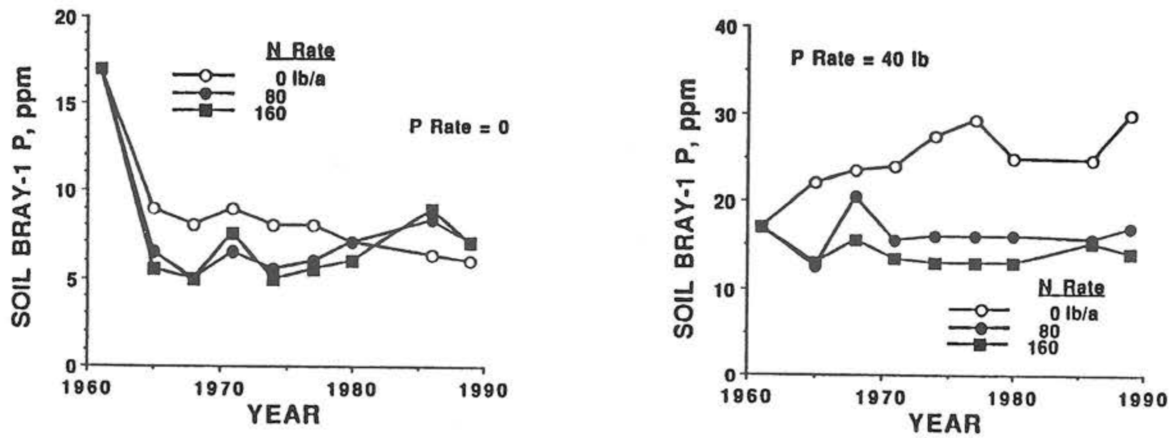


Figure 1. Effect of N rate on soil Bray-1 P level with and without additional P fertilizer on corn.

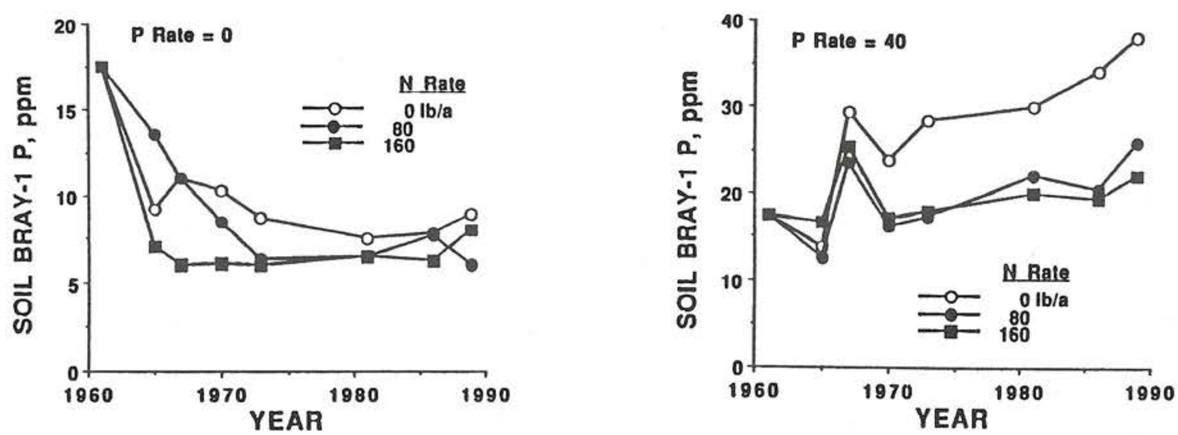


Figure 2. Effect of N rate on soil Bray-1 P level with and without additional P fertilizer on grain sorghum.

The nutrient content of the grain was not routinely measured except for recent years. Although based on limited information, the amount of N and P contained in grain was increased by P fertilizer and by increased N rates for both corn and sorghum (data not shown). Grain N and P content was about 50% more for corn than sorghum reflecting the higher yields by corn than sorghum. At optimum N rates, corn grain contained about 100 lb N/acre and sorghum grain about 70 lb N/acre. Phosphorus content of the grain was about 20 lb P/acre for corn and 14 lb P/acre for sorghum. Assuming these amounts of P removal to be typical of the entire study, corn removed more P than was supplied by fertilizer P (40 lb P2O5 is equivalent to 18 lb P) and sorghum removed slightly less. This corresponds to the slight decrease in level of soil P in the corn study and the maintenance of soil P level in the sorghum study.

Nitrate levels in the soil profile after 30 years of N and P applications were greater with higher N rates (Tables 2 and 3). At higher N rates, nitrate accumulation was less with corn than sorghum, reflecting greater N removal by corn. The addition of P reduced nitrate accumulation throughout the profile, particularly for sorghum. When high rates of N (160 lb/acre or above) were applied without P to sorghum, over 400 lb nitrate-N accumulated in the soil profile between 5 and 10 ft which is below most root growth. With reduced possibility of plant uptake, this nitrate is more susceptible to further leaching and could contaminate groundwater. This emphasizes the importance of a balanced fertility program and the environmental hazard of applying N fertilizer in excess of crop requirements.

The economic optimal N rate for corn is about 155 lb N/acre using the long term average yield (Fig. 3). This is about 10 lb N/acre less than the N rate producing maximum grain yield and 10 lb N/acre more than that producing least cost per bushel production. When production functions were determined by yield potential, the economic optimal N rate remained at about 155 lb N/acre for years with low, medium, or high yield levels (Fig. 4). For sorghum, the economic optimal N rate is about 135 lb N/acre based on long term average yields (Fig. 5). This compares to maximum grain yield obtained at 150 lb N/acre and least cost per bushel production obtained at 120 lb N/acre. The economic optimal N rate for sorghum at medium and high yield potential remained about 135 lb N/acre, while optimal N rate for low yield potential is about 120 lb N/acre (Fig. 6). This suggests that for a particular field that the optimum N rate is fairly constant. Therefore, the practice of applying additional N to provide adequate N in case of better than average growing conditions, so called "insurance" N, is unnecessary and reduces net return.

Table 2. Effect of 30 years of N and P applications on irrigated corn on soil NO_3-N content, Tribune, KS, 1990.

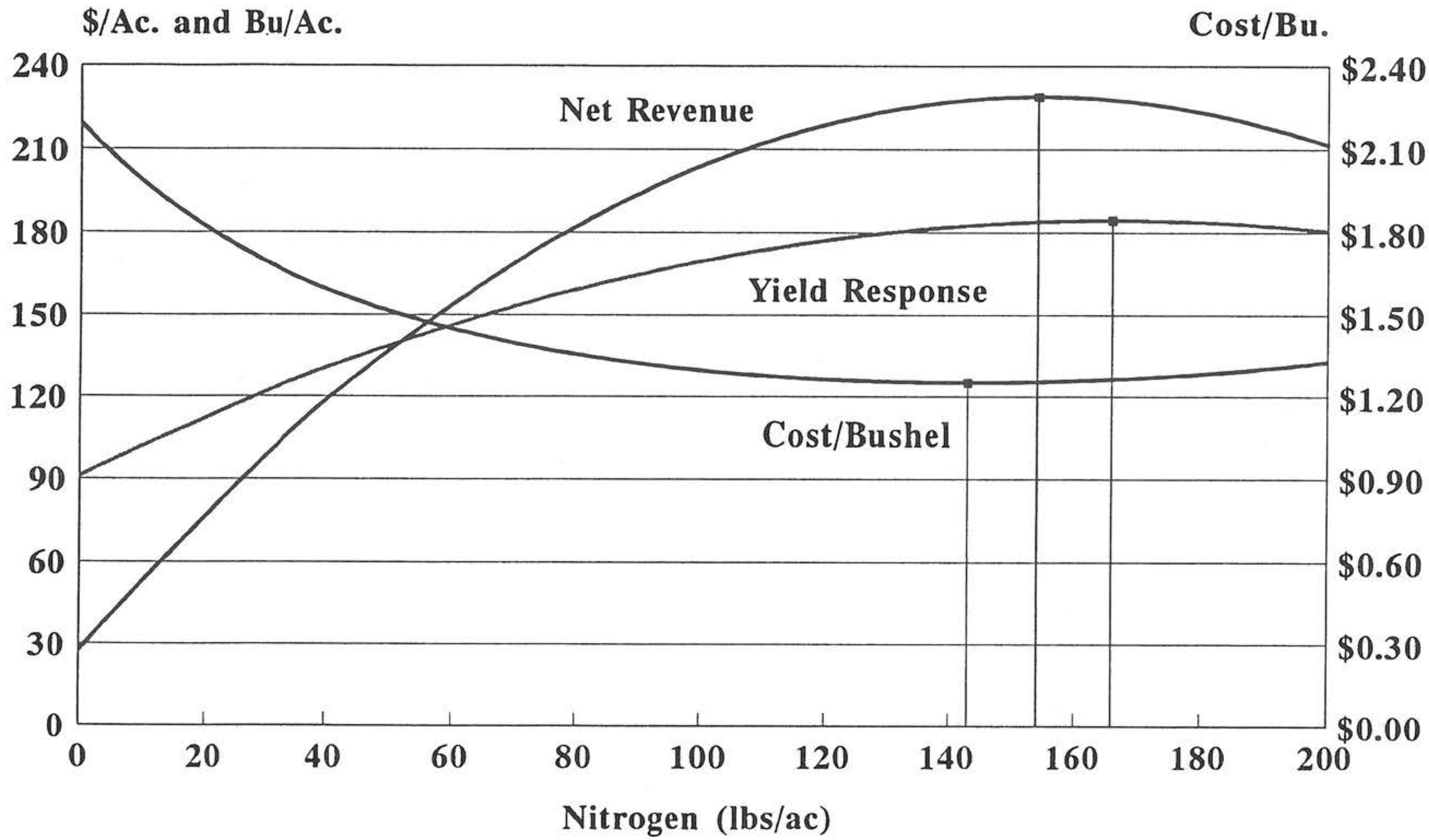
N rate	P_2O_5 rate	Depth, inches 0-6	6-12	12-24	24-36	36-48	48-60	60-72	72-84	84-96	96-108	108-120
lb/acre		- - - - - -	- -	- -	- -	lb NO_3-N/acre	- -	- -	- -	- -	- -	- -
0	0	2	1	1	2	1	1	1	1	2	2	2
40	0	2	1	1	1	1	1	1	2	2	2	3
80	0	3	2	2	2	1	1	1	2	3	4	5
120	0	9	3	9	11	8	5	3	3	6	10	13
160	0	6	4	20	38	20	21	21	21	26	24	24
200	0	3	2	8	24	22	18	14	12	14	15	18
0	40	2	1	1	1	1	1	1	1	2	2	2
40	40	2	1	2	1	1	1	1	1	1	1	2
80	40	2	1	2	4	3	3	6	7	7	7	2
120	40	3	2	2	1	1	1	1	2	2	3	4
160	40	5	3	4	3	2	2	4	6	7	7	7
200	40	7	5	25	20	17	22	17	12	12	13	17

N rate	P_2O_5 rate	Depth, ft 0-2	2-5	5-10	0-10
lb/acre		- - - - - -	lb NO_3-N/acre	- - - -	- - - -
0	0	3	4	7	15
40	0	4	3	9	17
80	0	6	4	15	25
120	0	21	25	36	81
160	0	29	79	116	224
200	0	14	63	73	149
0	40	4	4	8	15
40	40	4	3	6	14
80	40	4	10	29	43
120	40	7	4	12	22
160	40	12	6	30	48
200	40	36	59	71	166
$LSD_{.05}$		20	52	58	119

Table 3. Effect of 30 years of N and P applications on irrigated grain sorghum on soil NO_3-N content, Tribune, KS, 1990.

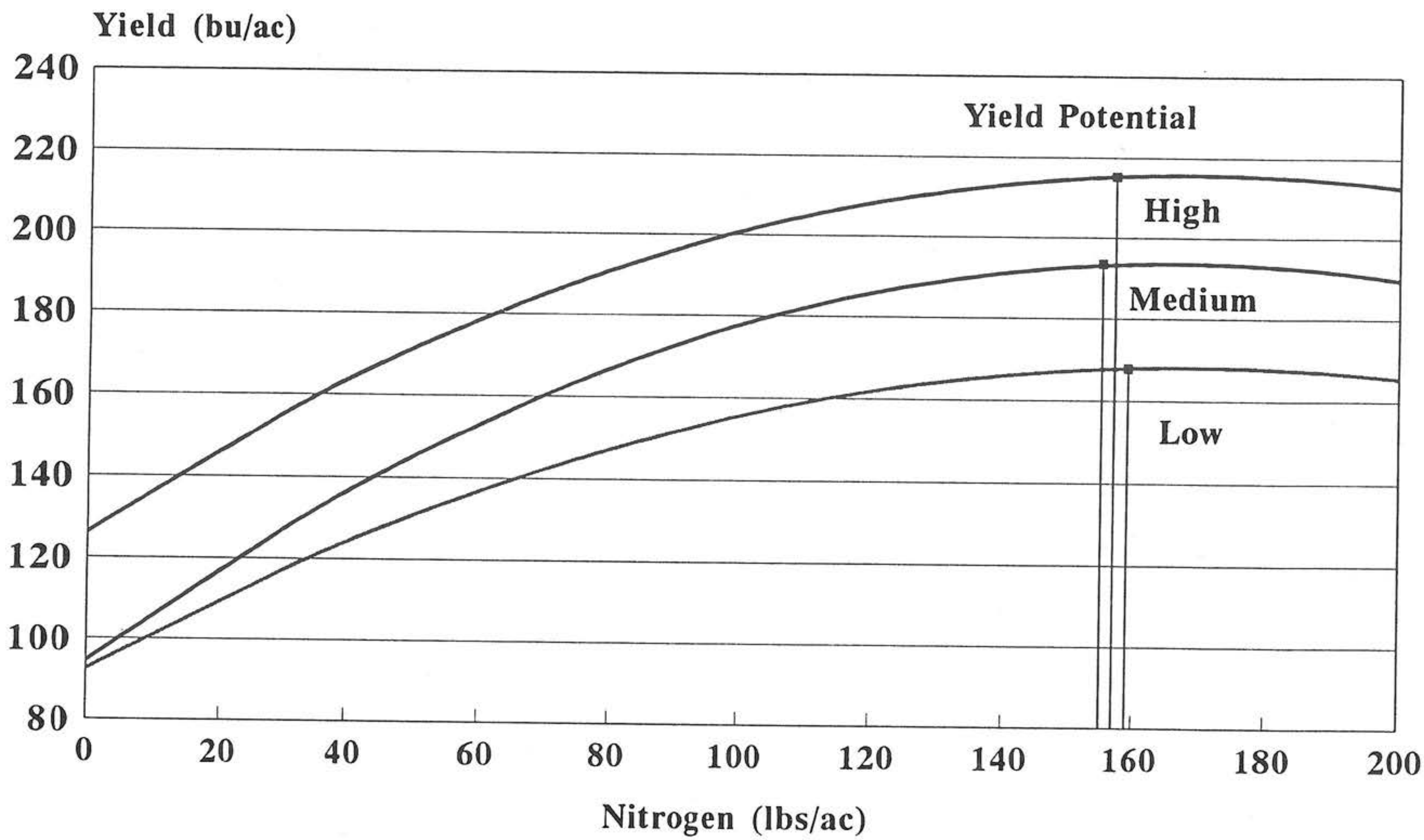
N rate	P_2O_5 rate	Depth, inches 0-6	6-12	12-24	24-36	36-48	48-60	60-72	72-84	84-96	96-108	108-120
lb/acre		- - - - - - - - - -					lb NO_3-N/acre				- - - - - - - - - -	
0	0	2	1	1	1	1	1	1	1	1	1	3
40	0	5	2	2	1	1	1	1	1	1	1	2
80	0	11	11	13	2	1	3	5	8	13	22	29
120	0	15	13	23	9	8	17	16	22	24	24	23
160	0	26	28	46	40	56	79	115	11	100	86	64
200	0	19	24	62	68	47	38	26	38	78	129	111
0	40	2	1	1	2	1	1	1	1	2	2	2
40	40	2	1	1	1	1	1	1	1	1	2	2
80	40	4	3	4	1	1	2	3	2	2	1	2
120	40	5	3	4	3	1	2	5	7	6	7	8
160	40	12	10	24	17	9	8	14	20	24	28	29
200	40	7	12	27	16	14	20	21	32	37	45	30

N rate	P_2O_5 rate	Depth, ft 0-2	2-5	5-10	0-10
lb/acre		- - - - - - -	lb NO_3-N/acre		- - - - - - -
0	0	4	2	7	12
40	0	9	2	6	17
80	0	35	6	76	118
120	0	51	34	108	193
160	0	99	175	476	750
200	0	105	156	382	643
0	40	5	2	7	14
40	40	4	2	7	12
80	40	11	4	10	25
120	40	12	6	33	52
160	40	45	35	115	195
200	40	45	50	165	260
$LSD_{.05}$		53	45	82	136



Pc=$2.50/bu, Pn=$0.15/lb, FC=$200/ac

Fig. 3. Estimated yield response, net revenue, and cost per bushel of irrigated corn averaged over 30 years, Tribune, KS.



Pc=$2.50/bu, Pn=$0.15/lb, FC=$200/ac

Fig. 4. Estimated economic optimal level of N for irrigated corn at three yield potentials, Tribune, KS.

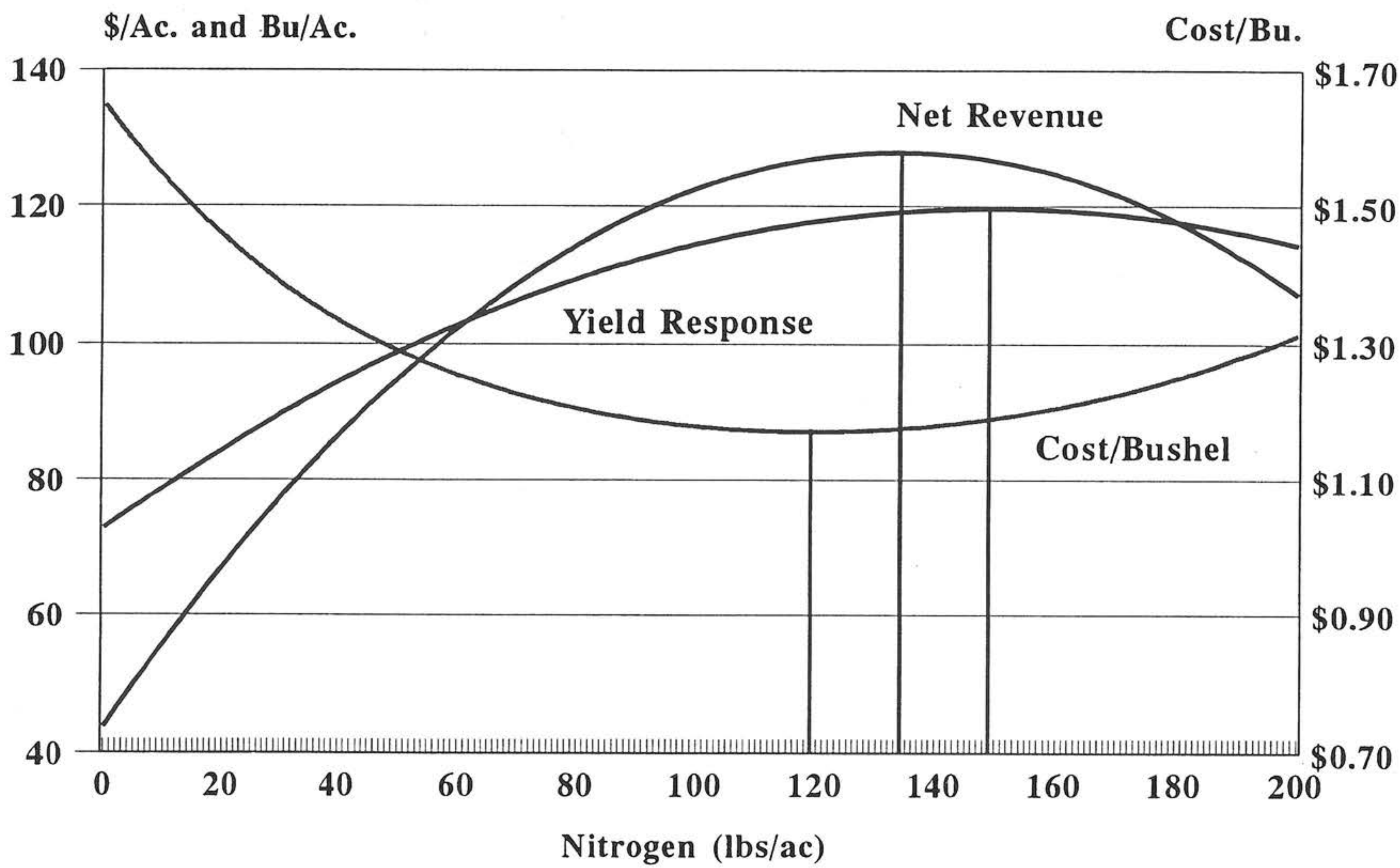


Fig. 5. Estimated yield response, net revenue, and cost per bushel of irrigated grain sorghum averaged over 30 years, Tribune, KS.

