1988

Great Plains Soil Fertility Workshop

Proceedings

DENVER, COLORADO

March 8 & 9, 1988

GREAT PLAINS SOIL FERTILITY WORKSHOP

RESEARCH EXTENSION INDUSTRY

PROCEEDINGS

OF THE

GREAT PLAINS SOIL FERTILITY WORKSHOP

DENVER, COLORADO

MARCH 8-9, 1988

Great Plains Soil Fertility Workshop Proceedings, Vol. 2
Kansas State University
Manhattan,KS 66506
Edited by J.L. Havlin

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TABLE OF CONTENTS

TABLE OF CONTENTS

STRATEGIES TO MINIMIZE NITRATE IN GROUNDWATER[1]

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ABSTRACT

Concern over groundwater contamination by nitrate has prompted a variety of improved management practices to reduce the potential for nitrate leaching. Tissue testing in corn has not been developed as a management tool to monitor plant nitrogen (N) status, but in the future may be used to indicate the need for additional fertilizer N. Leaf chorophyll and total leaf N concentration were measured in 1986 and 1987 before and after silking of 3 commercial corn hybrids grown under irrigation at 4 levels (0, 67, 134, and 268 lb/ac) of N fertility. Fertilizer was applied as sidedress anhydrous ammonia, with and without a nitrification inhibitor (N-Serve). Maximum yields were obtained with 67 and 134 kg/ha N fertilizer in 1986 and 1987, respectively. Leaf chorophyll and total leaf nitrogen concentration were positively correlated with corn yield for each hybrid, indicating that it may be possible to use one of these chemical assays to evaluate the need for fertilizer nitrogen during the growing season. Nitrification inhibitor application reduced the amount of plant available nitrogen in soil and leaf nitrogen concentration prior to silking. Apparently the nitrification inhibitor enhanced the transformation of fertilizer nitrogen into microbial biomass rather than permitting its rapid conversion to nitrate. Later during the grain fill period, nitrogen immobilized in microbial biomass was mineralized and became available to the crop. Leaf photosynthesis rate was found to increase with leaf nitrogen content ($r^2 = 0.85$), and supports the observed yield increases with increasing leaf nitrogen concentrations.

OBJECTIVES

Nitrogen (N) management practices to minimize nitrate contamination of ground water are numerous, but the fact remains that nitrate leaching is a physical process driven by excess soil water. For this reason simple physical solutions are sometimes assumed to be required when dealing with the problem. In reality, N undergoes many biological and chemical transformations in soil, with nitrate being the inorganic form which is leachable and is also a major component of the N nutrition of crops. It therefore follows that in addition to the more obvious soil and water management practices, some aspects of crop growth may offer a partial solution to the problem of groundwater contamination by nitrate. Obvious cautions are that corn hybrids may respond differentially to N fertilizer and that N rate by hybrid interactions would complicate interpretation of tissue analyses.

Balko and Russell (1980) indicated that genotypic selection may enable breeders to develop hybrids that do not require high N fertilizer rates to produce near maximum yields. More recent work by Carlone and Russell (1987) concluded that it is not possible to generalize among corn cultivars in regard to response to N, and that each genotype seems to have a unique pattern of N response that is independent of yield potential. Their work further showed genotypic yield response to N was influenced by plant population. Use of this type of information to guide breeding programs should be done with great caution because hybrid maturity, plant density, year, and location all effect corn yield response to N level (Duvick and Cavalieri, 1987). It follows that extrapolation of research data to commercial corn production may be premature until more is known regarding hybrid by environment interactions. However, Lambert (1987) showed management practices (including N fertilization) may need to be modified for each field to realize the genetic potential of corn hybrids.

The objectives of this research were to determine N uptake characteristics of several diverse corn hybrids and evaluate leaf N content and tissue testing as a possible N management tool.

METHODS AND MATERIALS

This study initiated in 1986 in Clay Center, Nebraska, was intended to study the interactions between sidedress fertilizer N rates, two tillage systems (double disk and no-till), three corn hybrids (Pioneer brand hybrids 3377, 3475, and 3551), and a nitrification inhibitor (N-Serve). Sufficient time has not elapsed for the no-till system to manifest any yield differences compared to the double disk treatment, so only the conventional tillage data will be discussed. Nitrogen rates used in this study were 0, 67, 134, and 268 lb/ac applied as sidedressed anhydrous ammonia to subplots 8 rows wide (30 inch rows) by 80 ft in length.

Leaf N concentrations were determined by compositing leaf disks (0.4 inch diameter) from at least 30 plants approximately one week before and two weeks after silking. The uppermost fully expanded leaf of each plant was sampled prior to silking, while the ear leaf and third leaf above the ear leaf were sampled after anthesis. Grain yields were determined by hand harvesting 4 rows each 10 ft in length. Stover yields were determined by randomly selecting 20 plants for chopping and subsampling. Leaf N concentration and grain yield were also determined for 6 commercial hybrids grown under irrigation with preplant N rates of 0, 80, 160, and 240 lb/ac at Schuyler, Nebraska, with an additional treatment receiving 80 lb N/ac preplant plus 80 N/ac sidedress application.

RESULTS AND DISCUSSION

All hybrids responded similarly to N fertilizer in 1986 and mean maximum yield across hybrids was produced with 67 lb N/ac (Figure 1). Lack of fertilizer response at higher N rates is attributed to moderate levels of residual soil N the first year of the study. Grain N uptake was not markedly affected by fertilizer N rate, however stover N uptake increased above 134 lb N/ac. In fact, over-fertilization (268 lb N/ac) caused yields to decline, increased residual soil N after harvest, and thereby increased the potential for groundwater contamination. Whether nitrate leaching occurs or not depends on climatic conditions and soil characteristics. Reasons for these yield declines are not certain, but may be related to high levels of plant N that could affect N metabolism. No hybrid by N rate interaction was found, but these 3 hybrids responded quite differently to N fertilizer than did another commercial hybrid grown adjacent to this study. A case in point is Farm Service brand 854 which responded well to N fertilizer rates up to 268 lb N/ac (data not shown) while three Pioneer brand hybrids (mean yield shown in Figure 1) produced maximum yields (~190 bu/ac) with only 67 lb N/ac.

Yields for 1987 were lower for P3377 than for either P3475 or P3551, but no hybrid by N level interactions were found (Figure 2). Yields were lower than expected because of hail damage estimated to be 10 to 20%. In 1987, N-Serve did not effect yield but did result in an N rate by N-Serve interaction. As expected, N-Serve reduced leaf N concentration at the lower fertilizer N rates which had the same effect on yields as reducing the fertilizer N rate. Although leaf N concentration increased with fertilizer N rate, hybrid differences were not significant even though the shape of the response curves appeared different (Figure 2).

Fertigation could be an effective N management practice if there was an easy and reliable way to determine the need for N fertilizer near the time of irrigation. Tissue sampling is one way to quantify plant N status, but interpretation of data may be difficult unless a specific plant part is sampled and sampling time and N concentration are calibrated against yield. Hybrid differences in leaf N concentration at the two lower N levels were expected based on visual color differences during the growing season. Over the range of N levels established in this study, results indicate that leaf N concentration prior to silking could provide a good estimate of yield (Figure 3). As an N management tool, leaf N concentration could be used to indicate the need for additional N fertilizer. Extrapolation of this linear relationship suggests that higher yields could be achieved by getting more N into leaves, but in view of the curvilinear nature of the N concentration and yield responses to N rate, this seems unlikely. Apparently the metabolic and physiologic processes are self regulating and in order to use leaf N concentration as a N management tool, one would need to determine the maximum leaf N concentration possible for that stage of growth. Available data are not adequate to determine what the maximum leaf N concentration might be, except to suggest that the highest N level approached this point for P3475 (Figure 3). As a precaution, one

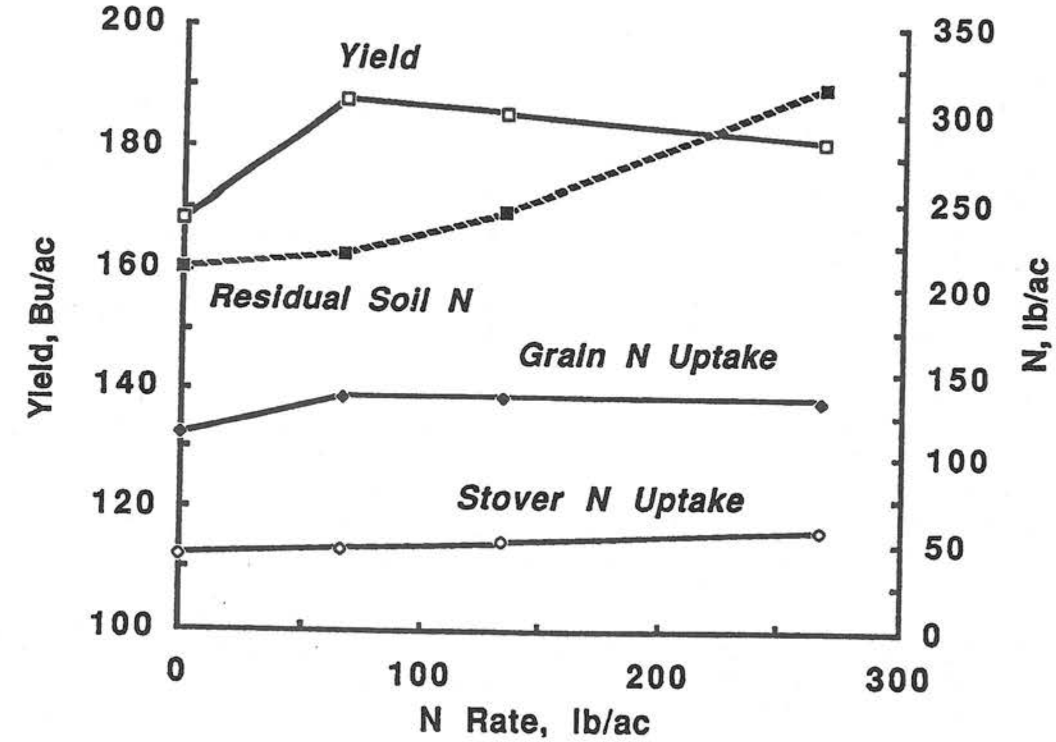

Figure 1. Effect of N rate on corn yield, N uptake in grain and stover, and residual soil N to 6 feet after the 1986 growing season, Clay Center, Nebraska.

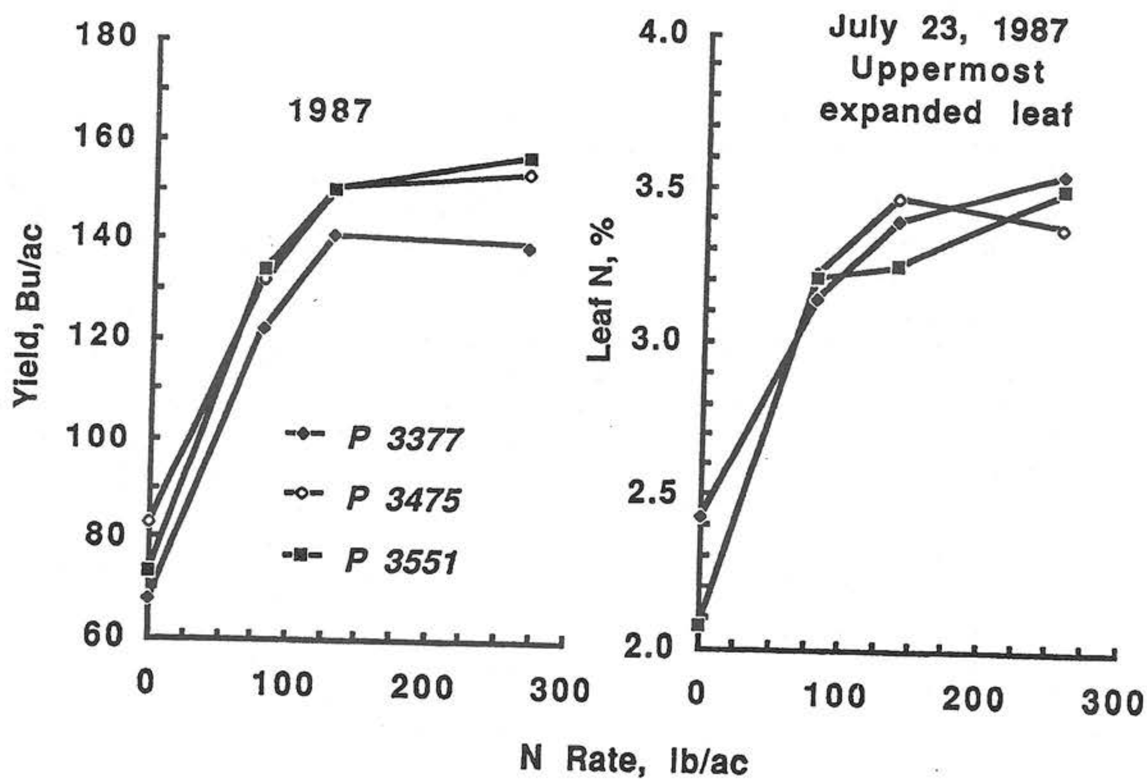

Figure 2. Effect of N rate on yield and leaf N concentration of three Pioneer brand corn hybrids in 1987, Clay Center, Nebraska.

should not be misled by the excellent relationship between leaf N concentration and yield because factors other than N (ie. temperature, water, insects, etc.) probably effect the slope of this relationship.

As an N management tool, nitrification inhibitors have the potential to modify the plant available N status of soils. The important consideration that should not be overlooked is to determine if such a modification is either metabolically or environmentally desirable. In the case of this study, sidedress N application with N-Serve reduced N availability and uptake at all but the highest N level, compared to where no inhibitor was applied (Figure 3). One might erroneously conclude from these data that nitrification inhibitors reduce corn yield, but in fact the product functioned as intended. Effective use of nitrification inhibitors depends on time of application, availability of other N sources, and likelihood of nitrate leaching below the root zone between the time of N application and uptake. Timing of N availability for maximum crop response is a management concept that is achievable by most producers. In fact, many producers already coordinate fertilizer N timing, amount, and form to best meet crop requirements. The recent emphasis on groundwater protection encourages N efficiency through traditional means as well as through less frequently used practices such as fertigation and nitrification inhibitors where appropriate, and accounting for all sources of crop available N. As more N management regulations are imposed on producers, it will become increasingly more important to grow corn hybrids that can capitalize on the nutrient regime created by the required management practices.

Grain yield may be viewed as an integration of photosynthetic activity and carbohydrate partitioning during the growing season. Instantaneous measurements of corn leaf photosynthesis (Ps) showed that Ps rate for P3475 increased with N level and the three leaves monitored had similar rates at the 268 lb/ac N rate (Figure 4). At lower N levels the 4th leaf above the ear had the highest Ps rate. Relative Ps rates for the other leaves were consistent across N levels and increased with leaf N concentration, regardless of leaf position (Figure 4). Although factors other than leaf N concentration influence Ps, these data suggest that leaf N concentration could be used to assess Ps rate (r^2=0.85) and perhaps yield potential (Figure 3). It should be noted that while Ps rate or yield prediction based on leaf N concentration may be desirable, these relationships were based on a wide range of leaf N concentrations and therefore application of these functions at near optimum N levels may not be very sensitive.

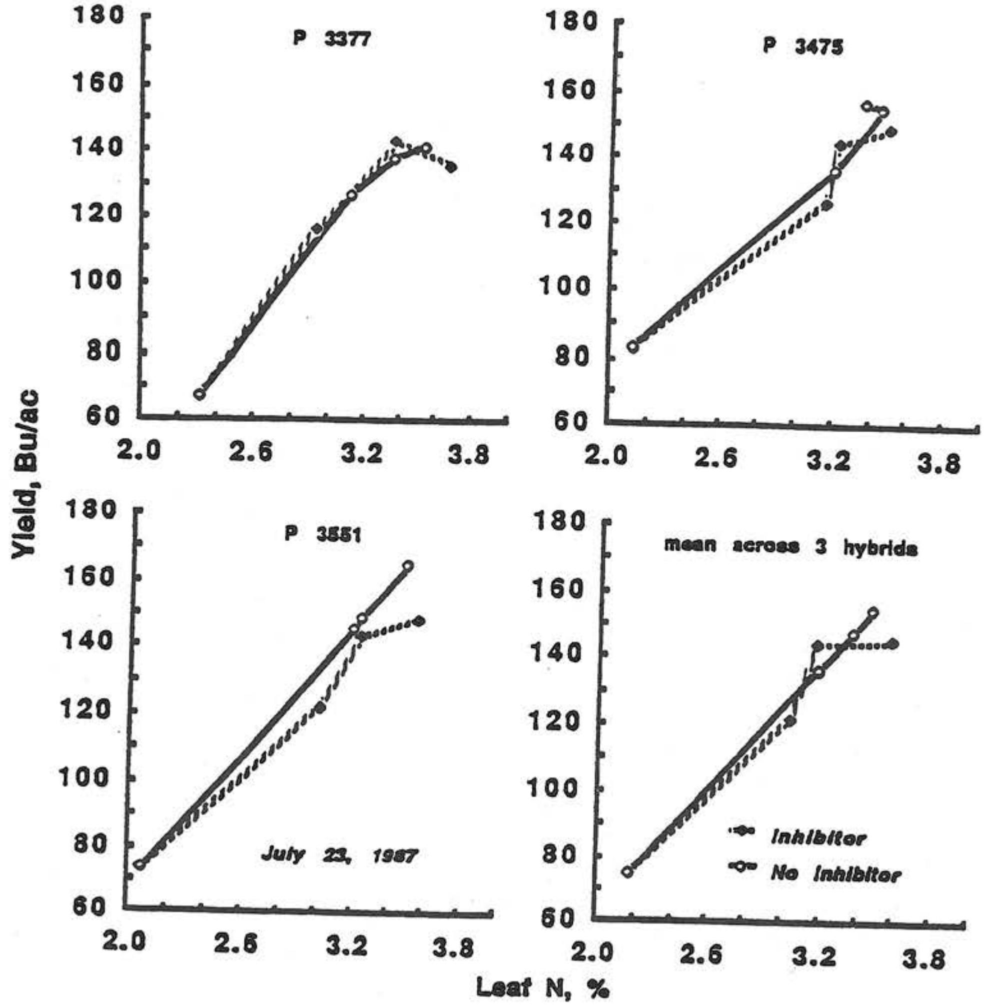

Figure 3. Effect of uppermost expanded leaf N concentration (sampled July 23) on grain yield of 3 Pioneer brand hybrids with and without nitrification inhibitor in 1987, Clay Center, Nebraska. Lines connect data points from low to high fertilizer N rates.

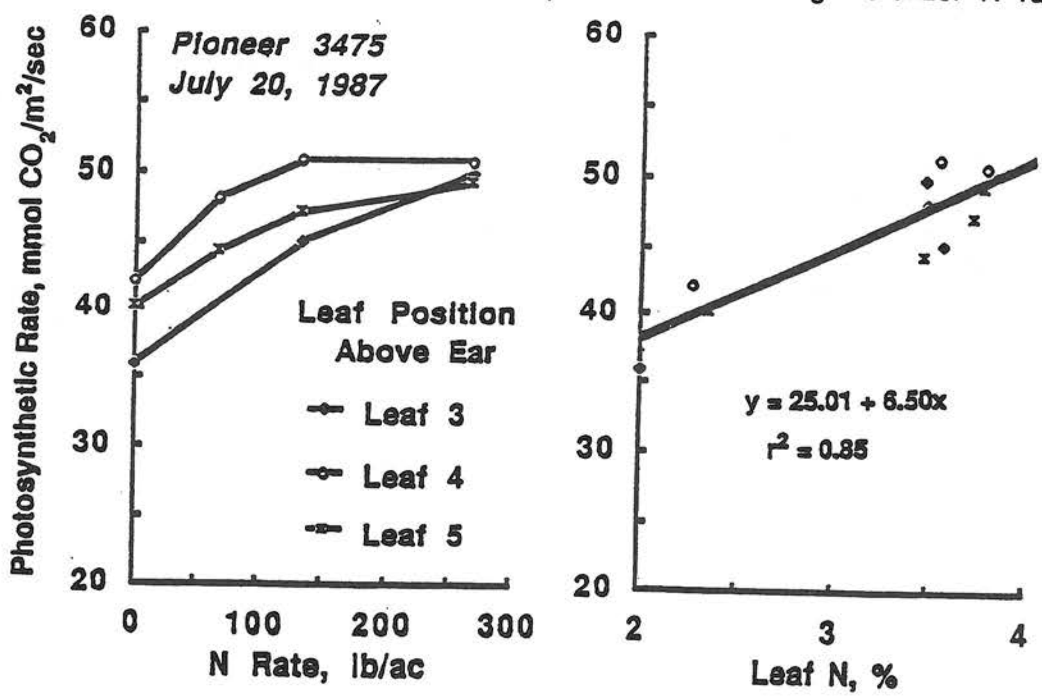

Figure 4. Effect of N rate and leaf N concentration on photosynthetic activity of selected leaves from Pioneer brand hybrid 3475.

In order to select hybrids that are best suited for their conditions, producers may need to categorize hybrids by how they respond to moderate N levels, what N level is required for maximum yield, how they respond to preplant and sidedress fertilizer N application, and if yields are effected by late season N availability. Many of these factors are related to the extent that hybrid consideration may not be based on those that will respond favorably, but rather those that are least likely to be adversely effected by N management regulations. Six Pioneer brand hybrids grown near Schuyler, Nebraska in 1987, were found to differ in how they respond to some of the above considerations (Table 1). This summarization indicates that P3475 and P3379 seemed to respond better than average to moderate N levels while yields for P3269 may be reduced at high N levels. Hybrids P3168 and P3377 responded favorably to split N application when compared to comparable or higher N levels, but yield of P3269 was reduced by split N application.

Table 1. Comparison of six corn hybrids for response to N fertilizer rates, Schuyler, Nebraska, 1987*.

Hybrid	Moderate N level**	High N level***	Utilize split N application	Maximum yield (bu/ac)	Optimum N rate (lb N/ac)
Pioneer Brand 3168	-	+	+	224	80 + 80
Pioneer Brand 3269	0	-	-	214	160
Pioneer Brand 3377	-	0	+	205	80 + 80
Pioneer Brand 3475	+	0	0	207	160
Pioneer Brand 3343	-	+	0	215	>240
Pioneer Brand 3379	+	+	0	224	>240

* Yield increase (+), decrease (-), and no effect (0) compared to other hybrids or comparable N rates.
** Adequate to achieve 70 to 80% of maximum yield.
*** Adequate to achieve near maximum yield (240 lb N/ac in this comparison).

Conclusions drawn from such a table should be guarded because they represent only one environment. After several years and environments are characterized, producers may be able to select hybrids best suited for their cultural practices and anticipated growing conditions. It is possible that if sidedress N applications or a nitrification inhibitor are required, then certain hybrids may not be advisable because their N uptake preferences do not coincide with soil N availability. One must realize that any comparison between hybrids can be affected by climatic conditions such as hail or by N sources other than fertilizer. A case in point occurred when a companion study to the Schuyler location discussed above was irrigated with 18" water containing 29 ppm nitrate-N (117 lb N/ac). This high nitrate water negated the N level differences created by fertilizer application rates and resulted in no yield differences, even when no fertilizer was applied.

A second caution when characterizing hybrid response deals with field variability. If plant available N levels in the moderate range (adequate for 70 to 80% of maximum yield) become common, then variation in yield can be expected to increase. This point is illustrated by the Schuyler study, where the C.V. associated with yield was 17, 10, 6 and 5% for the 0, 80, 160, and 240 lb N/ac rates, respectively. Therefore, hybrid development for improved N efficiency will be more difficult than in the past where N limitations were minimal. Producers may also experience more yield variability as N levels decrease because ample soil N seems to mask other nutrient deficiencies or crop damage. Ample N usually results in a more vigorous crop that may require a lower net expenditure of energy for nutrient uptake and leave more metabolite for grain production. Another reason for maintaining adequate plant N is that many of our current production systems are based on positive nutrient interactions, and as N for example is made limiting, any yield decrease due to N availability is accentuated by the loss of the positive nutrient interaction.

OTHER RELATED RESEARCH

Nitrate in Irrigation Water:

Nitrate in ground water that is used for irrigation represents an additional source of crop N. To evaluate utilization of nitrate in irrigation water by corn, a factorial study involving 3 levels of irrigation water nitrate (0, 10, and 20 ppm nitrate-N) and 4 fertilizer N rates (0, 45, 89, and 134 lb/ac) was conducted near Grand Island, Nebraska. Tagged-N (enriched ^{15}N) was used to quantify the relative utilization of N in water and fertilizer. Uptake of tagged-nitrate in irrigation water decreased from 44 to 30% as fertilizer N rate increased for 45 to 134 lb/ac, however apparent N utilization was 90, 72, and 60% at the 45, 89, and 134 lb/ac fertilizer N rates, respectively. Nitrate in irrigation water tended to increase yields at all fertilizer N rates, although these data emphasize the importance of adequate N prior to silking. This study indicates that nitrate in irrigation water may represent a significant source of crop N and could effectively reduce fertilizer N rates. Although only a portion of nitrate in irrigation was directly utilized by the crop, nearly an equivalent portion was made available and utilized through the dynamics of N cycling. Excess plant available N reduced crop utilization of nitrate in irrigation water and fertilizer N.

Potentially Mineralizable Nitrogen:

Mineralization is source of plant available N that is usually not considered when making fertilizer recommendations, but may represent a significant portion of the soil nitrate pool. Although long term biological incubation studies may provide a more meaningful indication of potentially mineralizable nitrogen (PMN), indirect chemical determinations may prove to be acceptable substitutes, provided they can be correlated with biological procedures and/or yield responses. While PMN determinations do not reflect the dynamics of N transformations under field conditions, they at least provide an estimate of the soils capacity to release organic N. No PMN procedure has evolved as the standard by which to compare all others. A diverse group of 10 Nebraska soils was used to compare the hot KC, autoclave, phosphate-buffer, water-logged, and electro ultra filtration procedures. All procedures were highly correlated with one another, however further research will be required to incorporate PMN procedures into N management practices.