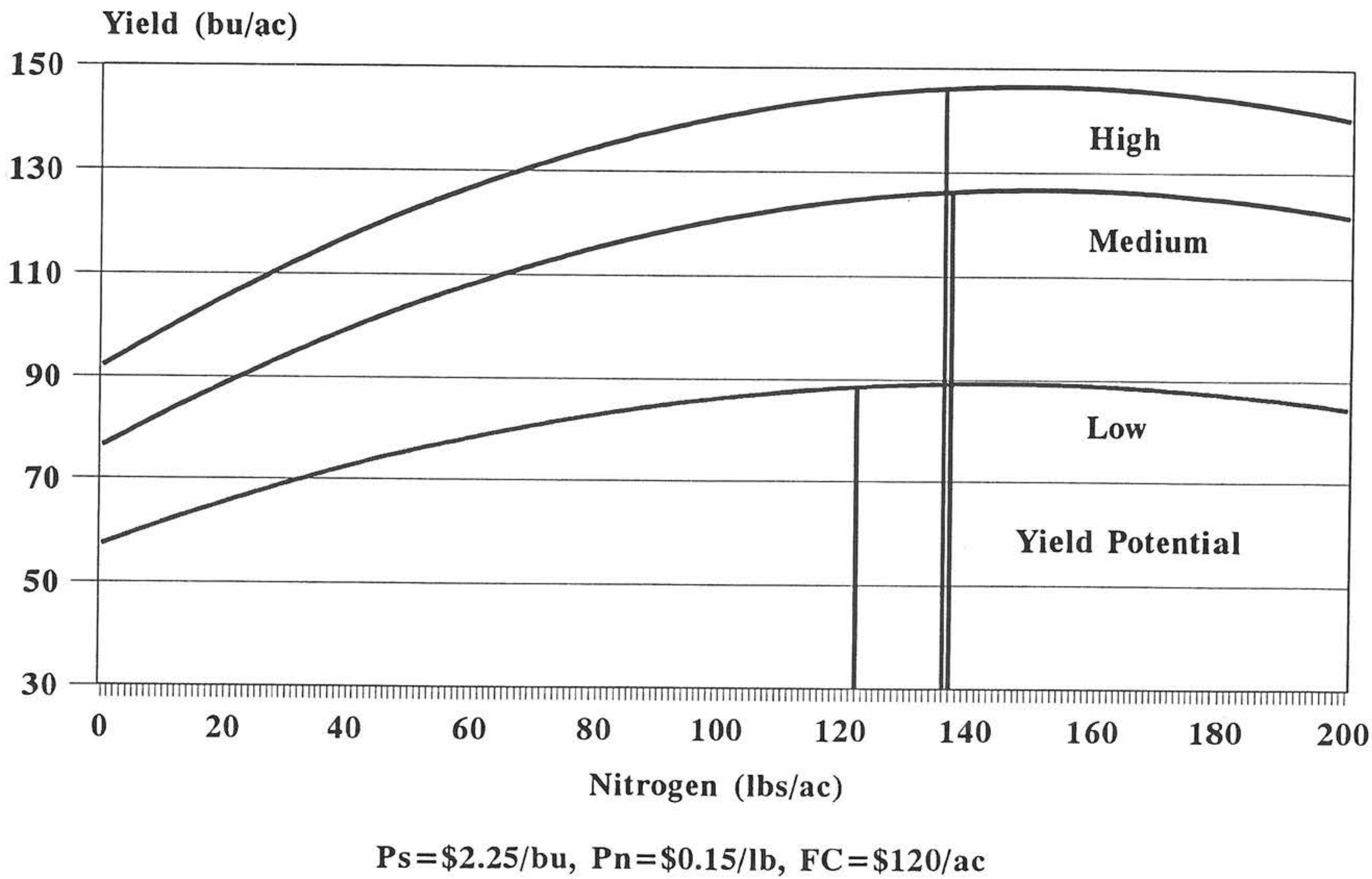


Fig. 6. Estimated economic optimal level of N for irrigated grain sorghum at three yield potentials, Tribune, KS.

NITROGEN MANAGEMENT FOR IRRIGATED SUGARBEETS

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ABSTRACT

Managing nitrogen (N) for profitable sugarbeet production presents unique challenges not experienced by most cereal producers. Excess late-season N can reduce crop quality and grower profit. Studies were conducted in Wyoming to examine sugarbeet response to N interactions with plant density and harvest date and to evaluate point injection and N timing as N management tools. In the first study, N interactions with plant density and harvest date were not significant. Data collected indicate that this may be caused by loss of excess N by NO_3 leaching, thus eliminating N interactions with plant density and harvest date. The second study indicates that point injection has potential to improve N efficiency through increased timing and placement options. In both studies, N rate was the most important treatment factor affecting sugarbeet yield and quality.

OBJECTIVES

Nitrogen (N) recommendations for sugarbeets emphasize providing adequate, but not excessive, available-N supply. In cereals, small to moderate N excesses do not usually affect yield or crop quality, but, in sugarbeets, excess late-season N can reduce crop quality and grower profit. Studies have been conducted to determine N management practices for optimum sugarbeet production (1, 2, 3, 4). High N rates used for irrigated sugarbeets create situations conducive to large N leaching losses and accurate N management can improve grower profit and reduce nitrate groundwater contamination.

Nitrogen recommendations for sugarbeets are site specific and may range from 50 to over 300 lbs/acre (4). Irrigated sugarbeet-producing states of the Great Plains make recommendations based on soil NO_3-N and generally recommend deep soil sampling (3 to 6 ft) because sugarbeets can utilize N from depths of 6 ft or more (5). Most recommendations account for contributions from soil organic-N mineralization, but are for preplant, broadcast N and do not account for cultural practices affecting crop response. Sucrose accumulates in the roots most rapidly between late July and early September (2). Excess N can prolong vegetative growth and delay sucrose accumulation. Lower optimum N rates would be expected when early harvest is anticipated (2, 5).

The objectives of the studies reported here were to (1) examine N-rate interactions with plant density and harvest date (Experiment 1) and (2) determine the potential of precision placement and timing - specifically point injection with a spoke-wheel injector - to improve N-use efficiency (Experiment 2).

MATERIALS AND METHODS

Experiment 1 was conducted at the University of Wyoming Research and Extension Center at Powell from 1989-1991. Sugarbeets were grown with furrow irrigation on a Garland clay loam with the following properties: organic matter, 1.3 %; pH, 7.3; available P, 12.3 ppm; and available K, 225 ppm. Nitrate-N (estimated from NO_3 concentration and average bulk density) in a 3-ft profile was 23, 41, and 55 lbs/acre in 1989, 1990, and 1991. Sugarbeets followed small grains each year. Experiment 2 was conducted at Powell in 1990 and 1991 and at Torrington in 1991. The Torrington study was conducted under sprinklers on a Bayard sandy loam with the following properties: organic matter, 1.4 %; pH, 8.0; available P, 8.2 ppm; and available K, 321 ppm. Nitrate-N in a 3-ft profile was 124 lbs/acre. Sugarbeets followed small grains at Powell and corn at Torrington.

Experiment 1 was conducted as a randomized complete-block design in a split-plot arrangement. Main plots were applied-N rates of 0, 100, 150, 200, 250, and 300 lbs N/acre. Nitrogen treatments were broadcast and incorporated before planting as ammonium nitrate (34-0-0). Subplots were target plant densities of 15,000, 25,000, 35,000 and 45,000 plants per acre. Plots were harvested at 20-day intervals in 1989 and at 14-day intervals in 1990 and 1991 beginning 13 Sept in all years. Plant density and harvest date are discussed only inasmuch as they interact with N.

Experiment 2 was conducted as a randomized complete-block design at Powell in 1990 and at Torrington in 1991 and as a randomized complete-block design in a split-plot arrangement at Powell in 1991. Treatments consisted of a control (0 N) and factorial combinations of N rates and application method/timing combinations. At Powell in 1990, N rates were 60, 120, 180, 240, and 300 lbs/acre. At Powell in 1991, N rates were 80, 160, 240, and 320 lbs/acre. At Torrington, N rates were 50, 100, and 150 lbs/acre. Method/timing combinations were broadcast (NH_4NO_3) and point-injection (UAN) before/at planting and after the first irrigation. At Powell in 1991, knife injections (UAN) were added for comparison with point injection. In Experiment 2, sugarbeets were thinned to a uniform population of about 27,000 plants/acre.

RESULTS AND DISCUSSION

Experiment 1: In all years, root yield increased with increasing N, but the increases at high N rates were small compared to the initial 150 lbs N (Table 1). Sucrose content was unaffected by N rate in 1989, but decreased slightly in 1990 and 1991. Sucrose loss to molasses (not shown) increased 0.15, 0.26, and 0.29 % in 1989, 1990, and 1991 with increasing N. Generally, N-rate interactions with plant density and harvest date were not significant.

Table 1. Sugarbeet response to nitrogen (N), plant density (D), and harvest date (H) at Powell.

N Rate	1989 Root yield	1989 Sucrose content	1989 Recov. sucrose	1990 Root yield	1990 Sucrose content	1990 Recov. sucrose	1991 Root yield	1991 Sucrose content	1991 Recov. sucrose
lb/A	Ton/A	%	lb/A	Ton/A	%	lb/A	Ton/A	%	lb/A
0	13.4	16.5	4270	17.7	16.5	5600	18.4	16.5	5790
100	18.6	16.5	6020	23.4	16.4	7340	22.8	16.4	7120
150	21.2	16.6	6750	25.1	16.3	7790	25.9	16.0	7840
200	21.4	16.5	6770	25.9	16.1	7910	24.3	16.0	7320
250	21.7	16.5	6840	26.0	16.0	7850	24.1	15.9	7190
300	22.4	16.4	7000	26.1	15.7	7690	25.1	15.6	7314
<u>ANOVA</u>									
N	**	NS	**	**	**	**	**	**	**
NxD+	NS	NS	NS	NS	NS	NS	NS	NS	NS
NxH++	NS	NS	NS	NS	*	NS	NS	NS	NS
NxDxH	*	NS	**	NS	NS	NS	NS	NS	NS

*, ** Significant at the 0.05 and 0.01 probability levels; NS = Nonsignificant

Soil nitrate profiles (1990 data shown in Fig. 1 as an example) indicated that significant nitrate movement occurred with irrigation. Leaching was indicated by increasing NO_3-N concentration at greater depth in the profile after the first and second irrigations. At harvest, NO_3-N profiles were similar for all N rates indicating that all applied NO_3-N was removed from the profile by plant uptake, leaching, or some other mechanism.

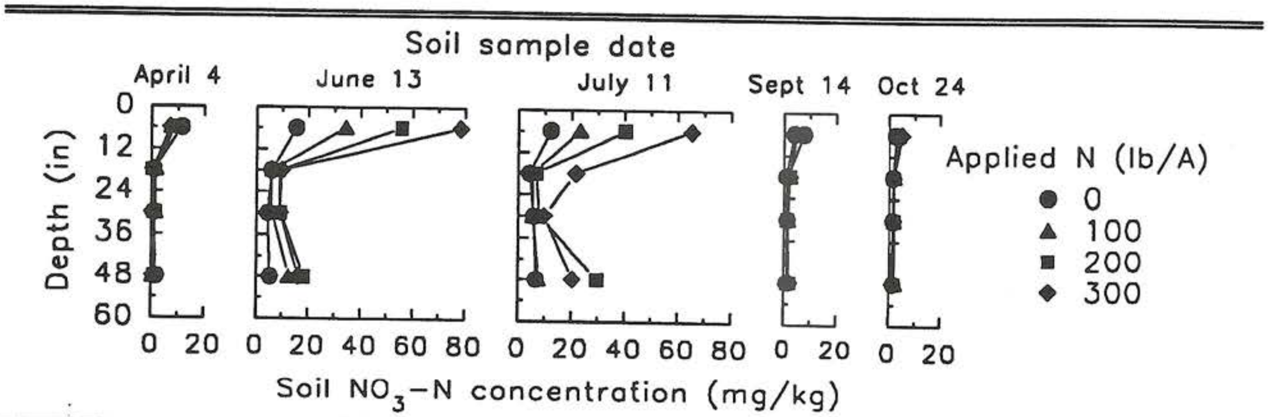

Fig. 1. Soil nitrate profiles with N application to sugarbeets in 1990.

Experiment 2: Nitrogen application method and timing effects, when significant, caused only small changes in sugarbeet yield and quality (Tables 2 and 3). At Torrington, high residual soil NO_3 limited response to applied N, and root yields were not affected by N rate, method, or timing although sucrose content was affected by both rate and method (Table 2). At Powell, beet quality was affected by application method and timing in 1990 but not in 1991. Root-yield differences were not significant among method and timing combinations at Powell in 1991, but there was a trend toward greater yields for broadcast and point injection before/at planting than for knife injection or N application after irrigation (Table 3). In 1991 at Powell, N applied before irrigation did not result in lesser loss to molasses than later N applications as in 1990. Also in contrast to 1990, there was a nonsignificant trend toward greater loss to molasses with point injection than with broadcast.

Table 2. Sugar beet response to N application method and timing at Torrington in 1991.

Application method	Petiole nitrate Aug 5	Petiole nitrate Sept 5	Root yield	Sucrose content	Sucrose yield
	------ ppm ------		Tons/A	%	lb/A
Before/at planting					
Broadcast	10670	6860	29.7	17.2	10170⁺
Point injected	9810	6010	28.5	17.9	10170
After first irrigation					
Broadcast	11490	7350	28.2	17.0	9600
Point injected	9370	6620	27.6	17.8	9830
ANOVA					
Time (T)	NS	NS	NS	NS	NS
Method (M)	*	NS	NS	*	NS
Rate (R)	**	NS	NS	**	*
T X M	NS	NS	NS	NS	NS
T X R	NS	NS	NS	NS	NS
M X R	NS	NS	NS	*	*
T X M X R	NS	NS	NS	NS	NS

*, ** Significant at 0.05 and 0.01 probability levels; NS = Nonsignificant

⁺Does not account for loss to molasses, which was not measured at Torrington.

Nitrogen rate was the N-treatment factor most affecting sugarbeet response (Table 4). At Powell, root yield and quality were significantly affected by N rate. In 1991, with the exception of knife injection after irrigation, maximum recoverable sucrose yield was attained at 160 lbs N/acre. This agrees well with data collected in Experiment 1. Root yield and sucrose decreased above this rate, while loss to molasses increased. In 1990, recoverable sucrose continued to increase with all methods in the range of rates used.

Table 3. Sugarbeet response to N placement and timing at Powell.

Application method	Petiole nitrate Aug 21	Petiole nitrate Sept 19	Root yield	Sucrose content	Loss to molasses	Recoverable sucrose
	--------- ppm ---------		Tons/A	%	%	lb/A
			1990			
Before/at planting						
Broadcast	1650	600	17.4	16.0	0.70	5340
Point injected	1340	660	18.5	15.9	0.66	5670
After first irrigation						
Broadcast	2090	880	18.3	15.9	0.76	5440
Point injected	1420	620	19.5	15.9	0.68	5940
ANOVA						
Time (T)	**	**	NS	*	**	NS
Method (M)	*	*	NS	NS	**	NS
Rate (R)	NS	NS	**	NS	**	**
T X M	**	NS	NS	NS	NS	NS
T X R	NS	NS	NS	*	**	NS
M X R	NS	NS	NS	NS	NS	NS
T X M X R	**	NS	NS	NS	NS	NS
			1991			
Before/at planting						
Broadcast	3970	740	25.9	16.3	1.09	7850
Point injected	4930	1740	25.7	16.1	1.11	7710
Knife injected	5920	2340	23.6	15.9	1.09	6940
After first irrigation						
Broadcast	5710	2040	24.4	16.1	1.06	7330
Point injected	7760	2790	24.2	16.0	1.17	7170
Knife injected	8370	3110	24.7	15.9	1.06	7290
ANOVA						
Time (T)	*	*	NS	NS	NS	NS
Method (M)	**	**	NS	NS	NS	NS
Rate (R)	**	**	*	**	**	**
T X M	NS	NS	NS	NS	NS	NS
T X R	**	NS	NS	NS	NS	NS
M X R	**	**	NS	NS	NS	NS
T X M X R	NS	NS	NS	NS	NS	NS
Contrasts						
No N vs N	**	**	**	**	**	**
Broadcast vs Inject	**	**	NS	NS	NS	NS
Point vs Knife	NS	NS	NS	NS	NS	NS

*, ** Significant at 0.05 and 0.01 probability levels; NS = Nonsignificant.

Table 4. Sugarbeet response to N rate at Powell.

N Rate	Petiole nitrate Aug 21	Petiole nitrate Sept 19	Root yield	Sucrose content	Loss to molasses	Recoverable sucrose
lbs/acre	ppm	ppm	Tons/A	%	%	lb/A
			1990			
0	1240	540	11.8	15.7	0.64	3560
60+	-	-	14.6	15.9	0.64	4470
120	1410	660	16.7	15.9	0.65	5100
180	1380	620	19.4	15.9	0.69	5920
240	1870	720	19.7	15.9	0.73	5990
300	1840	730	21.8	15.8	0.79	6500
			1991			
0	110	150	18.4	16.7	0.86	5810
80	1500	410	23.3	16.6	0.94	7294
160	4230	1180	26.0	16.4	1.00	8000
240	7260	2110	24.6	15.8	1.14	7220
320	12210	4949	25.2	15.3	1.31	7040

+ Petiole nitrate not measured at 60 lbs N/acre.

At Powell, petiole nitrate concentration was significantly greater for injected than for broadcast N at both application times and was greater for after-irrigation treatments than before/at planting treatments. If N is more available with injected than with broadcast methods, greater petiole nitrate concentrations would be expected. There is no obvious explanation for the substantially greater petiole-nitrate concentration with knife injection than broadcast without a corresponding increase in loss to molasses.

Conclusions drawn from these data are tenuous since there is little consistency among site-years. Weed control and stand problems at Powell in 1990, weed control and rain delays at Powell in 1991, and high soil nitrate and late-season moisture stress at Torrington in 1991 could have affected crop response and cloud interpretations.

In evaluating sugarbeet response to applied N in this study, the N rates chosen for the study should be considered. Lesser advantage for N placement would be expected at excessive N rates that at N rates near or below optimum. Considering that the recommended N rate based on soil nitrate for the Powell study site was about 150 lbs N/acre, the highest rates used in the study were excessive and may have masked any potential method or timing differences. When evaluated in terms of recoverable sucrose production, N point injection with a spoke-wheel injector seems to be as good as or better than broadcast N for a given time of application. The trend in two out of three cases presented here was for more recoverable sucrose with point injection than with broadcasting, but injection timing needs to be studied to determine how this technology can best be adapted to irrigated sugarbeet production.

Changes in sucrose content and sucrose loss to molasses with increasing N are relatively small in this system under present management. With regard to sucrose production, N can be managed independent of plant density and harvest date under these conditions. Small quality changes and lack of N interactions with plant density and harvest date may be caused by leaching of excess N from the soil before crop maturity thereby promoting sucrose formation and reducing impurities. If irrigation were managed to avoid overwatering, N management would be more critical. Techniques which emphasize efficient N use need to be adopted. Possible approaches may include irrigation techniques which minimize soil profile leaching or N-application techniques which improve N-use efficiency such as split-applications and/or fluid-fertilizer injection. If these methods can reduce leaching losses, optimum N rates could be reduced, and profitability could be enhanced.

ACKNOWLEDGEMENTS

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PHOSPHORUS FERTILIZATION EFFECTS ON WINTER WHEAT PRODUCTION IN ACID SOILS

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ABSTRACT

Field experiments were established at two locations to determine the effects of P fertilizer sources, rates, and methods of fertilization on forage and grain yield of winter wheat produced under acid soil conditions. Soil pH was 4.7 and 5.0 at Carrier and Hennessey, respectively. Sources of P included ammonium polyphosphate (APP, 10-34-0), monoammonium phosphate (MAP, 11-52-0) and diammonium phosphate (DAP, 18-46-0). Rates of P_2O_5 banded with the seed at planting were 30, 60 and 90 lbs per acre. A single broadcast rate of 60 lbs P_2O_5 per acre was included for method of placement comparison. Urea was applied preplant broadcast at 120 lbs N per acre and total fertilizer N was adjusted to 155 lbs N per acre using UAN (urea ammonium nitrate, 28-0-0). Forage and grain yield, soil test values and tissue concentrations for selected elements were determined. Increased forage yield due to applied P was observed at both locations, with banded P superior to broadcast P. Grain yield at one site was increased by P fertilization. No consistent differences in forage or grain yield were found due to P fertilizer source.

INTRODUCTION

Winter wheat is the main cultivated crop in Oklahoma and is grown for forage and/or grain. If livestock graze the winter wheat and are removed by early March, both forage and grain may be harvested. Dryland wheat production is more intensively managed in the central region of the state which receives 25 to 35 inches of rain annually. This area also extends into Kansas. Early records indicate soils of this region were somewhat acidic when first cultivated. However, intensive management and harvest of high yields over an extended period of time has increased soil acidity.

Soil testing is a common practice among wheat producers in this region. However, because lime sources are 50 to 100 miles from the area and lime application is very expensive, some producers do not lime fields when soil tests indicate the need. Consequently, soil pH values have declined to values as low as 4.0 and below and some fields have failed to produce a crop when soil pH was about 4.3.

Research conducted in Oklahoma identified that aluminum toxicity to seedling wheat was a major cause of crop failure at extremely low soil pH (Newton, et al, 1979). A common practice among producers successfully growing wheat in very acid soils was to apply phosphate fertilizers with the seed at planting. Aluminum and phosphate react in acid soils to create a "fixed" or unavailable form of phosphate. This reaction is responsible for decreasing phosphate fertilizer efficiency in acid soils. However, when phosphate is fixed, so too is aluminum since each is part of the unavailable aluminum phosphate complex. This "fixing" of aluminum in acid soils explains why producers that apply phosphate fertilizer with the seed can grow normal crop yields without liming. An attempt to quantify this phenomenon was necessary. Therefore, the objective of this research was to determine the effects of P fertilizer sources, rates and methods of placement on forage and grain yield of winter wheat produced under acid soil conditions.

MATERIALS AND METHODS

The two experimental sites selected for study were located in west-central Oklahoma. The Carrier and Hennessey locations had initial soil pH values of 4.7 and 5.0, respectively (Table 1). In order to obtain normal production from liming, a rate of about 1.2 ton per acre of effective calcium carbonate equivalent (ECCE) lime would be required (Johnson, et al, 1991). Mehlich III soil test P index values were 155 (very high) and 66 (high) at Carrier and Hennessey, respectively. These soil test indices were high enough that under normal conditions no P response would be expected. Phosphate fertilizer sources used included APP (10-34-0), MAP (11-52-0) and DAP (18-46-0). Three P fertilizer rates (30, 60 and 90 lb P_2O_5 per acre) were banded with the seed at planting. A 60 lb per acre rate of P_2O_5 was broadcast preplant. An untreated check was also included. The experimental design was a randomized complete block with four replications.

Table 1. Chemical characteristics and classification of experimental soils.

Location	pH	NO_3-N	Mehlich III P	Mehlich III K	Exchangeable Al	Exchangeable Mn	CEC
		---- lb acre^{-1} ----			--- ppm ---		meq (100g)$^{-1}$
Carrier	4.7	18	155	890	86	112	12
Hennessey	5.0	10	66	528	30	76	15

Classification
Carrier - Pond Creek Silt Loam (Fine, Silty, Mixed, Thermic Pachic Argiustolls)
Hennessey - Shellabarger Sandy Loam (Fine, Loamy, Mixed, Udic Argiustolls)

RESULTS AND DISCUSSION

In this paper, only data for the Carrier site will be discussed. Figures 1 through 4 illustrate the effectiveness of P fertilizer applied with the seed on wheat forage and grain yields in 1990 and 1991 on an acid soil.

No significant differences were found in sources of P for forage, grain and soil measurements in 1990. These parameters included forage and grain yield, forage and grain P concentration, in-row soil pH, soil P, Al and Mn concentrations. A significant response to P rate was noted in forage yield, forage and grain P, in-row soil pH and soil test P concentrations. Forage and grain yield was maximized at 60 and 30 lb P_2O_5 per acre, respectively. Banded treatments were superior to broadcast treatments for forage yield. Grain yield was not affected by method of placement. Forage P and in-row P concentrations were increased by banding.

The data for the 1991 crop year include forage and grain yield, in-row pH and P concentration. No significant differences were found in sources of P. Significant rate responses were observed for forage and grain yield and in-row soil P concentration. Forage yield followed the same response pattern as in 1990. The 1991 crop year was extremely dry after spring growth had occurred and grain yield was reduced by lack of rainfall. Grain yield response was maximized at 60 lb P_2O_5 per acre. Method of placement was also more important in 1991, as grain yields were superior when P was banded compared to broadcast.

SUMMARY

Phosphorus application significantly increased early forage growth, which was important to overall forage yield response. However, grain production was not as strongly influenced by early fall growth. Compared to the control without P application, phosphate placed with the seed is economical. In these experiments, each 30 lbs of P_2O_5 costs about $7.50. The grain yield increase of 15 bushels per acre, would have a value of at least $30.00 for a 4 to 1 return from fertilizer. The increase in forage from 60 lbs of P_2O_5 per acre ($15.00) would support about 140 lbs of beef gain (worth greater than $70.00) resulting in a 5 to 1 return from applying P fertilizer.

Liming is a more effective and usually an economical solution to acid soil problems, especially for fields that already have an adequate supply of phosphorus. For this experiment, 1.2 tons of ECCE lime would cost about $30.00 and would last approximately five years. Maintaining maximum yields for five years using P fertilizer placed with the seed would cost $37.50 for grain production and $75.00 for forage production. Phosphorus fertilizer placed with the seed is an effective alternative to liming strongly acid soils for winter wheat production. Use of phosphate fertilizer instead of lime is economical when lime costs are high and when considered on a short-term basis. In most instances, especially if phosphate fertility is already high, standard liming practices will be more economical for long-term management strategies.

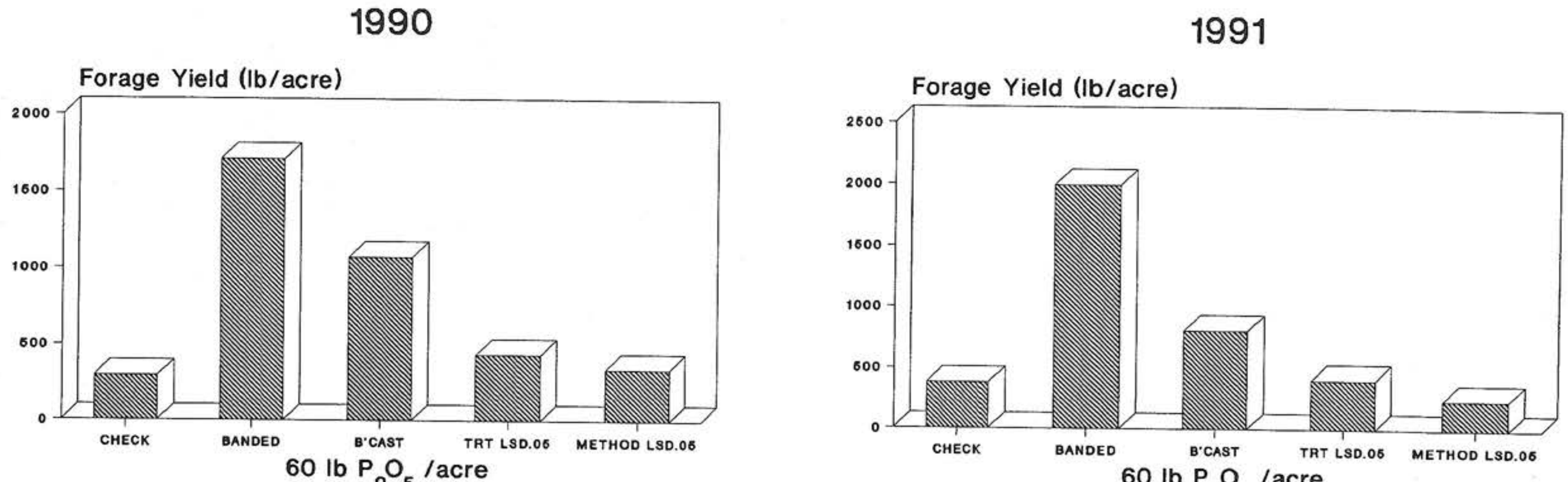

Fig. 1. Relationship between method of P placement and forage yield in 1990 and 1991.

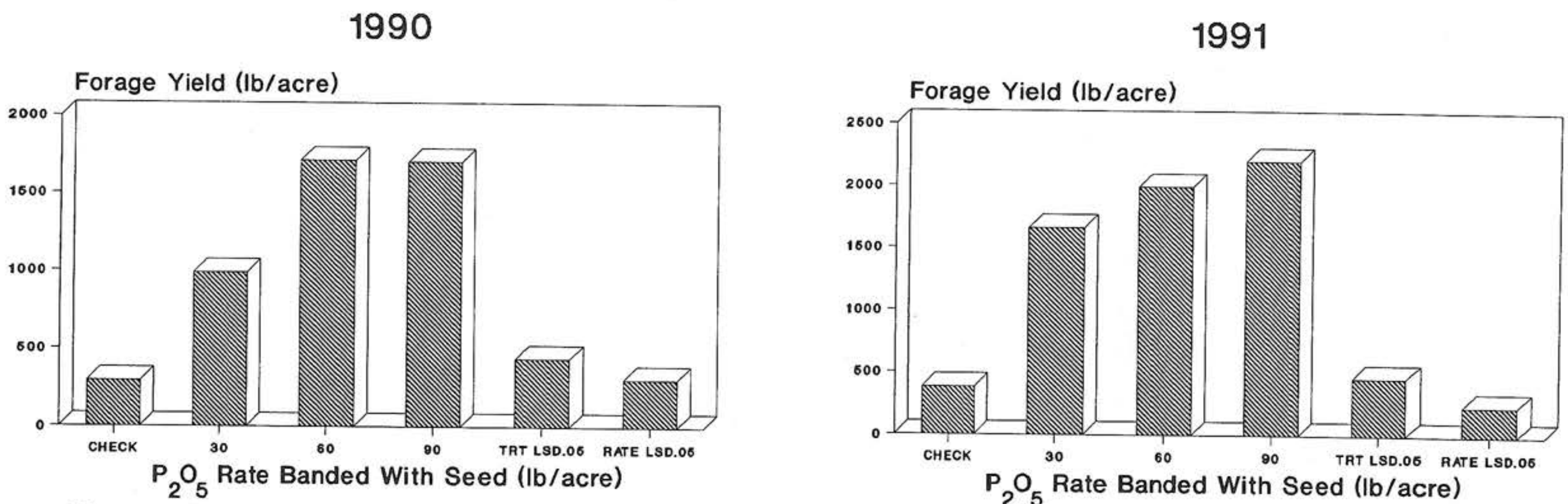

Fig. 2. Relationship between P rate and forage yield in 1990 and 1991.

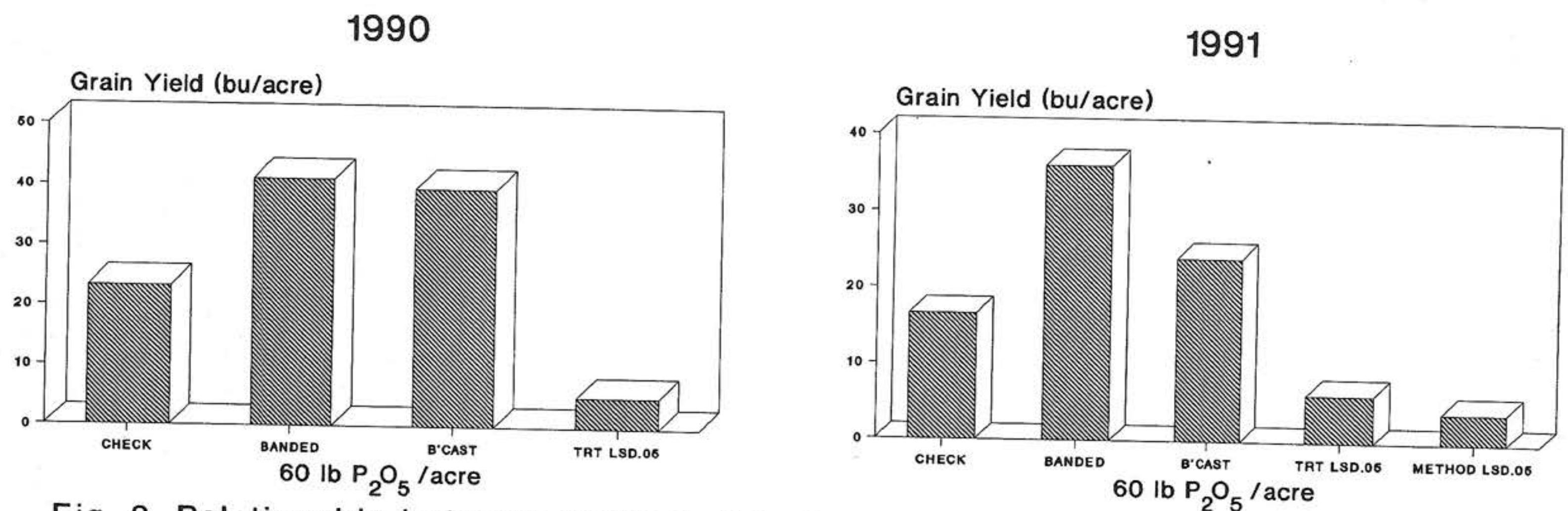

Fig. 3. Relationship between method of P placement and grain yield in 1990 and 1991.

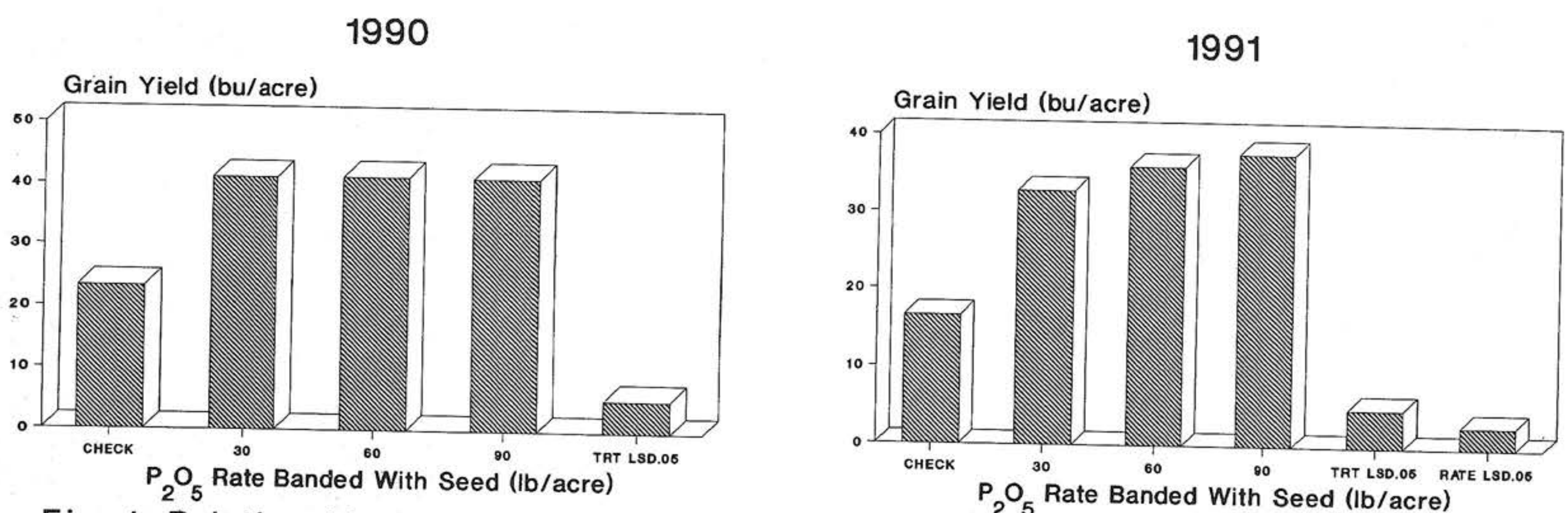

Fig. 4. Relationship between P rate and grain yield in 1990 and 1991.

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RESPONSE OF DRYLAND WINTER WHEAT TO RESIDUAL P

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ABSTRACT

Phosphorus studies were conducted in Kansas and Nebraska to determine the effects of P fertilizer placement method on the availability of residual P fertilizer in a reduced tillage winter wheat-fallow rotation and in a continuously cropped winter wheat system under dryland conditions. The results of these studies indicate that on soils testing very low in available P, band applications of P fertilizer at low rates (< 50 lb P_2O_5/a) are more effective than broadcast P fertilizer during the first year of application. As P rates increase, differences in yield potential between band and broadcast application methods decrease. Winter wheat responded equally to banded or broadcast residual P fertilizer when the broadcast P was initially incorporated. Residual P needs to be considered when making P fertilizer recommendations.

INTRODUCTION

The frequency of band application of fertilizer phosphorus (P) has increased in the last decade. Banding of low rates of P fertilizer near the seed on soils testing low in available P has been more effective than broadcast applications of P fertilizer at the same rate during the year of application in the Central Great Plains. The residual availability of fertilizer P in these bands to successive crops will depend on many factors such as the rate applied, row spacing, soil test P level, time between application and P uptake of the successive crop, and extent of band disturbance by tillage. As soil test P levels increase, yield differences between banding and broadcast applications are expected to decrease (Peterson, et al., 1981). On a long-term basis, a broadcast application of P fertilizer may be equally as effective as a band application at equal rates for wheat production (Wagar et al., 1986). Long-term P studies conducted in the northern Great Plains indicate that benefits from a single P fertilizer application may last as long as 16 years, depending on initial rate of P application and cropping history (Black, 1982; Halvorson and Black, 1985; Roberts and Stewart, 1987; Wager et al., 1986). Halvorson (1989) showed positive yield responses of irrigated winter wheat to residual P at Akron, CO. Halvorson and Black (1985) suggested that a one time, high rate application of P fertilizer may be one way to satisfy the P needs of crops grown with reduced tillage and no tillage systems for several years. The studies reported here evaluate this suggestion in addition to comparing the effects of P placement method on the long-term effectiveness of residual P fertilizer with reduced tillage systems. The specific objectives of the studies reported here were to determine the effects of P fertilizer placement on residual P fertilizer effectiveness within a reduced tillage winter wheat-fallow production system and a no-till continuous winter wheat cropping system.

MATERIALS AND METHODS

The research was located at two sites, one site located in Butler County, Kansas and one site near Morrill, Nebraska. Both sites involved dryland cropping systems and were seeded with hoe type drills (12 inch row spacing) equipped to band fertilizer with the seed, below the seed, or over the seed row. Winter wheat was planted at both sites from mid- to late-September each year. Herbicides were used to control weeds during non-crop periods and within the growing crop. Approximately 900,000 seeds/a or 60 lb/a were planted at both sites. Grain yields were determined by harvesting each plot with a plot combine. Specific details of each site are presented below.

Morrill, NE Site: A split-split plot, randomized block design was used with P placement method as main plots, P fertilizer rate as sub-plots, and N fertilizer rate as sub-sub plots with four replications. Fertilizer P placement methods were: BCI (broadcast with shallow incorporation, 3 inch depth); BS (band below seed about 2 inches or 3 inch soil depth); and SD (placed directly with seed at 50% of established P rates for 2 crop years). The fertilizer P (0-45-0) rates were 0, 23, 46, and 92 lb P_2O_5/acre and the N (34-0-0) rates were 0 and 40 lb N/acre for crop-1 and 50 lb N/a for crop-2 and 3. The study was initiated in September 1984 on a Mitchell silt loam soil with a 4 ppm Olsen P soil test level (0 to 6 inch depth) and a pH of 7.3. A no-till system was maintained for crop-1 and 2, but converted to a reduced tillage system (residual herbicide over winter and then sweep tillage during summer of fallow period) for crop-3. Nitrogen was broadcast applied without incorporation at the specified rates just prior to planting. The study included duplicate sets of treatments and plots to allow a crop to be present each year from 1985 to 1990. Therefore, one set of treatments was established in September 1984 and the other set in September 1985. The yield data reported here represent two years of data for each crop or eight replications of each treatment.

Butler County Kansas Site: No-till winter wheat was established in 1988 on a Woodson silt loam soil that had been in grain sorghum in 1987 (P treatments were initially applied to sorghum in spring 1987). The soil had a pH of 5.6 and a 3 ppm Bray-1 P level (0 to 6 inch depth). These plots were chemical fallowed during summer 1988, and were no-till planted to wheat in the fall 1988, 1989, and 1990. Phosphorus was applied at 15, 30, and 45 lb P_2O_5/a as ammonium polyphosphate (10-34-0). Method of application included broadcast with no incorporation (BCNI); band (dribble) over the seed row (DR); band 2 inches below the seed (BS); and directly with the seed (SD). A check treatment was included with each placement method. Treatments were replicated four times in a randomized complete block design. Duplicate sets of SD treatments were established when sorghum was planted in 1987 (24 inch row spacing). One set received no additional P during the winter wheat phase of the study [SD(87)], therefore, yield responses are to residual P. The other SD treatments received a 2nd application of P in the fall of 1988 and then no further P applied. The DR treatments received P in 1987, 1988, and 1989 at the specified rates and no additional P in fall 1990. The BS and BCNI treatments received the specified P rates each crop year (1987-1990). Therefore, winter wheat responses to P were the result of both residual and newly applied P fertilizer. Nitrogen (UAN) was broadcast after planting at 80 lb N/a.