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NITROGEN MANAGEMENT FOR GROUND WATER QUALITY AND FARM PROFITABILITY

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ABSTRACT

Federal and state scientists are preparing a user-oriented publication entitled, "Nitrogen Management for Ground Water Quality and Farm Profitability". The focus of the publication will be the protection of ground water quality based upon minimizing nitrate leaching out of the crop root zone while optimizing crop yields. The publication will provide flow-charts, examples, and a computer program diskette to make the publication user friendly.

OBJECTIVES

The objective of this effort is to prepare an "advanced state-of-the-art" publication of concepts about management of nitrogen (N) that minimize amounts of nitrates (NO_3-N) in the crop root zone during periods that NO_3-N may leach out of the root zone, into the vadose zone, and eventually into ground water. This paper describes the approach that will be used for preparing the publication. Optimal yields are emphasized to maximize uptake of fertilizer-, residual-, and mineralized-N. The concepts and approaches are also to be used to develop an IBM PC-AT (International Business Machines) compatible personal computer program. The publication and the computer program are for those who work with and advise agricultural producers, and for those producers who want to directly utilize this information.

METHODS

Guidelines and methods to minimize NO_3-N leaching for fertilizer, water, and cropping system management alternatives are being developed into a user-oriented publication by a national team of federal and state scientists. Scientists and/or representatives from five federal agencies, seven universities, The Fertilizer Institute and one fertilizer company, and the Soil Science Society of America were invited to participate in a meeting held in Lincoln, NE on July 1 and 2, 1987. The purpose of the meeting was to allow attendees and authors of the publication the opportunity to resolve issues relating to overall content and structure of the publication and to resolve final assignments of responsibilities for preparation of information to be published. Twenty-five individuals agreed to be involved in the preparation of materials for this publication. The publication will be in English units and the Soil Science Society of America is to serve as publisher. Guidelines and other information that are provided are somewhat general in nature because of the publication's national scope. The physical environment (i.e. climate, soils, and ground water geography) is emphasized. Once developed the reader can choose to read chapter by chapter, use a flow-chart (in the form of a logic diagram) as a guide to the appropriate chapter sections relevant to a particular situation, or use an IBM compatible computer program diskette.

RESULTS AND DISCUSSION

The initial concept of the user oriented publication resulted from an Agricultural Research Service sponsored ground water quality workshop held in Atlanta, GA in 1986. Following the workshop an ad hoc group of scientists began developing an outline and accompanying flow-chart of the processes that would need to be considered to maximize uptake of fertilizer-, residual-, and mineralized-N and to minimize movement of NO_3-N out of the crop root zone and potentially into ground water. The logic diagram was developed in five sections as follows: initial conditions, water management, N-management, crop and soil management, and evaluation. Each part of the flow chart is cross referenced to a chapter or chapter(s) within the publication itself (Figure 1). Therefore, use of the flow chart allows a user to be directed to only those parts of the publication that deal with the conditions encountered or chosen for consideration by that user. Chapter XII explains the use of the flow chart and provides examples. This allows chapters or sections of the publication that do not pertain to the user's needs to be skipped. To further adapt the publication to user needs and capabilities, an IBM compatible program based upon information in the publication will be available on floppy diskette. The computer program is user friendly with Chapter XIII in the publication devoted to instruction for its use.

Figure 1. Chapter titles for the user oriented publication entitled, "Nitrogen Management for Ground Water Quality and Farm Profitability".

Chapter
- I. Overview and Introduction
- II. Agricultural and Land Resources and Potential Ground Water Problems
- III. A National Perspective on Ground Water Protection
- IV. Water Percolation: An Indicator of Nitrogen Leaching Potential
- V. Calculation of Nitrogen Budgets for Crop Production VI.
- VI. Proper Accounting for Nitrogen
- VII. Fertilizer Nitrogen Management
- VIII. Estimating Nitrate Leaching in Soil Materials
- IX. Soil, Crop, and Water Management
- X. Water Balance and Management
- XI. Fate of Nitrates in Subsurface Drainage Waters XII.
- XII. Decision Flow-chart and Examples
- XIII. Application of Personal Computer Program

APPENDIX

Initial conditions:

To aid users in establishing initial conditions that need consideration; maps, tabular and graphical data, and schematic information is provided. This information will include regional soil and ground water information. Where site specific information is available from other sources and is preferable to use, guidelines for its use are included. General information on ground water protection policies and drinking water standards are provided. Where the user has records, soil characteristics, residual-N profiles with depth down to the water table, and type of water management; this information is also used to establish initial conditions and approaches to protect the ground water.

Water management:

Management of water resources, whether for irrigated or non-irrigated conditions is of major importance for controlling the transport of NO_3-N through and out of the crop root zone where it can move into ground water. Soil texture and soil properties related to water retention as well as topography and other factors influence the potential for NO_3-N leaching. On irrigated land, where high inputs of both water and N-fertilizers are possible, it becomes especially important to consider irrigation scheduling, amounts, and water application methods. Precipitation and its conservation and use for either irrigated or non-irrigated agriculture can influence the potential for leaching NO_3-N below the crop root zone. Soil texture, leaching class, and other soil characteristics can also influence water management. In addition, lower topographic positions and depressions may accumulate run-on water while higher positions promote run-off, thus resulting in greater or lesser potential for leaching in those landscape positions, respectively.

Nitrogen management:

Management of not only the N added to the soil for producing a crop, but also residual- and mineralized-N in the soil is essential to minimizing movement of NO_3-N out of the crop root zone and potentially into ground water. The concept of assessing residual NO_3-N levels within the crop root zone by using soil testing is important to the efficient use of available-N for crop growth. For ground water aquifers that are beginning to show excessive NO_3-N movement into them or for fields with soil and other properties that are conducive to NO_3-N leaching, deep soil sampling may be necessary to assess the overall hazard. The use of deep rooted or perennial crops may be one mechanism to aid in scavenging NO_3-N from the soil profile to deeper depths than with annual crops.

Realistic yield goals that are attainable, based upon the management capabilities and soil and climatic resources of a particular farmer, also become factors in the amount of fertilizer-N that should be applied. Both manure- and legume-credits, as well as residual- and mineralized-N also are considerations in assessing the amounts of additional N that may be required to produce a crop. Management of N that is applied to cropland includes rates, amounts, method of application, timing, and stabilizers as ways to help optimize N-use efficiency while maximizing crop yields and farm profitability.

Crop and soil management:

Managing N to assure ground water quality involves not only management of soil, water, and N resources; it also involves managing the crop. Season of crop growth, canopy development, total water use, and maximum rooting depth all affect water runoff and percolation through soils. The NO_3-N present in the crop root zone interacts with all of these.

Tillage practices directly affect water infiltration into soil. However, their effect on infiltration is also dependent upon certain soil properties such as soil texture and structure. Crop residues and/or canopy protect soil structure and thus promote water infiltration and less surface runoff. Runoff is also controlled by tillage direction in relation to slope. When runoff is minimum and infiltration is maximum, the management system has optimized the opportunity for efficient use of either precipitation or irrigation. However, the opportunity for water escape through the crop root zone may be increased. In addition to controlling runoff, surface residues also slow evaporation from the soil surface. The total effect of practices that keep the soil covered and reduce stirring is to maintain moist surface soils for longer periods of time and potentially for more water to pass through the soil profile. Thus, as improvements in water infiltration occur, it becomes increasingly important to use this stored water. In systems where crop residues are maintained on the surface, the moist soil and available carbon supply results in an environment more favorable to microbial growth and the temporary immobilization of N in organic form such as microbial biomass. Decomposition of organic forms of N during a growing season can release available N to the growing crop.

Cropping systems and the crop being grown can be major factors in regulating NO_3-N movement through the crop root zone. Rooting depth, water requirement and use rate, and N-uptake can all be influenced by the cropping system used. Deeper rooting crops have greater potential to intercept and use residual NO_3-N and water from deeper in the soil profile. The presence of active roots during those times of the year when NO_3-N leaching potential is high are more effective at controling NO_3-N leaching than if there were no active roots. Winter cover crops (hairy vetch, for example) can utilize some of the precipitation and residual NO_3-N during the time between annual summer crops. Unfortunately, use of certain crop combinations cannot be synchronized. Thus, options for using cropping systems to control NO_3-N leaching are limited.

Evaluation:

Evaluation of the soil, climate, water table and other conditions; water-, N-, crop-, and soil-management alternatives; and residual NO_3-N profiles allows alternative management systems to be considered.

Besides levels of residual NO_3-N that are found within or below the crop root zone, evaluation of the degree to which water percolates through the crop root zone and the amount of NO_3-N in the percolate are needed. The possibility exists for an N-deficiency to occur and thus farm profitability to decrease through failure to produce the optimum possible crop yields. If so, then suggestions are made to the user concerning how to better estimate crop fertilizer-N requirements. Conversely, if excess NO_3-N is observed or projected to be in the soil profile, then the user is guided to sections of the publication dealing with improved fertilizer management or to sections dealing with alternative crop and soil management systems. Reevaluation can be repeated until the user is satisfied that the best combination of alternatives have been determined.

OTHER RESEARCH ACTIVITIES

Other soil fertility research besides that reported above and which is related to Great Plains agriculture that is being conducted by the Soil-Plant-Nutrient Research Unit of ARS in Fort Collins includes that described in our two in-house CRIS projects. The CRIS project titles, objectives, researchers, and approach are as follows:

1. Title - Importance of gaseous N reactions and transport in soil-plant systems.

   Objective - To develop new technology for assessing, predicting, and improving N-use efficiency by determining the effects of various soil, plant, and environmental parameters on N uptake, reactions, and transport in soil-plant systems.

   Researchers - W.D.Guenzi, A.R.Mosier, G.L.Hutchinson, and R.F.Follett.

   Approach - Field, laboratory, and growth chamber studies are used to assess the impact of actively growing plants on soil N mineralization, fertilizer N immobilization, and N loss by denitrification from ^{15}N fertilized soils. Soil and foliar gaseous N exchange phenomena is studied using soil cover and micrometeorological methods in the field and a small flow-through growth chamber in the laboratory. Other laboratory studies investigate interrelationships between soil redox potentials, pH, O_2, available soil C, and the production and consumption rates of N reaction intermediates.

2. Title - Identify and quantify plant-soil and biological N-fixation processes to increase N-use efficiency.

   Objective - To determine soil and fertilizer nutrient recovery by plants and the loss of nutrients through leaching as influenced by Great Plains management systems, (i.e., for irrigated crops, dryland wheat, and grasslands).

Researchers - R.F.Follett, L.K.Porter, F.A.Norstadt, W.J.Hunter, and A.R.Mosier.

Approach - Turnover of biomass and organic C and N, mineralization and immobilization of N and plant uptake of nutrients are determined for sites from grasslands and conservation tillage systems. Fertilizer N carryover, movement through and below the root zone, and interchange with soil N as they affect fertilizer N-use efficiency and increased plant recovery are measured in field, greenhouse, and laboratory studies. Soil aggregates from tilled and grassland sites are compared for biological activity, anaerobic conditions, reducible metals, and pH. Viruses, bacteriocins and genetically altered rhizobia are used to investigate rhizobia competitiveness in the establishment of effective nitrogen fixing legume root nodules.

AMMONIUM AND NITRATE NUTRITION OF CORN

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ABSTRACT

The concepts of ammonium nutrition and variable hybrid response are being investigated in two studies, at three locations, in Kansas and Nebraska. Preliminary data from these studies has shown yield differences with N sources providing different ammonium:nitrate ratios, and yield differences when a nitrification inhibitor is applied. Hybrid response has been variable, with no hybrid response in the Kansas studies, and hybrid differences in yield and fertilizer N recovery in the Nebraska study.

OBJECTIVES

Considerable interest has existed the last 2-3 years in the concepts of ammonium nutrition and variable hybrid response of corn. With increasing concerns about the influence of nitrogen fertilizer use on groundwater quality in the midwest, the selection of hybrids and nitrogen sources to optimize N use efficiency is seen as a possible future "best management practice". Two studies to investigate various aspects of ammonium nutrition/hybrid response are currently in progress in Kansas and Nebraska. This paper will report preliminary findings from these two projects.

RESULTS AND DISCUSSION

Grain yield from the two Kansas locations are shown in Table 1. Nitrogen response data from lower N rates at each location (data not shown) indicates that nitrogen rates were near optimal for yield at the corn location, and that yields were unaffected by N fertilization at the sorghum location. (The sorghum location had been fallow the previous year, and may have had elevated levels of residual nitrogen.) For both crops, there were no differences in yield with either hybrid or timing variables. For the corn location, grain yield was significantly greater for the two sources with a 50:50 ratio of ammonium to nitrate. Grain yield from the sorghum study follows somewhat the same trend, although results are less definitive than the corn study. This may be related to the site having been fallow the previous year and having elevated levels of soil nitrogen. Nitrogen sources providing greater amounts of ammonium (urea and UAN) resulted in lower yields for both crops. Ammonia volatilization is not a likely cause of the yield reduction, since all sources were watered in soon after application.

Yield components from the KSU corn study are shown in Table 2. The number of kernels per ear ranged from 630 with urea to 710 with ammonium nitrate. Mean kernel wt ranged from 273 mg for urea to 292 mg for calcium nitrate. Yield differences related to the N source - ammonium:nitrate ratio were apparently influenced early in the expression of yield components. The number of kernels per ear, which is determined relatively early in the life of the plant, was significantly influenced by N source. At that stage of plant growth, it is not likely that total N was limiting, but possibly rather that amounts of ammonium were excessive with N sources containing primarily ammonium. Kernel wt, determined much later in the life of the plant, was also apparently influenced by the ammonium:nitrate ratio, with increasing kernel wt with increasing N-source nitrate content.

Table 1. Grain yield of corn and grain sorghum, KSU studies.

N Sources	$NH_4:NO_3$	Yield Grain Sorghum	 Corn
		----- Bu/acre	-----
Urea	100:0	131.7 b	140.8 b
UAN	75:25	135.0 ab	137.9 b
AN	50:50	140.9 a	152.0 a
UCN	50:50	136.2 ab	152.4 a
CN	0:100	138.4 ab	142.1 b

Yields from the 1987 Nebraska study are shown in Figure 2. In 1987, residual N levels were considerably lower in the lower N rate plots than 1986. Consequently, a more typical N response curve was seen. Yields were reduced somewhat in 1987 due to hail and possibly a period of heat stress. It appears that P3377 was more severely affected by the stress, especially were N-Serve was not applied. Hybrid yield differences may also be related to differences in patterns of N uptake. Nitrogen was sidedressed relatively late (V8), and some plots appeared to be more N stressed than others prior to sidedressing.

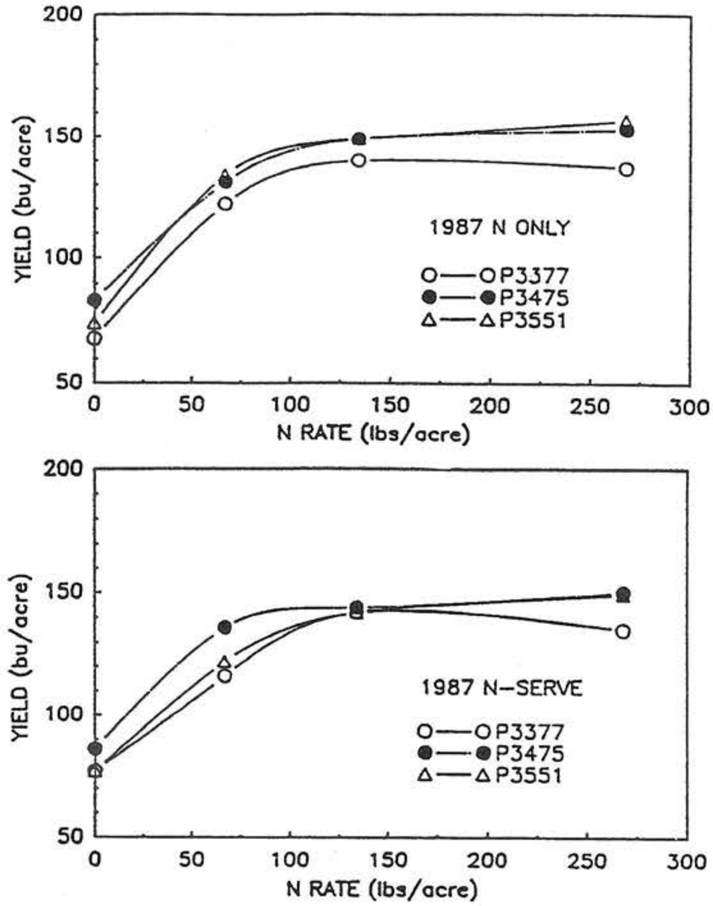


Figure 2. Grain yield, 1987 Nebraska study, with and without N-Serve.

Fertilizer nitrogen recovery according to nitrogen rate in 1986 is shown in Table 3. Fertilizer N recovery was fairly low in 1986 (mean = 20.3%), due in part to the elevated levels of soil residual nitrate. Fertilizer N recovery in the grain was of course significantly influenced by the N rate, ranging from 35.5% recovery at the 67 lb N/acre rate to 7.9% at the 267 lb N/acre rate. Stover N recovery was not influenced by N rate. Although 1987 data concerning N recovery is not available, it should differ considerably from the 1986 data since residual soil N levels were considerably lower prior to planting in 1987 (76 lb NO_3-N/acre for the unfertilized check plots).

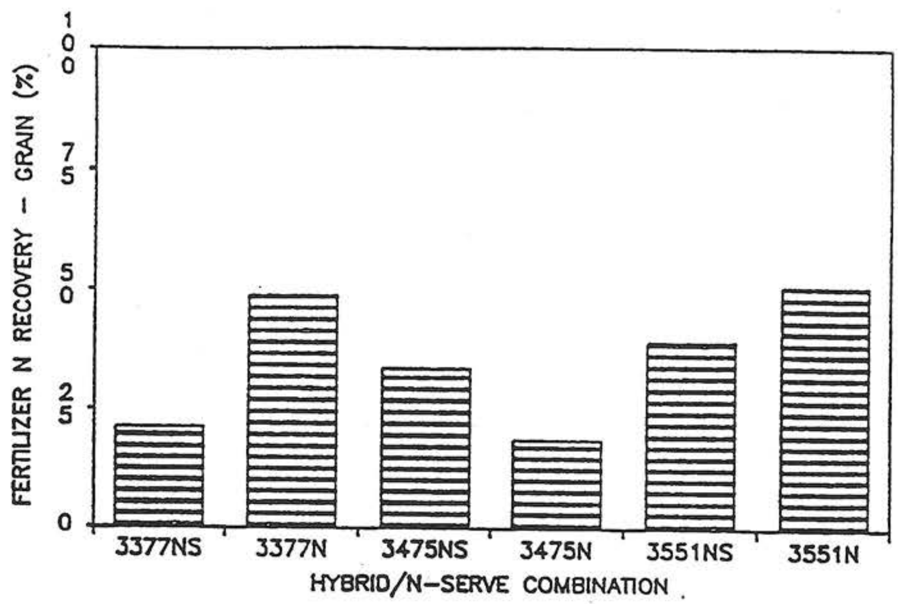


Figure 3. Fertilizer nitrogen recovery in grain, 67 lb N/acre N rate, separated by hybrid/N-serve combination, 1986 Nebraska study.

SUMMARY

Data from these two studies are definitely not conclusive concerning ammonium nutrition and variable hybrid response, nor is it intended to be, since this is preliminary data from multiple-year studies. However, it is evident from the Kansas data that increased amounts of ammonium may not necessarily be beneficial. Both sites of the Kansas study were located on relatively sandy soil, with possibly less buffering concerning the soil solution ammonium:nitrate ratio. It may be that under these conditions, with high rates of N containing primarily ammonium, that toxic levels of ammonium are expressed in the plant.

The Nebraska study was conducted on a finer textured soil, with a greater buffering capacity concerning the soil solution ammonium:nitrate ratio. While extractable ammonium/nitrate was measured during the season for both the Kansas and Nebraska studies, data analysis is not yet complete. One can speculate that wider differences in the ammonium:nitrate ratio may be seen during the season on the sandier Kansas sites than on the finer textured Nebraska site. Hybrid differences in yield and fertilizer N recovery were found in the Nebraska study, while none were seen in the Kansas study. These differences point out the need for considerable hybrid screening efforts, to separate hybrids which may respond to higher N rates, and to different soil solution ammonium:nitrate ratios.

The Nebraska study, initiated in 1986 at Clay Center, is part of a larger project designed to investigate the potential for agricultural impact on groundwater quality. The nitrogen subproject contains treatments designed to evaluate the impact of tillage method, nitrogen rate, the use of a nitrification inhibitor, and hybrids on nitrogen use efficiency and nitrate leaching. The Kansas study, initiated in 1987 at Manhattan and Rossville, is designed to evaluate the influence of nitrogen source on N use efficiency for both grain sorghum and corn.

METHODS

The Kansas grain sorghum study was located on a Haynie sandy loam (coarse-silty, mixed, calcareous, mesic Typic Udifluvent) near Manhattan. Treatments were N source/ammonium:nitrate ratio (urea 100:0, urea-ammonium nitrate 75:25, ammonium nitrate 50:50, urea- calcium nitrate 50:50, and calcium nitrate 0:100), timing (50% preplant, 50% at V5; and 33% preplant, 33% V5, 33% boot stage), and hybrid (Funks G1711 and Dekalb DK59E). Nitrogen was applied at the rate of 250 lb N/acre, as banded solutions, immediately watered in by sprinkler irrigation. A nitrification inhibitor was used with all N sources - nitrapyrin was applied with the preplant treatments at the rate of 1.0 lb ai/acre, DCD was applied with the later applications at the rate of 7.5 lb/acre. The corn study was located on a Eudora silt loam (coarse-silty, mixed, mesic' Fluventic Hapludoll) near Rossville. Treatments were the same as the grain sorghum study with the exception of hybrids (Pioneer 3377 and Funks G4673A) and nitrogen rate (300 lb N/acre). The third N application for the timing variable on corn was applied at V17. Measurements during the season for both locations included soil samples for ammonium and nitrate, plant samples for dry matter accumulation and nitrogen content, grain yield, dry matter accumulation and nitrogen content at physiological maturity.

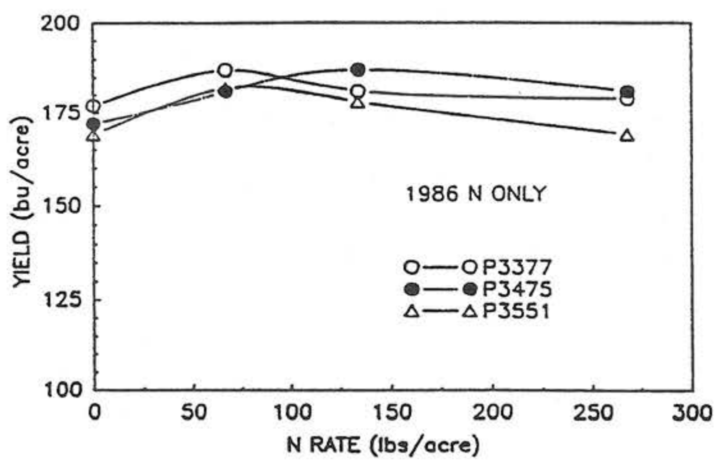
The Nebraska study was located on a Crete silt loam soil (fine, montmorillonitic, Pachic Argiustoll). Treatments were N rate (0, 67, 134 and 268 lb N/acre), tillage method (no-till and conventional chisel and disk), nitrification inhibitor (with and without 0.5 lb ai/acre nitrapyrin) and hybrid (Pioneer hybrids 3551, 3475 and 3377). Nitrogen was applied as sidedressed anhydrous ammonia. The site was irrigated with a linear movement sprinkler irrigation system. Measurements taken included soil samples during the season for nitrate and ammonium, plant samples for dry matter accumulation and nitrogen content, dry matter accumulation and grain yield at physiological maturity, and residual ammonium and nitrate to 6 ft at harvest and prior to planting.

Table 2. Kernels per ear, mean kernel wt, KSU corn study.

N Sources	$NH_4:NO_3$	Kernels ear^{-1}	Kernel wt (mg)
Urea	100:0	630 c	273 c
UAN	75:25	663 abc	273 c
AN	50:50	710 a	278 bc
UCN	50:50	643 bc	286 ab
CN	0:100	698 ab	292 a

Means with the same letter are not significantly different ($LSD_{0.05}$).

Grain yield in 1986 from the Nebraska study is shown in Figure 1. Yield generally declined at N rates above 67 lb/acre. but the yield decline was lessened when nitrapyrin was applied. The residual nitrate levels on this field were moderately high prior to planting (~120 lb NO3-N/acre), resulting in relatively high yields without any nitrogen fertilizer. There was a hybrid by N-Serve interaction, with the yield decline of P3551 at higher N rates without N-Serve, being more severe than for the other two hybrids.



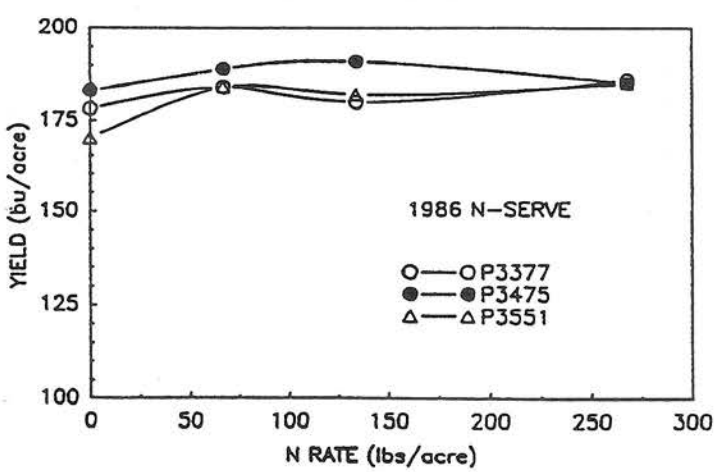


Figure 1. Grain yield, 1986 Nebraska study, with and without N-Serve.