RESULTS AND DISCUSSION

Morrill, NE Site: Grain yields were significantly increased with increasing P rate for all P placement methods for crop-1 (1985 & 1986). Yields were not significantly affected by P placement method, indicating that the SD P was as effective at the 50% P rate as the BS and BCI treatments at full P rate. The tendency was for the band treatments (BS and SD) to be more effective at the 23 and 46 lb P_2O_5/a rates. The yield response (P treatment-check plot) to P fertilizer rate for each P placement method is shown in Fig. 1 for those treatments receiving 40 lb N/a. Because of limited space, only data from the treatments receiving N will be reported here. In general, P responses with N were greater than P responses without N most years. Based on the data presented in Fig. 1, grain yields were not maximized at this site by the highest P rate.

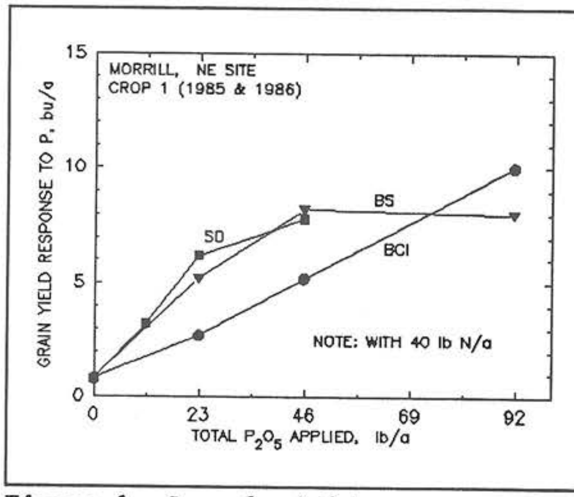

Figure 1. Crop-1 yield response to P fertilization.

Winter wheat grain yields for crop-2 (1987 & 1988) responded positively to residual P from the BCI and BS treatments, increasing as initial P rate increased. Without P fertilization, N application resulted in a decrease in grain yield. The yields from the BCI and SD (2nd P application) treatments were similar at the highest P rate, with the SD yields tending to be higher at the lower P rates. The grain yield response (P treatment-check plot) to increasing P levels is shown for each P placement method in Fig. 2 for crop-2.

Grain yields for crop-3 (1989 & 1990) increased significantly with increasing residual P levels (Fig. 3) with no significant difference in grain yield between P placement methods. Total cumulative grain yield response (crop 1+2+3) to P fertilization and

P placement methods are shown in Fig. 4. Cumulative grain yields were very similar for all P placement methods at all P rates. The data indicate that the highest P rate (92 lb P_2O_5/a) was not sufficient to maximize grain yields at this site when N was also applied.

Assuming a wheat price of \$3.75/bu, P_2O_5 cost of \$.284/lb, and a N cost of \$.18/lb, a simple economic analysis was conducted to estimate the return to P and N fertilization. A net loss of \$25/a was estimated when N was applied without P over three crops. When P was added, estimated returns to P rates of 23, 46, and 92 lb P_2O_5/a were \$13, \$17, and \$59 for BCI; \$10, \$26, and \$27 for BS; and \$12, \$27, and \$51 for SD treatments, respectively, for three crops. The SD P rates tended to show a higher level of profitability for crop-1 than the higher, one-time P applications of the BCI and BS treatments. However, this difference in profitability disappeared with each additional crop year.

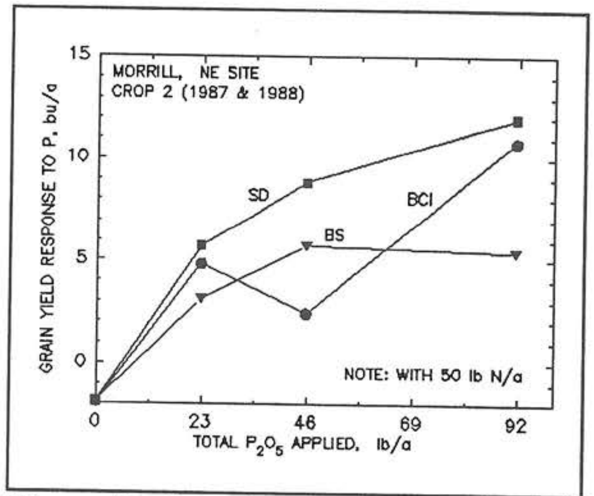

Figure 2. Crop-2 grain yield response to P fertilization.

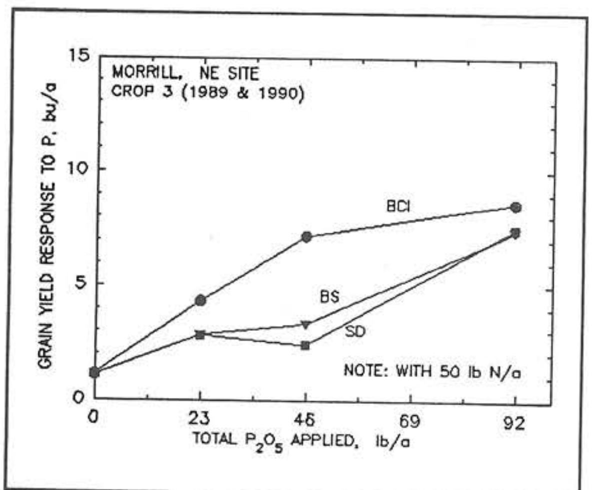

Figure 3. Crop-3 grain yield response to P fertilization.

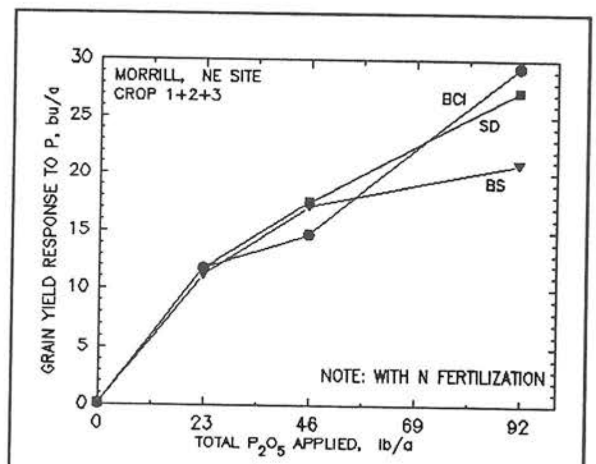

Figure 4. Total grain yield response to P fertilization in 3 crops.

<u>Kansas Site:</u> The extreme drought stress experienced in 1989 reduced regional wheat grain yields severely as well as those at the study site (Fig. 5). The highest yields were obtained only with the BS and SD treatments at the highest P rate. The extreme dry surface soil conditions that occurred during tillering (fall and early spring) reduced P availability with the DR and BCNI treatments, resulting in a

significantly lower yield. Winter wheat responded positively to the residual P applied SD('87) in 24 inch rows with the grain sorghum in 1987 (Fig. 5). This 24 inch row spacing was to wide to provide adequate P to all rows of wheat in 1989. Visual symptoms of P deficiency were obvious in alternate wheat rows in 1989. These data do, however, indicate a yield response to residual SD P similar to that of the DR treatments when compared on an equal P rate basis.

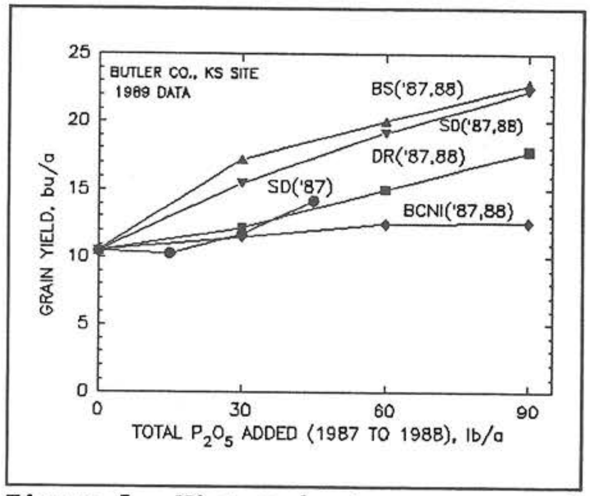

Figure 5. Winter wheat response to P fertilizer placement and rate.

In 1990 the rainfall quantity and distribution were near normal. Wheat yield responses to P with all methods of application were observed; however, BS P increased wheat yield about 20 bu/ac more than BCNI applied P (Fig. 6). Wheat yields of the DR treatments were similar to the BS treatments at the higher P rates. Wheat response in 1990 to residual P of the SD treatments showed a significant increase in grain yield with increasing level of P application. Yields of the SD(87, 88) treatments were similar or equal to those of the DR treatments when expressed on an equivalent P rate basis. Phosphorus application with the SD method did not provide sufficient P for optimum yield in 1990. These data indicate that on a low P soil, band P applications will provide residual available P for successive crops. Additional P was required to optimize yield for all P placement methods in 1990.

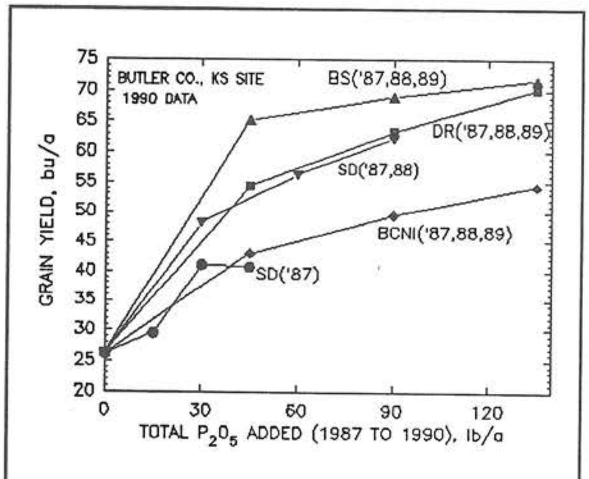

Figure 6. Winter wheat response to P fertilizer placement and rate.

In 1991, wheat yields were again reduced because of drought (Fig. 7), although not as much as in 1989. Grain yield were significantly increased with increasing rates of P application for all P placement methods. Responses to residual P fertilizer were similar to those of the BS and BCNI treatments. Broadcast application of 75 lb P_2O_5/a to previously unfertilized plots resulted in similar grain yields as continuous application of 30 lb BCNI P_2O_5/a (total 120 lb P_2O_5/a). Sufficient P was not available from any of the placement methods to maximize grain yields in 1991.

The cumulative winter wheat yield response to P fertilization

(3 crops) is shown in Fig. 8 as a function of P placement method. Total response to P fertilizer rates was similar for all band application methods, even when the yield response resulted from residual P. The BCNI treatment showed the lowest total response in three crops, possibly because of the drought conditions in 1989 and no incorporation of the P which caused the P to be positionally unavailable. The 1991 data would indicate that the residual P from the BCNI treatments may be becoming more available with time, as the P gets incorporated with each successive seeding operation.

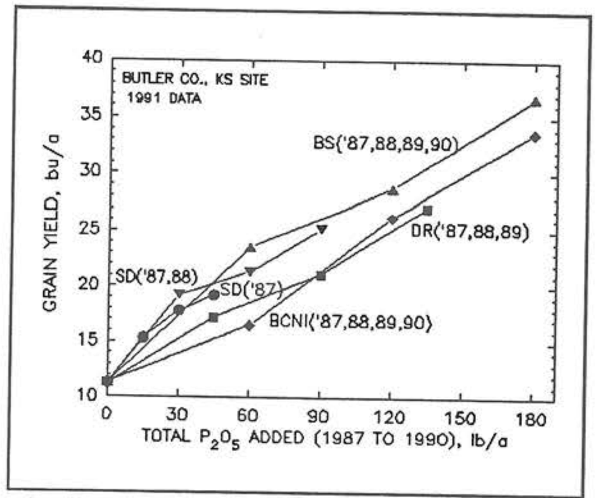

Figure 7. Winter wheat response to P fertilizer placement and rate.

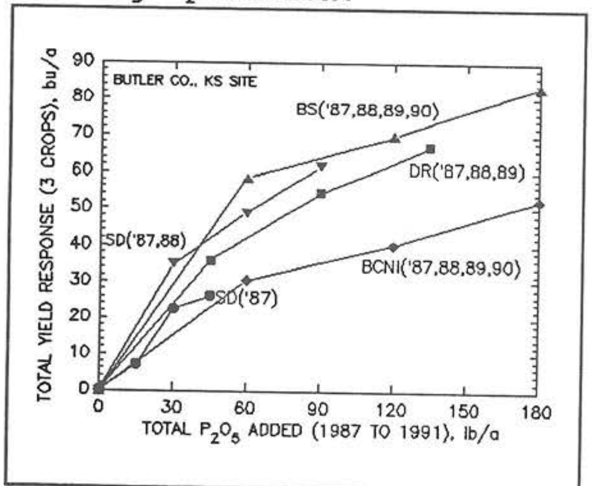

Figure 8. Total yield response to P fertilization (3 crops)

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PHOSPHORUS PLACEMENT AND RATE RESPONSES OF HARD RED WINTER WHEAT IN CENTRAL SOUTH DAKOTA

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ABSTRACT

Field studies were established in central South Dakota beginning in 1988 to document wheat growth and grain yield responses to applied P. Fertilizer P as 10-34-0 was applied at rates of 0, 30, 60 and 120 lbs P_2O_5/A by either spoke wheel or anhydrous applicator knife injection. The response of early dry matter (EDM) and grain yield were significant for P application rates at most sites. This indicated that grain yields may be limited by available P in these soils. There were no differences in any growth or yield parameters due to placement by knife or spoke. Either of these two methods were suitable for fluid fertilizer placement at higher application rates. Experimental site locations had the greatest influence upon EDM, EDM P concentration, test weight and grain yield. Differences in site cultivation history as well as tillage practices seem to influence EDM, EDM P concentration and grain yield responses to P application rates more than differences due to organic matter, pH and soil extractable P between sites.

INTRODUCTION

Half of all wheat acreage in South Dakota is planted to hard red winter wheat. About 25% or 500,000 acres of winter wheat is grown in the central counties of the state. Total annual precipitation averages 16 inches and wheat grown in these counties follows a black fallow period to accumulate subsoil moisture. Tillage is accomplished by wide-bladed sweeps, is very shallow and is used mainly to control weeds and partly bury crop residue. The soils are derived from the Pierre shale formation, have a heavy clay texture and exhibit vertic properties. The terrain is gently undulating and the crowns of the hills are frequently eroded, exposing subsoils which have free carbonates. Organic matter is generally higher in lower topographic positions.

Fertilizer applications have been seriously considered in the central region of the state only in the last decade. Available nutrients in unfertilized systems originated mainly from that released by organic matter mineralization, crop residue recycling and that relaeased from weathering of native minerals. Studies on these soils have shown that P is a limiting factor in maintaining winter wheat grain yield levels. Fertilizer P applied as broadcast applications could be of limited value because of the high fixation capacity of these soils and the shallow incorporation due to the sweep-tillage method.

OBJECTIVES

Replicated field trials were established in the fall of 1988 to determine how placement of different rates of liquid fertilizer P by either spoke or injector blades would increase soil P availability levels and increase grain yields of winter wheat.

METHODS

Three field locations on cooperator farms in Jones county were prepared in 1988, 1989 and 1990 by tilling with a wide-bladed sweep during summer months preceding planting. Fertilizer P, as liquid 10-34-0, was injected either by a standard anhydrous ammonium knife applicator to 10 cm depth or by a Cady spoke wheel with an arc of vertical distribution from 1-4 in. in depth. Fertilizer P was applied at the rates of 30, 60 and 120 lbs P_2O_5/A at 14 in. centers for the injector knife and at 11 in. centers for spoke wheel. Wheat was planted with a hoe-drill at the rate of 90-100 lb seed/A in a 10 in. row spacing perpendicular to fertilizer placement direction. This minimized single row responses. Treatments were replicated four times in a randomized complete block design in plots which were 5 ft. wide and 30 ft. long. Fertilizer N was applied as a broadcast application in the spring to equalize liquid N applied and to meet crop requirements for a yield goal of 60 bu/A.

Soil samples were removed from 10-12 random locations in the plot areas prior to applying fertilizer treatments. Samples were removed to a depth of 24 in. and separated into 6 in. increments of depth. Samples were dried with a force draft blower at 85°F and ground to pass through a 2 mm sieve. Analysis for dilute-salt extractable NO_3-N, Bray P-1 extractable P, Olsen P extractable P, ammonium acetate extractable K, pH, electrolytic conductivity and organic matter by dry combustion were performed on the samples (Table 1) by methods compiled by the NCR-13 committee in 1988.

Table 1. Chemical analysis of soil (0-6 in) on cooperator sites by year.

Cooperator	Bray P-1 Extr. P			Olsen Extr. P			NH_4OAC Extr. K		
	1989	1990	1991	1989	1990	1991	1989	1990	1991
	-----	ppm	----	-----	ppm	----	----	ppm	----
Patterson	11.0	6.0	6.0	6.5	4.0	-	858	525	444
Miller/Rank	11.6	7.0	3.1	4.0	6.0	-	691	600	431
Fuoss	6.3	11.0	6.0	2.5	6.5	-	675	575	558

	pH			Electrical Conductivity			Texture
				-	mmhos/cm	-	
Patterson	-	8.0	-	-	0.8	-	clay loam
Miller/Rank	-	7.8	-	-	1.2	-	clay loam
Fuoss	-	7.8	-	-	0.6	-	clay loam

Precipitation was measured during the spring of the growing season (Table 2). The Patterson site was abandoned in 1991 due to emergence variability. Shoot growth was harvested from each treatment plot prior to jointing stage (Feekes stage 5) in 1990 and 1991. The plant tissue was dried at 150°F and ground to pass through a 40 mesh sieve. Total plant tissue P was solubilized by a wet digestion procedure and P determined by a colorimetric procedure. Grain was harvested with a small plot combine to estimate yields.

Table 2. Growing season precipitation measured from April-June by cooperator site and year.

Cooperator	1989	1990	1991
	----------	in	----------
Patterson	3.2	6.5	-
Miller/Rankin	4.1	8.3	8.2
Fuoss	1.8	4.4	10.8

RESULTS AND DISCUSSION

Significant differences for early shoot dry matter (EDM), EDM P concentration, grain test weight and grain yield were observed between experimental site locations (Table 3). Early shoot dry matter (Table 4) was significantly greater at the Fuoss site than the other sites. The EDM P was generally lower at the Miller/Rankin site (Table 5). Grain yield was higher at the Fuoss site (Table 6). The test weight values were also higher at the Fuoss site for combined data years (Table 4).

Table 3. Analysis of Variance (ANOVA) table testing main effects for early shoot dry matter (EDM), EDM P concentration, grain test weight and grain yield pooling 1989-1991 data and experiment locations.

Main Effects	EDM	EDM P Conc.	Test Weight	Grain Yield
	-------------	Pr > F		-------------
Cooperator Site	.001	.001	.001	.001
P Application Rate	.868	.001	.887	.001
P Placement	.777	.169	.812	.370
Site * Rate	.999	.034	.998	.586
Site * Placement	.932	.311	.812	.403
Rate * Placement	.979	.264	.979	.877

The EDM was also higher in 1991 for the Miller/Rankin and Fuoss sites than in 1990 (Table 4). Higher rainfall in 1991 for the Fuoss site probably contributed to the difference observed there.

Early dry matter P concentration increased as P rates increased for each of the experimental sites (Table 5). The differences between sites were generally observed at the lower P rates.

Table 4. Comparison of mean early shoot dry matter weights and test weights among cooperator sites for 1989-1991 data.

Cooperator	Early Shoot Dry Matter		Test Weight
	1990	1991	1989-91
	- lb/6 ft row -		lb/bu
Patterson	.071	-	55.4
Miller/Rankin	.065	2.45	56.1
Fuoss	.153	6.25	59.6
LSD	.011	0.42	0.8

Comparisons of mean dry matter and test weight responses between two cooperator sites were significantly different at the .05 significance level if the differences exceeded the LSD value.

Table 5. Response of mean early shoot dry matter P concentration to P application rates among cooperator sites for 1989-1991 data.

P Application Rates	Cooperator Sites			
	Patterson	Miller/Rankin	Fuoss	LSD
lbs P_2O_5/A	%			
0	.187	.146	.182	.019
30	.179	.150	.194	.018
60	.201	.168	.203	.021
120	.205	.205	.220	.035
LSD	.030	.028	.026	

Comparisons of mean shoot P concentration responses between two cooperator sites within a P rate or two application rates within a cooperator site were significantly different at the .05 significance level if the differences exceeded the LSD value.

No differences in EDM P concentration between application methods for any P rate were observed when data for all sites and years was pooled (Table 6). The spoke and knife applicators did equally as well at increasing the P availability to the plant as P application rates increased. However, plugging of the applicator openings in the spoke wheel was observed in these heavy clay soils at the lower application rates. At the higher P application rates, either method would be suitable. In all sites for 1989 and for the Fuoss site in 1991, the fertilizer was not applied until after germination due to time constraints. At the time of application, it was speculated that crop growth would have been affected. However, fall growth was observed to be vigorous and visual differences for early growth were observed between P application rates at the Fuoss site in the following spring. Soil moisture was adequate during the fall of 1990 at this site, which may have minimized possible crop damage from the knife.

Table 6. Response of mean early shoot dry matter P concentration and grain yield to P application method and rates pooling cooperator sites for 1989-1991 data.