Considerable differences were seen in 1986 among hybrids in fertilizer N recovery (Table 4) and with hybrid by N-Serve interactions (Figure 3). At a relatively low fertilizer N rate (67 lb/acre), P3551 recovered the greatest amount of fertilizer N. At a higher N rate (268 lb/acre), P3377 recovered the most fertilizer N. These trends are consistent with "reputations" for these two hybrids. P3551 is supposed to be a relatively low responder to N, while P3377 has the potential to respond well to higher N rates.

At the low N rate (67 lb/acre), considerable differences were seen among hybrids with and without N-Serve. Fertilizer N recovery was greater for P3377 without N-Serve, but greater for P3475 with N- Serve. These differences in N recovery are reflected in yield for these two hybrids at the 67 lb N/acre rate. Nitrogen recovery for P3551 was greater without N-Serve at the 67 lb N/acre rate, but this was not reflected in yield. At the 268 lb N/acre rate (data not shown), there was a trend towards reversal of the N-Serve effects at the 67 lb N/acre rate. Nitrogen recovery tended to be higher with N- Serve for P3377 and P3551, but lower with N-Serve for P3475.

Table 3. Fertilizer nitrogen recovery, 1986 Nebraska study.

	% of Applied N Recovered		
N Rate (lb/A)	Grain	Stover	Total
67	35.5	5.6	41.1
134	17.4	5.2	22.6
268	7.9	5.0	13.0
LSD (0.05)	14.0	NS	23.2
PR > F	0.0001	0.9787	0.0001

Table 4. Fertilizer nitrogen recovery in grain, 1986 Nebraska study.

	Fertilizer N Rate (lbs/acre)	
	67	268
Hybrid	Fertilizer N Recovery (%)	
3377	35.1 ab	10.7 a
3475	26.2 b	4.9 b
3551	45.3 a	8.1 ab
PR > F	0.034	0.011

Means with the same letter are not significantly different, 0.05 level, Duncans Multiple Range Test.

NITROGEN MANAGEMENT FOR NO-TILL GRAIN SORGHUM

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ABSTRACT

Field experiments evaluating the effects of nitrogen management for no-till dryland grain sorghum have been conducted from 1985 through 1987. Nitrogen rates (0, 50, 100 lbs N/A) and placement methods for urea ammonium nitrate solution (UAN) have been evaluated in eastern Kansas. Placement methods have included surface broadcast, surface banded, pressure injected, and knifed. Results to date show that nitrogen consistently increases yields and tissue and grain N contents, and that method of UAN placement produces significant effects on grain yields and tissue and grain N contents. The knifed placement produced consistently and significantly higher yields and tissue and grain N levels than any other placement method. The surface broadcast placement methods always produced the lowest grain yields and tissue and grain N levels. Other placement methods produced yields and tissue and grain N levels intermediate between broadcast and knifed placements. The addition of 10% by volume of ammonium thiosulfate in the UAN had inconsistent effects, but in some cases resulted in higher yields and tissue and grain N contents.

OBJECTIVES

The acreage of land farmed using conservation tillage in Kansas continues to increase. With the conservation compliance features of the 1985 Farm Bill, conservation tillage acreage will likely continue to increase as farming with more residue on the soil surface will be a part of many conservation plans. However, increased amounts of residue on the soil surface have raised questions regarding efficiency of surface broadcast N applications with no incorporating tillage. Potential problems include volatilization and/or immobilization of applied N. Research in other states has confirmed reduced N efficiency with surface broadcast applications on no-till corn.

This work was initiated to evaluate the effects of urea-ammonium nitrate solution (UAN) placement methods on continuous no-till grain sorghum.

METHODS

The work has been conducted on the North Agronomy Research Farm near Manhattan, KS., on a Reading silt loam soil. These soils are deep, nearly level, well-drained soils formed in alluvial sediments. In addition, in 1987 a study was conducted in Greenwood county in east-central Kansas on a Woodson silty clay loam soil (poorly drained, very slowly permeable soil formed in clayey sediments).

Nitrogen rates of 50 and 100 lb N/A were applied as urea-ammonium nitrate solution (UAN-28). Placement methods evaluated included surface broadcast, dribble (surface band, 20" centers), pressure injected (2000 PSI stream through orifice run along soil surface on 20" centers, developed by Arcadian Co.), and knifed (6" deep on 20" centers by coulter applicator). In 1986, the pressure injection applicator was unavailable, so that treatment was replaced with surface broadcast UAN with 10% v/v ammonium thiosulfate (ATS). The ATS treatment was included because work in other states had shown some potential as a urease inhibitor. (Fairlie and Goos, 1986; Fox and Piekielek, 1987; Gascho and Burton, 1987; Goos, 1985a; Goos, 1985b.) At the Greenwood county site in 1987, the ATS variable was included for all placement methods. In 1987, sulfur was balanced on all treatments with calcium sulfate at both sites.

At the Agronomy Farm, Paymaster DR 1125 grain sorghum was seeded at 65,000 seeds per acre using a Buffalo no-till slot planter. Phosphorus (0-46-0) was applied in a band near the seed at planting at 40 lb P_2O_5/A. Furadan was applied at planting (1 lb A.I./A) for insect control. Excellent weed control was obtained by using a split application of Bicep herbicide (3 qts/A). In Greenwood county, a International 400 planter was used and the starter P was applied as 10-34-0. Leaf tissue samples were collected at boot stage for analysis. Grain yields were measured and samples were retained for analysis. The Agronomy Farm site has been continuous sorghum since 1982, and the Greenwood county site had been in sorghum in 1986.

Table 1 summarizes N fertilization, planting and harvest dates, residue levels at planting, and rainfall information for 1985 through 1987.

Table 1. Fertilization, planting, and harvest dates, and other information.

	Agronomy Farm			Greenwood Co.
	1985	1986	1987	1987
N application date	April 3	May 30	June 2	May 16
Planting date	May 22	June 2	June 3	June 12
Surface residue at planting	4000 lbs/A	4500 lbs/A	4500 lbs/A	2500/lb/A
Harvest date	Oct. 15	Oct. 6	Sept. 22	Oct. 8
Rainfall (June-Sept.)	18.86 in.	23.36 in.	21.67 in.	24.20 in.

RESULTS AND DISCUSSION

Results of this work to date are summarized in Tables 2 through 5. Grain yields were excellent all years due to the very adequate and well-distributed rainfall during the growing seasons.

Large and significant yield responses to nitrogen occurred all years and, averaged across placement methods, the 100 lb N/A rate produced significantly more sorghum than did the 50 lb N/A rate, except in Greenwood county in 1987. With the exceptional yields and the yield response curve still going up, a higher N rate would have been desirable but a lack of space limited our study size. Nitrogen application also significantly increased both tissue and grain N contents.

Method of UAN placement had consistent significant effects on grain yields and tissue and grain N contents. In 1985 at the Agronomy Farm (Table 2), the knifed placement resulted in higher yields and grain N levels than any other placement method, producing significantly more grain than the broadcast and pressure injected placements. The surface broadcast method produced the lowest yield and tissue and grain N contents, being significantly lower in yield than both the dribble and knifed placement methods. The pressure injection placement method performed much like the dribble placement because we found only about 0.5" soil penetration with the pressure injection in the high residue situation.

Table 2. Comparisons of nitrogen rates and placement methods on no-till grain sorghum, North Agronomy Farm, Manhattan, 1985.

N Rate lb/A	Method of Placement	Yield -bu/A-	Grain Moisture ---%----	Test wt -lb/bu-	Leaf N -%-	Grain N -%-
0	-----	74.0	19.3	52	1.86	0.84
50	Broadcast	103.9	18.1	55	2.20	0.95
100	Broadcast	116.3	17.3	55	2.52	1.12
50	Dribble	109.6	17.9	55	2.75	0.90
100	Dribble	131.2	17.0	57	2.47	1.17
50	2000 PSI	110.5	17.9	56	2.36	1.03
100	2000 PSI	124.0	17.5	55	2.59	1.10
50	Knifed	117.9	17.9	56	2.41	1.05
100	Knifed	138.1	16.6	57	2.72	1.31
LSD (.05)		14.8	2.3	3	0.20	0.09
Mean Values:						
N Rate 50		110.5	18.0	56	2.28	0.98
100		127.4	17.1	56	2.58	1.17
LSD (.05)		6.9	NS	NS	0.09	0.05
Method	Broadcast	110.1	17.7	55	2.36	1.03
	Dribble	120.4	17.5	56	2.36	1.04
	2000 PSI	117.3	17.7	56	2.48	1.07
	Knifed	128.0	17.3	57	2.57	1.18
	LSD (.05)	9.7	NS	NS	0.13	0.07

In 1986, the pressure injection applicator was unavailable so that placement method was replaced with a surface broadcast placement with 10% v/v ammonium thiosulfate added to the UAN. Results are shown in Table 3.

Table 3. Nitrogen management for no-till grain sorghum, 1986. Agronomy Farm, Manhattan, KS.

N Rate lbs/A	N[1] Placement	Grain Yield bu/A	Grain Moist %	Test Weight lbs/bu	-----%N------ Tissue	Grain	2 Year Avg. Yield, bu/A
0	------	64	18.4	53	1.57	0.99	69
50	Broadcast	98	16.7	55	2.06	0.95	101
100	Broadcast	120	16.5	56	2.52	1.02	118
50	Broadcast+ATS	103	17.1	56	2.17	1.00	---
100	Broadcast+ATS	134	16.4	56	2.68	1.06	---
50	Dribble	99	16.9	56	2.13	0.97	105
100	Dribble	130	16.3	55	2.70	1.07	131
50	Knifed	131	16.0	57	2.75	1.05	125
100	Knifed	141	15.9	57	3.02	1.26	140
LSD (.05)		14	1.1	2	.26	.07	
Mean Values:							
N Rate:	50	108	16.7	56	2.28	0.99	109
	100	131	16.3	56	2.73	1.10	129
LSD (.05)		5	NS	NS	.14	.03	
N Placement	Broadcast	109	16.6	56	2.29	0.98	110
	Broadcast+ATS	118	16.8	56	2.43	1.03	---
	Dribble	114	16.6	56	2.42	1.02	117
	Knifed	136	15.9	57	2.89	1.15	132
LSD (.05)		9	NS	NS	.19	.05	

[1] All N applied as UAN (28% solution), ATS is ammonium thiosulfate (12-0-0-26S) mixed with UAN 10% v/v to make a 26-0-0-3S.

The knifed placement method produced significantly higher grain yields and tissue and grain N contents than any other placement method. Using a two year average, knifing in UAN produced 22 more bushels per acre than broadcasting and 15 bushels more than the dribble placement. Of interest in 1986, however, is the fact that the addition of ATS in the surface broadcast situation significantly increased yields and grain N content and raised tissue N content, though not significantly. This is interesting in light of other work that has shown ATS as a possible urease inhibitor with the possible implications on volatilization losses. In our work, no detailed measurements were taken, so this effect can't be substantiated.

This same study was repeated in 1987 at the Agronomy Farm (Table 4). Yields were excellent and again the knifed placement produced significantly higher grain yields and tissue and grain N contents than any other placement method. Three-year average yields indicate the knifed placement being 15 bushels better than the dribble placement and 20 bushels better than the broadcast placement. Interestingly, ATS effects were nonsignificant at this site in 1987.

Table 4. Nitrogen management for no-till grain sorghum, 1987. Agronomy Farm, Riley Co.

N Rate	N[1/] Placement	Grain Yield	Plant Tissue N	Plant Tissue S	Grain N	3 Year Avg. Yield
lb/A		bu/A	----- % ----		%	bu/A
0	---	51	1.43	.05	1.20	63
50	B'cast	93	1.97	.07	1.12	98
100	B'cast	122	2.29	.08	1.25	119
50	B'cast + ATS	99	1.91	.07	1.09	---
100	B'cast + ATS	114	2.16	.07	1.28	---
50	Dribble	91	1.85	.06	1.10	100
100	Dribble	125	2.43	.09	1.29	129
50	Knifed	117	2.24	.08	1.32	122
100	Knifed	131	2.60	.09	1.52	137
LSD (.05)		15	.18	.01	.16	
Mean Values:						
N Rate	50	100	1.99	.07	1.16	106
lb/A	100	123	2.37	.08	1.34	128
LSD (.05)		8	.10	.01	.08	
N	B'cast	108	2.13	.07	1.19	109
Place-	B'cast+ATS	107	2.04	.07	1.19	---
ment	Dribble	108	2.14	.08	1.20	114
	Knifed	124	2.42	.09	1.34	129
LSD (.05)		10	.14	.01	.12	

[1/] All N applied as UAN (28%) solution, ATS is ammonium thiosulfate (12-0-0-26S) mixed 10% v/v with UAN, dribble is surface banded on 20 inch centers, knifed is injected 6-7" deep on 20" centers.

Yields at the Greenwood county site in 1987 were average and N effects were less dramatic, but some trends were noted. (Table 5)

Table 5. Nitrogen management for no-till grain sorghum, 1987. Bonczkowski Farm, Greenwood Co.

N Rate	N[1/] Placement	Grain Yield	Plant Tissue N	Plant Tissue S	Grain N
		bu/A	----- % ----		%
0		59	1.87	.07	1.52
50	B'cast	63	1.98	.08	1.55
50	Dribble	66	2.21	.07	1.59
50	Knifed	78	2.17	.09	1.66
50	B'cast + ATS	69	2.05	.07	1.54
50	Dribble + ATS	70	2.12	.08	1.57
50	Knifed + ATS	76	2.19	.08	1.65
100	B'cast	67	2.27	.08	1.59
100	Dribble	66	2.33	.09	1.80
100	Knifed	76	2.51	.10	1.82
100	B'cast + ATS	72	2.10	.08	1.51
100	Dribble + ATS	71	2.37	.09	1.79
100	Knifed + ATS	83	2.49	.10	1.87
LSD (.05)		13	.18	.01	.15
Mean Values:					
N Rate	50	70	2.12	.08	1.59
lb/A	100	73	2.35	.09	1.73
LSD (.05)		NS	.08	.01	.06
N Method	B'cast	68	2.10	.08	1.56
	Dribble	68	2.26	.08	1.69
	Knifed	78	2.34	.09	1.75
LSD (.05)		6	.09	.01	.07
ATS	Without	69	2.24	.08	1.67
	With	74	2.22	.08	1.66
LSD (.05)		4	NS	NS	NS

[1/] All N applied as UAN (28% solution, ATS is ammonium thiosulfate (12-0-0-26S) mixed 10% v/v with UAN, dribble is surface banded on 20" centers, knifed is injected 6-7" deep on 20" centers.

Consistent with the Agronomy Farm data, the knifed placement method produced significantly higher grain yields than either broadcast or dribble placements, and significantly higher tissue and grain N contents than the broadcast placement method. The addition of ATS in the UAN consistently increased yields and averaged across all N rates and placement methods significantly increased yields, but had no effect on tissue or grain N contents. The yield increase due to the ATS is difficult to attribute entirely to less volatilization loss since the effect was also noted on the knifed placement method. Since sulfur was balanced on all treatments, the yield increase probably wasn't just a sulfur response.

SUMMARY

Based on the results of this and other research, nitrogen management is more critical in the high residue environments associated with conservation tillage systems. Nitrogen efficiency is greatly affected by placement. Knifing in, which completely avoids residue contact, appears to be the most efficient way to apply UAN in high residue situations. The dribble placement (surface banding), though not as good as knifing, has performed better than surface broadcast in some cases. Based on these results, surface broadcast UAN applications are inefficient in high residue situations where there is no incorporating tillage. The addition of ATS to the surface broadcast UAN appeared to increase N efficiency in some cases and further investigations are needed to explain the mechanism of response and evaluate UAN/ATS ratios. Additional research is needed as we expect to see a fairly rapid growth of conservation tillage acres in Kansas and neighboring states over the next several years, and identification of nitrogen management systems that maximize efficiency in high residue situations remains a critical need.

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FARMING SOILS, NOT FIELDS

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ABSTRACT

Traditional approaches to farming, where large fields are managed as one homogeneous unit are becoming obsolete. Most fields contain several soils with different soil properties that influence soil productivity. This soil variability should be reflected in management needs that reflect each soil's potential. "Averaged" inputs of fertilizer, on these variable fields translate into under-fertilization in some areas and over-fertilization in others with a net result of decreased profitability. By tailoring fertilizer and other inputs to soil properties, costs can be reduced, profitability can be increased, and the quality of soil and water resources can be maintained or improved. Preliminary results of field experiments conducted at Havre and Whitehall, Montana, are presented as an evaluation of the potential for managing fertilizer inputs according to soil yield potential.

OBJECTIVE

The Farming Soils, Not Fields approach to improved soil fertility management was initiated in 1987 to investigate the potential for managing soil fertility inputs on different soils or soil management units within fields.

METHODS

Soil variability was delineated from soil survey reports, color-infrared (CIR), aerial photographs, satellite imagery, ground truth, producer knowledge, and professional soil scientist experience. A soil management map was then generated indicating different soil management units. Soil test information was collected from each soil management unit for routine fertility analysis (Table 1). Fertilizer recommendations were calculated based on soil test results, yield estimates for management units, and Montana State University fertilizer guidelines. Application rates at Havre were 0.5, 0.75, 1.0, 1.25, and 1.5 times the recommended N rate for each management unit and a 40 bu/a yield potential suggested by the producer. Application rates for P and K were 0, 1.0, and 1.5 times the recommended rates for the soil management unit. Yield estimates identified by the SCS for the Assiniboine variant, Hillon/Kevin, and Scobey/Phillips management units were 26, 32, and 34 bu/a, respectively. Seeding and fertilization operations were completed with a research drill.

Nitrogen and P applications at Whitehall were near recommended rates for each soil management unit based on soil test results, yield estimates, and Montana State University fertilizer guidelines. An "average" application was also made based on average soil test results and an average estimated yield as if the field was a homogeneous unit. All fertilizer treatments were applied to each soil management unit. Yield estimates identified by the SCS for the Ethridge, Varney, Yawdim, and Yetull management units were 37, 33, 11, and 20 bu/a, respectively. Fertilizer treatments and seeding operations were implemented with a commercial (farmer cooperator) no-till drill which resulted in actual applied rates of N and P being slightly different than recommended rates. Grain yields were determined at each location by harvesting four replications with a research plot combine.

Table 1. Soil test results and spring wheat yield estimates for soil management units by location.

Management Unit	Soil Test NO_3-N	Soil Test P	Yield Estimates	Applied Rate N	Applied Rate P	Applied Rate K
	lbs/a	ppm	--bu/a--	--------lbs/a--------		
Havre*						
Assiniboine variant	44	15	40	56	9	27
Hillon/Kevin	56	12	40	44	9	27
Scobey/Phillips	68	17	40	32	9	27
Whitehall**						
Average	19	11	29	35	10	0
Ethridge	10	8	44	125	17	0
Varney	21	13	35	59	6	0
Yawdim	10	25	16	40	8	0
Yetull	18	7	19	22	15	0

* N sampled in spring to 48 inches, P sampled to 6 inches.
** N sampled in spring to 24 inches, P sampled to 6 inches.

RESULTS AND DISCUSSION

Grain yields presented are the average of four replications for a given fertilizer treatment at each location. Economic data was calculated by subtracting fertilizer cost (N = \$0.24/lbs, P = \$0.44/lbs, K = \$0.16/lbs) and application cost (\$5.00/a) from the price of grain at the elevator (spring wheat = \$2.84/bu).

Havre

Grain yield responses to N and P applications were compared to the check (Table 2). Compared to the recommended fertilizer treatments for each soil management unit, the equivalent of the average fertilizer treatment for the whole field produced higher or comparable grain yields. Further grain yield increases were observed with fertilizer inputs greater than recommended rates for the Assiniboine and Hillon/Kevin soil management units. A 6 bu/a increase in grain yield was obtained on the Scobey/Phillips soil management unit with less fertilizer input than the

Table 2. Grain yields by fertilizer treatments and soil management units (Havre, Montana).

Treatment	Management Unit (N-P-K treatment)		
	Assiniboine	Hillon/Kevin	Scobey/Phillips
	-----lbs/a-----		
Check	25.7	35.5	37.3
Average	43.1 (.75-1-1)	39.3 (1-1-1)	44.7 (1.5-1-1)
Recommended	41.6 (1-1-1)	39.3 (1-1-1)	40.4 (1-1-1)
High Yield	45.5 (1.5-1.5-1.5)	45.2 (1-1.5-1)	46.4 (1-1-0)

average or recommended rates. Averaged across all fertilizer treatments, a mean yield of 36.0, 39.2, and 41.6 bu/a was obtained on the Assiniboine, Hillon/Kevin, and Scobey/Phillips soil management units, respectively, which compared favorably with the estimated 40 bu/a yield.

The average treatment resulted in higher net returns than the check treatment on the Assiniboine and Scobey/Phillips soil management units (Table 3). Check treatments produced higher net returns than the average and recommended treatments on the Hillon/Kevin soil management unit and the recommended treatment on the Scobey/Phillips management unit. Higher yields did not necessarily translate into increased economic return. While the 1-0-0 treatment on the Scobey/Phillips unit produced the highest yield and the greatest returns, treatments which resulted in the greatest returns did not produce the highest yields on the Assiniboine and Hillon/Kevin units.

Table 3. Economic return from fertilizer treatments and grain yields based on soil management units (Havre, Montana).

Treatment	Management Unit (N-P-K treatment)		
	Assiniboine	Hillon/Kevin	Scobey/Phillips
	$/a		
Check	68.07	95.82	100.90
Average	99.01 (.75-1-1)	87.89 (1-1-1)	102.06 (1.5-1-1)
Recommended	91.40 (1-1-1)	87.89 (1-1-1)	93.92 (1-1-1)
High Yield	91.67 (1.5-1.5-1.5)	102.41 (1-1.5-1)	115.22 (1-1-0)
High Return	101.74 (1-1-0)	102.92 (1-0-0)	115.22 (1-1-0)

Whitehall

As predicted from soil test results and subsequent fertilizer recommendations, grain yield responses were obtained from N and P applications (Table 4). The fertilizer treatment corresponding to the soil management unit (i.e., Ethridge fertilizer treatment applied to the Ethridge soil management unit) did not result in the highest yields on all soil management units. In fact, only on the Ethridge soil unit was the recommended rate the optimum rate. The yield from the Varney rate was nearly 4 bu/a below the Ethridge rate on the Varney unit. The tailored rate for the Yawdim and Yetull units ranked fourth out of the five fertilized treatments in both cases. Average yields across all fertilized treatments were 31.6, 33.7, 28.7, and 29.5 bu/a for the Ethridge, Varney, Yawdim, and Yetull soil management units, respectively. Actual grain yields compared favorably to SCS yield estimates only for the Varney unit. If the field (44 acres) was treated as one homogenous unit at the average fertilizer rate, a calculated mean of 34.1 bu/a would have been obtained, assuming an equal area of the field was occupied by each soil management unit. The same manipulations using the highest yields obtained from each soil management unit regardless of fertilizer treatment resulted in a calculated mean of 42.0 bu/a. Since the drill that was used was the producers' and not a "research drill", the potential opportunities become even more attractive.

The economic return based on grain yield is presented for each of the fertilizer treatments on the soil management units (Table 5). The highest economic return was obtained on two (Ethridge and Varney rates on their respective units) of the four soil management units. The average fertilizer treatment resulted in a net return of $69.32/a compared to a return of $84.34/a at the optimum fertilizer rate for each unit. Grain yield and preliminary economic analysis, without protein considerations, strongly support the concept of managing soils according to their respective productivity levels. However, methods of deriving fertilizer recommendations for soil management units need to be improved, so that recommended rates are consistently the optimum rate.

The recommended rates on the Yawdim and Yetull were too low because the estimated yields for these soils was too low; these soils do not have characteristics typical of Yawdim and Yetull or the unusually high rainfall resulted in yields much higher than expected on these two sandy soils.

Table 4. Grain yields by fertilizer treatments and soil management units (Whitehall, Montana).

Treatment	Management Unit			
	Ethridge	Varney	Yawdim	Yetull
	------------------lbs/a------------------			
Check	15.5	11.2	12.8	15.7
Average	35.9	35.3	30.5	34.6
Ethridge	46.3	44.7	27.2	39.7
Varney	30.6	40.8	37.1	29.8
Yawdim	25.9	24.7	25.6	22.1
Yetull	19.1	21.1	23.2	23.0

Table 5. Economic return from fertilizer treatments and soil management units based on grain yields (Whitehall, Montana).

Treatment	Management Unit			
	Ethridge	Varney	Yawdim	Yetull
	------------------$/a------------------			
Check	44.07	31.67	36.44	44.62
Average	74.39	72.80	59.20	70.90
Ethridge	89.04	84.55	34.82	70.27
Varney	65.22	93.99	83.45	62.86
Yawdim	55.41	52.08	54.47	44.56
Yetull	37.42	48.87	48.53	43.13

SUMMARY

Preliminary results support the potential for managing soils, not fields. Adjusting fertilizer inputs, in addition to seed, pesticide and other production inputs, according to soil properties will result in more efficient production, higher profits, better crop quality, and improved management of water and soil resources. Accurate information is essential to the success of a farming soils, not fields approach. Soil survey reports, farmer experience, and professional soil scientist expertise are essential to the delineation of practical soil management units. SCS yield estimates are a good starting point for the reliable estimate of soil productivity levels. Accurate soil test results, fertilizer response information, yield estimates, detailed records of past management inputs, and other unknowns to be identified are required for optimum use of the farm soils, not fields concept.

ADDITIONAL SOIL FERTILITY RESEARCH PROGRAMS

Maximizing N Efficiency for Small Grains in the Northern Great Plains. Objective: Determine optimum rate and placement of N materials and sources for small grains in Montana. PI: Bauder and Jacobsen.

Small Grain, Cropping Systems, and Sugarbeet Production Practices for Eastern Montana. Objective: To determine optimum N and S production practices for eastern Montana. PI: Bergman and Eckhoff.

Tree Fruit Fertilization. Objective: To determine optimum K and Zn fertilization practices for tree fruits. PI: Callan.

Nitrogen, Chloride, and Irrigation Studies in Small Grains. Objective: To determine optimum N and Cl fertilization practices for dryland and irrigated wheat and barley. PI: Engel.

Phosphorus Reactions in Calcareous Soils. Objective: To evaluate the effect of water soluble soil organic matter on the kinetics of calcium phosphate precipitation. PI: Inskeep.

Field Crop Production. Objective: To evaluate N and P placement in no-till cropping systems. PI: Jackson and Kushnak.

Soil P Fractionation. Objective: To evaluate the effects of time, soil, P rate, and plant uptake on P soil fractions. PI: Jacobsen.

Nutrient Partitioning in Spring Wheat. Objective: To determine the distribution of nutrients in plant parts during the growing season. PI: Jacobsen and Skogley.

Phytoavailability Soil Test. Objective: To develop a soil testing methodology characteristic of root uptake. PI: Skogley.

Potassium Processes in Montana Soils. Objective: To evaluate the effects of temperature, soils, and water on K diffusion processes in Montana soils. PI: Skogley.

Cropping Systems Based on Cereal-legume Rotations. Objective: To evaluate the potential for cereal-legume rotations in Montana. PI: Sims and Ditterline.

Crop Production, Nutrient and Water Management. Objective: To determine optimum production, nutrient and water management practices for potatoes, broccoli, and tart cherries. PI: Westcott.

Forage Crop Production. Objective: To evaluate N management practices for grasses, legumes, and sweet clover. PI: Wichman.

AN OVERVIEW OF PHOSPHORUS PLACEMENT

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INTRODUCTION

Which is better, band or broadcast P applications? Are all band P application methods equal in effectiveness? How much can I reduce broadcast P recommendations if I band apply instead? Questions such as these continue to generate much debate as to the merits of various P application methods. These debates are often fueled by research results which seem to point in different directions in regard to these questions.

The first question--which is better, band or broadcast P applications?--can only be answered by relating the factors affecting crop response to fertilizer P to the expected conditions for each field. Soil test levels, the P buffering capacity of soils, crop to be grown, and other factors all affect the relative efficiency of band and broadcast P applications.

For example, P placement for small grains generally seems to be more important than for row crops. This is due in part to a colder, wetter soil environment and a less extensive root system, which may reduce P availability and increase the response to band-placed P as compared to broadcast.

There are many types of band P applications in use today. Drill-row applications for small grains and starter (2 x 2) applications for row crops have been the standards by which other band methods are judged. Research conducted in Kansas during the 1970's indicated that preplant, dual-deep band P applications of N and P to wheat was more effective than broadcast applications on low testing soils (Table 1. Leikam, et al. 1980). Later research throughout the Great Plains has generally indicated that dual-deep band applications are equal in effectiveness to drill-row P applications. Preplant surface band applications are an outgrowth of work conducted in Indiana which indicated surface band applications, which were subsequently moldboard plowed, were superior to broadcast applications (Barber, 1980). However, very little moldboard plowing is currently done in the Great Plains.

Dribble over the row applications have recently been studied in the Great Plains (Westfall, 1987) and have been reported as being more effective than broadcast P applications. While these applications are made to the top of the soil surface, it appears that soil sloughs into the seeding trench, made by the hoe-drill during the winter. This often results in a "shallow" band application. It is questionable if these same results would be obtained with double-disk opener drills.

1988 Great Plains Soil Fertility workshop Proceedings Denver, Co. March 8&9, 1988 J.L. Havlin, ed. KSU, Manhattan KS.

The following discussion attempts to cover some of the aspects involved in determining the relative effectiveness of the various P application methods. Apparently contradictory recommendations concerning the best method and placement of fertilizer P often result, in part, due to the fact that only certain conditions influencing P fertilizer response may be the same in the specific research used to form recommendations.

FACTORS INFLUENCING FERTILIZER P RESPONSE

Phosphorus placement comparisons should always be evaluated with the factors influencing fertilizer P response in mind. These factors include (1) soil test phosphorus level of the nonfertilized soil, (2) root contact with the fertilized soil, and (3) phosphorus concentration of the fertilized soil solution.

Phosphorus Level of the Nonfertilized Soil

As the P soil test level of the surface soil increases, the relative proportion of plant P uptake derived from the P fertilizer decreases. At high soil test levels, the addition of fertilizer has little effect on P uptake. This seems simple enough, however, anyone who has studied soil test calibration data understands that the soil test level at which there is no response to fertilizer P varies from soil to soil and from year to year. It is safe to say, however, that the probability of response decreases as soil test level increases.

Soil to soil and year to year fluctuations in the mineralization of organic phosphorus may be responsible for part of this response variability. Although most subsoils of the Great Plains are low in soil test P, some are medium-high and can influence P response if sufficient subsoil root development occurs. Total root length and distribution relative to shoot growth is likely one of the more important factors influencing the soil test P level required for optimum growth as well as the response to applied P fertilizer. A plant with an abundance of roots relative to shoots will require a considerably lower soil test level for optimal growth than if root development is limited. Root development will be discussed in more detail in the next section.

Root Contact with the Fertilized Soil

No factor influencing plant response to P fertilizer placement is more important than the degree of root contact with the fertilized soil. Total root length/activity, the volume of soil fertilized, and location of the fertilized soil are major considerations relative to root contact.

Total root length generally increases as yield increases; however, a multitude of factors appear to influence the magnitude of the increase. A number of studies on several crops have demonstrated that shoot growth is increased more than root growth as available water increases. One can envision a season where root growth is abundant relative to shoot growth and very little P response occurs since the plant is able to obtain adequate P from the unfertilized soil. This is likely a common reason for lack of response at a low soil test level. Low soil temperature and very wet soils decrease both total root length and root activity and can be a major factor affecting the magnitude of P response, even at higher P soil tests. Root disease, insect damage, soil compaction, variety, ammonium level, and other factors all influence viable root length and activity. Mycorrhizae (a beneficial root fungus) infection may also be a variable influencing apparent root length and activity.

The volume of soil fertilized influences the degree of root contact with the fertilized soil. If we assume that a broadcast-moldboard plow application fertilizes 100% of the soil, a band application at a 30-inch spacing fertilizes only about 1% of the soil volume. (calculated for a Poinsett SiCl, 25 lbs P205/A, 20 days post application.) Even though only 1% of the soil volume may be fertilized in a typical starter band, more than 1% of the root system is affected by bands due to a proliferation of roots in the band. This proliferation can be estimated for corn, soybeans, and wheat by the expression $Y=x^{0.7}$ where x is the fraction of soil fertilized and Y is the resulting fraction of the root system in the bard (Yao and Barber, 1986). Thus, a 1% band may contain approximately 4% of the root system, still leaving 96% of the root system unaffected by the applied P fertilizer. From strictly a root contact standpoint, this is not desirable. The presence of ammoniacal N in the P band has further increased root proliferation in some cases and is likely part of the dual N-P effect (Duncan and Ohlrogge, 1958).

In reduced till systems where P bands are not disturbed by subsequent tillage, residual effects may be quite significant. Over time, total band volume increases due to multiple applications and diffusion, resulting in a greater portion of the root system contacting the fertilizer P affected soil. In cases where the residual bands are destroyed by subsequent tillage, a system resembling previous broadcast P applications would likely result.

Another significant aspect of the soil volume fertilized was recently demonstrated by Nebraska researchers (Eghball and Sander, 1987). Their data show that under normal operating conditions, pumps commonly used for banding produce a series of droplets rather than continuous bands once a critical minimum application rate is reached. This rate is band spacing dependent and is approximately 20.2, 12.6 and 5.0 gallon/A respectively for 6", 12", and 30" bands (80, 50, and 20 lb P205/A using 10-34-0 and assuming that a 0.6 cm gap will close by diffusion in a few weeks). The authors suggest that discontinuous bands could be detrimental to fertilizer P efficiency since a root intercepting a droplet may only exploit the droplet volume rather than a continuous band volume of unlimited length. The speed of the applicator and the diameter of the fertilizer delivery tube also affects this relationship.

Location of the fertilized soil is the third factor influencing root contact. Since fertilizer P is relatively immobile in soils, the objective is to place the fertilizer where roots are most concentrated and active. The central South Dakota wheat data in Figure 1 is a good example of where this was not accomplished. When P was broadcast and only shallowly incorporated with sweeps prior to seeding, wheat yields were still increasing at the highest rate of applied P (200 lb P205/A). Fertilizer P efficiency had obviously been affected. Table 2 shows that the minimally incorporated fertilizer had influenced soil solution P concentrations in only the top 2" of the soil profile. This soil layer has limited root activity in the hot, dry environment of central South Dakota resulting in the fertilizer being positionally unavailable and very inefficient. In addition to the soil moisture effect illustrated here, soil temperature, distance of fertilizer band from the seed, soil compaction, as well as other factors influencing root activity impact the optimum location of the fertilized soil. Severe stratification of P, and resulting poor performance of broadcast P applications, is likely commonplace in much of the wheat/fallow region of the Great Plains (Figure 2).

Phosphorus Level of the Fertilized Soil

The impact of fertilizer on the P status of the soil to which it is applied is the third major factor influencing fertilizer P response. The basic relationship between applied fertilizer P and the P concentration of the soil solution is shown by line A in Figure 3. The first increment of fertilizer has only a minor impact on P in solution because it is either satisfying high energy soil adsorption sites or is precipitated with cations. As the application rate increases, more and more P remains in soil solution where it can have an immediate effect on root P uptake.

Soils with high P buffering potentials (fixation) have curves that are shifted to the right (line B, Figure 3). An example of such a soil is the Wakonda series shown in Figure 4. In this study, after two growing seasons, 400 lbs P205/A had exerted only a minor influence on the P soil test levels, and even less of an influence on soil solution P concentration. Soil properties associated with high P buffer potential include a low soil test P level, high clay content, high content of finely divided carbonates and elevated iron or aluminum oxide content.

If only the P buffering relationships of soils are considered, P fertilizer should be mixed with as little soil as possible. This would result in a maximum amount of P in solution and a minimum amount of fixation. However, another relationship must be considered and is shown in Figure 5. Root P uptake initially increases rapidly with increasing solution P concentration but gradually approaches a maximum rate of uptake. Therefore, if banded fertilizer increases the P concentration in the band beyond that which the roots in the band can utilize, root P uptake will plateau and overall P efficiency will decline.

As a result of the previously discussed factors influencing fertilizer P response, the best placement for a given situation will be the one providing optimal balance between minimizing fertilizer reaction with the soil and maximizing contact with roots. Considering the multitude of factors influencing this balance, it is not surprising that placement studies do not always yield the same results and that placement recommendations are constantly debated. As we review placement comparisons, these many factors must be kept in mind.

COMMON APPLICATION METHODS

A wide variety of application alternatives exist today. The major types are listed in Table 3 along with an estimate of the soil volume fertilized by each. It is critical that depth and/or type of incorporation be defined for surface methods since this has a marked effect on volume of soil fertilized and the location of the fertilized soil. For band methods, band location relative to seedling roots and spacing are critical when describing the method. As band spacing narrows, the soil volume fertilized increases but not as rapidly as one might expect.

When band spacings are narrowed at a constant P rate, the soil volume affected does not increase proportionally since less P is applied in each band causing individual band diameters to decrease. The affected soil volumes in Table 3 are theoretical estimates calculated from effective diffusion coefficients for a Poinsett silty clay soil. However, Eghball and Sander (1986) measured similar rate effects on affected soil volume for three Nebraska soils.

Based on an uptake model that incorporates many of the factors discussed earlier, it has been estimated that on soils likely to give P response, the optimum fertilized soil volume for a rate of 50 lbs P205/A varies from 1 to 20% (Kovar and Barber, 1987). The soil for which the estimates in Table 3 were derived results in a predicted optimum of approximately 3% for a 25 lbs P205/A rate (Fixen, unpublished data). As discussed earlier, the location of the fertilized soil relative to seedling roots is equally critical under the growing conditions of the Great Plains.

BAND VS. BROADCAST COMPARISONS

The entire issue of P placement frequently simplifies to two basic questions when dealing with farmers: (1) Do I band or broadcast? and (2) If I band, what rate adjustments are possible?

There are no universal answers to these questions, since the relative effectiveness of band vs. broadcast varies depending on the specific situation involved. At least four relationships between band and broadcast applications have been demonstrated by research in the Great Plains (Figure 6).

Situation A

Band equals Broadcast. This situation has most commonly been observed where soil test levels are relatively high resulting in limited fixation of broadcast P. Thorough incorporation of P results in good root contact and increases the probability of the fertilizer being located in moist soil. Warm season crops such as sorghum, soybeans, sunflowers, and to a lesser extent corn are more likely to exhibit this type of relationship, in part due to normally warmer growing conditions.

Situation B

Band exceeds broadcast at low rates but both eventually reach the same maximum yield. Response B has been reported in numerous studies and is likely the expectation of most agronomists. The factors normally associated with this response are low soil test levels, high P fixing soils, and cold wet soil conditions.

It is because of research results similar to response B that recommendations are frequently made that the P application rate can be reduced if the fertilizer is band-applied rather than broadcast, broadcast/band equivalency relationships such as those developed in Nebraska (Table 4) are often used to show that the band rate required for near maximum yield will be lower than broadcast applications at low soil test values while similar amounts are needed at higher soil tests.

Recent Kansas data (Figure 7, Whitney and Lamond, 1986) shows the increased efficiency of band applications to winter wheat, with broadcast P rates of nearly double the band rate needed to achieve equal grain yields. Unfortunately, there is no clear indication in this study that broadcast applications would produce yields equal to band P at rates higher than those studied. It's possible that this more nearly resembles response C.

Situation C

Broadcast never attains band yield. At least two different sets of circumstances can lead to response C. The first situation might include a cold wet soil leading to a large early growth response to banded P when this accelerated early growth rate is critical in achieving a growing season's full potential. South Dakota data on corn following fallow illustrates this situation (Figure 8, Fixen et al., 1985). Other 1984 and 1985 studies in South Dakota also illustrated this response type.

A second set of circumstances resulting in response C includes a relatively low P soil test value, minimal incorporation of broadcast P applications and relatively dry surface soil conditions. Nebraska work conducted on wheat (Figure 9, Sanders 1985) illustrates these types of results. Another interesting conclusion from this work was that, contrary to many recommendations where less fertilizer P is recommended for band application as compared to broadcast (response B), the optimum rate of band applied P may sometimes be higher than for broadcast applications. This may possibly be the case for the data presented in Figure 7 and discussed in the previous section.

Situation D

Broadcast more efficient than band (reverse of B). This response generally surprises both the reader and the scientist conducting the experiment. It shouldn't. It is quite understandable when one considers the factors influencing crop P response. Response D is most likely on low P fixing soils that have heavy residue cover and a warm, moist soil surface. Such may be the case in no-till systems in humid environments or for irrigated no-till. Under these conditions, root density is frequently highest at the soil surface which is where broadcast P is located. Band treatments may be less effective because of insufficient root contact. The irrigated no-till corn data from Nebraska (Table 5) illustrates this response. In colder environments and/or crops where early growth is critical, a combination of broadcast and band placement will likely give best results.

The previous types of relationships between band and broadcast P responses have also been reported from areas other than the Great Plains as evidenced from the information presented in Figure 10 (Welch, et al., 1966). These studies illustrate the fact that the relationship between band and broadcast P application does vary depending or the specific conditions encountered.

Back to the Questions

Do I band or broadcast? The answer depends largely on the specific conditions an individual is most likely to encounter. The factors affecting crop response to fertilizer P discussed earlier must be considered, together with the hypothetical response types that are possible 1A, B, C, or D). Rate adjustments, if any, can be developed once the most likely response type is determined. Although these questions do indeed seem simple, the answer involves an integration of many complex factors and their interactions.

SUMMARY

A common problem in many oral and written discussions on P placement is overgeneralization. There are few unqualified statements that can not be proven false if the proper set of conditions exist. There are exceptions to nearly every placement rule in the book. The cause of these common sins of overgeneralization are frequent questions of the form "Generally what is the best P application method?"

Fully appreciating these generalizing errors, the following are the authors, general ranking of common placement methods for low P testing soils in the Great Plains. In general, if there is a difference in crop response due to P application method--band applications will perform equal to, or better than, broadcast applications. Response D will occur only infrequently under normal conditions in the Great Plains. Be aware of exceptions and apply the rankings with caution. Also, in addition to agronomics, there are many other factors that are equally important in a grower's decision as to the best P application method, equipment availability, labor requirements, product availability from reliable dealers and other considerations need to be addressed when recommending application methods.

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Small Grains

Drill-Row Dual/Deep Band > = Band Below Seed	Dribble Over Seed (hoe drill)	> B'cast./Inc. Surface Band/Inc	B'cast/No Inc. Surface Band/No Inc. > Dribble Over Seed (disk openers)

Row Crops

Starter (2 x 2)	> = Dual Deep Band >	Surface Band/Inc > B'cast/Inc.	Surface Band/ No Inc. Broadcast/No Inc. Dribble Over Seed

FIG. 1. BROADCAST P ON WHEAT

FIXEN – S. DAKOTA, 1986

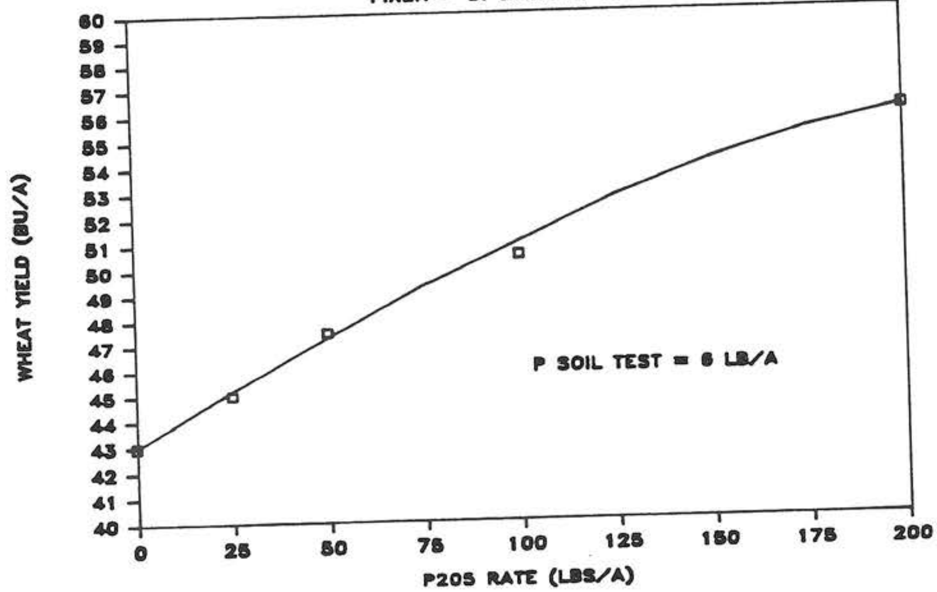


FIG. 2 STRATIFICATION OF SOIL P

SOUTH DAKOTA

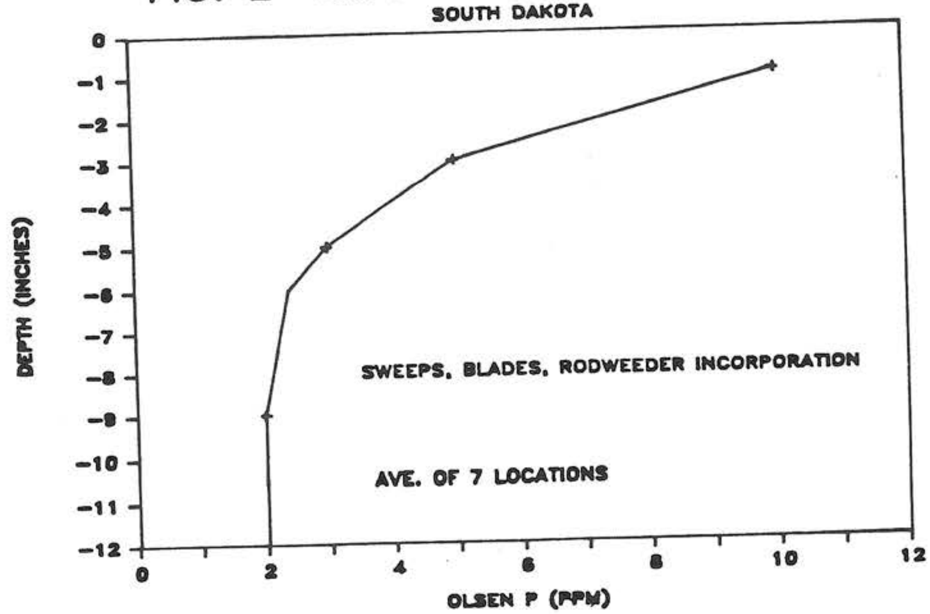


FIG. 3. P RATE EFFECT ON P CONC.

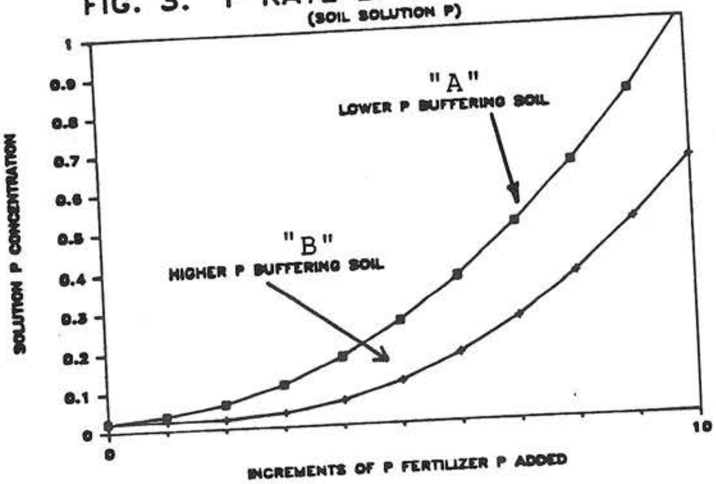


FIG. 4. P RATE EFFECT ON SOIL TEST P

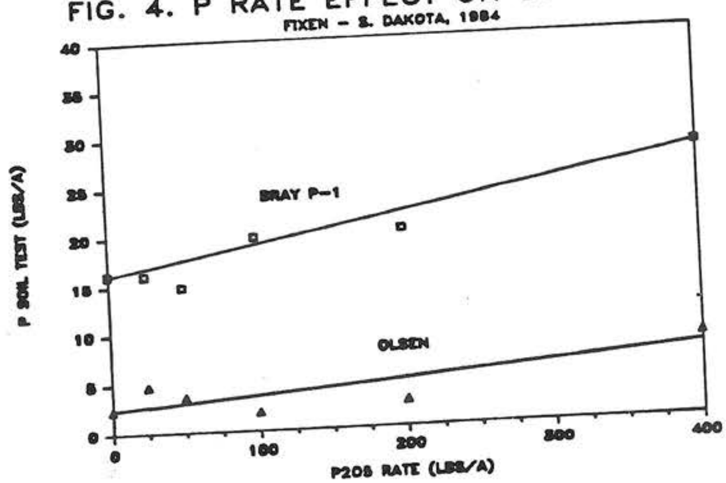


FIG. 5. ROOT P UPTAKE POTENTIAL

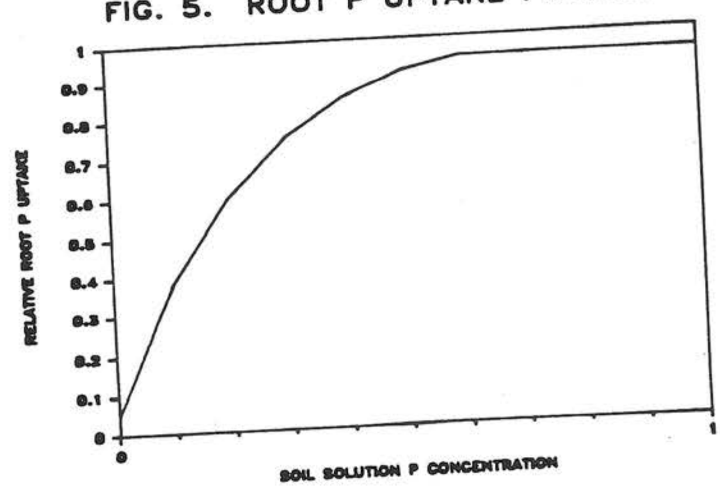
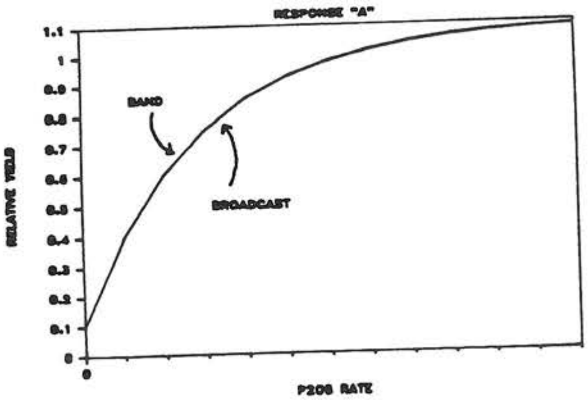
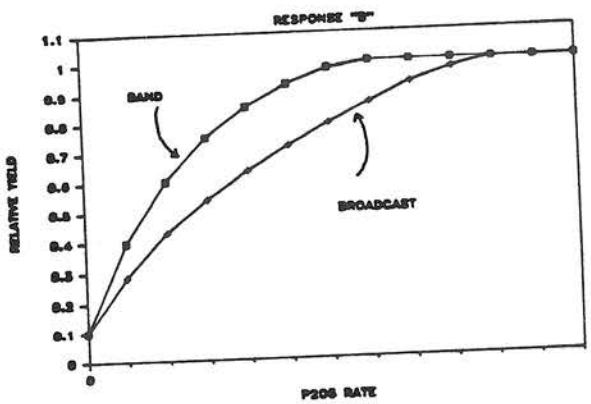