P Application Rate	P Concentration			Grain Yield		
	Spoke	Knife	LSD	Spoke	Knife	LSD
lbs P_2O_5/A	-------- % -------			------ bu/A -----		
0	.171	.168	.016	45.2	42.8	4.8
30	.173	.173	.014	46.0	45.2	4.7
60	.181	.197	.013	47.2	47.7	4.5
120	.208	.214	.014	52.0	50.5	4.0
LSD	.018	.017		6.4	5.8	

Comparisons of shoot P concentration and grain yield responses between two application methods within a P rate or between two P application rates within an application method were significantly different at the .05 significance level if the differences exceeded the LSD value.

Grain yield increased slightly for each increment of P rate increase for the Patterson and Miller/Rankin sites when data for all years was pooled (Table 7). Grain yields increased over the unfertilized treatment at the higher P rates. This indicated that soil P availability was probably a limiting factor to grain yields.

Table 7. Response of mean grain yield to P application rates at cooperator sites pooling application methods for 1989-1991 data.

P Application Rates	Cooperator Sites			
	Patterson	Miller/Rankin	Fuoss	LSD
lbs P_2O_5/A	---------------- bu/A ----------------			
0	37.0	35.6	56.5	6.3
30	39.2	38.7	56.8	6.2
60	41.7	41.6	56.8	5.9
120	42.7	46.9	61.6	5.2
LSD	5.5	7.3	9.6	

Comparisons of grain yield responses (corrected to 13.5% moisture) between two cooperator sites within a P rate or between two P application rates within a cooperator site were significantly different at the .05 significance level if the differences exceeded the LSD value.

Leaf rust infection was very strong in 1991 at the Miller/Rankin site but only slight at the Fuoss site. This may have contributed to the higher overall mean grain yields at the Fuoss site compared to the Miller/Rankin site.

Grain yield was strongly correlated with EDM at the Patterson site and with EDM and EDM P concentration at the Miller/Rankin site for data pooled for all years. However, grain yield increases were not correlated strongly with EDM or EDM P concentration at the Fuoss site indicating that grain yield was independent of the growth parameters measured there. The analysis of the soil from each site (Table 1) indicated that there were slight differences in chemical parameters between sites but the differences were seemingly not great enough to effect the growth parameters which were measured. However, the field at the Fuoss site was removed from permanent pasture and cultivated only in the last 8-10 years. The other sites have been cultivated for at least 15-20 years. Perhaps tilth factors related to the shorter cropping history at the Fuoss site affected crop growth more favorably than at other sites. In addition, the operators at the Patterson and Miller/Rankin sites cultivated their fields more often during the fallow summer period preceding planting operations than the operator at the Fuoss site. This certainly may have had an impact on the pre-plant moisture level and establishment of the subsequent wheat crop.

Table 8. Correlation of mean early shoot dry matter weight (EDM), shoot dry matter P concentration, grain test weight and grain yields at cooperator sites for 1989-1991 data.

	Patterson			Miller/Fuoss			Rankin		
Parameter	EDM P Conc.	Test Wt.	Grain Yield	EDM P Conc.	Test Wt.	Grain Yield	EDM P Conc.	Test Wt.	Grain Yield
	r								
EDM	.688	-.067	.730	-.165	-.481	-.540	-.386	-.691	.227
EDM P Conc.	-	.180	.641	-	.566	.716	-	.435	.169
Test Wt.	-	-	-.516	-	-	.436	-	-	.799

DIFFERING RESPONSES OF POPULAR SPRING WHEAT VARIETIES TO PHOSPHORUS FERTILIZATION

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ABSTRACT

A greenhouse study showed that spring wheat varieties grown in the Northern Great Plains may differ dramatically in response to phosphorus (P) fertilization. One variety, Marshall, showed better growth, tillering, and main stem development under low soil P conditions than the other varieties tested. By contrast, early maturity daylength insensitive varieties (Butte 86, Grandin) suffered more severe reductions in growth and development than Marshall. Field studies compared the response of Marshall to either Grandin or Butte 86 to four rates of P drilled with the seed. At two sites Butte 86 or Grandin appeared to require more P than Marshall, but the opposite was true at a third site.

INTRODUCTION

Wheat variety trials are usually performed on very high fertility sites, and tolerance to low fertility conditions is not a selection objective of most breeding programs. Recent studies in Oregon (Gardiner and Christensen, 1990; Sullivan, 1981) have shown that soft white winter wheat varieties can differ significantly in their tolerance of low soil P conditions. Breeding for enhanced P uptake in alfalfa has been successful in New Mexico (Miller et al., 1987).

Recently we evaluated the response of six spring wheat varieties to P fertilization and <u>Penicillium bilaji</u> inoculation (Goos et al., 1991). Inoculation had little effect on wheat growth, but dramatic P fertilization x variety interactions were observed in plant development. Thus, we have expanded our P x variety studies. The purpose of this paper is to summarize our results to date.

MATERIALS AND METHODS

Greenhouse and field studies were performed. The greenhouse studies involved two rates of P (0, 50 mg/pot) by six varieties of wheat. The field studies involved two varieties (Butte 86 or Grandin vs Marshall) and four P rates drilled with the seed (0, 10, 20, 40 lb P_2O_5/A as 0-45-0).

Measurements included main stem development (Haun stage), tiller initiation, dry matter production, number of leaves produced on the main stem, P uptake and grain yield (field studies only). The greenhouse studies were performed on low testing soils, while the field studies were conducted on medium or high testing soils.

RESULTS AND DISCUSSION

Greenhouse study

The effect of phosphorus fertilization on the development and yield of six wheat varieties is shown in Table 1. All varieties responded dramatically to P fertilization. Main stem development was advanced 0.6-0.9 Haun unit for all varieties except Marshall. Maturity of Marshall was only advanced 0.1 leaf by P fertilization.

All varieties tillered more profusely with P fertilization. The vast majority of grain production in spring wheat comes from the main stem, T1, and T2 tillers. Two varieties, Butte 86 and Grandin, produced virtually no T1 and T2 tillers in the absence of P fertilization. By contrast, Marshall tillered well at the T1 and T2 position in the absence of P fertilization.

An unexpected result from this study was how P deficiency influenced the number of main stem leaves produced. Butte 86 and Grandin produced almost all 7 leaf plants in the absence of P fertilization and almost all 8 leaf plants in the presence of P fertilization. By contrast, Amidon and Marshall produced 8-leaf plants regardless of P regime. We believe that this may be the first study to show that main stem leaf number can be altered by P nutrition.

P fertilization increased the yield of all varieties. Relative yield was 84% for Marshall and 63-72% for the other varieties. The Haun, tillering, main stem leaf number, and yield data was all consistent in suggesting that Marshall was least damaged by P deficiency on this soil while Butte 86 and Grandin were perhaps the most impacted. These observations were consistent with their general growth habits. Grandin and Butte 86 are early maturity varieties that grow rapidly early in the season (lower GDD requirement/leaf produced). Marshall is a late semi-dwarf variety that develops more slowly, and tillers more profusely than Grandin or Butte 86.

Our subsequent hypothesis for establishing the field studies was that the rapid growing varieties Grandin or Butte 86 might require more P for proper early growth and development than Marshall.

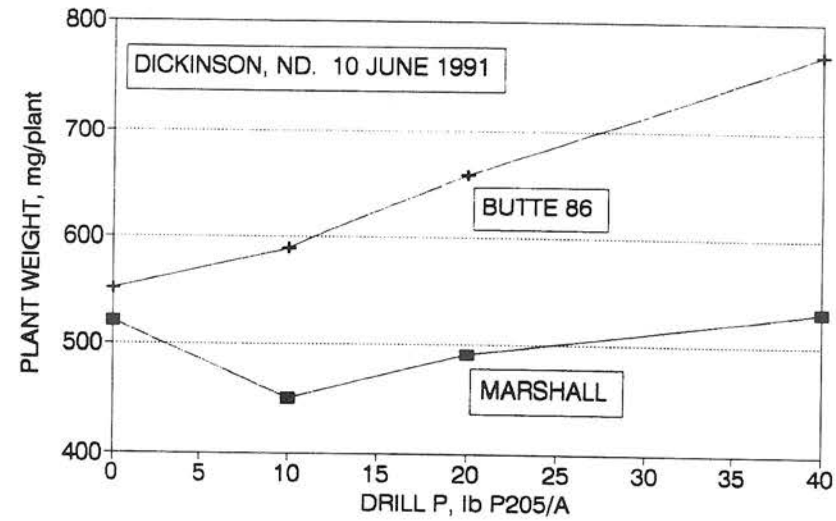
Field studies

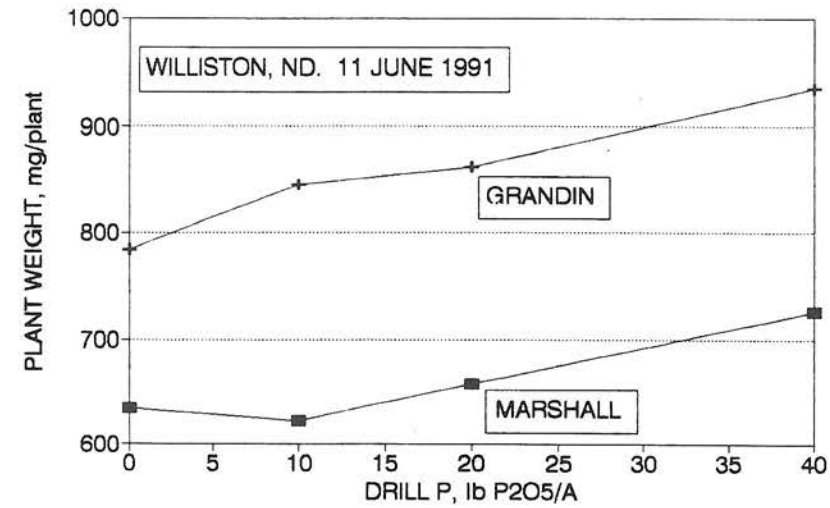
The effects of drill applied P on Grandin or Butte 86 vs Marshall on plant growth at about the 6 leaf stage is shown in Figures 1-3. Three differing sets of results were obtained. At Dickinson the results support our hypothesis. Butte 86 gave a much larger response to drill P than Marshall (44% vs 2% increase). Both varieties gave similar response at Williston. At Langdon, Butte 86 seemed to give a smaller growth response than Marshall (9% vs 28% growth increase).

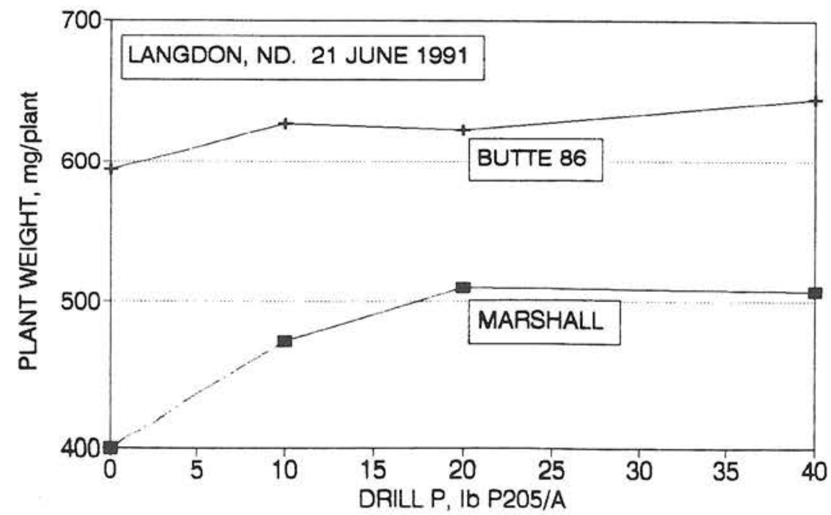
Table 1. Effect of P fertilization on development and yield of six spring wheat cultivars. Greenhouse data, North Dakota, 1990.

Variety	P	Main stem Haun	Tiller initiation T0	T1	T2	Other	Total	MS Leaves+ 7	8	DM Yield	Relative Yield++
	mg/pot		------Tillers/plant-------					% of plants		g/pot	%
Amidon	0	7.3	0.0	0.3	0.7	0.0	1.0	0	100	2.6	-
	50	7.9	0.4	1.0	1.0	0.5	2.9	0	100	4.1	63
Butte 86	0	9.4	0.0	0.0	0.0	0.0	0.0	72	28	2.9	-
	50	10.1	0.0	0.5	1.0	0.1	1.6	4	96	4.2	69
Grandin	0	9.0	0.0	0.0	0.0	0.3	0.3	100	0	3.1	-
	50	9.6	0.1	0.9	0.9	0.8	2.7	8	92	4.3	72
Len	0	6.8	0.0	0.1	0.5	0.2	0.8	13	87	2.2	-
	50	7.5	0.1	1.0	0.9	0.5	2.5	0	100	3.3	67
Marshall	0	7.4	0.0	0.5	1.0	0.1	1.6	0	100	2.7	-
	50	7.5	0.0	1.0	1.0	0.7	2.7	0	100	3.2	84
Stoa	0	7.6	0.1	0.0	0.2	0.0	0.3	29	71	2.4	-
	50	8.5	0.0	0.8	0.9	0.2	1.9	0	100	3.8	63

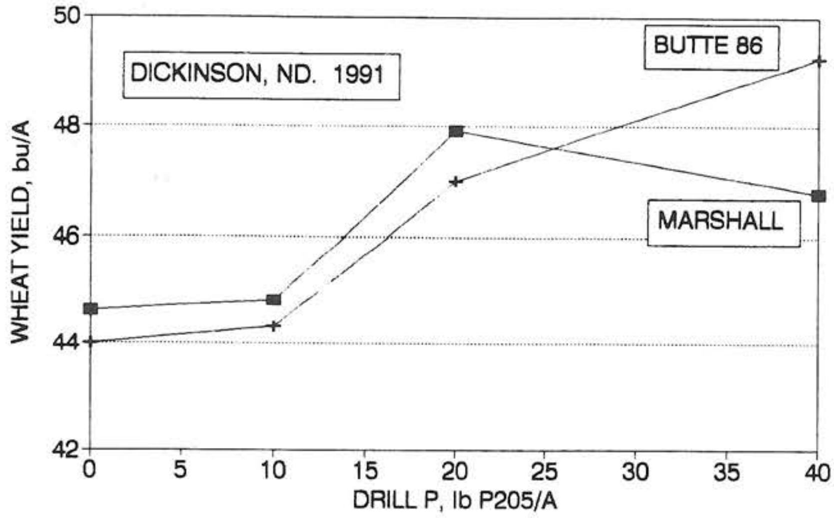
+ MS Leaves = number of leaves produced on the main stem.
++ Relative yield = 100x (yield without P/yield with P).

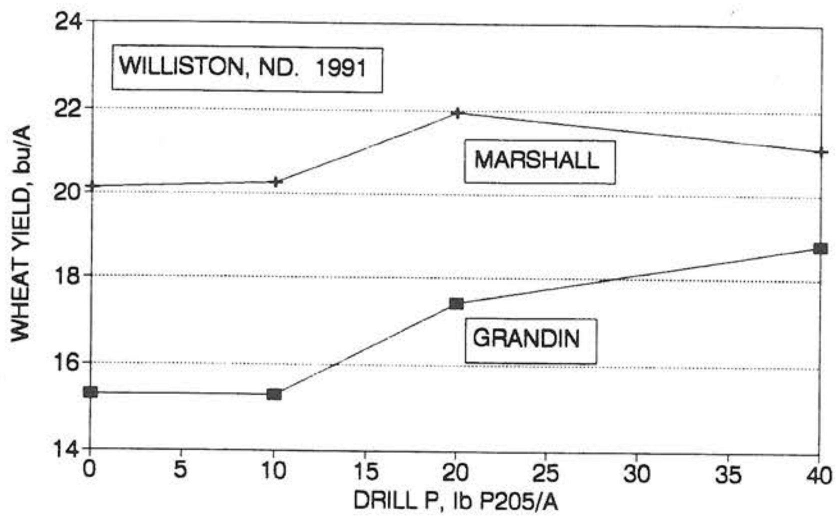


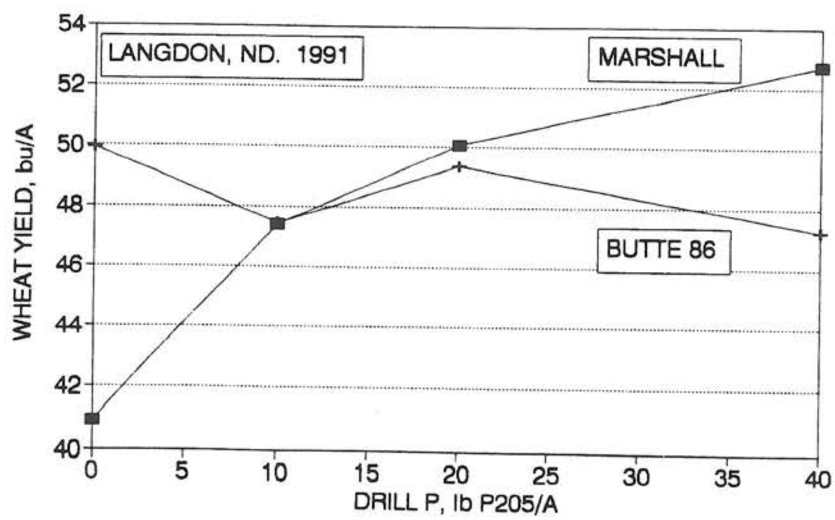




Figures 1-3. Effect of drill P on plant dry matter, 6 leaf stage.







Figures 4-6. Effect of drill P on grain yield.

The grain yield data (Figures 4-6) from Dickinson and Williston tended to support our hypothesis. Maximum yield of Butte 86 or Grandin was observed at 40 lb P_2O_5/A, while maximum yield was obtained with 20 lb P_2O_5/A for Marshall. However, the grain yield data from Langdon showed the opposite. At Langdon, there was little response of Butte 86 to P fertilization, but Marshall gave a 12 bu/A response to P fertilization. We have no explanation for the Langdon results unless weather conditions favored the later maturing variety Marshall.

Our conclusion is that significant P x variety interactions do occur, and that these interactions are little understood and perhaps difficult to anticipate. However, it may prove beneficial to screen larger populations of germplasm for tolerance to low P conditions.

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P AND K FERTILIZER PLACEMENT IN ALFALFA

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ABSTRACT

Studies were conducted by Kansas State University and Agriculture Canada, Brandon Research Station to investigate the response of established alfalfa stands to various levels and placements of P and K fertilizer. Small yield increases occurred with K applications in both locations, while yield increase with P application was 30% at Kansas, nonsignificant at the first and 87% at the second Manitoba site. In the Kansas study, placement did not significantly influence alfalfa yield, although response to K fertilizer was greater when fertilizer was knifed rather than surface dribbled or broadcast. On the sandy loam soil in Manitoba, knifing fertilizer led to stand damage, reducing yield relative to a broadcast application. On the clay loam soil, however, knifing did not damage the alfalfa stand sufficiently to reduce yield and total yield was higher when fertilizer was knifed rather than broadcast. The preferred method of fertilizer application will depend on soil type and fertility, environmental conditions, and relative costs of fertilizer, forage and the knifing operation.

INTRODUCTION

Alfalfa is the predominant forage legume grown in North America. As the N requirements of alfalfa are nomally satisfied through symbiotic N fixation, P and K are the nutrients which most commonly limit alfalfa production. Since these two nutrients are relatively immobile in the soil, their availability to the plant may be strongly influenced by the method of placement. However, placement of P and K in established alfalfa stands has shown mixed results. Leyshon (1982) observed that banding fertilizer in established alfalfa stands reduced yield due to mechanical damage to the plants and the decrease persisted for 2 more years. In contrast Goos et al. (1984) found that injection of ammonium polyphosphate solution was more effective than surface application in increasing alfalfa yield at the first but not the second harvest, while a yield reduction to deep placement occurred at only one of three sites. Goos recommended that banded P may be best applied in late fall or early spring when stands are dormant and little remains of the previous years growth.

Studies were established independently by Kansas State University and by Agriculture Canada, Brandon to establish optimum fertilizer management practices for dryland alfalfa production, by determining the response of alfalfa yield and nutrient content to: (1) phosphorus and potassium levels and (2) placement (broadcast, dribble or knife of fluid sources in Kansas and broadcast or knife of granular sources in Manitoba).

MATERIALS AND METHODS

In the Kansas study, an experimental site was established in fall, 1987, with 26 fluid fertilizer treatments randomized in a complete block with 4 replications. Two separate analyses of the data were run for the 1990 data. The first analysis compared liquid fertilizer P levels of 0, 40, 80, and 120 lb P_2O_5 acre^{-1} and K levels of 0, 80, and 160 lb K_2O acre^{-1} when dribble applied. The second analysis compared broadcast, dribble and knife at 4 inch application methods at P levels of 40 and 80 lb P_2O_5 acre^{-1} and K levels of 0 and 80 lb K_2O acre^{-1}. Fertilizer was applied preplant in September of 1987, and in the established stand in September of 1988 and 1989. Four cuttings were taken from a 3 x 20' area from each plot on May 11, June 29, August 17, and Nov. 14 in 1990, and analyzed for yield and nutrient content.