Figure 6. Four Relationships Between Broadcast and Band Phosphorus

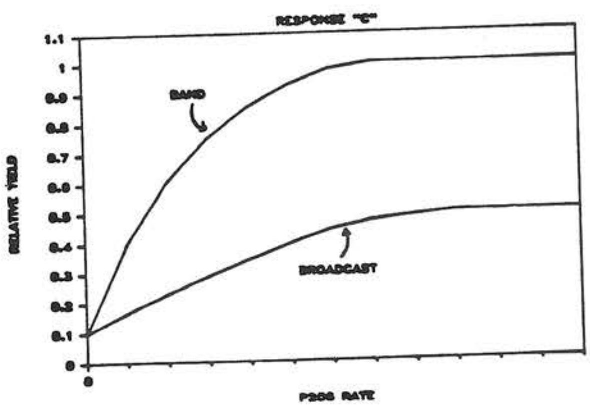
<u>Typical Conditions</u>



1. High soil test level
2. Warm moist soil
3. Warm season crops
4. Through incorporation

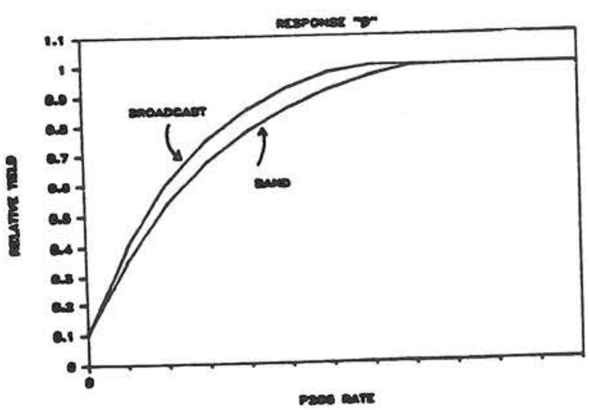


1. Low soil test level
2. Cold wet soil
3. High P fixing soils



a. 1. Cold wet soil
   2. Early growth critical

b. 1. Low soil test level
   2. Minimal incorporation
   3. Dry soil surface



1. Low P fixing
2. Heavy residue cover
3. Warm moist soil surface
4. No tillage or cultivation

FIG. 7. P PLACEMENT ON WHEAT
WHITNEY AND LAMOND, KANSAS

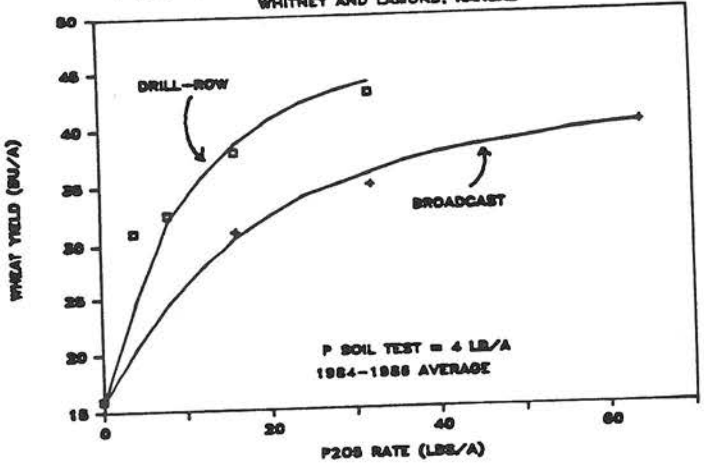


FIG. 8. P EFFECT ON CORN YIELDS
FIXEN - S. DAKOTA, 1984

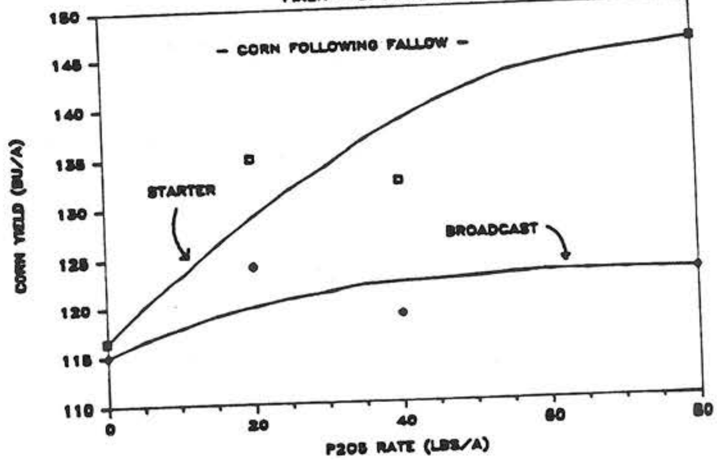


FIG. 9. P PLACEMENT ON WHEAT
SANDERS - NEBRASKA, 1978-82

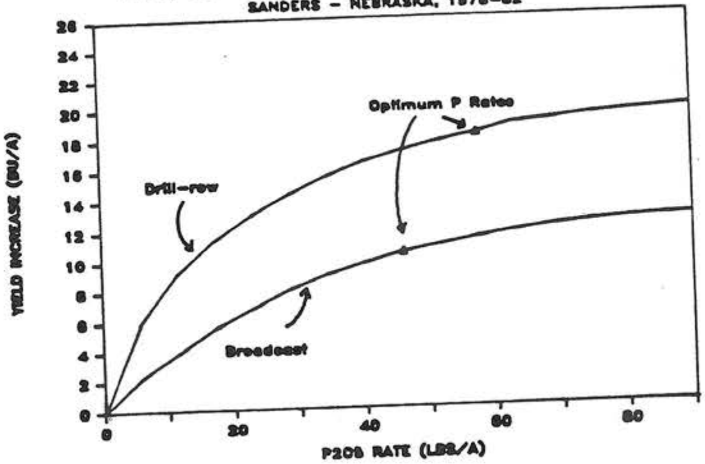


Figure 10. Effect of P Method on Corn Yield (Welch, et. al - Illinois)

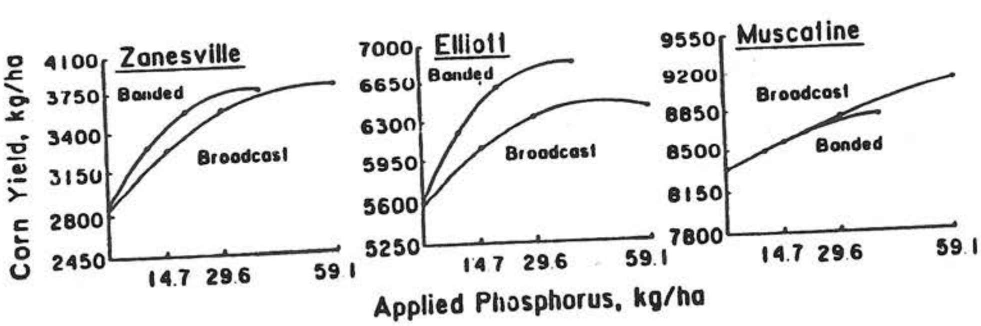


Table 1. Effect of P Application Method on Wheat Yield (Kansas 1979)

Method		
N	P	Yield
--	--	46
Knife	--	51
Broadcast	--	44
Knife	Knife	64
Knife	Broadcast	63
Broadcast	Knife	56
Broadcast	Broadcast	52

N at 75 lb/A as Ammonia, P_2O_5 as 10-34-0 lb/A

Table 2. Effect of Fertilizer P on Soil Solution P Concentration of Patterson Site, 1986.

Depth Increment	lbs P_2O_5/A 0	200
Inches	uM	
0-2	1.6	5.1
2-4	1.6	1.4
4-6	1.4	1.3

Table 3. Effect of P Application Method on the Proportion of a Six-Inch Soil Volume Fertilized.

Placement Method	Incorporation Depth	Theoretical Soil Portion Fertilized
	Inches	%
Surface Applications		
Broadcast/Incorporated	6	100
Broadcast/Minimal Inc.	2	33
Broadcast/Unincorporated	0.4	7
Preplant Surface Band	0-6	1-100
Band Applications	Depends on Spacing	
Drill Row (Seed Contact	6"	1.9
Preplant Dual/Deep Band	15"	1.5
Band Near Seed	30"	1.1
Dribble Over Seed		

Bands estimated at 25 lbs. P_2O_5/A 20 days after application on a Poinsett SiCl; percentages would increase as rate increases.

Table 4. Effect of Soil Test P Level on the Ratio of Broadcast: Row P Fertilizer Rates Required to Obtain Equal Yield Response (Wheat, Nebraska)

Bray P-1 Soil Test	Broadcast To Row Ratio
ppm	
8	3.1
10	1.6
14	1.5
17	1.0
19	1.0
19	1.2

Table 5
A Situation Where Broadcasting Was Superior To Banding for Corn (3-year average, Nebraska).

Placement	Grain Yield
	Bu/A
Check	66
Band Below Seed	95
Band Beside Seed	89
Knife Dual Placement	105
Broadcast	121

Olsen soil test = 1.5 ppm
Average of 18 and 36 lb P_2O_5 rates.
Row spacing = 30", Knife spacing = 15".

RESIDUAL FERTILIZER PHOSPHORUS IN THE NORTHERN GREAT PLAINS

T.L. Roberts and J.W.B. Stewart, Saskatchewan Institute of Pedology
University of Saskatchewan, Saskatoon, Saskatchewan

ABSTRACT

This review was initiated following recent studies in the Northern Great Plains, which have shown residual applications of fertilizer P to yield as well and often better than annually applied seed-placed P for periods of up to 15 years. Detailed investigations of the forms of applied P remaining in the soil showed that after 5 years less than 15% had been converted to unavailable forms. The remaining fertilizer P should be available for subsequent crops for many years. Cost benefit analysis using Saskatchewan yield data, current fertilizer P costs, simulated grain prices and discount interest rates has shown that the utilization of residual fertilizer P may now be considered a viable management option for cereal production in the Northern Great Plains, particularly in the calcareous, high pH soils of the Brown, Dark Brown and Black soil zones of the Canadian prairies.

INTRODUCTION

Traditionally, fertilizer phosphorus (P) has been considered relatively inefficient. Its limited effectiveness (generally less than 25%), in the year of application, was attributed to the rapid "fixation" of applied P by soil constituents in forms of very low plant availability. These so-called "fixed" forms of P were thought to be of negligible economic importance to subsequent crops. However, it is now known that in many relatively unweathered soils such as Mollisols, a large portion of the P remaining after the first crop year is not "fixed" but is indeed available to succeeding crops (Sadler and Stewart 1974). In fact, the utilization of residual P may now be considered as a viable management option for cereal production on Mollisols in the Northern Great Plains (Jose and Nilsen 1982, Wagar et al. 1986a).

Much progress has been made in the past decade in understanding the dynamics of organic P (P_o) and the contribution of P_o and inorganic P(P_i) to plant uptake of soil P (Barber 1984, Stewart and McKercher 1982, Tate 1984, Stewart and Tiessen 1987), the reactions and transformations between fertilizer P and the soil (Olsen and Flowerday 1971, Sadler and Stewart 1974, Sample et al. 1980), and the long-term availability of residual P (Smeck 1985, Tiessen and Stewart 1985). This paper reviews recent research on residual fertilizer P and discusses its long-term availability and practical implications.

Recent Residual P Studies

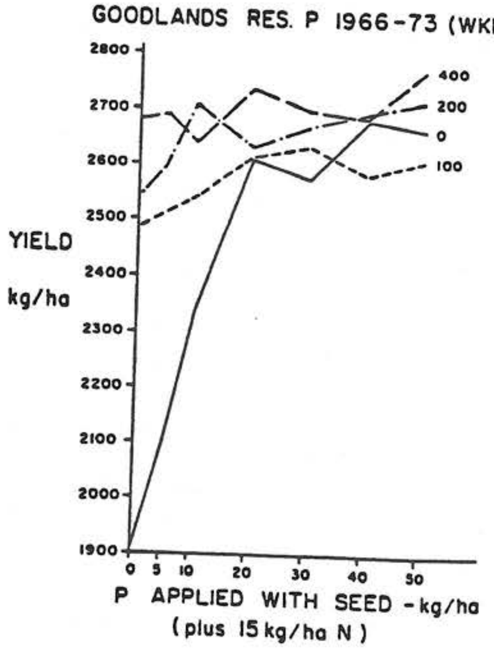
Early workers have documented residual crop yield responses to large single applications of phosphate fertilizer for periods of 3 to 9 years in field studies and up to 19 successive crops in greenhouse studies (Sadler and Stewart 1974, Bowman et al. 1978). Recoveries of applied P by consecutive crops have ranged from 38% for field crops to 87% for greenhouse crops. Initial large applications of phosphate have been shown to increase crop productivity as effectively as several smaller annual applications. Residual crop yield response has also been observed from regular applications of small amounts of P over an extended period of years.

The relative effectiveness of residual fertilizer P can also be evaluated by the status of available soil P. Numerous studies have demonstrated residual effects by measuring labile P_i with time. Results of such studies show that the intensity of available P_i can be maintained or increased from a large single application of P fertilizer or from the frequent application of small amounts of fertilizer P over periods of several years. Several researchers have developed simulation models which attempt to predict the availability of applied P with time (Russell 1977, Barrow 1980). Based on the observed behavior of phosphate fertilizers, Barrow (1980) built a simple model which describes the changes in available soil P status over several fertilizer regimes. The model predicted that regular annual additions of P fertilizer result in a steady net increase in available P status. If, after a few years the annual applications cease, the decrease in available P status is quite rapid. However, if annual applications continue for 10 years or longer, a high available P status can be maintained for several years.

Residual effects of applied P (0, 100, 200, and 400 kg P/ha) on Mollisols were evaluated in Manitoba and Saskatchewan over an 8-year period (Read et al. 1977). The added effect of small annual additions of P was included by superimposing seed-placed treatments on the plots receiving the single P applications. The 8-year average wheat yield showed residual response to all applications and this was reflected in increased levels of available P (Fig. 1). Superimposing seed-placed treatments on the single P applications did not significantly increase grain yield. There was a little "starter effect" from seed-placed P if sufficient plant available P was present in the soil. Their research indicated that when the level of soil $NaHCO_3$-extractable P was greater than 10 ppm (20 kg/ha), little response could be expected from phosphate applied with the seed.

In contrast, Alessi and Power (1980) in North Dakota, reported that after 6 years of continuous wheat, the residual effects of an initial application of 160 kg P/ha resulted in an average grain yield increase of 10% and that 15 kg/ha of seed-placed P brought about an additional 10% increase in grain yield. These authors concluded that additional banding of P with the seed is necessary to attain maximum yields regardless of the amount of P previously applied and even though more than 15 ppm of $NaHCO_3$-extractable P is present in the soil.

More recently in Montana, Halvorson and Black (1985a,b) showed that long-term (16 years) crop response to residual P fertilizer was closely related to available nitrogen (N). In their study, one time applications of P fertilizer at rates of 0, 22, 45, 90, and 180 kg P/ha were applied in conjunction with different N rates (0, 45, 90 kg N/ha). Continuous cropping was used for the last 6 years of the study, while a crop-fallow system was employed initially. Under continuous cropping, average grain yield increased with increasing levels of residual P fertilizer when sufficient N was present in the soil (Fig. 2). Yields did not increase if residual soil NO_3-N was low unless fertilizer N was applied. In the crop-fallow system average grain yield increased with residual P with or without N fertilization (Fig. 2).



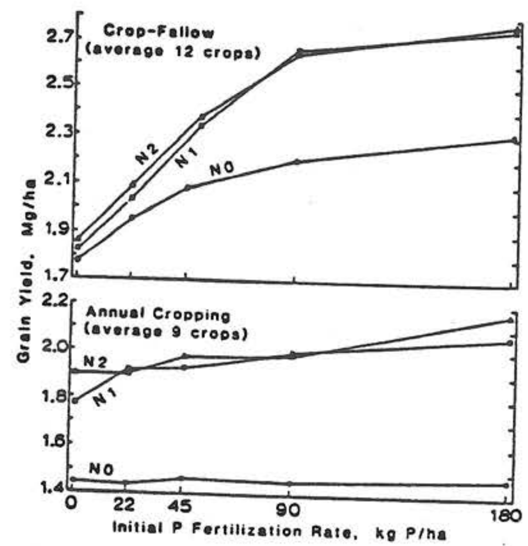


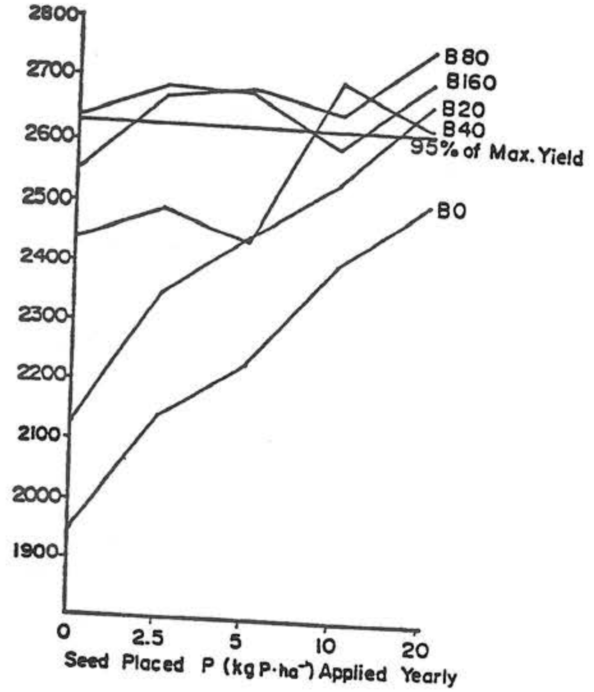
Fig. 1 & 2. Average grain yields from single broadcast (B) and annual seed-placed application of P fertilizer on a Waskada clay loam (Fig. 1 from Read et al. 1977), and from crops grown under crop-fallow and annual cropping systems as a function of N & P fertilizer on a glacial till William loam (Fig. 2 from Halvorson et al. 1985b).

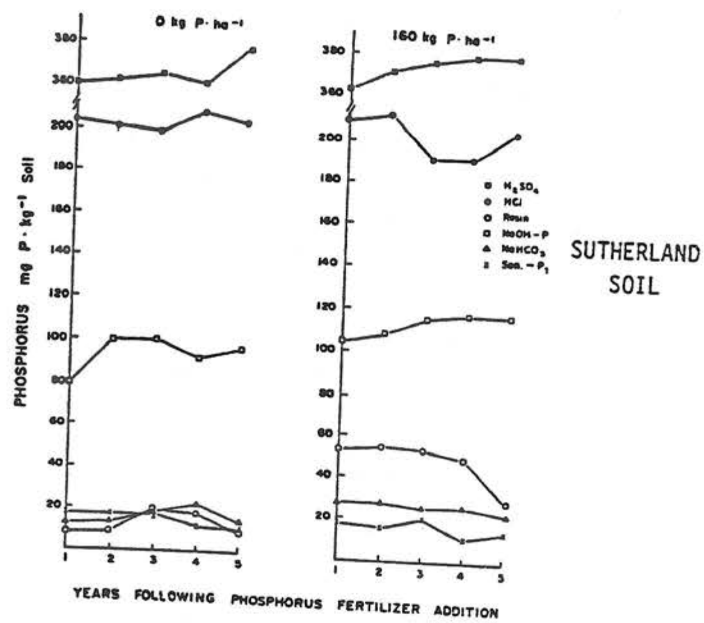
Another recent study, on a Chernozemic soil in Saskatchewan compared the residual effects of P fertilizer with repeated annual seed-placed applications on wheat over a 6-year period (Wagar et al. 1986a). In this study N fertilizer was applied to ensure that N was not limiting yield. At the initiation of the study, single P application treatments were broadcast and incorporated at rates of 0, 20, 40, 80 and 160 kg P/ha. Within each of these treatments, seed-placed P was applied at rates of 0, 2.5, 5, 10, and 20 kg P/ha. Each year another set of seed-placed treatments was added while established seed-placed treatments were repeated. Thus over the first 5 years of the study, 5 sets of seed-placed treatments were established, with the first having received 5 consecutive applications of seed-placed P.

Wagar and co-workers (1986a) found that crop response increased with residual P (Fig 3). Where no seed-placed P was applied, the 6 year average yield increase over the control was 9, 24, 33, and 35% for the 20, 40, 80, and 160 kg P/ha treatments respectively. Both the single and the multiple seed-placed P treatments resulted in yield increases over five years with the latter exceeding control amounts by 10% for the 2.5 kg P/ha treatment and up to 29% for the 20 kg P/ha treatment. A comparison of the first 5 years of the study of plots receiving only broadcast P with those receiving only consecutive seed-placed P showed little difference in average yield for the higher P applications. This led the authors to conclude that a single broadcast P application can produce yields comparable to annual seed-placed P applications without requiring additional P inputs. This conclusion is in agreement with the findings of Read et al. (1977).

The Form and Availability of Soil P with Time and Rate of Application

Detailed investigations of the changes in form and availability of residual P with time on Chernozemic soils have shown that half of the fertilizer P residues remaining in the soil were in plant-available forms, even after 8 years of continuous cropping (Wagar et al. 1986b). Using a sequential P extraction technique, Hedley et al. (1982) documented the transformations of applied P fertilizer in soils used for residual P studies in Manitoba (Read et al. 1973, 1977, Bailey et al. 1977) and Saskatchewan (Wagar et al. 1986a). One year after application, most of the fertilizer residues were present in highly available forms, i.e. as resin extractable P_i and $NaHCO_3$ extractable P. After an initial increase, one year following P application, these levels slowly declined to what appeared to be a new equilibrium level, higher than the level originally present in the soil (Fig. 4). Together, resin-and $NaHCO_3$-P accounted for 41, 49, and 50% of the fertilizer P remaining in the soil for the Waskada 200, Waskada 400, and Sutherland 160 treatments after 8 and 5 cropping years for the Waskada and Sutherland soils, respectively. A relatively small amount of recoverable fertilizer P was extractable by NaOH in the Waskada soils. Conversely, NaOH-P accounted for 36% of the remaining fertilizer P after 5 years in the Sutherland soil (Fig. 4). A significant proportion of the NaOH-P was present and persisted in the P_o fraction over the 5 years of the study, thus illustrating the importance of organic P forms in the long-term availability of applied P in some Chernozemic soils.





Figs. 3 & 4. Average grain yields from single broadcast P and annual seed-placed application of P fertilizer on a Sutherland clay (Fig. 3 from Wagar et al. 1986a), and soil P fraction extracted from the surface horizon of the same soil receiving 0 and 160 kg P ha^{-1} sampled annually up to 5 yr from fertilization (Fig. 4 from Wagar et al. 1986b).

The HCl-extractable P fraction represents a relatively unavailable pool thought to consist largely of stable Ca-bound P, characterized by hydroxyapatite (HA) which is released to the soil-plant system through pedological weathering processes (Smeck 1973, 1985). A considerable proportion of the applied P had moved into HCl-extractable fraction in the Waskada soil after 8 crops (27 and 29% for Waskada 200 and 400, respectively) while very little applied P had transformed into an acid-extractable form in the Sutherland soil after 5 crops (Fig. 4). The initial increase and decline of HCl-P in the Waskada 200 and 400 soils suggest that this form was slowly contributing available P, particularly towards the end of the study (Fig. 3). Therefore it was not likely that the applied P had been transformed into P forms characterized by HA. Wagar et al. (1986b) suggested that the HCl-P fraction in the Waskada soil represents the formation of other sparingly soluble compounds capable of supplying available P to plants, such as Mg-phosphates or b-tricalcium phosphate (TCP). Several others have implicated TCP as a significant mineral phase in P fertilized soils (Fixen and Ludwick 1982, Fixen et al. 1983, Havlin and Westfall 1984). Very little fertilizer P was converted to unavailable forms (residue-P). These findings support Sadler and Stewart's (1974) earlier conclusions that 75% of the P fertilizer applied on Chernozemic soils not used by the first crop remains in plant available forms for use by succeeding crops.

How long applied P will remain available to subsequent crops has yet to be determined. The expected period of utilization will ultimately depend on soil conditions, the type and frequency of crop grown, and the initial application rate of P. Spratt et al. (1980) tried to predict the effectiveness of residual fertilizer P with time using data from the earlier studies of Read and co-workers. Based on A values and $NaHCO_3$-extractable P_i as an estimate of available P these workers estimated the time (years) required to reach a base level of 15 ppm extractable P. By considering the curvilinear decline of available P with time, it was theoretically predicted that initial applications of 100, 200, and 400 kg P/ha would last for 5, 10, and 20 years, respectively, for the Waskada soil used by Wagar et al. (1986b). These time periods could be expected to be extended much longer if the P present in less available forms, both inorganic and organic, were considered and they remained within the effective reach of growing crops.

The work of Wagar et al. (1986b) has shown that 5 years following application a considerable portion (36%) of the applied P had been moved into the subsurface horizons (below 15 cm). Organic P was the main contributor to the increase. Similar observations have been reported by Read and Campbell (1981) for another Chernozemic soil which had received large broadcast applications of P. They suggested that the downward movement of P was by plant roots through a bio-cycling process. However recent research has shown that the leaching of low molecular weight acid materials, enriched in P, may be a significant mechanism for P loss in Luvisolic soils and redistribution in Chernozemic soils in western Canada (Schoenau and Bettany 1987) St. Arnaud et al. 1988).

The buildup of organic P in the study of Wagar et al. (1986b) occurred with and without the addition of inorganic P fertilizer. Its accumulation was attributed to a change in cropping practices from a wheat-fallow rotation, which was employed before the study was initiated, to one of continuous wheat which was used during the study. Under the continuous cropping system, the stimulation of microbial activity through additional C inputs resulted in significant quantities of applied P being converted to organic forms. This type of transformation of fertilizer P into P_o forms demonstrated the important role P_o plays in the recovery efficiency and the long-term availability of applied P.

Practical Implications and Economics

The apparent long-standing effects of residual fertilizer P offers several agronomic advantages for crop production in western Canada. Large one-time applications of P have been suggested as a viable alternative to the traditional approach of applying small amounts of P annually with the seed (Read et al. 1977, Wagar et al. 1986a). A large single application of P, prior to crop initiation could be particularly important in supplying the P requirements for future crops under a minimum or zero tillage system. It would also be advantageous for rotations that include crops with a high P requirement, such as canola or flax, which are sensitive to high rates of P placed with or near the seed (Harapiak and Beaton 1986). Residual P applications could provide a means of overcoming the variable P deficiency that is commonly associated with eroded knolls and leveled land. Application rate, kind of crop and rotation system, and the inherent soil properties will determine how well and for how long a crop's P requirements could be met. However, economics will ultimately determine the practicality of large single P applications.

An attempt was made to evaluate the profitability of residual P over a 5-year period using yield data (Table 1) from the study of Wagar et al. (1986b). A simple cost-benefit analysis using simulated fertilizer P costs, grain prices and interest rates allowed a comparison of the net present value (NPV), of return between single broadcast P applications and consecutive annual seed-placed treatments. The NPV for the single broadcast P application (Equation 1) and consecutive annual seed-placed P (Equation 2) were calculated as follows where:

$$NPV = \sum_{t=0}^{4} (P \cdot \Delta y_t)\left(\frac{1}{1+r}\right)^t - FC \quad [1]$$

$$NPV = \sum_{t=0}^{4} (P \cdot \Delta y_t - FC_t)\left(\frac{1}{1+r}\right)^t \quad [2]$$

P = price of grain (S/kg)
t = time (years)
Δy_t = yield increase over control (kg/ha)
r = discount interest rate
FC = fertilizer cost (S/kg) + appl. cost (S/ha)

The above calculations assumed P cost of \$0.78/kg and application costs of \$5.00/ha for the initial broadcast treatment (Equation 1) and \$0.50/ha for the consecutive annual seed-placed treatments (Equation 2). All other production costs were assumed the same for each treatment. The NPV was calculated over a range of possible grain prices and discount interest rates.

Table 1. Average wheat yield data from plots receiving an initial broadcast P at rates of 20, 40, 80 and 160 kg P/ha and plots receiving consecutive annual seed-placed P at rates of 2.5, 5, 10, and 20 kg P/ha, without broadcast P.

Initial single broadcast treatment

Crop Year	0	20	40	80	160
	(kg P/ha)				
1	2841	2906	3296	3458	3287
2	1572	1474	1767	2158	2086
3	1070	995	1244	1255	1257
4	1981	2421	2389	2508	2868
5	2253	2834	3068	3380	3571

Consecutive seed-placed P treatment

	0	2.5	5	10	20
	(kg P/ha)				
1	2841	2912	2841	3028	3202
2	1572	1684	1660	1736	1717
3	1070	1157	1182	1157	1210
4	1981	2355	2433	2779	2924
5	2253	2602	3042	3328	3510

† adapted from Wagar et al. (1986b)

Results of the cost-benefit analysis clearly show that a large single broadcast P application can be as economically viable as annual seed-placed P applications over 5-year period provided sufficient P was applied initially (Table 2). For both the broadcast and the seed-plant treatments, the NPV increased with increasing grain prices and decreasing interest rates. At comparable grain prices and discount interest rates broadcasting 80 kg P/ha initially resulted in a higher NPV than a total application of 100 kg P/ha applied annually at rates of 20 kg P/ha treatment, but only at the grain prices greater than $75/tonne. A change in the price of fertilizer would cause the NPV to increase or decrease but would have no effect on the overall trends observed.

While the grain prices and interest rates used in the above calculations may not reflect actual market conditions, they do demonstrate that applying large single applications of fertilizer P can produce superior returns compared to annual applications over a wide range of grain prices and interest rates. Generally, greater economic benefits could be expected the longer a residual application of P could sustain increased yields.

It should be pointed out that the preceding discussion on cost-benefit analysis is applicable only to the study of Wagar et al. (1986b). Extrapolation of the conclusions to other residual P studies should be cone cautiously as cost-benefit analysis in other situation may not give the same results. In support of the above observations, Jose and Nilsen (1982) did an economic comparison of annual vs. residual P applications for the data of Read et al. (1977) and found residual applications were economically feasible in three of the four locations evaluated. This led them to conclude that there is a potential economic advantage for the residual application of fertilizer P in the higher rainfall areas of the prairies where wheat can be grown continuously or with limited summerfallowing. The economics of residual P should be determined on a case by basis as results will depend not only on the interactions of fertilizer P in the soil, but the agronomic expertise of the farmer and the current market conditions.

Table 2. Net present value ($/ha) of return for dollars invested in fertilizer for initial single broadcast applications and consecutive seed-placed treatments after 5 years.

Interest Rate (%)	Grain Price ($/tonne) 75	150	225	300	Grain Price ($/tonne) 75	150	225	300
	Broadcast 20 kg P/ha				Seed-Placed 2.5 kg P/ha			
8	30.87	82.34	133.82	185.29	49.64	109.84	170.05	230.25
10	27.50	75.60	123.70	171.80	47.09	104.40	161.70	219.01
12	24.41	69.42	114.43	159.44	44.74	99.36	153.99	208.62
	Broadcast 40 kg P/ha				Seed-Placed 5 kg P/ha			
8	91.87	219.95	348.02	476.10	64.75	148.46	232.18	315.90
10	86.75	209.69	332.64	455.58	60.48	139.31	218.14	296.97
12	82.01	200.23	318.44	436.65	56.56	130.89	205.21	279.54
	Broadcast 80 kg P/ha				Seed-Placed 10 kg P/ha			
8	124.97	317.34	509.71	702.08	101.99	239.77	377.55	515.33
10	117.72	302.85	487.97	673.10	96.02	226.66	357.29	487.92
12	111.03	289.45	467.88	646.31	90.54	214.59	338.63	462.68
	Broadcast 160 kg P/ha				Seed-Placed 20 kg P/ha			
8	76.84	283.47	490.11	696.74	102.16	273.75	445.33	616.92
10	67.78	265.37	462.95	660.53	96.03	259.20	422.37	585.53
12	59.42	248.64	437.87	627.09	90.41	245.82	401.23	556.64

Another factor that must be considered when using high application rates of P, is the interaction with other nutrients. Halvorson and Black (1985a) found a highly significant NxP interaction. Other workers have found significant interactions between applied P and micronutrients. Spratt and Smid (1978), working on the residual P plots of Read et al. (1977), found that high rates of P decreased the concentrations of zinc (Zn) and copper (Cu) to near critical levels. Similarly, Wagar et al. (1986a) noticed that high P rates significantly reduced Zn levels in the wheat plant tissue and suspected the Zn disorder may have had a yield-limiting effect. Further investigations by Singh et al. (1986) on the same residual plots confirmed there was indeed a P-induced Zn deficiency and that it could be alleviated by the application of Zn fertilizer. Thus when applying high rates of fertilizer P, the potential interaction with other nutrients must be considered.

ACKNOWLEDGEMENTS

This paper is an abbreviated version of a review written by the authors, funded by Western Co-operative Fertilizer Ltd. of Calgary, Alberta and published by the Saskatchewan Institute of Pedology as Paper R 523. The authors would like to thank Dr. G.C. Van Kooten, Department of Agricultural Economics, University of Saskatchewan for his helpful assistance with the cost-benefit analysis.

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PHOSPHORUS RATE AND PLACEMENT FOR GRAIN SORGHUM

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ABSTRACT

Grain sorghum (Sorghum bicolor L.) response to phosphorus fertilization is influenced by soil test P level and growing conditions during grain fill. Results from P rate studies indicate probable P responses when soil test levels fall below 25 ppm Bray-1 P, although this is not universal for all soils. In general, band P placement methods improve P fertilizer efficiency over broadcast P when normal moisture conditions exist during grain fill. Under drought stress, broadcast P can improve efficiency by delaying maturity to avoid the drought stress, however, delayed maturity can also result in freeze injury. Dry matter production is improved with banded P compared to broadcast P, even under drought stress. Interpretation of P fertilizer research with sorghum should include evaluation of growing season moisture.

INTRODUCTION

Grain sorghum is a major economic crop in the central and southern Great Plains regions. Annual pruduction in Kansas is 200,000,000 bushels or about 25% of total U.S. production. As a result aggresive sorghum breeding and management research programs exist in Kansas and other Great Plains states. Compared to nitrogen (N) management research in Kansas, relatively few phosphorus (P) fertilization studies have been reported over the last 25 years. Although this is partly due to fewer P responsive soils relative to N, grain sorghum has been generally considered less responsive to P fertilization than, for example, winter wheat. Generally, grain sorghum is P responsive, however, adverse growing conditions during grainfill can greatly influence response to P management.

Grain sorghum is a warm season crop with grain fill initiated in early August or about 60 days after planting. At this time at least 60% of P uptake has occurred. In Kansas the highest probability of drought conditions also occurs during late July and August. Phosphorus fertilization will enhance maturity by as much as several weeks. In some years advanced maturity can avoid drought periods, however drought stress often coincides with grain fill in earlier maturing plants. In contrast, delayed maturity with P stress can increase the probability freeze injury. Therefore, results from P fertilizer management studies with grain sorghum have not been consistent, even on low P soils, and should be interpreted carefully. The objectives of this paper are to review results from P rate and placement studies with grain sorghum conducted over the last several decades and to illustrate the effects of drought stress on yield response to P fertilization.

PHOSPHORUS RATE STUDIES

As with other crops, the degree of grain sorghum response to P is inversely related to soil test P level. Phosphorus recommendations for sorghum vary between states, but generally they indicate probable P responses below 25 and 11 ppm Bray-1 and $NaHCO_3$ extractable P, respectively (Table 1). Some studies have shown P responses only to 10 lbs P_2O_5 on soil testing very low (<5 ppm Bray-1) in available P, although these upland soils tested medium to high on available P below 2 feet (Thompson, 1975).

Results from long-term N and P rate studies in east central Kansas on a low P soil illustrate the effect of moisture stress on P response (Janssen et al., 1979; 1980). When averaged over all 7 years significant sorghum responses were not observed above 40 lb P_2O_5/A (Fig. 1a). Similar results were found in dry years (Fig. 1b). However, when moisture was adequate, additional yield response to P was observed (Fig. 1c). After 7 years of P application Bray-1 P levels increased two- and four-fold with 40 and 80 lb P_2O_5/A, respectively. Similar increases in Bray-1 P were observed in N - P rate studies with irrigated sorghum in western Kansas (Fig. 2; Herron et al., 1979). In this study, even with adaquate moisture, sorghum responses above 40 lb P_2O_5/A were not observed.

Table 1. Phosphorus recommendations for dryland grain sorghum.

	Kansas		Nebraska		Colorado	
	Bray-1 P	P Rec[1]	Bray-1 P	P Rec[2]	$NaHCO_3$-P	P Rec
	-- ppm --	lb/A	-- ppm --	lb/A	-- ppm --	lb/A
V.Low:	0 - 5	30 - 40	0 - 5	80	0 - 3	40
Low:	6 - 12	20 - 30	6 - 15	40	4 - 7	20
Medium:	13 - 25	0 - 20	16 - 25	0	8 - 11	0

[1] P recommendations are for sorghum in central Kansas. Increase or decrease P Rec 10 lb/A for eastern or western Kansas, respectively. P Rec's for irrigated sorghum are 50-70, 30-50, 20-30, and 0-20 lb/A for the v. low, low, medium, and high P levels, respectively.

[2] P recommendations are decreased 50% if P is row applied. Starter P (15-20 lb/A) is recommended on medium P soils if conditions are cool and wet.

Residual fertilizer P is also important to consider when evaluating grain sorghum response to P fertilization. A recent Nebraska study on a very low P soil, evaluated dryland sorghum response to three P rates applied two years before the sorghum crop was planted (fall, 1982), just prior to planting (spring, 1984), and spring P applied over residual P (fall, 1982, + spring, 1984) (Fig. 3; Penas and Sander, 1984). Results show that yields were still increasing with the spring, 1984, and residual P treatments at 69 lb P_2O_5/A and that the spring P treatments increased grain yield compared to residual P. With the combined P applications (F82 + S84), sorghum did not respond above the 46 lb/A rate. Similar results were obtained in Kansas studies, where preplant P with residual P from previous applications improved production over residual P alone (Janssen and Whitney, 1983).

Phosphorus application frequency was evaluated in a long-term study in east central Kansas on a low P soil (Janssen et al., 1983). Phosphorus was applied annually, biennially, and quadrennially at rates of 50, 100, and 200 lb P_2O_5/A, respectively. Thus, at the end of two and four years the same quantity of P had been applied as the 50 lb/A annual rate with the 100 and 200 lb/A rates, respectively (Fig. 4). In the first year (1974), a significant response to increasing P rate from 50 to 200 lb/A was observed. At the end of the first application cycle (1977), P applied annually improved yields over less frequent applications. No yield differences were observed with application frequency after the beginning of the second application cycle (1978-81). Bray-1 P soil test levels after 1980 indicated very little difference in available P, which explains the similar yield increases to applied P with all treatments. Results in the first 4 years of the study were strongly influenced by environment. Drought stress during grain fill in 1975 and 1976 masked differences between application frequency compared to the 1st and 4th years where rainfall was normal. 1980 was also a very dry year, however, in 1981 moisture during grain fill was above normal and still no yield differences between treatments were observed. Regardless of P application frequency, after 8 years of P fertilization this soil was still responsive to P, because Bray-1 P levels were increased to only 15 ppm P (medium soil test).

Results from other Kansas studies suggest that consistent yield responses to P fertilization occur on soils testing below 25 ppm Bray-1 P, although one would not expect this value to be representative of all soils. Recent experiments in southwest Kansas evaluated the effect of soil test P on grain sorghum response to starter P (Hooker and Timm, 1986). Extractable Bray-1 P ranged from 4 to 23 ppm. Grain sorghum was planted with and without 20 lb/A starter P_2O_5 (Fig. 5). Two-year results indicated that sorghum response was observed in both years of the study on soils testing < 8 ppm Bray-1 P. Marginal responses were observed between 8 and 12 ppm P, which meant that the response to starter P was not consistent between years. Above 12 ppm P no responses were observed. These data suggest that the Bray-1 P level below which a response to P fertilization is probable is < 12 ppm P, however, grain yields were maximized only on plots testing near 20 ppm P. The starter rate used in this study was too low to realistically evaluate the effect of soil test level on fertilizer P response. Therefore, earlier observations are probably correct that sorghum yield responses to P are probable on soils below 25 ppm P Bray-1 P, provided drought stress does not occur during grain fill.

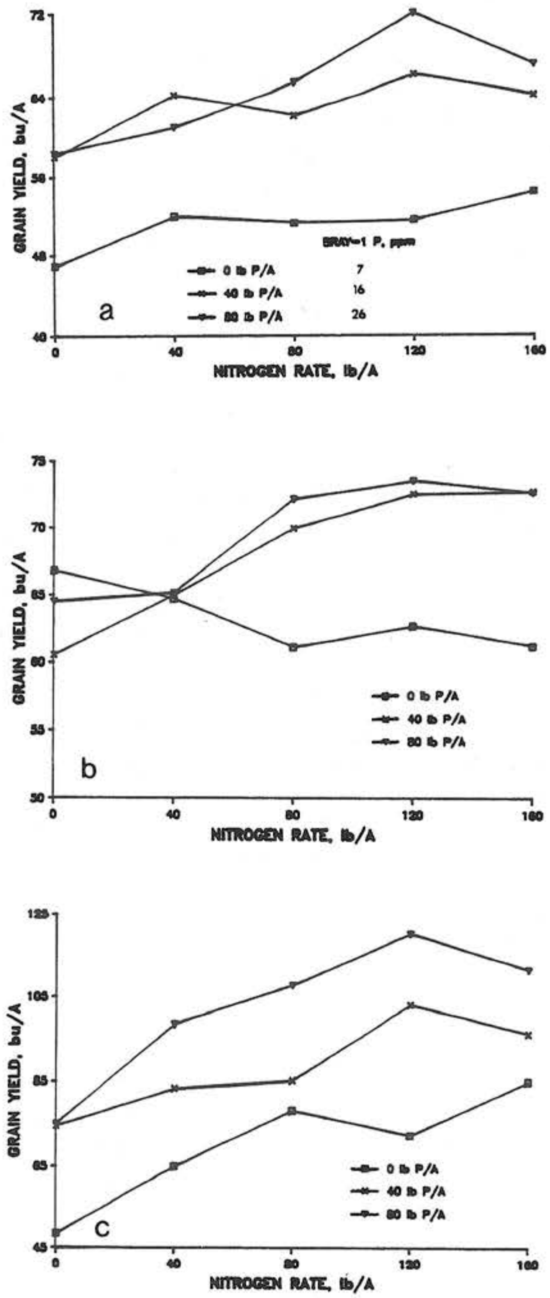

Figure 1a-c. Dryland grain sorghum response to N and P in east central Kansas (a) averaged over 7 years, (b) in a drought year, and (c) in a normal rainfall year. Soil test data shown in 1a were from samples taken the last year of the study.

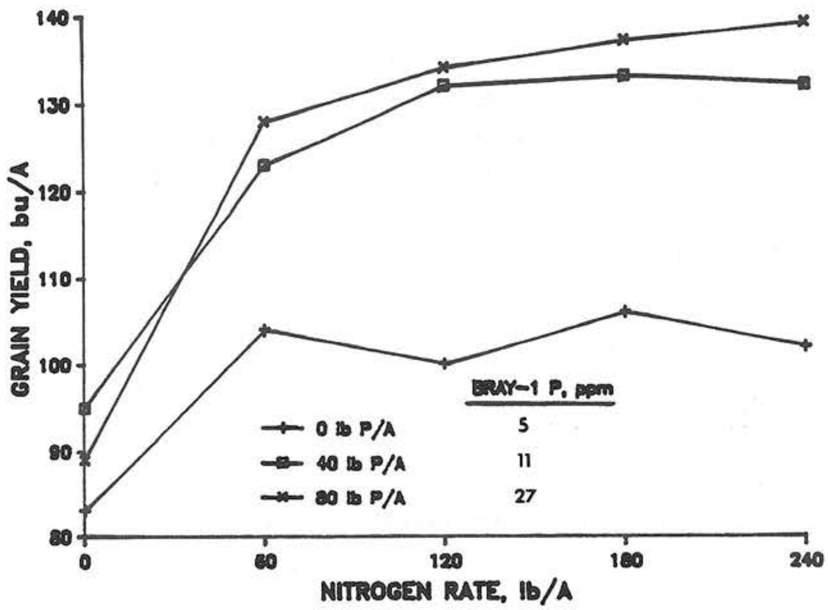

Figure 2. Irrigated grain sorghum response to N and P in southwestern Kansas from 1976 to 1979. Soil test levels shown are from samples taken April, 1979.

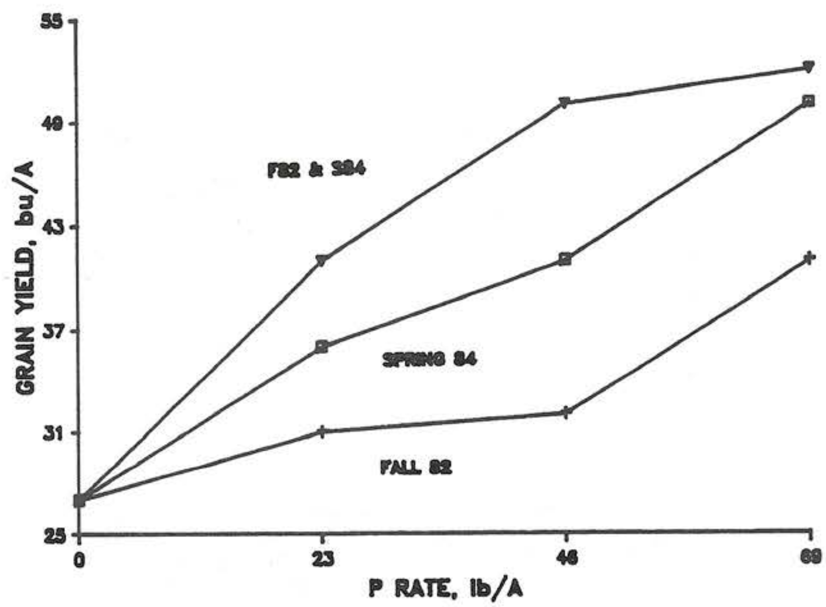

Figure 3. Effect of residual and preplant P on dryland grain sorghum yields in Nebraska in 1984.

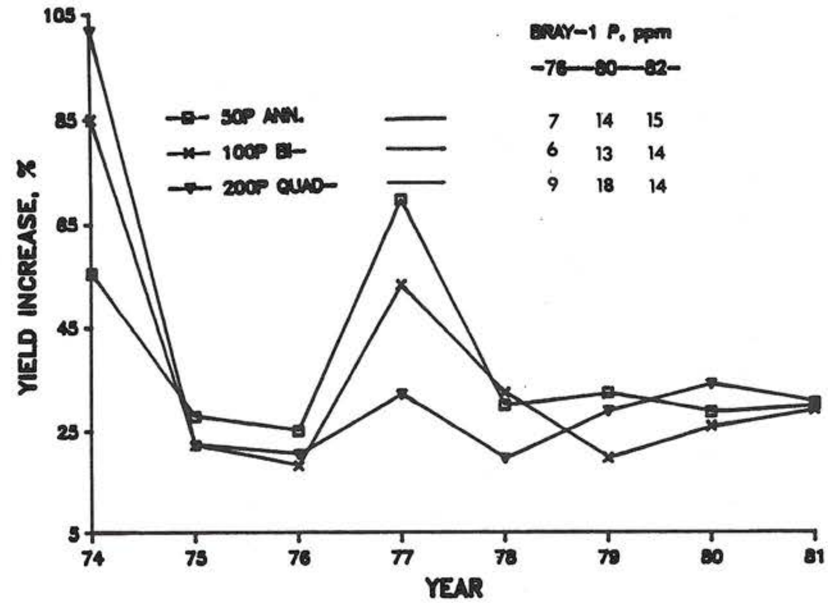

Figure 4. Effect of P application frequency on dryland grain sorghum yield in east central Kansas from 1974 to 1981. Soil test data are from samples taken in April of the year shown.

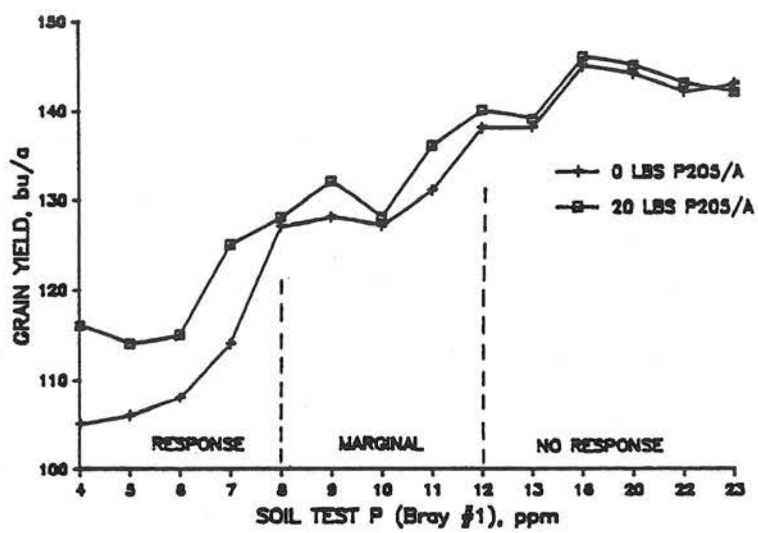

Figure 5. Influence of soil P level on grain sorghum response to starter P in southwest Kansas from 1985 to 1986.

PHOSPHORUS PLACEMENT

Grain sorghum response to P placement also depends on soil test level and drought stress during grain fill. Advantages to P placement are greatest on soils low in available P, which is similar to other crops. However, if banded P advances maturity such that grain fill coincides with a drought period, then broadcast P placement can actually increase production over banded P. Under this condition crop maturity will be delayed with broadcast P compared to banded P and, thus, potentially avoid the drought stress. Therefore, P placement research results are inconsistent and often difficult to interpret.

When normal moisture conditions exist, P placement results are similar to those reported, for example, with winter wheat. Phosphorus placement studies in southeast Kansas have shown knife (8" depth) and seed placed P improved yield over broadcast P (Fig. 6; Lamond, 1981). On this low P soil, 80 lb/A broadcast P produced similar yields to 20 lb/A knife or seed applied P. Under conditions of drought stress, opposite results have been reported, which are due to P placement effects on maturity and moisture conditions during grainfill. In east central Kansas on a low P soil, P banded 2x2 reduced dryland sorghum yield compared to broadcast and knife (6-8" depth) P (Fig. 7; Janssen and Whitney, 1981). The 2x2 band placement advanced maturity relative to broadcast and knife P so that grain fill coincided with drought conditions. Subsequent years of this study generally resulted in higher yields for knife P compared to both broadcast and banded P. Similar results were obtained in studies in Nebraska (Penas and Sander, 1984)

Even though yields can be reduced by P placement under drought stress, dry matter production is generally increased. Recent P rate and placement studies in south central Kansas illustrate this effect. Several P placement methods were evaluated at 15, 30, and 45 lbs P_2O_5/A on a very low P soil. These included broadcast, 2" band below the seed (BBS), dribble over the row (DOR), with the seed (SEED), and 7" band sprayed over the row (BOR). Severe drought conditions occured between late July and August. Grain yield results are shown in Fig. 8 (J.L. Havlin and R.E. Lamond, 1987, unpublished data). Sorghum maturity with all the banded P treatments (BBS, SEED, and DOR) was about 20 days advanced of broadcast and BOR treatments. As a results grain yields were lower with banded P compared to surface broadcast applications. The yield difference between band and broadcast P treatments increased with increasing P rate (Fig. 9). The reverse was true with dry matter production (Fig. 10). Banded P significantly increased dry matter throughout the growing season compared to broadcast/BOR P. Dry matter accumulation with the DOR application was intermediate between broadcast and banded P treatments. These data illustrate the dramatic influence of growing conditions during grain fill on dryland grain sorghum response to P placement. These studies will be continued over the next several years.

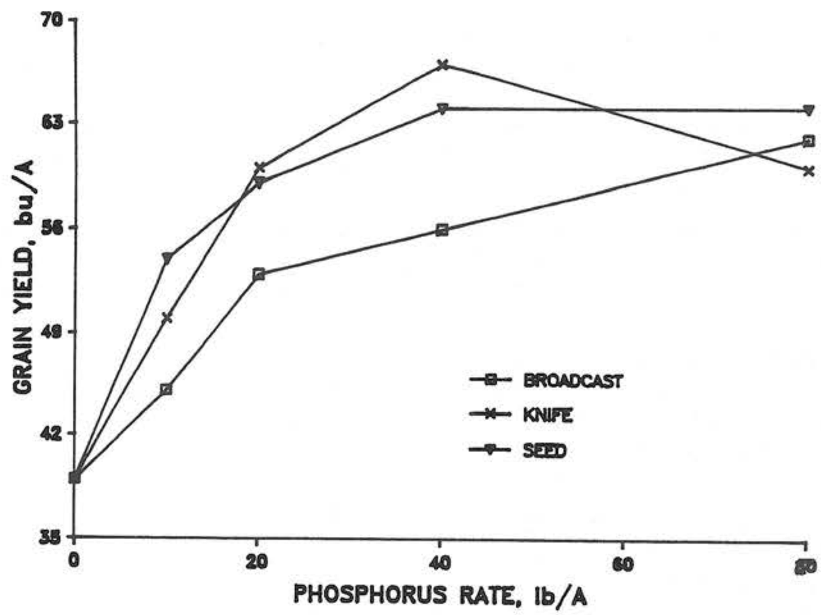

Figure 6. Interaction of P rate and placement on dryland grain sorghum yield in southeast Kansas in 1981.