In the Manitoba study, two sites were established in 1989 on producers' fields, in three-year old stands of Algonquin alfalfa. The soils were thin black Chernozems, one being a sandy loam and the other a clay loam. Four levels of phosphorus (0, 40, 80, and 160 lb P_2O_5 acre^{-1}) as granular $NH_4H_2PO_4$ and three levels of K (0, 27, and 54 lb K_2O acre^{-1} on the clay loam soil and 0, 54 and 107 lb K_2O acre^{-1} on the sandy loam soil) as KCl were applied, broadcast by hand on the soil surface or banded 2 inches deep and 7 inches apart with a double disc drill, modified to facilitate penetration to the correct depth. A treatment also included the banding operation with no fertilizer. The experiment was a full factorial, with 24 treatments, arranged in a randomized complete block design, with four replications on two sites for a total of 192 plots. Fertilizer was applied early in the spring, generally in the latter part of April. The entire 10 x 16 ft. plot was harvested at full bud, in mid-June and late July on both sites. On the sandy loam soil, sufficient regrowth existed to take an additional harvest in late September to early October. On the clay loam soil, a third harvest could only be taken in 1989, as regrowth was insufficient in 1990 and 1991. Plant tissue was dried, weighed, ground and analyzed for concentration of both macro and micronutrients. Statistical analysis was conducted using the GLM procedure of SAS and the Student-Neuman-Keuls' test was used for mean separation (SAS Institute 1985).

RESULTS AND DISCUSSION

Alfalfa Yield Response to Levels of P and K

In the Kansas study, first cut yield increased with P additions of up to 120 lb P_2O_5 acre^{-1} and K applications of up to 80 lb K_2O acre^{-1} (Table 1). First cut yield increased more with P application than did subsequent harvests, with first cut yield increasing 30% with 40 lb P_2O_5 acre^{-1} while subsequent cuttings showed little to no increase. Total yield over the growing season was increased by 14% as compared to the control with application of 40 lb P_2O_5 acre^{-1} and by 25% as compared to the control with application of 120 lb P_2O_5 acre^{-1}. Applying K fertilizer at 80 lb

K_2O acre^{-1} increased first cutting by 11% and final yield by 8%, but increasing the K level to 160 lb K_2O did not increase alfalfa yield as compared to the 80 lb level.

Table 1. Individual cutting and total yield of alfalfa in 1990 as affected by P and K rates of dribble-applied fluid fertilizer (Kansas study).

	Yield at 12% Moisture				
	Cutting				
Treatments	1	2	3	4	Total
	--------------tons/a--------------				
P_2O_5 (lb./acre)					
0	1.03	0.93	0.76	0.46	3.18
40	1.39	1.09	0.74	0.39	3.61
80	1.46	0.96	0.87	0.41	3.70
120	1.60	0.94	0.99	0.44	3.97
LSD (0.05)	0.14	ns	0.15	ns	0.30
K_2O (lb./acre)					
0	1.27	0.93	0.79	0.41	3.40
80	1.41	1.02	0.83	0.42	3.68
160	1.44	0.99	0.90	0.44	3.76
LSD (0.05)	0.12	ns	ns	ns	ns
INTERACTION	ns	ns	ns	ns	ns

In the Manitoba study, in 1991, there was no significant response to application of P at any harvest on the sandy loam soil, in spite of the very high yields obtained (Table 2). However, yield at the second harvest was increased by approximately 10% with the addition of 107 lb. K_2O acre^{-1}. There was no interaction between P and K on the sandy loam soil. On the clay loam soil, yield at each harvest was increased by the application of 40 lb P_2O_5 acre^{-1} and increased further by the application of 80 lb P_2O_5 acre^{-1}. Increasing the level of application to 160 lb. acre^{-1} did not increase yield at any harvest above that obtained with 80 lb. P_2O_5 acre^{-1}. Total yield was increased 87% by the application of 80 lb. P_2O_5 acre^{-1}. Application of 27 lb. K_2O acre^{-1} also increased yield of alfalfa at the first harvest. Increasing the level of K application to 54 lb. K_2O acre^{-1} did not increase yield further. Neither yield at the second harvest nor total dry matter yield was increased significantly by K application, although total yield tended to be higher when K was applied then when it was not added. There was a PxK interaction at the first harvest and for total yield production, with yield being greatest when both K and P were applied at the highest levels.

Table 2. Individual cutting and total yield of alfalfa in 1991 as affected by levels of granular fertilizer P and K on a sandy loam soil (Manitoba Study).

	Dry Matter Yield							
	Cut 1		Cut 2		Cut 3		Total	
Treatments	Broad	Knife	Broad	Knife	Broad	Knife	Broad	Knife
	--------------------------tons/a--------------------------							
P_2O_5 (lb./acre)								
0	3.36	3.12	1.91	1.89	1.55	1.64	6.82	6.64
40	3.31	3.22	1.77	1.71	1.54	1.64	6.61	6.57
80	3.40	3.01	1.85	1.68	1.55	1.49	6.80	6.18
160	3.39	3.15	1.87	1.76	1.62	1.69	6.87	6.60
MSE	ns	ns	ns	ns	ns	ns	ns	ns
K_2O (lb./acre)								
0	3.33	3.15	1.76b[1]	1.78	1.49	1.61	6.58	6.54
54	3.36	3.14	1.83a	1.72	1.58	1.58	6.77	6.45
107	3.40	3.09	1.94a	1.77	1.63	1.65	6.98	6.51
MSE	ns	ns	0.034	ns	ns	ns	ns	ns
INTERACTION	ns	ns	ns	ns	ns	ns	ns	ns

1. Mean comparisons were conducted on the P levels and K levels separately. Within these groupings, numbers within a column followed by the same letter do not differ at the 5% level of significance, using the Student-Neuman-Keuls' method for comparison.

Table 3. Individual cutting and total yield of alfalfa in 1991 as affected by levels of granular fertilizer P and K on a clay loam soil (Manitoba Study).

	Dry Matter Yield					
	Cut 1		Cut 2		Total	
Treatments	Broad	Knife	Broad	Knife	Broad	Knife
	----------------------tons/a----------------------					
P_2O_5 (lb./acre)						
0	0.94c[1.]	1.01c	0.71c	0.91c	1.65c	1.92c
40	1.51b	1.56b	1.16b	1.31b	2.66b	2.87b
80	1.72a	1.61b	1.31a	1.40ab	3.09a	3.01b
160	1.79a	1.81c	1.37a	1.50a	3.10a	3.31a
MSE	0.052	0.068	0.014	0.021	0.102	0.123
K_2O (lb./acre)						
0	1.58a	1.48	1.12	1.28	2.51	2.76
27	1.50ab	1.53	1.11	1.32	2.61	2.85
54	1.38b	1.48	1.12	1.25	2.76	2.73
MSE	0.052	ns	ns	ns	ns	ns
INTERACTION	PxK	ns	ns	ns	PxK	ns

1. Mean comparisons were conducted on the P levels and K levels separately. Within these groupings, numbers within a column followed by the same letter do not differ at the 5% level of significance, using the Student-Neuman-Keuls' method for comparison.

Alfalfa Yield Response to Placement of P and K

In the Kansas study, individual cutting or total yields were not significantly affected by fluid fertilizer placement method in 1990 (Table 4). However, the second harvest and the total yield were affected by a method by K interaction. This was due to larger increases in yield with knifed K fertilization than with either surface K application method.

Table 4. Individual cutting and total yield of alfalfa in 1990 as affected by placement method and P and K rates of dribble-applied fluid fertilizer (Kansas study).

	Yield at 12% Moisture				
	Cutting				
Treatments	1	2	3	4	Total
	---tons/a---				
Method:					
Broadcast	1.43	1.04	0.73	0.38	3.58
Dribble	1.41	1.03	0.78	0.39	3.59
Knifed	1.42	1.04	0.82	0.36	3.63
LSD (0.05)	ns	ns	ns	ns	ns
P_2O_5 (lb./acre)					
40	1.35	1.08	0.73	0.37	3.53
80	1.49	0.99	0.82	0.38	3.67
LSD (0.05)	0.12	ns	ns	ns	ns
K^2O (lb./acre)					
0	1.35	0.94	0.75	0.35	3.39
80	1.49	1.13	0.80	0.40	3.82
LSD (0.05)	0.12	0.10	ns	ns	0.20
INTERACTION	ns	MxK PxK	ns	ns	MxK

In the Manitoba study, there was no interaction between either P or K and placement on either site at any cutting, in their effect on alfalfa yield (Table 5). On the sandy loam soil, the knifing operation damaged the alfalfa plants, resulting in lower dry matter yield at the first and second cuttings when fertilizer was knifed as compared to broadcast. By the third harvest, yields from broadcast and knifed applications were equal, but the total dry matter yield over the season was approximately 4% higher when fertilizer was broadcast as compared to knifed. As cost of the broadcast application is lower than that of the knifed, broadcast applications would definitely be preferable to knifed applications on this soil.

In contrast, on the clay loam soil, knifing did not damage the alfalfa stand sufficiently to depress yield at the first cutting.

In fact, first cutting yield on this site was numerically higher when a knifing operation was conducted than when no knifing was done, even when no fertilizer was applied. At the second harvest, yields were greater with knifed fertilizer than with broadcast fertilizer (Tables 3 and 5). Total yield over the season was about 6% higher when fertilizer was knifed than when it was broadcast, when averaged over fertilizer treatments (Table 5). Knifing performed better on the clay loam soil than on the sandy loam soil. This may be because dry conditions on the clay loam soil reduced rooting near the soil surface, leading to less root pruning on the clay loam from the knifing operation. The clay loam soil was also more responsive to P fertilizer than the sandy loam soil, so there was more scope for yield increases due to increased fertilizer efficiency. Whether this difference warrants the increased cost of knifing depends on the relative costs of fertilizer, alfalfa forage and the knifing operation.

Table 5. Individual cutting and total yield of alfalfa in 1991 as affected by placement of granular P and K fertilizer on two sites (Manitoba Study).

	Dry Matter Yield						
	Sandy Loam				Clay Loam		
	Cutting				Cutting		
Treatments	1	2	3	Total	1	2	Total
	tons/a						
Broadcast	3.36a[1]	1.85a	1.56	6.78a	1.49	1.14b	2.63b
Knifed	3.12b	1.76b	1.61	6.50b	1.50	1.28a	2.78a
MSE	0.066	0.039	ns	0.231	ns	0.018	0.114
INTERACTION	ns	ns	ns	ns	ns	ns	ns

1. Numbers within a column followed by the same letter do not differ at the 5% level of significance, using the Student-Neuman-Keuls' method for comparison.

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PLANT STAGE AND METHODS FOR ASSESSING PHOSPHORUS STATUS OF SPRING WHEAT

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ABSTRACT

Concentrations of total P in whole-shoot samples of spring wheat and of total and extractable inorganic P in leaf samples, were monitorred through the growing season at eight sites with several P treatments. Each of the three tests, carried out at any time from ten through fifty days after crop emergence, could provide a fairly good basis for discriminating between P-deficient and sufficient growth in this study. However, results from sampling within about four weeks of crop emergence was favoured for diagnostic purposes because fewer test levels were close to the critical levels. The inorganic P test was also better than the total P tests in that respect.

OBJECTIVES

Plant analysis for cereals is commonly based on composition of whole plant samples taken at or near the time of heading. For phosphorus, the range of concentrations detected in tissue by this approach is often too narrow for definitive diagnosis. The objectives of this research were to evaluate various plant stages and three test methods for the assessment of the P status of spring wheat under field conditions. Both total and extractable P were determined. The soluble level of nutrients in tissues can show more variation with nutrient status, so may be more sensitive indicators. Despite more recent interest in use of extractable P for cereal tissue P testing (e.g. Knowles et al. 1990), the technique has not been widely popular with field crops. It is adaptable to use in the field.

MATERIALS AND METHODS

Experiments were carried out at five locations in 1990 (sites A-E) and three in 1991 (F-H) on a wide range of soils (Table 1). Sites had been in cereal production (A-G) or flax (H) the preceding year. Spring wheat (var. Katepwa) was seeded at 2 bu/ac with a double disc drill, in long narrow plots to allow repeated sampling of undisturbed sections of each plot throughout the season. Four or five P treatments, with P applied as granular MAP (12-51-0) were used in a RCBD design with five replicates at each site:

- CH - no P applied
- SL - 10 lb/ac P_2O_5 placed in the seedrow
- SH - 41 lb/ac P_2O_5 placed in the seedrow (sites F-H only)
- BC - 41 lb/ac P_2O_5 broadcast and incorporated
- HI - 41 lb/ac P_2O_5 placed in the seedrow, plus 102 (1990) or 204 (1991) lb/ac P_2O_5 br/inc.

Table 1 Site and Soil (0-6 in) Characteristics

Site Desig.	Soil Series	Taxonomy Subgroup	Text.	pH	CO_3-C (%)	$NaHCO_3$-P (ppm)
A	Rignold	Aquic Haploboroll	FSL	7.1	0.0	14
B	Elm River	Typic Udiflurent	SiCl	7.6	1.6	5
C	Willowcrest	Aquic Haploboroll	LS	7.9	0.0	18
D	Plum Ridge	Aeric Calciaquoll	FSL	8.0	1.1	9
E	Lakeland	Aeric Calciaquoll	CL	7.9	1.4	30
F	Reinfeld	Udic Haploboroll	FSL	7.3	0.0	9
G	Elm River	Typic Udofluvent	SiCl	7.7	1.1	3
H	Osborne	Vertic Cryaquoll	C	7.8	1.1	5

The broadcast MAP and all other nutrients required to meet or exceed expected requirements were incorporated, in most cases with a rotovator.

Plant tissues were sampled 7-10 days after crop emergence and at intervals of approximately 10 days thereafter, to a total of six samplings at each site. "Shoot" samples consisted of all the above-ground plant material from a 7.65 ft^2 area within each plot. Separate "leaf" samples of 40-80 of the youngest expanded leaf blades were taken just prior to shoot harvest from the same areas, starting at the second or third sampling time. For the initial sampling(s) without separate leaf samples, the "shoot" samples are also regarded to be "leaf" samples in this report. Total P content was determined for all samples by ignition and colorimetric determination of the P in solution. Extractable inorganic P was determined for all fresh leaf samples the day after sampling. Samples of 2.5 g (fwb) were ground with 2% acetic acid (HOAc) and acid-washed coarse sand in a mortar. The total liquid volume was then brought to 75 ml with 2% HOAc, and the mixture was mixed with a blender. It was filtered and analyzed for orthophosphate-P by the colorimetric procedure. Grain was harvested at crop maturity.

RESULTS AND DISCUSSION

Growing conditions were good in both years, though differed in that 1990 was very moist at all sites until early July, after which almost no rain was received, whereas 1991 was relatively dry to mid-June and moist for the remainder of the season. Leaf diseases (tan spot/septoria) likely reduced yields at sites A, D, F, and H).

The time from crop emergence required for the plants to reach specific growth stages was quite consistent among sites. Time from emergence to heading was 43±2 d at most sites. The typical growth stages (Zadoks/Feekes) at selected days after emergence (DAE) were as follows: 10 DAE (13/1.2), 15 (20/1.9), 20 (22/2.9), 25 (30/5.5), 30 (31/6.2), 40 (46/9.7), and 50 (64/10.5). These relationships can be used to relate DAE to specific growth stages; all following discussion refers to DAE only.

Shoot total P concentrations (dry weight basis) usually declined through the growing season (Fig. 1a), though treatments

Table 2 Grain yields as affected by P treatments

P Trt.	Site A	B	C	D	E	F	G	H
	Grain Yield (bu/a)							
CH	53.6	44.1	36.6	44.7	51.6	35.9	15.2	17.4
SL	53.7	48.0	38.6	46.2	52.3	39.6	23.4	19.9
SH	--	--	--	--	--	40.4	35.6	29.0
BC	54.8	51.6	37.6	47.7	54.1	40.0	37.3	25.3
HI	53.5	59.1	35.5	49.2	51.0	41.7	51.2	49.5
LSD(.05)	4.1ns	6.9	6.9ns	2.8	6.5ns	3.7	5.8	3.8

which were very deficient in P (as indicated by grain yield depression) showed little change to about 30 DAE. It would be important to accurately consider sampling stage if late season shoot P levels are used as a basis for analysis. Concentrations of total P in the leaves were more-or-less constant during the 30 to 60 DAE period. However, they also converged slightly among sites and treatments.

Concentrations of orthophosphate-P extractable by the procedure used ("inorganic P") showed more relative variation among sites and treatments than those of total P (Fig. 1c). They also tended to converge as the growing season progressed. Levels of inorganic P increased quite consistently beyond approximately 30 DAE due to declining moisture content of the leaves (results are expressed on the fresh weight basis rather than dry weight basis as used for total P). Inorganic P levels expressed on the leaf dwb for the 1990 results showed that they too are fairly stable over the 30-60 DAE period (Tomasiewicz and Racz 1991). If testing is carried out in the field samples would not be dried and moisture contents would not be accurately known.

The practical value of plant tests must be measured in terms of how closely and reliably the test values are related to yield depressions. Results from all sites were used to show how relative final grain yield levels were related to tissue test levels for selected times from 10 to 50 DAE (Fig. 2; graphs for 15 and 25 days were also used but are not shown). Each yield is plotted as the ratio (as %) of the wheat grain yield of the treatment to that of the HI P treatment at the same site. All relative yields shown below the 95% line were significantly less than 100% (lsd; $p<.05$), while none above that line were significantly different from 100. The vertical line on each graph was located so as to minimize the number of points in the negative quadrants, using the 95% yield line as the basis on the y-axis; it is considered to be at the "critical level" (CL) P concentration. Since all sampling was not done on the reference number of DAE (10, 15, etc.), values for the reference DAE were calculated by linear interpolation of the values for the same site and treatment at the two sampling days bracketing the reference day.

Very few points are present in the negative quadrants in any of the graphs, suggesting effective discrimination between P-deficient and sufficient conditions for all three tests at all sampling times.

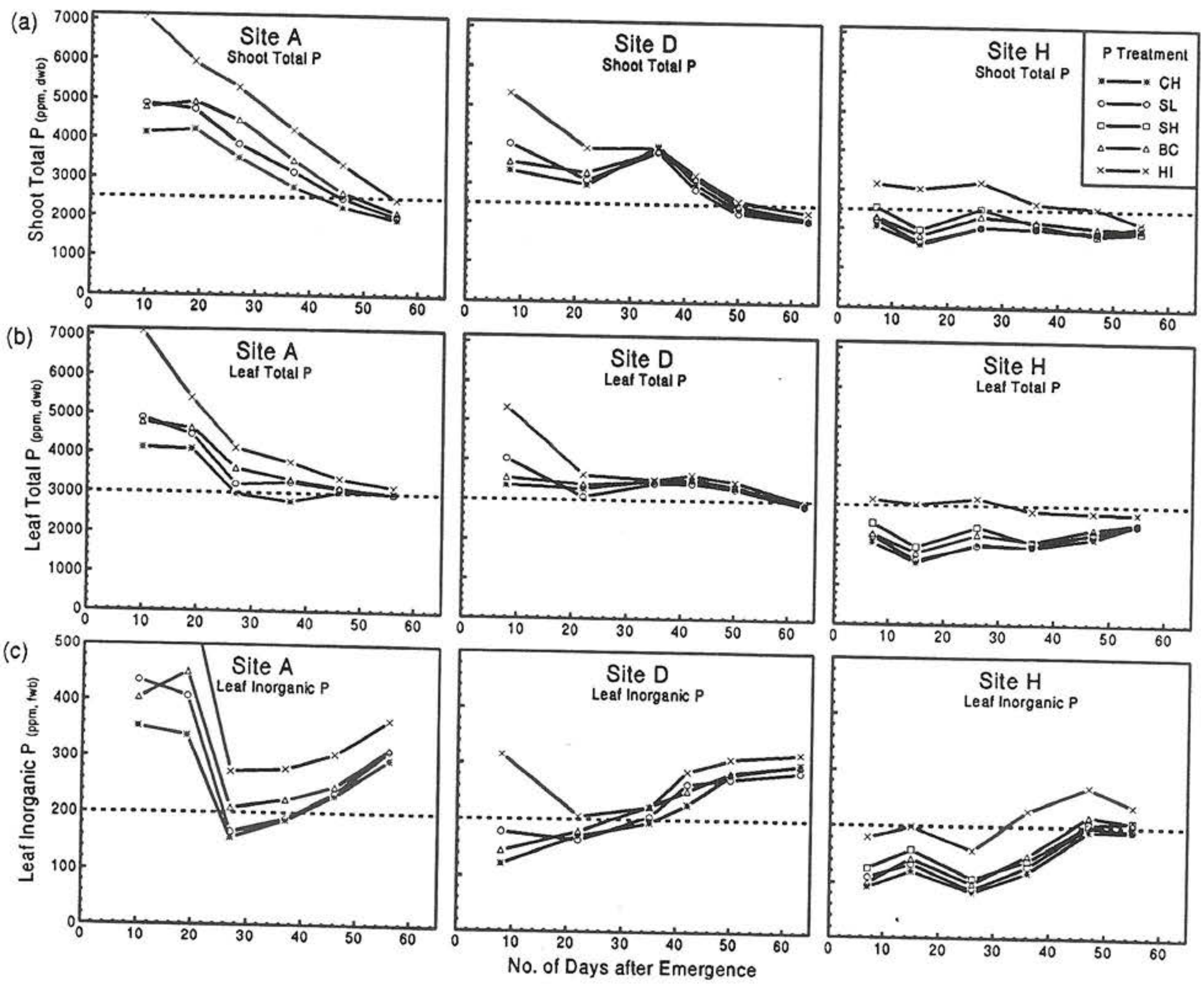

Figure 1. Plant tissue P test levels by three procedures through the growing season for three selected sites. Sites A, D, and H were sufficient, slightly deficient, and severely deficient in P, respectively.