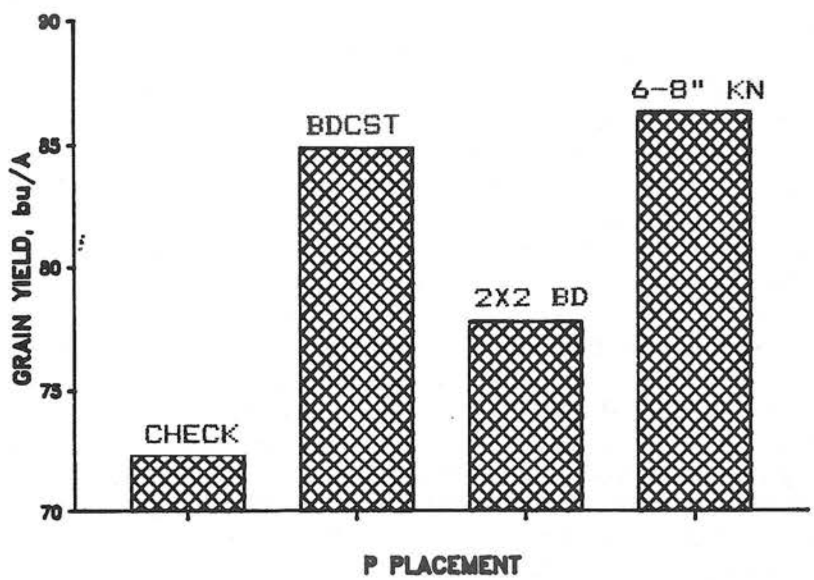

Figure 7. Phosphorus placement effect on dryland grain sorghum in east central Kansas from 1980 to 1983 . P rate was 40 lb P_2O_5/A.

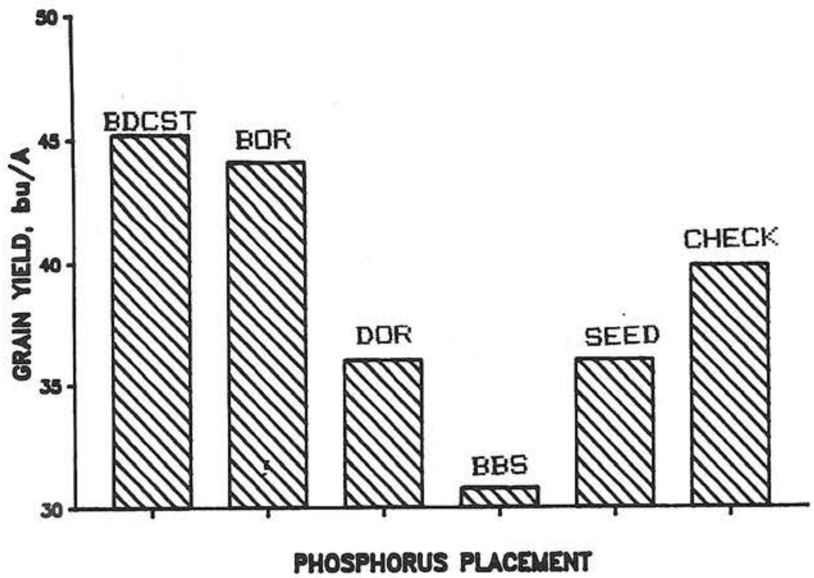

Figure 8. Effect of P placement on dryland grain sorghum yield in southcentral Kansas in 1987. Placement averaged over three P rates. See text for description of placement methods.

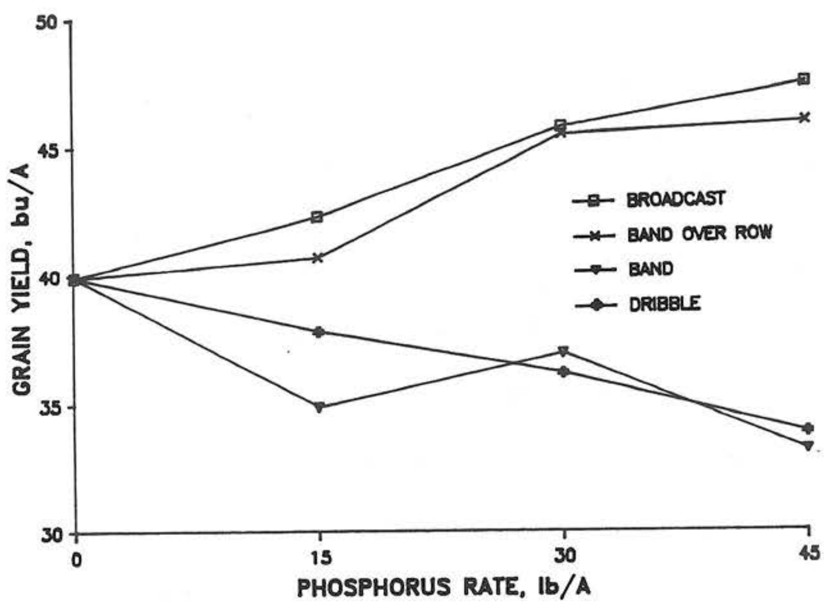

Figure 9. Phosphorus rate and placement effects on dryland grain sorghum yield in southcentral Kansas in 1987. See text for description of placement methods.

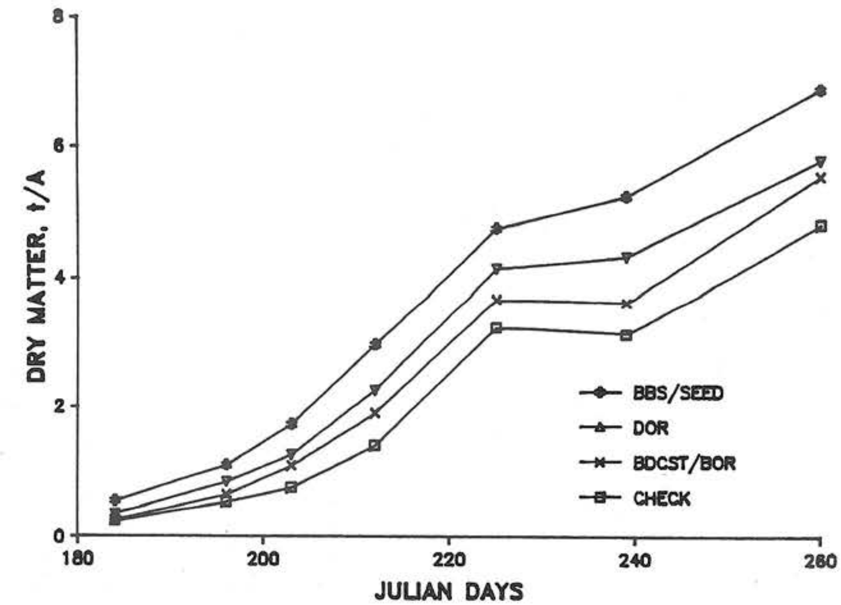

Figure 10. Phosphorus placement effect on sorghum dry matter accumulation in southcentral Kansas in 1987.

CONCLUSIONS

Dryland grain sorghum response to P fertilizer rate and placement depends primarily on the availability of native P and residual P from previous P fertilization. In years with adequate soil moisture, crop response to residual P reserves can be substantial, but yield responses to additional P at planting can be realized. Although the soil test P level which separates responsive from nonresponsive soils varies between soils, current use of 25 ppm Bray-1 P to separate medium from high P soils appears valid. Drought stress during grain fill reduces the probability of sorghum response to both P rate and placement. Compared to broadcast P, banded P can advance sorghum maturity where grain fill will occur during the time of greatest probability of drought stress. In normal rainfall years, banded P increases P efficieny on low P soils relative to broadcast P. In addition, banded P is more efficient in producing dry matter than broadcast P even in dry years.

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WINTER WHEAT RESPONSE TO HIGH RATES OF PHOSPHORUS[1]

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ABSTRACT

Winter wheat responses to high rates of P fertilizer application were studied on a calcareous loam soil with a medium $NaHCO_3$ soil test P level, 10.2 ppm, during the 1986 and 1987 crop years. With the application of 50 lb N/acre, winter wheat grain yields increased with increasing rates of P up to 207 lb P_2O_5/acre when broadcast incorporated or banded below the seed. A rate of 276 lb P_2O_5/acre was needed to maximize grain yields when the P was broadcast without incorporation. Grain yields were significantly lower when the P fertilizer was placed directly with the seed at 25% of the rates used with other P placement methods. A significant response to N fertilization was obtained. The results indicate that higher rates of fertilizer P than those normally recommended may be needed to minimize P deficiency as a yield limiting factor in the Central Great Plains. However, to be cost effective, the P fertilizer may need to be amortized over several years.

OBJECTIVE

Limited information is available in the Central Great Plains on P fertilizer placement and rate effects on winter wheat yields in reduced and no-till dryland farming systems. Banding low rates of P fertilizer near the seed on soils testing low in P is generally more effective than broadcasting the same rate of P during the first year of application (Leikam et al., 1983; Westfall et al., 1987). As soil test P levels increase from low to high, the yield difference between banded and broadcast P applications is 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 (Sleight et al., 1984). Several 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 (Alessi and Power, 1980; Halvorson and Black, 1985; Read et al., 1977). Halvorson (1987) reported irrigated winter wheat, grown annually, responded positively to residual broadcast P fertilizer under no-till conditions in Colorado.

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[1] Contribution from USDA, Agricultural Research Service and Kansas State University. Kansas Agric. Exp. Sta. contribution no. 88269-A. In Proceedings of 1988 Great Plains Soil Fertility Workshop, Denver, Colorado, March 8-9, 1988.

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 and no-till systems for several years. This study was designed to evaluate their suggestion in addition to comparing the effects of placement method on the long-term effectiveness of residual P fertilizer within a reduced tillage system. Study objectives are to (1) evaluate the efficiency of P placement methods for winter wheat production in reduced tillage systems, (2) determine the level of P fertilizer needed for optimum winter wheat yields with and without N fertilization, (3) determine the residual P fertilizer effects on winter wheat yields, and (4) determine the effects of N and P fertilization on water-use efficiency by dryland winter wheat. This paper reports results obtained during the first year of P fertilizer application from two adjacent identical sets of plots.

MATERIALS AND METHODS

The research site was located about 10 miles west of Peetz, Colorado on a Rosebud-Escabosa loam soil, with a pH of 7.8 and organic matter level of 2.4%. The initial sodium bicarbonate-extractable soil P level (0 - 6" depth) was 10.2 ppm, a medium soil test level. A split-split plot, randomized block design was used with P placement method as main plots, P fertilizer rate as subplots, and N fertilizer rate as sub-subplots, with four replications. Specific treatments were as follows: 1) P placement methods (a) broadcast prior to planting with no incorporation, (b) broadcast prior to planting with shallow incorporation with a disk (3" deep), (c) deep banded at planting with drill at about a 4" soil depth (3" below seed), and (d) banded directly with seed at 25% of P rates of other methods for each of 4 crop years; 2) fertilizer P_2O_5 (0-45-0) rates for broadcast and deep banded treatments of 0, 69, 138, 207, and 276 lb P_2O_5/acre (applied only one time); and 3) fertilizer N (34-0-0) rates of 0 and 50 lb N/acre. Duplicate sets of treatments were established on adjacent plot areas to allow the harvest of a winter wheat crop each year. One set was established in September 1985, from which a crop was harvested in 1986, and the other in September 1986, from which a crop was harvested in 1987. A no-till crop-fallow rotation was followed. Tam 105 winter wheat was grown in 1986 and Tam 107 in 1987. Wheat was planted about mid-September and harvested in mid-July each year. A no-till drill with dual seed row openers (two rows 3" apart) on each shank with 12" shank spacing was used. A plot combine was used to harvest the plots. Herbicides were used to control weeds. Soil samples were collected for soil NO_3-N and water (0-4,) and P (0-6") analyses.

RESULTS AND DISCUSSION

Winter wheat yields averaged over the 1986 and 1987 growing seasons are shown in Figure 1. Grain yields increased with increasing rates of P fertilization for all placement methods. Grain yields were near or at maximum with the application of 207 lb P_2O_5/acre plus N for the broadcast and band-below-seed placement methods. When the fertilizer P was broadcast prior to planting, but not incorporated, yields were maximum at the 276 lb P_2O_5/acre rate. The grain yields of the seed-placed P treatments (P rates 25% of other placements) increased with increasing P rate but were considerably lower than those obtained with the other P placement methods with and without N. The leveling off of grain yields at 69 lb P_2O_5/acre may have been the result of some stand loss with this seed-placed P rate. Although no stand counts were taken, visual observation, particularly in 1986, indicated that wheat stands were much poorer for this P rate and placement method. Winter wheat grain yields were increased significantly by the application of 50 lb N/acre (Table 1). The P x N interaction was not significant at the 95% level.

Table 1. Average winter wheat grain and straw yields, grain test weight, and 1986 grain protein and P content as affected by P placement method. P fertilizer rate, and N fertilizer rate of N.

Treatment	Grain Yield	Straw Yield	Heads per Acre	Grain Test Weight	1986 Grain Protein	1986 Grain P Content
	bu/A	lb/A	million	lb/bu	%	%
P Placement*						
BC Incorp	59.4	4131	2.53	59.2	12.6	0.400
BC no Incorp	56.7	3908	2.42	58.8	12.5	0.409
Deep Band	58.7	4019	2.54	59.7	12.3	0.442
Seed Placed	51.9	3693	2.27	58.3	12.4	0.422
LSD(.05)	4.2	N.S.	0.16	N.S.	N.S.	0.031
P205 rate, lb/acre						
0	50.4	3505	2.07	58.5	12.5	0.408
69	55.1	3726	2.28	59.0	12.5	0.404
138	58.1	4063	2.55	59.3	12.6	0.418
207	59.5	4161	2.65	59.1	12.4	0.424
276	60.2	4234	2.65	59.2	12.4	0.427
LSD(.05)	2.2	234	0.11	0.5	N.S.	0.015
N rate, lb N/acre						
0	53.8	3744	2.34	59.2	I2.0	0.422
50	59.6	4131	2.54	58.9	12.9	0.415
LSD(.05)	1.2	162	0.07	0.3	0.2	N.S.

*BC Incorp=broadcast incorporated; BC no Incorp=broadcast without incorporation; Seed Placed P at 25% of the given P_2O_5 rate.

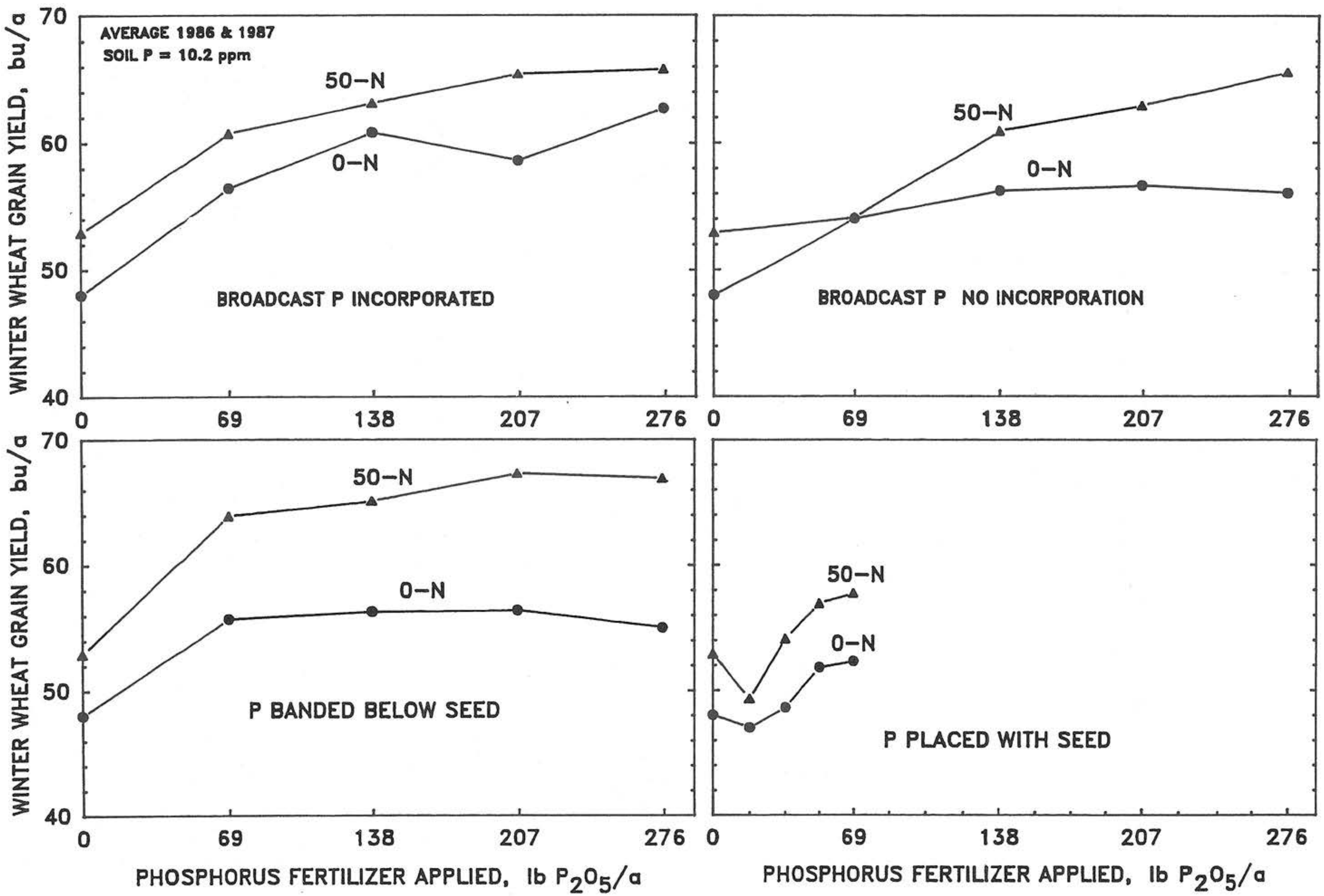

Figure 1. Winter wheat grain yield as a function of phosphorus fertilizer application rate and placement method.

Water supplies during both growing seasons were adequate, with 9.6 and 11.7 inches of precipitation from April until harvest for 1986 and 1987, respectively. Soil water measurements indicated very little soil water-use in 1986, with only 0.6 inch depleted from the 0 to 4 ft soil depth at harvest and 2.2 inches in 1987. This resulted in an average estimated total water use by the wheat crops in 1986 and 1987 of about 12.1 inches. Since soil water-use was not affected by fertility level, the water-use efficiency by winter wheat increased significantly as fertility level increased. Estimated water-use efficiency was 3.97 bu/inch for the check (zero N and P) treatment and 5.29 bu/inch for the 276 lb P_2O_5/acre plus 50 lb N/acre treatment. Phosphorus and N fertilization resulted in a significant increase in straw yield and number of heads/unit area at harvest (Table 1). Phosphorus placement significantly affected number of heads/acre, with seed-placed P treatments having the lowest number of heads/acre. Grain test weight was increased by P fertilization and decreased by N fertilization.

Nitrogen fertilization significantly increased grain protein from 12.0% without N to 12.9% with 50 lb N/acre in 1986 (1987 data not available). The effect of P placement on grain protein and P concentration was not significant. Grain protein decreased slightly as the rate of P application increased.

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USDA-ARS SOIL FERTILITY RESEARCH AT AKRON, COLORADO

The purpose here is to briefly outline the soil fertility research projects being conducted by USDA-ARS and cooperators at the Central Great Plains Research Station at Akron, Colorado.

PROJECT TITLE: Effect of N fertilization on water-use efficiency by winter wheat, barley, and corn in the Central Great Plains.
Objective: Determine the effects of N fertilization on crop yields, quality, and water-use efficiency with reduced tillage and annual cropping under dryland conditions.
Personnel: Ardell D. Halvorson and C. A. Reule

PROJECT TITLE: Effect of N source, placement, and rate on dryland winter wheat yields in a no-till system.
Objective: Determine the effectiveness of several N sources for use in no-till production systems and the best method of managing these N sources to obtain optimum economic returns.
Personnel: Ardell Halvorson, USDA-ARS, and Hunter Follett, CSU

PROJECT TITLE: Management of P fertilizer for dryland winter wheat in reduced tillage systems.
Objective: Determine most efficient method of P placement for optimum economic yields and the value of residual fertilizer P for future wheat production.
Personnel: Ardell Halvorson, USDA-ARS, Akron, CO and John Havlin, Kansas State University, Manhattan.

PROJECT TITLE: Crop rotation and N fertilization for efficient water use.
Objective: Determine the potential of producing economical dryland corn or sorghum yields following winter wheat in a wheat-corn-fallow rotation using reduced tillage systems. The N fertilizer requirements for optimum crop production and efficient water use are being evaluated.
Personnel: Ardell Halvorson, USDA-ARS.

PHOSPHORUS PLACEMENT IN DRYLAND WINTER WHEAT

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ABSTRACT

Phosphorus fertilizer placement under a no-till summer fallow dryland winter wheat (Triticum aestivium) production system in eastern Colorado was studied over a three year period. Surface broadcast (SB) and banded below the seed (BBS) methods and a new method, dribble over the seed row after closure (DOS) were evaluated for their effect on grain yield, P uptake, and N uptake. The DOS and BBS methods were superior to the SB method in P and N uptake, and grain yield. The DOS and BBS were equally effective placement methods. The mechanism of P uptake for DOS placement is a result of soil sloughing into the drill furrow which covers the fertilizer band and allows initiation of crown root growth into the covered fertilizer band. Dribbling fertilizer over the seed after row closure was found to be an efficient fertilizer placement technique, and wheat producers using deep furrow drills can expect to obtain maximum P fertilizer efficiency and yield response when employing this P placement system.

OBJECTIVES

Phosphorus is immobile in the soil, and therefore availability of P fertilizer is directly dependent on P fertilizer placement. Phosphorus fertilizer placement becomes particularly important in semi-arid regions such as the Central Great Plains where soil moisture is low at the surface for much of the growing season. With these ideas in mind, a project was conducted with the objective of comparing the efficiency of different P fertilizer placement methods on grain yield, and N and P uptake in a no-till summer fallow dryland winter wheat production system in eastern Colorado. The identification of a P placement method that could be easily adopted by wheat producers in the Central Great Plains was also an objective of the study.

MATERIALS AND METHODS

Phosphorus fertilizer placement studies were initiated in 1983 and conducted through three growing seasons. Experiments were conducted at Akron, Platner, Eads, Matheson, and Ft. Morgan, Colorado over the three year period. This paper reports data for the 1984-1985 and 1985-1986 growing seasons. Results from the 1983-1984 growing season were excluded, because high N rates resulting in seedling emergence damage confounded P placement results. Data were combined across location but not across years because significant year differences existed. The Eads and Platner sites were used during the 1984-1985 growing season, and the

Matheson and Ft. Morgan sites were used during the 1985-1986 growing season.

The experimental design at each site was a randomized complete block with four replications. Phosphorus placement treatments included were: (SB) preplant broadcast without incorporation; (BBS) banding the fertilizer one inch below the seed at planting; and (DOS) dribbling the fertilizer over the seed row after row closure at planting. Fertilizer rates included 30 and 60 lb N/A, and 0 and 30 lb P_2O_5/A. All placement treatments included the combination of N and P fertilizer rates in complete factorial combination. The effect of P rate on a particular placement included the effect of N rate (averaged across 30 and 60 lb N/A).

Planting and fertilizer application were accomplished with the planter/fertilizer applicator described by Westfall and Strohman (1987). The semi-dwarf and medium height hard red winter varieties "Vona" and "Sandy" were planted at 45 lb seed/A. Fertilizer was applied as 32-0-0 and 10-34-0 solutions. Plots were 6 ft wide by 56 ft long, and were planted on a 12 inch row center. The middle four rows of each plot were harvested with a plot combine.

Grain samples were collected at harvest for determination of N and P concentrations. Grain samples were digested using a sulfuric and hydrogen peroxide digestion procedure (Thomas, et al, 1967). Total N in the digested grain was determined colorimetrically using the indolphenol blue method (Keeney and Nelson, 1982) with a Technicon autoanalyzer. Total P in the digested grain was determined colorimetrically using a phosphovanadomolybdo complex procedure. Nitrogen and P grain uptake was calculated using N and P concentrations, and grain dry weights.

RESULTS AND DISCUSSION

Phosphorus application significantly increased grain yields both growing seasons (Table 1). Grain yields for banded placements (DOS and BBS) were superior to yields from broadcast treatments in both growing seasons. Both banded placements performed equally in producing grain both growing seasons. Grain yields were 9 and 11% greater during 1984-1985 and 1985-1986, respectively, with the DOS placement than with SB placement. Similar trends were observed for the BBS placement method.

A significant P rate by placement interaction on grain yield existed in 1984-1985, but not in 1985-1986 (Table 1). The significant interaction in 1984-1985 was due to no yield increase with P application for the surface broadcast treatment, while banded placements showed yield increases.

Phosphorus application caused a significant increase in N and P uptake in the grain both growing seasons (Table 1). The methods of application were significantly different both years with the BBS and DOS methods resulting in greater N and P uptake as compared to the SB treatment. Phosphorus uptake was 12% greater with DOS placement than with SB placement both years. Nitrogen uptake was 15 and 12% greater with DOS placement in 1984-1985 and 1985-1986, respectively, than with SB placement. Similar trends were observed for the BBS versus SB placement. No significant difference in N or P uptake existed between DOS and BBS placements either year (Table 1). A significant P rate by placement interaction on P uptake in grain occurred both growing seasons. The plants with the DOS and BBS placements showed a greater increase in P uptake at 30 as compared to 0 lb P_2O_5 than did plants with the SB placement.