The site H point often in the upper left quadrant is for the HI P treatment; it may have been deficient in P, so it is possible that all relative yields for that site may be too high including the reference HI P yield set at 100%.

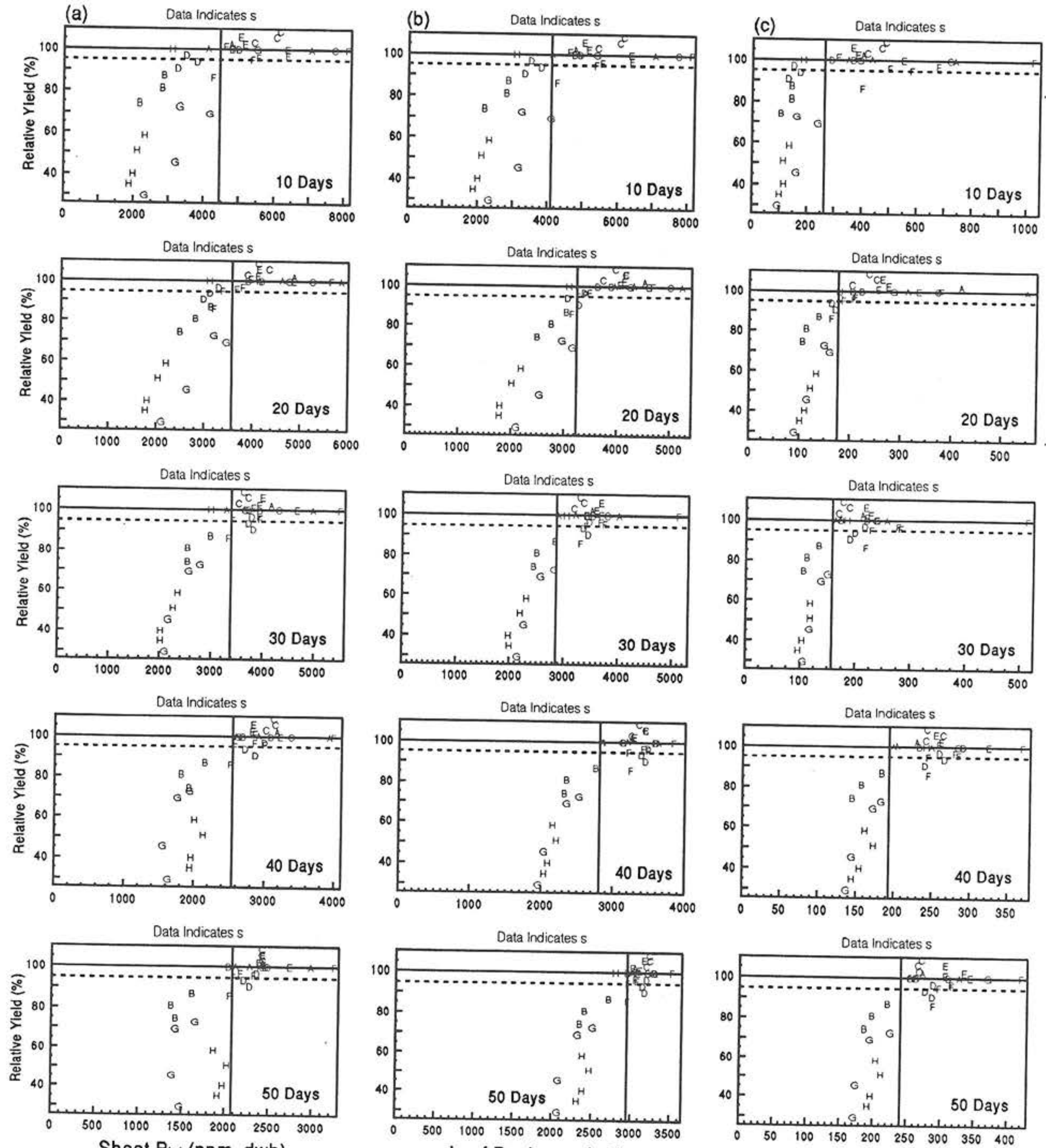

Figure 2. Relative grain yields of treatments as related to (a) shoot total P, (b) leaf total P, and (c) leaf inorganic P, at 10, 20, 30, 40, and 50 days after emergence. Points indicate site designation. Note Y-axis scales differ among all graphs.

Despite reasonable success with each test at each selected DAE time in empirically discriminating between P-stressed and non-stressed treatments (especially prior to about 25-30 days), not all time/test combinations are of equal value in practical terms. Test values close to the CL should be regarded as "marginal" in that no reliable diagnosis can be made. Of the total 35 site/treatment combinations in this study, the proportion of the test values falling close to the CL's varied among the tests and among the DAE times (Fig. 3). At all reference times, the leaf inorganic P test had a much smaller proportion of the observed test mean values close to the CL. At 50 DAE in particular (when plant analysis is often carried out), test values were converging around the CL despite the wide range in P response among sites and treatments. Not only are there more values relatively closer to the critical level at later growth stages, but some of them are for treatments with very low relative yields. Fitting the relative yield data to regression functions may provide a more quantitative basis for comparison. Relative dry matter accumulation through the growing season for the 1990 sites suggested that the growth restriction due to P deficiency occurs primarily early in the season (Tomasiewicz and Racz 1991). Rapid changes in CL's with time are undesirable for diagnosis. The leaf total P test shows least variation with time, especially after 30 DAE (Fig. 4).

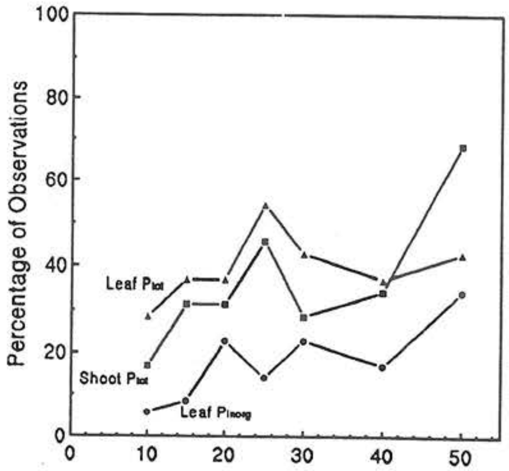

Figure 3. Pecentage of the 35 site/treatment combinations with tissue P test values falling within 15% of the CL.

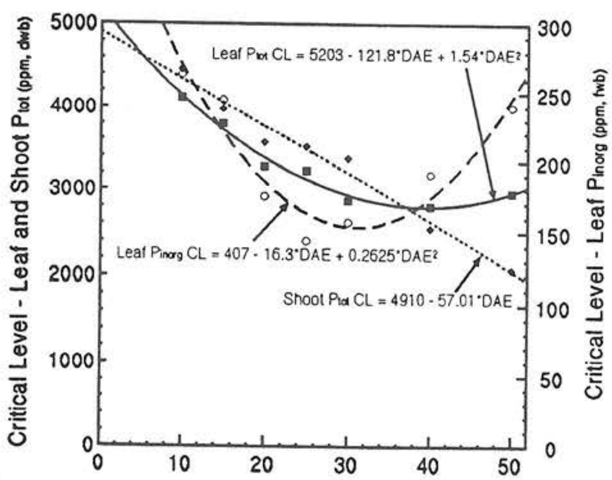

Figure 4. Critical levels for wheat tissue P concentration through the growing season for three different tissue tests.

In conclusion, concentrations of total P (dwb) in the whole shoot or youngest expanded leaf blades only, and of extractable inorganic P (fwb) in the leaves, all provided a reasonably good basis for assessing the P status of wheat as it affected grain yield in this study. Practical considerations, especially the need to minimize the proportion of test levels too close to the CL, favoured testing at an early stage (e.g. 15-30 DAE). The determination of fresh leaf tissue extractable P provided at least as good a basis for assessing the P status of wheat as did the total P tests.

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A SUMMARY OF CHLORIDE RESEARCH IN THE GREAT PLAINS

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ABSTRACT

Research in Great Plains has indicated that application of Cl containing fertilizers can increase yield in selected cultivars of wheat and barley. In general, Cl yield responses have been modest and greater than 200 lbs/a in only 30% of the cultivar x site x year episodes. Though the mechanisms involved are still not clear there are several factors which appear to be important in Cl response prediction these include soil Cl levels to a depth of 24", cultivar selection, plant Cl levels, and plant diseases. Considerable attention has been focused on the role of Cl in disease suppression. Chloride has produced small reductions in root rot infections caused by *C. sativus*. The effects on foliar diseases symptoms caused by *Pyrenophora tritici-repentis*, *Septoria avenae f. sp. triticea*, *Puccinia recondita* though temporary have sometimes been observed to be dramatic and visually obvious. Chloride has been shown to accelerate the rate of spike development in wheat, and frequently increases wheat and barley kernel weights at harvest. This latter effect may be due to an increase in grain-fill duration and/or kernel growth rate.

INTRODUCTION

Chloride has been recognized as an essential plant nutrient since 1954 (Broyer et al., 1954). Initially it was classified as a micronutrient with plants requiring only trace amounts for their physiological functions. As soil Cl levels and inputs from rain were considered adequate to meet this requirement, until recently there was comparatively little attention given to Cl as a fertilizer. During the mid-1980's interest in Cl fertilizers developed in the Great Plains. This interest can probably be attributed to two factors: 1) studies in the Pacific Northwest indicating that Cl in fertilizers increased yield and suppressed take-all root rot caused by *Gaeumannomyces graminis* var. *tritici (Ggt)* in winter wheat (Christensen et al., 1981; Taylor et al., 1983), and 2) previous studies in the region documenting significant yield and quality responses by wheat and barley to KCl on soils with seemingly abundant supplies of available K (Zubriski et al., 1970; Skogley, 1976; Schaff and Skogley, 1982). Since the mid-1980's numerous studies on Cl fertilizers and their effect on cereal grains have been initiated. The objective of this report is to summarize the major conclusions of published studies, and to update the reader on current developments in Cl research within the Great Plains.

In South Dakota, soil Cl levels to a 24" depth successfully separated sites into responsive and non-responsive groups (Fixen et al., 1986b). A summary of 36 field experiments from 1982-86 showed a response frequency to Cl by spring wheat of 69%, 31%, and 0% for soil Cl levels < 30, 30-60, and > 60 lbs/a, respectively (Fixen et al., 1987). The fertilizer recommendation proposed by the authors was to apply sufficient Cl so the sum of fertilizer + soil Cl equaled 60 lbs/a. Though Cl levels and distribution in the soil profile are undoubtedly important in response prediction, researchers in other regions have found this guideline to be unreliable (Engel and Grey, 1991; Evans and Nelson, 1990; Lamb and Windels, 1989; Mohr and Flaten, 1992, pers. comm.).

Recently investigators have found Cl yield responses in wheat are affected by cultivar selection (Table 1). Spring wheat cultivar studies in South Dakota indicate 'Marshall' and 'Butte' are more responsive to Cl than 'Guard' (Cholick et al., 1986). Winter wheat studies in Kansas indicate the cultivar 'Arkan' is more responsive to Cl than 'Newton' (Bonczkowski, 1989). Studies in Manitoba have indicated the spring wheat cultivars 'Biggar' and 'Marshall' are more responsive to Cl than 'Katepwa' and 'Roblin'. Cultivar effects may be a contributing factor to apparent conflicts in data from different regions.

Table 1. Spring and winter wheat responses to Cl have been sensitive to cultivar selection in South Dakota and Kansas, respectively.

State	Cultivar	Control	Chloride	Response
		---------- bu/a ----------		
S.Dakota†	Marshall	57.3	62.1	4.8
	Butte	54.8	59.3	4.5
	Guard	58.2	57.9	-0.3
Kansas‡	Arkan	47.6	53.9	6.3
	Newton	43.2	43.1	-0.1

† Mean of six site-years Moody Co. 1984, Day Co. 1984, Moody Co. 1985, Day Co. 1985, Lake Co. 1986, and Hamlin Co. 1986 (Cholick et al., 1986).
‡ Mean of three years at Powhattan, 1985-1987 (Bonczkowski, 1989).

As with soil analyses, plant Cl concentrations were reported by Fixen et al. (1987) to be useful in distinguishing potentially responsive and non-responsive sites. In this study a Cate-Nelson analysis of relative yield vs plant Cl in control plots resulted in

CHLORIDE EFFECT ON YIELD

Yield results from wheat and barley studies over 5 states in the Great Plains indicates that significant responses to Cl have occurred over a wide range of environments (Fig. 1). Disagreement appears to exist over the responsiveness of crop species to Cl. Reports from North Dakota suggests that barley is more responsive to Cl than wheat (Goos, 1986). South Dakota (Fixen, 1991, pers. comm.) and Manitoba (Mohr and Flaten, 1992, pers. comm.) research suggests wheat has been more responsive to Cl than barley. Fixen et al. (1986a) observed that oats generally do not respond to Cl. In general most investigations in the Great Plains have found that Cl yield responses are modest. Overall, in only 30% of cultivar x site x year episodes has the response to Cl been greater than 200 lbs/a. In many cases the yield response to Cl has been only marginally adequate to pay for the material applied. However, in the Great Plains a high percentage of applied Cl can remain in soil profile following harvest (Goos et al., 1987; Schumacher and Fixen, 1989). As only small amounts of Cl are removed in the grain, the profitability of Cl applications may be enhanced where its positional availablility to the crop extends beyond 1 yr.

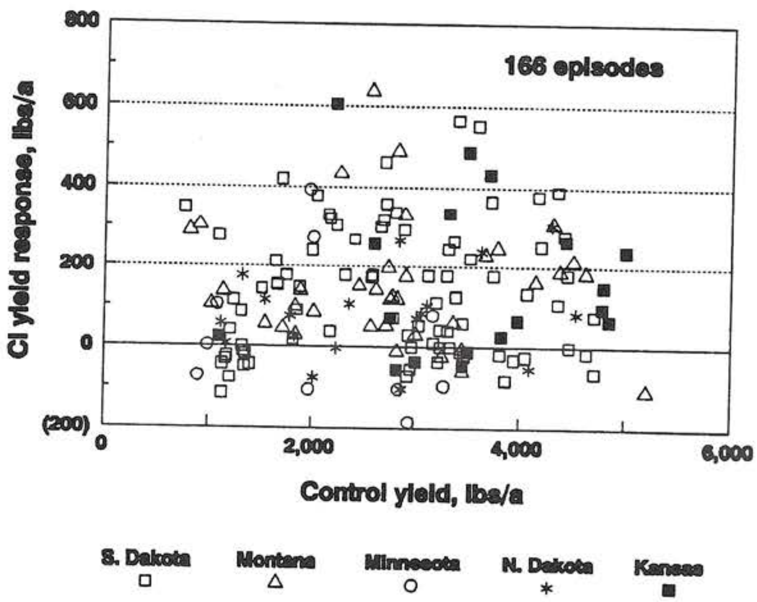

Figure 1 Chloride yield response (Cl - control) vs. control yields over a five state region in the Great Plains. Each data point represents the response to Cl at a cultivar x site x year episode.

The mechanism(s) by which Cl acts to increase yield has (have) not been clearly established. Many investigators have expressed some difficulty and frustration in this regard. This difficulty may be a result of the fact that responses are often small, more than one mechanism is involved, and environmental factors strongly interact with Cl affecting the probability of a response. Although the processes involved are unclear, there are several factors which have been implicated as being important in response prediction.

a .15 % critical Cl level and place 83% of the observations in positive quadrants. A comprehensive survey from four Great Plain states (Montana, N. Dakota, S. Dakota, Kansas) of relative yield-plant Cl relationships in <u>responsive</u> cultivars is depicted in Fig. 2. Three zones of differing Cl status can be distinguished: a low range (≤.12% Cl), where Cl responses up to 35% have been observed in 14 of 18 episodes; a transition range (>.12 -.40% Cl), containing an approximately equal mix of responsive and non-responsive episodes, but where significant response occur they are less than 14%; and an adequate range (>.40% Cl) where few significant responses to Cl are observed.

Considerable attention has been given to the role of Cl in disease suppression. Several studies in the Great Plains (Timm et al., 1986; Engel and Mathre, 1988) and elsewhere (Christensen and Brett, 1985) have attempted to connect yield responses to Cl with a reduction in plant diseases. However, there have been many examples of significant yield responses to Cl in the Great Plains where no reduction in disease was observed (Bonczkowski, 1989; Engel and Mathre, 1988; Engel and Grey, 1990; Fixen et al., 1986a; Goos et al., 1989; Mohr and Flaten, 1992, pers. comm). Presently the link between yield responses and disease suppression by Cl, particularly root diseases, would not appear to be as important as previously believed.

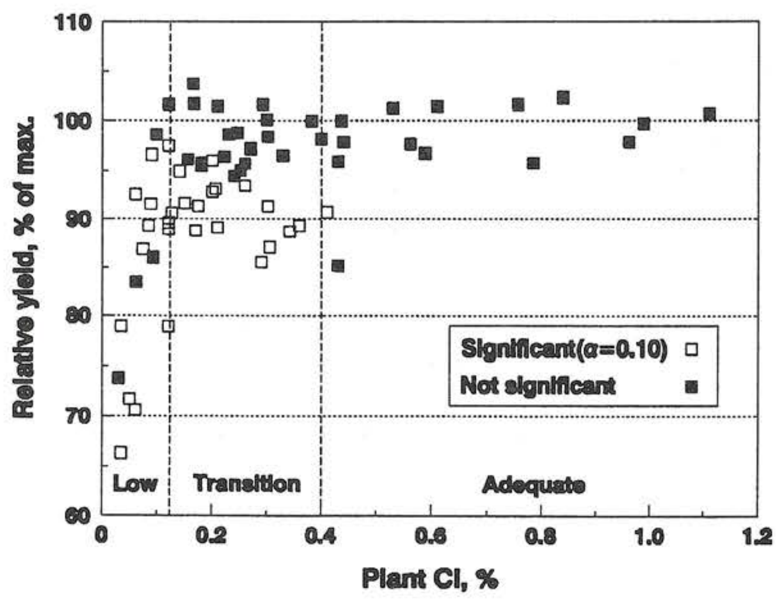

Figure 2. Relationship between whole plant Cl concentrations (boot to flowering) and relative grain yield in control plots. 1982-1990. Studies from four Great Plain states. Observations limited to cultivars known to be responsive to Cl.

DISEASE SUPPRESSION

The role of Cl in cereal root disease suppression has been of interest in the Great Plains since studies in Oregon demonstrated it reduced take-all root rot caused by *Ggt* (Christensen et al., 1981; Taylor et. al, 1983). Several studies (Timm et al., 1986; Goos et al., 1986,1989; Shefelbine et al., 1986; Mohr and Flaten, 1992, pers. comm.) have shown that Cl can sometimes reduce the incidence and/or severity of common root rot in barley and wheat caused by *Cochliobolus sativus (C. sativus)*. Other studies have indicated little or no effect by Cl on symptoms of root rot incited by *C. sativus* (Stover, 1991; C.E. Windels and J. A. Lamb, 1991, pers. comm.), *Fusarium culmorium* (Engel and Grey, 1991), and Ggt (Engel and Mathre, 1988; R. Lamond, 1991, pers. comm.), respectively. In general, where root rot suppression by Cl occurs the effects are small. The fungicide imazalil, when used as a seed treatment, has been more effective than Cl in reducing *C. sativus* (Goos et al., 1989) root rot symptoms. Suppression of *C. sativus* root rot may play only a minor role in explaining Cl yield responses. In several cases barley yield has not been improved even though *C. sativus* infection symptoms on roots were reduced by Cl and imazalil (Goos et al., 1989, Shefelbine et al., 1986).

Foliar diseases in cereal grains have been observed to be suppressed by Cl in North Dakota (Stover, 1986), South Dakota (Fixen et al., 1986b; Buchenau, 1991, pers. comm.); Montana (Engel, 1991, unpublished data); and Kansas (Lamond, 1991, pers. comm.). In several cases the disease suppression though temporary has been noted to be dramatic and visually obvious. Tanspot *(Pyrenophora tritici-repentis)*, septoria leaf spot *(Septoria avenae f. sp. triticea)*, and leaf rust (*Puccinia recondita*) are the diseases most often observed to be affected by Cl. Results from South Dakota suggest the relationship between Cl yield responses and disease suppression is stronger for foliar than root diseases. In field experiments conducted from 1984-1988 Cl suppressed leaf spot (tanspot + septoria) and leaf rust symptoms in spring wheat (Table 2). In general, yield response to Cl was more frequent and larger in high disease environments than low. Also, application of the fungicide propiconazole (Tilt) to Cl responsive cultivars, i.e. Butte and Marshall, frequently reduced or eliminated Cl disease suppression and yield responses (Buchenau, 1991, pers. comm.).

To date the mechanism by which Cl suppresses plant diseases has not been determined. Some investigators have speculated that a decrease in water potential and an increase in turgor pressure caused by Cl accumulation may inhibit infection by plant pathogens (Christensen et al., 1981; Fixen et al., 1986b). Chloride may also affect disease levels through its effect on nitrate (Goos et al., 1987, 1989; Timm et al., 1986) and Mn levels in the plant (Beaton et al., 1988). The lack of a definite relationship between disease symptoms and yield has made it difficult to determine the economic importance of Cl as a "disease fighter". This may be due to the inaccuracy of disease severity indices (Engel and Mathre, 1988), the fact that Cl often provides only temporary disease suppression (Bonczkowski, 1989), and the interaction of diseases with cultivars (Granade et al., 1990). It is also possible the most important role of Cl in disease environments is not related to suppression of the pathogen, but to resistance in the plant (Christensen et al., 1990).

Table 2. Effect of Cl on foliar diseases and grain yield in three spring wheat cultivars. Selected studies from South Dakota (Buchenau, 1991, pers. comm.).

Year†	Cultivar	Foliar disease				Yield	
		Leaf spot‡		Leaf rust			
		-Cl	+Cl¶	-Cl	+Cl	-Cl	+Cl
		%				bu/a	
1984	Butte	55	*40	54	*45	44.8	*50.8
	Marshall	15	*11	24	*7	44.9	*52.9
	Guard	38	*31	2	1	49.4	48.5
1985	Butte	99	*82	40	*22	62.1	*68.2
	Marshall	67	*50	1	*12	59.8	*69.1
	Guard	82	*78	<1	<1	63.4	63.4
1986	Butte	85	*50	50	40	44.4	*49.4
	Marshall	75	*38	40	*11	50.8	51.8
	Guard	68	*50	10	*4	54.2	54.2

† 1984, 1985, and 1986 from sites South II, South I, and South I, respectively.
‡ Leaf spot a combination of tanspot and septoria.
¶ 55 lbs/a Cl applied as KCl prior to seeding.
* Significantly different from -Cl at $P < 0.05$ level

CHLORIDE EFFECTS ON CEREAL GRAIN DEVELOPMENT AND KERNEL WEIGHT

Chloride has been shown to accelerate the rate of reproductive development in spring wheat. In a two-year study Schumacher (1990) found the beginning of spikelet primordia formation, development of terminal spikelet, date of anthesis initiation was advanced by Cl. In general, the effects on plant development were more pronounced in Cl responsive cultivars, i.e. 'Marshall', than non-responsive cultivars, i.e. 'Guard' (Fig. 3).

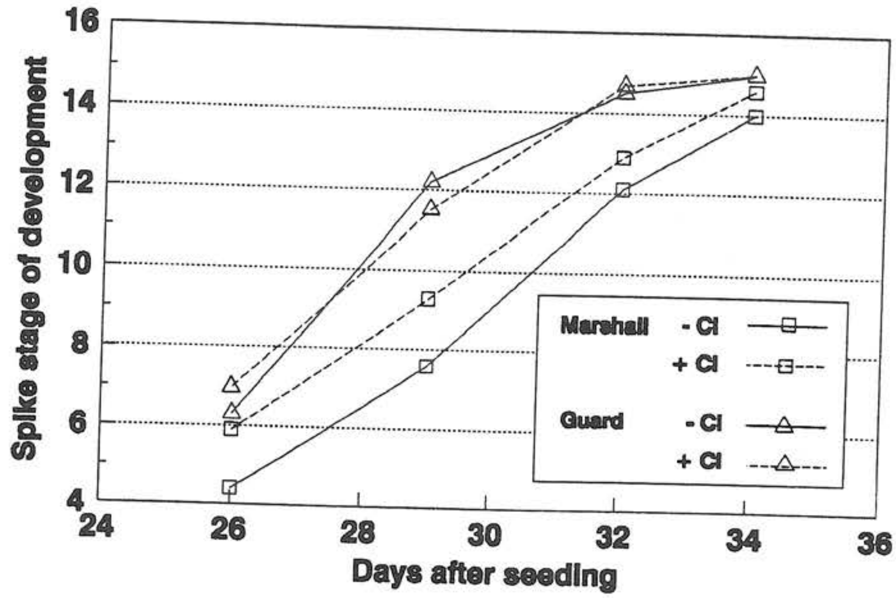

Figure 3. Effect of Cl on reproductive development in spring wheat. Growth stages are based on the George scale (Schumacher, 1990).

Chloride has been observed to increase kernel weight, kernel volume (plumpness), and test weight in wheat and barley. These parameters are sometimes affected more frequently than grain yield. Kernel weight increases up to 14% (Cholick et al., 1986) and 12% (Engel, 1991, unpublished data) have been observed in spring and winter wheat in the Great Plains, respectively. Higher kernel weights in cereal grains at maturity can be attributed to two possible mechanisms, 1) a longer grain-fill period (i.e. flowering to maturity), or 2) an accelerated rate of kernel growth. Schumacher (1990) found no effect from Cl on the rate of kernel growth during the linear phase of development in 'Marshall' spring wheat. However, grain-fill duration and maximum kernel weight were increased 1.5 days and 4% by Cl, respectively. His results suggested that increased kernel weights from Cl application were a result of its affect on grain-fill duration and not its effect on rate of kernel growth. However, a 1991 study in Montana indicated a very different conclusion. Engel (1991, unpublished data) found the rate of kernel growth in six winter wheat cultivars was significantly increased by Cl (Fig. 4), while grain-fill duration was unaffected. Though the differences between the Cl and control treatments were small (7%), they were highly significant ($P < 0.0001$) and great enough to account for differences in kernel weight and grain yield at maturity.

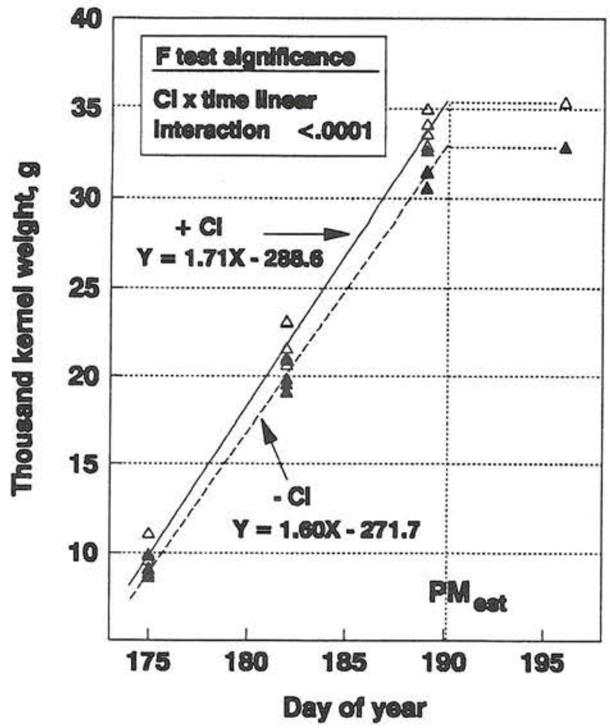

Figure 4 Effect of Cl on rate of kernel growth in winter wheat. Mean of six cultivars. Garryowen, Montana. 1991. PMest = physiological maturity estimate (Engel, 1991, unpublished data).

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The authors wish to extend their sincere thanks to the following individuals John Lamb, Carol Windel, and Sam Evans University of Minnesota; Paul Fixen, PPI North Central Region Director; Ray Lamond and Dan Sweeney, Kansas State University; George Buchenau, South Dakota State Univ.; Ramona Mohr and Don Flaten, Univ. of Manitoba for reports and summaries of ongoing Cl studies. Much of this information was used in the development of the relationships in Figs. 1 and 2.

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NUTRIENT AND WATER MANAGEMENT STRATEGIES FOR TEXAS HIGH PLAINS COTTON PRODUCTION

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ABSTRACT

Cotton production on the Southern High Plains of Texas is limited first by water supply during the growing season and secondly by a combination of growing season length and nitrogen supply. The goal of our research program has been to develop management strategies which will maximize yields within the constraints of the water supply which ranges from dryland production through full irrigation. Nitrogen management strategies have been developed which maximize water use efficiency and fiber quality. The results have indicated that water supply is primarily responsible for the production of fruiting site formation. Nitrogen supply has major influence on fruit retention and fruit size. A ratio of 5 pounds of N per inch available water appears to be an optimum N supply. Due to the variation in soil textures across the region and the large variation in rainfall patterns, multiple application of N throughout the growing season are better than single applications early in the season.

INTRODUCTION

Within a 120 mi radius of Lubbock, TX, 30*-35% of the total U.S. cotton acreage is planted annually resulting in 25% of the total U.S. lint production. Yields are lower than the rest of the Cotton Belt due to lack of an adequate water supply throughout the growing season resulting in periodic, but often intense, water stress. Approximately 40% of the area has supplemental irrigation capabilities. In the irrigated production systems, yields are limited by growing season length measured in heat unit accumulation rather than days and by soil nutrient supply. Due to the elevation of the area (3300 feet) and the semi arid nature of the environment, night temperatures in the early part of the growing season and again during the latter part of the season are below optimum delaying plant development and fiber maturity. The area has been a major cotton producing region for well over 50 years. Yields progressively increased through the early 1970's due to increasing irrigated acreage, better management, and better cultivars. Beginning in the mid 70's and continuing essentially to present, average yields (both irrigated and dryland) have been declining at a rate equivalent to 10 pounds-acre-1-year-1. The rate of decline has been greater under irrigated conditions in the sandy soils than those having clay soils (southern vs northern areas). The decline has also occurred in the dryland production systems. The cause of this decline has been a major concern with essentially every public and private agency associated with Texas High Plains Cotton production. Recent soil surveys conducted by the High Plains Underground Water District have revealed very low levels of soil NO_3-N and organic matter. The NO_3-N and organic matter was greater in the irrigated clay soils than in the sandy soils due to rotations with grain crops. In most counties that are essentially a cotton monoculture the residual soil N is only adequate to support lint yields of 300 pounds/acre^{-1} no matter what the water supply.

Since cotton fibers (lint) are produced from seed coats and since the seed is very high in protein (-25% by weight), we hypothesized that lack of an adequate N supply was limiting productivity when the water supply was adequate for growth following a rain or irrigation event. Due to the fact that the soil profile is usually only partially recharged with water during the winter period, and due to the unpredictable nature of the summer rainfall, very little preplant fertilizer is applied. If supplemental N is not provided during the growing season, then yields are limited by N supply and water is wasted.

We began a project in 1983 and are continuing today to evaluate the interaction between water supply and N supply on cotton productivity and quality on the Texas Southern High Plains.

MATERIALS AND METHODS

Field experiments have been conducted on two soil textures. The Texas Tech Agronomy Research Center, 30 miles north of Lubbock, has an Olton clay loam soil which is typical of the northern half of the cotton production area. The Texas Tech Crop Production Research Center at Brownfield, Texas about 35 miles SW of Lubbock, has an Amarillo loamy fine sand which is typical of the southern half of the production area. At both locations sprinkler irrigation is used to provide various water supplies used as experimental variables. Water supply treatments have ranged from dryland (rainfed) to full irrigation (100% ETa replacement) . Several intermediate levels have been included each year. Experiments began in 1983 and are continuing today. When we began the experiments we evaluated several combinations of N and P rates and times of application. we also tested zinc applications comparing soil applied to foliar treatments. For the purpose of this presentation, I will use only the N response data in conjunction with the water supply treatments. Soil tests were conducted each year to depths of 3 feet. Preplant N was applied broadcast and incorporated with the dinitroaniline herbicide (Prowl) . Sidedress N was applied prior to flowering (about 60 days after emergence) and was chiseled into the middle of the row about 3-4 inches deep. N rates were a variable at each time of application using a factorial design initially (2x2) After several years of preplant versus sidedress experiments we developed a multiple regression equation that defined cotton lint yields as a function of water supply, residual N, preplant N and midseason N applications. Following the development of the regression equation, the past 4 years have been used to test the relationship between N supply and water supply required to optimize water use efficiency. A wider range of both water supplies (4) and N supplies (4) have been tested in a factorial design. Plant response has been evaluated using traditional growth analyses, which includes the number of fruiting sites produced and their retention and location on the plant. Yield was determined by hand harvesting 0.002 ac (87 sq. ft.) and determining the number of plants, number of mature bolls, and average lint and seed weights per boll. Statistical analyses included ANOVA and regression analyses.

RESULTS AND DISCUSSION

Water management:

Over the course of the total experiment, lint yields ranged from about 200 pounds/acre^{-1} (< 1/2 bale/ac^{-1}) to over 1500 pounds/ac^{-1} (> 3 bales/ac^{-1}) depending upon water supply, N supply and growing season length. In every year, supplemental irrigation increased yields with the yield response to water supply being dependent upon both the N supply and the amount of heat units accumulated.

Analyses of the relative contribution of individual yield compo nents to total yield indicated that boll number component was primarily responsible for the yield variation with only minor variation in lint per boll due to treatment (Table 1). The fruit number component is a function of plants/acre^{-1} and fruit/plant^{-1} These two components are inversely related but the correlation coefficient is not very large. Our previous research indicates that if within-row density exceeds 4 plants per foot of row, the boll number per plant and the average lint weight per boll declines. Increasing water supply increased the number of fruiting sites being produced per plant which resulted in more fruit per plant (Fig. 1). In a short growing season the more fruiting sites that can be produced early in the fruit development period, the greater the yield potential.

Table 1. Correlation coefficients for lint yield and components of yield.

	Lint yield	Bolls·ac^{-1}	Plants·ac^{-1}	Bolls·plant^{-1}
Lint yield				
Bolls·ac^{-1}	0.9416*			
Plants·ac^{-1}	0.5226*	0.5707*		
Bolls·plant^{-1}	0.5026*	0.5212*	0.3459*	
Lint wt·boll^{-1}	-0.1285	0.0269	0.0462	0.0567

*Significant at the 0.05 probability level.

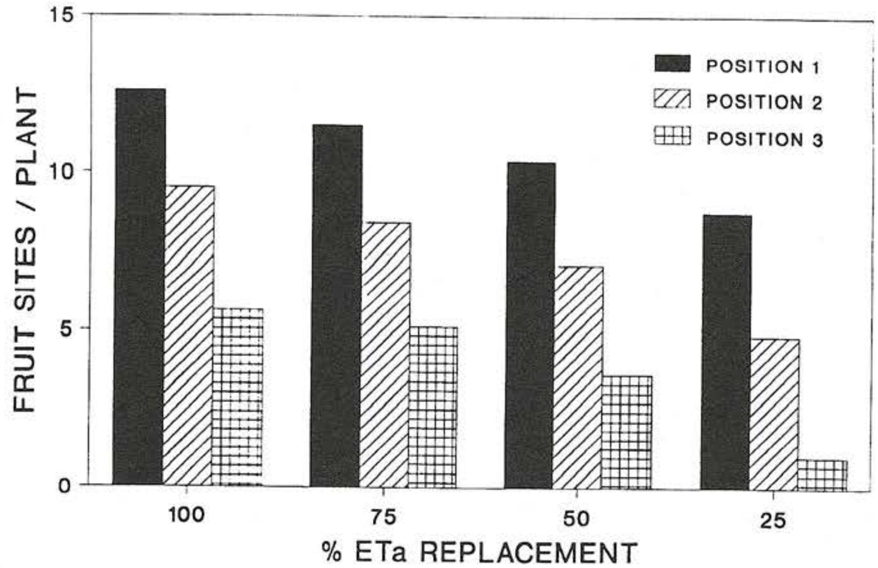

Figure 1. Fruit sites per plant as affected by water.

Nitrogen management:

Analyses of the three sources of N (e.g. residual, preplant, and midseason) revealed that the greatest effect on yield was from mid-season applications. An interaction existed between residual N and preplant applied N. If the residual N exceeded 5 ppm (5 $\mu g \cdot g^{-1}$ soil) no yield response was observed from the preplant applied N. Most continuous cotton production systems were found to have residual N levels of 1-3 ppm and preplant applications are beneficial under these low levels of residual N. The total amount of N required to produce a given yield was totally dependent upon the water supply. Based upon lint:seed ratios of 1:1.6 and a protein concentration in the seed of 25% (4% N) it is apparent that 1 pound of N is required to produce 10 pounds of lint and the associated seed.

Water-Nitrogen interactions:

As the water supply increases, the yield potential increases but that additional potential is only realized if supplemental N is available (Fig. 2). Based upon the linear relationship between lint yield and water supply (water use efficiency) we estimate that each inch of water above a base requirement of 4 inches should result in 50 pounds of lint (Fig. 3) . Using a production function of 1 pound N being required to produce 10 pounds of lint, it is apparent that the N:water ratio should be 5 pounds N per inch of water available to the crop. If the soil test $NO_3^{-1} \cdot N$ exceeds 5 ppm in the top 3 feet of the soil profile, preplant applications of N are not beneficial and the N should be supplied during the growing season as the water supply increases.

Using the approach of managing N supply based upon the water supply results in maximum N and H20 use efficiency due to the maximum possible yields per unit of available water which is the primary yield limiting environmental component.

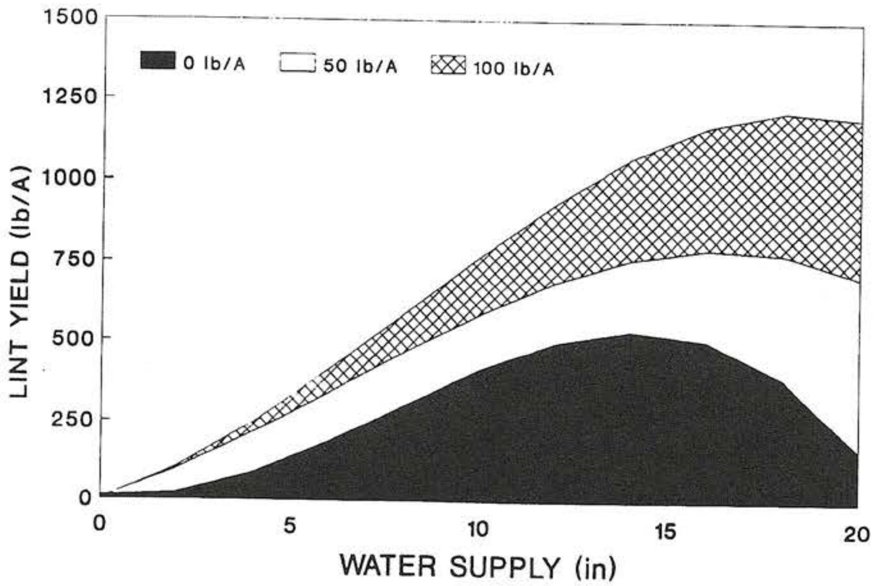

Figure 2. Lint yields as a function of water supply within each nitrogen supply.

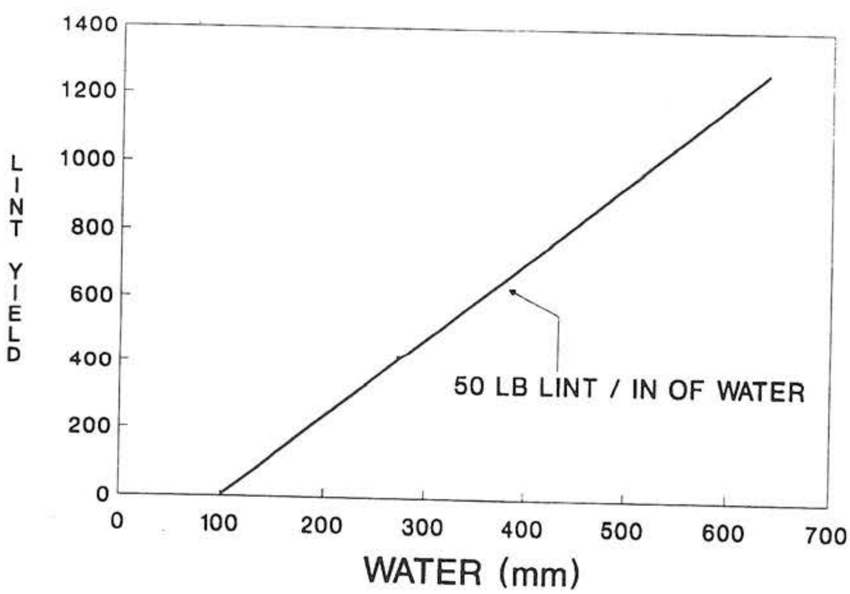

Figure 3. Lint yield as a funciton of water supply.

SUMMARY AND CONCLUSIONS

The results of this research program resulted in an integration of the N supply with the available water resource. Maintaining a N:H20 ratio of 5 pounds N per inch of water maximized productivity within the limits of the water supply.

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