Table 1. Effect of P rate and placement on grain yield, and N and P uptake by the grain at harvest (averaged across locations and N rates).

	1984-85			1985-86		
P rate	Yield	N	P205	Yield	N	P205
		uptake			uptake	
lb P205/A	bu/A	---(lb/A)---		bu/A	---(lb/A)---	
			Broadcast (SB)			
0	56	52	24.9	53	59	25.6
30	56	53	25.7	55	61	25.9
			Banded below seed (BBS)			
0	57	56	26.4	54	60	26.1
30	60	60	28.0	61	68	27.9
			Dribbled over seed (DOS)			
0	58	56	26.0	54	62	25.6
30	61	61	28.7	59	68	29.1
P rate X placement	**	***	***	NS	NS	**
Averages						
P rate						
0	57	55	25.8	54	60	25.8
30	58	58	27.5	58	66	27.6
Rate LSD	**	**	**	**	**	**
Broadcast1	56	53	25.7	55	61	25.9
Banded below seed[1]	60	60	28.0	60	68	27.9
Dribble over seed[1]	61	61	28.7	61	68	29.1
Placement LSD 0.05	3	3	1.5	2	4	1.3*

, * Indicates significance at 0.05 and 0.01 levels, respectively.
* LSD at the 0.10 level of significance.
1. To evaluate the effect of placement, the zero rate was deleted.

The results indicate that surface banding (DOS placement) is as effective in providing P to dryland winter wheat as subsurface banding (BBS placement). Other workers (Peterson, et al, 1981), have shown subsurface banding to be the most efficient method of P placement for winter wheat. Our results create a logical dilemma because surface banding of P would not be expected to be as efficient in providing P to the wheat plant as subsurface banding. Westfall, et al (1987) and McConnell, et al. (1986) have resolved the logical dilemma by hypothesizing a mechanism of P uptake by the wheat plant subsequent to surface banding. Their postulate of the mechanism of uptake is as follows, and is shown diagramatically in Figure 1. With time, soil sloughs into the seed row and covers the fertilizer band that was originally placed over the seed row at planting. As crown roots are initiated, they intercept the covered fertilizer band. The result is efficient uptake of N and P that equals subsurface banding.

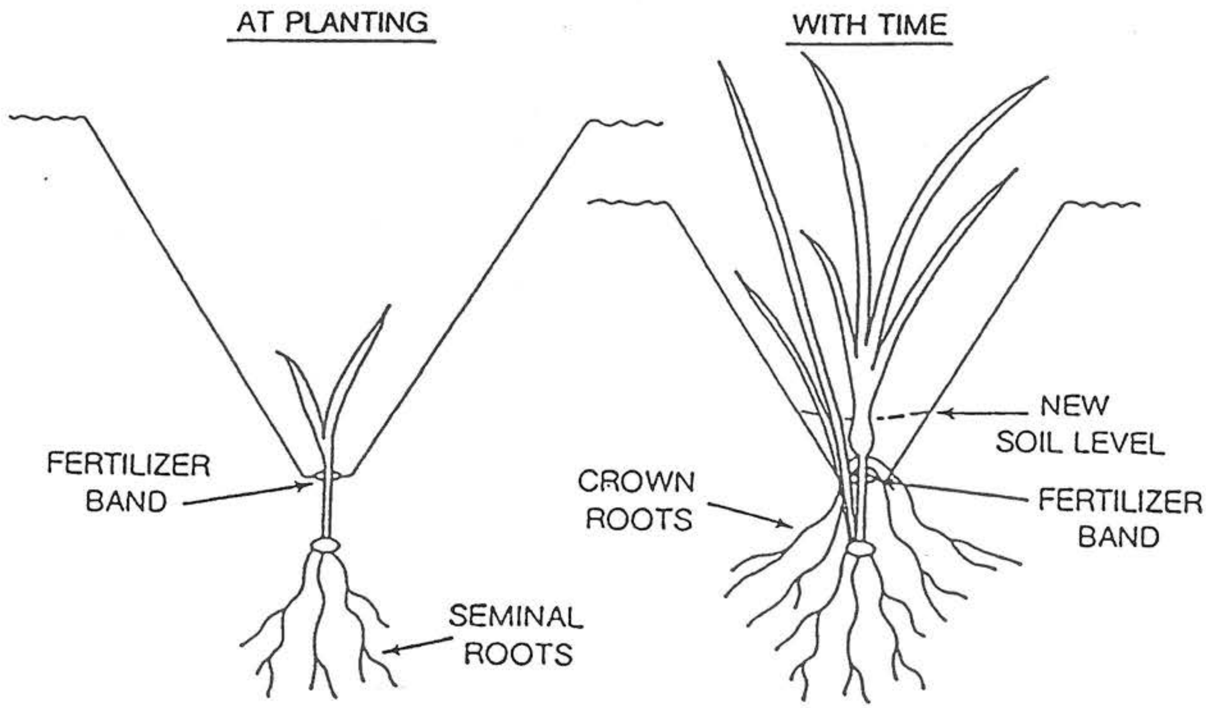

Figure 1. Soil surface configuration at planting and with time. Surface banded fertilizer becomes subsurface with time as soil sloughing into drill row occurs. (Westfall, et al, 1987)

It should be noted that the effectiveness of surface banding of fertilizer for dryland winter wheat is dependent on the type of planter/fertilizer applicator used. The type of planter/fertilizer applicator used in this study is commonly known as a "hoe" drill. Hoe drills are used extensively across the Great Plains where dry surface soil at planting must be thrown to the row middle to allow seed placement in moist soil. After seed placement, the moist soil is pressed firmly around the seed with a press wheel. This type of planter/fertilizer applicator is ideally suited for utilization of the DOS placement system. Implementation of the dribble over the seed placement system is easy to adopt and relatively inexpensive. The only equipment required is a squeeze pump (or a dribble applicator for dry fertilizer), tubing to direct the flow of fertilizer over the seed row, and a tank if liquid fertilizer is used.

CONCLUSIONS

Subsurface and surface banding of P and N fertilizers is superior to surface broadcast methods in dryland winter wheat systems. Surface banding of P and N fertilizers over the seed row after row closure is equal in providing P and N to wheat in dryland systems as compared to banding below the seed. Dryland winter wheat producers can expect maximum fertilizer efficiency and yield response when employing the dribble over the seed after row closure placement system (DOS). Equal effectiveness of the surface band method is largely due to soil and fertilizer band configurations resulting from the use of "hoe" type planter/fertilizer applicators. Conversion of existing equipment to the DOS placement system is easy to adopt and relatively inexpensive.

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FERTILIZER INDUSTRY OUTLOOK

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ABSTRACT

The outlook for North American fertilizer producers improved dramatically during 1987. A combination of events - a strengthening domestic market, significant improvements in the financial condition of American farmers and sharply improved exports - improved current demand and established a base for improved business conditions in the years ahead.

DISCUSSION

After five years of declining domestic demand, falling prices, huge industry-wide losses, and numerous bankruptcies, the North American fertilizer industry appears to have turned the corner. After significant reductions in capacity in some segments of the industry, a strong increase in demand last year depleted producer inventories and significantly increased annual shipping rates of the industry.

1986/87 REVIEW

In the export market, potash set the pace with a 35 percent increase in shipments by North American (U.S. and Canadian) producers. The 3.8 million short tons of K_2O exported in 1986/87 set a new record for North American potash export volume.

Exports of phosphate chemicals by U. S. producers increased 27 percent in 1986/87 from the preceding year. The tonnage recovery resulted from increased sales to a number of importing countries. However, increased volume sold to China was especially important in the tonnage rebound.

U. S. nitrogen exports were also sharply higher - up 31 percent from 1985/86 - but fell short of the tonnage exported in 1984/85 by a fairly wide margin.

Although domestic fertilizer consumption declined in 1986/87 for the third consecutive year, sales volume in the spring was quite strong and the more positive tone of the domestic market mirrored the growing optimism of American agriculture. Cropland acreage planted in 1987 in the United States was down about seven percent. However, with the first significant increase in application rates per acre in several years, there was only a modest two percent decline in fertilizer use.

AGRICULTURAL OUTLOOK

Although world consumption of grain has been trending steadily upward, the fortunes of U. S. agriculture have been steadily declining for several years. The 1985 Farm Bill incorporated several significant provisions to attempt to rectify this situation. Primary among the objectives of the Farm Bill were attempts to make U. S. agricultural commodities more competitive in the world market by reducing support prices and to protect and hopefully enhance farmer incomes.

While attempting to achieve these objectives, U. S. government administrators faced the pressing issue of excessive stocks of agricultural commodities. For several years, reductions in planted crop acreage have been implemented as part of U.S. farm policy administration. Finally, in 1987, the combined effects of a weakening U. S. dollar, export enhancement programs by the federal government and increasing offshore import demands combined to increase the volume of U. S. wheat, corn, and soybean exports. Both wheat and soybean stocks have been sharply reduced and substantial reductions in corn stocks have also been achieved.

At the same time, in 1987, several factors indicate that the financial stress in American agriculture has been substantially reduced. Farm land prices in most regions of the U. S. have stabilized or increased after several years of decline. Liabilities of American farmers have been reduced and farmer equity has been increased. U. S. cash farm income in 1987 is expected to reach a record level of 57 billion dollars. All of the above factors give strong indications that American agriculture has finally "turned around".

When forecasting U. S. fertilizer demand, it is now necessary to attempt to anticipate legislative and administrative changes in federal agricultural policy. In our opinion, inventories of wheat and soybeans have been reduced to near acceptable levels. Within a year, corn stocks will also be near acceptable levels. This assumption leads us to believe that agricultural policy administration will permit and even encourage increases in crop acreage to some extent in 1988 and to a much greater degree in 1989.

U. S. FERTILIZER DEMAND

Following three years of consecutive declines in fertilizer consumption, a modest one or two percent increase is expected in 1987/88. Crop acreage in the U. S. is not expected to change significantly in 1988. However, next year (in 1988/89), we expect significant increases in wheat and soybean acreage that should boost U. S. fertilizer consumption by about five percent. With continued increases in crop acreage in subsequent years, fertilizer consumption growth averaging about three percent is projected.

U. S. FERTILIZER EXPORTS

Phosphate chemical exports from the U. S. in 1987/88 are expected to slightly exceed the 1986/87 levels. The established trend towards importing phosphoric acid or other finished phosphate fertilizers instead of phosphate rock is expected to continue. Increases in phosphate chemical capacity in Africa will cause some erosion of the historic U. S. share of world trade, however, growth in U. S. exports of P_2O_5 is expected to increase at an average rate of two to three percent for the next several years.

In 1986/87, North American potash exports increased 35 percent to a new record high. That level is expected to be maintained in 1987/88 with two to three percent average growth expected over the next several years.

Nearly 50 percent of U. S. nitrogen exports are in the form of ammonium phosphates. Mowever, most of the fluctuation in nitrogen exports is caused by significant changes in exports of urea and anhydrous ammonia. On balance, little growth is expected in U. S. nitrogen exports. However, if the world nitrogen supply/demand balance tightens as some forecasters expect, U. S. nitrogen exports could increase in the early 1990's.

NORTH AMERICAN FERTILIZER SUPPLY/DEMAND

The U. S. phosphoric acid shipping rate is expected to reach 83 percent in 1987/88. At the present time there are no capacity expansion projects underway in the United States nor have any plans to invest in new capacity been announced.

With no increase in capacity and growth expected in both domestic use and export sales, the average U. S. phosphate industry operating rate is expected to reach the 90 percent level by the early 1990's. If world phosphate chemical capacity is adjusted to reflect the industry's capability to supply product, a shipping rate of 90 percent of supply capability will be reached in the early 1990's on a worldwide basis as well. Based on expansion plans, world phosphoric acid capacity will increase only three percent over the next five years.

The world's capability to produce potash has declined in the last two years due to water problems in mines in Canada and in the U.S.S.R. Over the next five years, supply capability of the world potash industry is expected to increase by 12 percent as modest supply expansions occur and assuming a return to production of the currently disabled mine in Canada.

In North America, the industry's shipping rate in 1988/89 is expected to fall to 76 percent and then slowly increase slowly over the next four years to about 83 percent of production potential. Both domestic and export demand for North American potash is expected to grow two to three percent per year. However, the industry's ability to produce is also expected to increase thus limiting the improvement in average industry operating rates.

U. S. ammonia capacity is not expected to increase during the foreseeable future. Average industry operating rates are expected to increase from about 85 percent currently to over 90 percent by 1993. However, the anticipated significant tightening of supply/demand worldwide during the next five years could significantly increase the demand for U. S. nitrogen products in export markets in the early 1990's.

In summary, most expert observers sense a growing optimism within the North American fertilizer industry that the long-awaited agricultural recovery is at hand. Prices are stronger and volumes are higher in most major products.

Lessons learned in times of adversity may well have prepared this highly competitive industry to work itself out of the recent difficulties. Experts remain cautious that such a turnaround will not happen overnight.

Commenting on the signs of a recovery in the fertilizer business as the proverbial light at the end of the tunnel, Billie B. Turner, president of IMC Fertilizer Group, Inc., in a presentation on the North American fertilizer situation, said, "The light indeed is getting brighter, and it certainly beats cursing the darkness."

UNIVERSITY/INDUSTRY RELATIONS

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In the paper titled "Industry-University Relationships and the Land-Grant System" (Ref. 1), the authors point out that the nineteenth century legislation that established the Land Grant University and the State Agricultural Experiment Stations did not give any attention to agribusiness or consider that it would become a major client of the system. It also did not take into account the possibility that technology would become a marketable commodity that the largest and most dynamic farmers would be willing to buy from specialized private management consulting services.

With this in mind, it is understandable why we have difficulty dealing with the subject University/Industry Relations. The relations, as we know them, are non-structured and non-governed. They have evolved with agribusiness and are maintained on an individual basis. Each university has developed its own policy in regards to relations with agribusiness clients, a policy that sometimes changes when there is a change in policy makers.

The segment of agribusiness that represents the fertilizer industry has no set policy for relations with university. Relations are established on the basis of mutual interest and values to business. In most cases, a relation between a university and industry is maintained by three or four individuals. Personalities and leadership play a major role in determining the strength of the relationship. Because of the role that individuals play, relations can change when one individual retires or transfers to another assignment or location.

The non-governed relationship between university and industry has served both adequately over the years without major conflict. However, the system does have its critics and they have voiced concern about the influence that industry has on university. Until recently, the continual demands for technology by a growing, expanding agricultural production system has blocked out the critical voices but agriculture crop production in this country has stopped growing and expanding. And, there is evidence that the existing relationships between university and industry is sailing into some uncharted waters.

The supply of products and services that agribusiness markets to crop producers exceeds the demand and some would have us believe that we have more crop yield enhancement technology that we need. The public perception is that we have won the war against starvation and it is time to mothball part of the U.S. crop production system. In fact, over 70 million acres of cropland were mothballed in 1987, some 23 million under a ten year conservation reserve contract between Federal Government and crop producers. More cropland is scheduled for mothball in 1989 and 1990.

This is a traumatic turn of events in itself for both university and industry but the side effects are even more difficult for most of us to comprehend. Some members of our society have singled out university and a greedy industry as being responsible for excess crop production and the resulting financial stress that has confronted crop producers. The yield enhancement technology that we have been so proud of is sometimes cited as an irresponsible effort to increase the use of fertilizer and chemicals without concern for their effect on the environment.

On September 29, 1987, the Omaha World-Herald newspaper contained an article with the headline "Farmer-Conservationist Urges Ban on Chemicals". The article stated that Bob Warrick, a leading Nebraska farmer-conservationist has proposed a complete ban on the use of commercial fertilizers, pesticides and herbicides in commercial agricultural production. Mr. Warrick said that a ban would solve the problem of crop surplus and save millions of tax dollars to store surplus crops. He also said that it would end what he called the worsening contamination of underground water supplies in Nebraska.

In summary, Mr. Warrick was proposing a close out of the fertilizer-ag chemicals industry. It would be interesting to see a total economic impact analysis on the combined result of the Federal Government plan to mothball up to 100 million acres of cropland (45 million conservation reserve-ten year contract) and Mr. Warrick's proposed ban on use of fertilizer and ag chemicals. There is not much question that a ban on use of fertilizer would sharply reduce corn production. Dr. Darrell Nelson, Department Head, Department of Agronomy, University of Nebraska, Lincoln had a letter published in the December 1987 issue of Agrichemical Age magazine covering the subject of Soil Test Comparison Studies. Using the data presented in the letter and averaging yields across sites, the long-term, UNL fertilized, irrigated corn yield average was 161 bushels per acre. The yield average for non-fertilized corn on the same sites was 82 bushels per acre, a difference of 49 percent.

Most of us have been very comfortable using data like that obtained by the University of Nebraska to show why we recommend the use of commercial fertilizer. And, we were not well prepared to deal with critics who say that it clearly indicates that fertilizer is the principal cause of grain surplus. Mr. Warrick would probably tell us that if irrigated corn yield was only 82 bushels per acre, there would not be a surplus of corn and cash price would be high enough to reduce the need for Government supports. He might also say that there would be less nitrate nitrogen in Nebraska ground water if farmers did not apply fertilizer nitrogen.

It is not clear at this time how universities and the fertilizer industry will respond to public and political pressures that are building against them. The initial changes to date are merely adjustments made necessary by shortfalls in revenue. Many universities have had a substantial cut in federal and state funds and industry has been forced to cope with losses rather than profits. Management planners and policy makers are just beginning to address the major issues of a world capacity to produce surplus quantities of food and fiber and environmental contamination caused by fertilizers and chemicals being applied to agricultural cropland.

In the past, university-industry relations have been built around a foundation of mutual support. Industry has relied on university to provide a flow of technology that it could use to profitable advantage. University, in turn, has relied on industry's political support for its requests for public funds plus contributions of private funds. If an abundant supply of high-quality agricultural products can be used as criteria for evaluating the effectiveness of this relationship, it would have to be rated as highly successful.

The question that we need to ask is how will the relation be affected if a university moves away from yield enhancement research emphasis to a sustainable agriculture research emphasis. The fertilizer industry is on record as being wary of sustainable agriculture projects. It does not recognize them as being projects that will generate profit opportunities. At this time, industry does not indicate that it will voluntarily support a university that places sustainable agriculture high on the priority list. It is also unsupportive of low-input projects that have been announced by some universities.

During recent months, the industry has been busy adjusting to the effects of the 1985 Food Security Act and the decline in fertilizer consumption caused by reduced acreage of the crops that represent a major portion of the fertilizer market. The Fertilizer Institute (TFI), which represents the fertilizer industry in the political arena, has concentrated most of its activity on attempting to influence Federal Government Farm Programs that affect fertilizer consumption. In the future, we can anticipate that TFI may give more attention to state government and university activities that threaten to reduce use of fertilizer.

The course of action industry takes in reaction to any threat nearly always involves money. Money is a powerful tool that quickly gets the attention of Government. In 1987, the Chief Executive Officer of ConAgra forced a major change in Nebraska's corporate tax law by threatening to build a new food processing research lab in another state and move ConAgra's corporate headquarters out of Nebraska. Arcadian Corporation won a major concession from Nebraska's Omaha Public Power District by threatening to close down its LaPlatte, Nebraska nitrogen fertilizer plant unless it received a better rate on electricity. Arcadian is OPPD's biggest customer and loss of the Arcadian account would force OPPD to raise rates to all other customers. There are many other examples in public records of how industry uses money successfully to cause or prevent actions by Government and public funded institutions.

Although the fertilizer industry may not realize it yet, it is probably better organized now to battle a threat than at any time in recent history. Due to consolidation, the supply of commercial fertilizer in the United States is financially controlled by a fairly small number of companies. Most people are aware of the consolidation that has taken place at the basic producer level but few realize that large blocks of the retail supply system is now controlled by a relatively small group of companies that purchase product and channel it through a multiple number of retail outlets. A basic producer, such as Arcadian Corporation, may have an impressive customer list in a particular state but a check of the sales record can show that up to 70% of the Corporation's total product sales in that state is moving through six to ten large tonnage buyers.

The highly competitive nature of the business has kept this handful of companies from recognizing the force they could be in a collective effort but eventually they will form a united structure to deal with common interest issues. At the present time, they work through state associations on an individual basis. Because many of them operate in more than one state, they may see an advantage to organizing regional associations in the future. All it will take to pull them together is a major common cause and a strong leader. Two unique aspects of this group of large volume suppliers to the retail market are that they do not own basic fertilizer production facilities and they will purchase products from either foreign or domestic producers. Buying decisions are based almost solely on price.

It is very hard to project how this new emerging organizational structure in the fertilizer industry will impact on university-industry relations. The fact that industry now relies heavily on university for the agronomy research and education it needs in support of sales, and the fact that industry needs university for technical support in dealing with the environmental issues almost assure that industry will continue to work with university. There is some indication that industry will be selective in building a relationship. Some predict that industry will develop a close relationship with those universities that have a strong aggressive agronomy department and ignore those that do not. An end result of this might be that a few universities would have the financial support needed to build and maintain a very active agronomy staff while others may have difficulty sustaining their current level of activity.

In summary, we can conclude that the need for technical support by industry will insure the continuation of a relationship with some universities. University policy and direction of emphasis will determine which universities will have the best relation with industry. In this presentation, only the fertilizer industry has been considered. There are many other components of agribusiness that have a need to maintain a relation with university. A university that may not have a good relation with the fertilizer industry could work closely with industry in plant breeding, weed science, entomology, or other disciplines. It would be logical to assume that each university will place emphasis on its existing strengths and attract support from that segment of industry that has a business interest in that discipline. It would also be logical to assume that over a period of years, expertise in a particular discipline could become more concentrated than it is today. The need to have an integrated approach to crop production research could draw several disciplines together and concentrate research talent to the point that some Land Grant universities may have minimal influence on crop production technology in the future.

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LONG-TERM TILLAGE EFFECTS ON SOIL TEST LEVELS

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ABSTRACT

Research was conducted to determine long-term effects of tillage on soil fertility. Our objective was to determine whether crop residue placement caused by differences in tillage would result in changes in levels of plant available nutrients and other metals in the soil. After 16 years of cultivation with plow, stubble mulch, and no-till treatments, soil test values (NH_4HCO_3-DTPA extract) were obtained for samples from the 0- to 5-, 5- to 10-, 10- to 20-cm depths. Except at the lower depths, plow tillage, as compared to no-till or stubble mulch, decreased levels of soil organic matter and extractable K, Zn, Cu, and Pb, while extractable Ni was decreased at only one site and extractable P, Fe, Mn and Cd were decreased at the other site. Fertilization with N decreased soil pH and extractable inorganic P and Zn levels but increased extractable organic-P, Fe, Mn, Pb, Cd, and Ni in the 0- to 5-cm depth. This study shows that the adoption of no-till, compared to stubble-mulch or plow-tillage, maintains fertility status of topsoil nearer to that of native prairie soil. Accumulation of crop residue and maintenance of soil organic matter levels appear to be key factors in sustaining soil fertility status of Great Plains soils.

OBJECTIVES

Tillage systems influence soil properties, including availability of many plant nutrients. Consequences of widespread adoption of reduced and/or no-tillage on soil nutrient status and chemical properties in Great Plains soils is not adequately understood.

The study reported here was conducted to determine long-term effects (16 years) of plow-, stubble mulch-, and no-tillage on soil fertility status of a wheat-fallow rotation in the Great Plains as determined by standardized soil-testing procedures.

METHODS

Details for experimental conduct are reported by Fenster and Peterson (1979) and Lamb, et al. (1985). Soil samples were taken in April 1986 (fallow year) from all plots at depths of 0- to 5-, 5- to 10-, and 10- to 20-cm, air dried, and ground to pass a 2 mm stainless-steel sieve. Soils were extracted with NH_4HCO_3-DTPA extracting solution (AB-DTPA) and available K, Zn, Fe, Mn, Cu, Cd, Pb, and Ni were determined (Soltanpour et al., 1982). Colorimetric determination of available P (soil-P) was made (Olsen and Sommers, 1982). The same extract was analyzed by ICP-AES to obtain total extractable P (total-P). Subtraction of the colormetrically determined P on the AB-DTPA extract from the total-P provided an estimate of extractable organic-P.

RESULTS AND DISCUSSION

Soil pH:

Nitrogen fertilization at the reseeded sod site significantly decreased soil pH in the 0- to 5-cm depth (Table 1). The same effect also occurred at the 5- to 10-cm depth (significant at p = 0.10), but not at the 10- to 20-cm depth. No-till and stubble mulch treatments had lower soil pH than did the plow treatment at the 0- to 5-cm depth and only at the reseeded sod site. At the native sod site, soil pH was significantly lower on cropped treatments compared to native grass (regardless of type of tillage) at the 5- to 10-cm and 10- to 20-cm depths. This same relationship also existed for the 0- to 5-cm depth, at the 0.10 rather than 0.05 level of probability. It may be concluded that the wheat-fallow cropping system itself caused the lowering of soil pH because differences observed were primarily between the sod treatment and all other treatments (Table 1) and because all depths were affected.

Phosphorus:

Extractable P levels (soil, total, or organic) at the native sod site were 50 to 75% greater than those observed at the reseeded sod site (Table 1). This was an expected outcome, since the native sod site is also much higher in O.M. and has a shorter cultivation history than the reseeded site.

Tillage treatment had no measurable effect on soil-P at the native sod site. By comparing effects of tillage on total- and organic-P in the 0- to 5-cm layer, one can see the development of a pattern. Total-P decreased significantly from sod to plow in order of increased soil disturbance and decreased soil cover. The same trend was also observed for organic-P (significant at P = 0.10).

A tillage by N fertilizer interaction (significant at P = 0.10) was observed for soil-P in the upper soil layers at the reseeded sod site. Declines of P were associated with N fertilization and moldboard plowing. No-till has the highest soil-P levels (significant at P = 0.05) in the 0- to 5-cm soil layer. Since fertilizer P has been applied to this site whenever soil-P tests indicated a need, one would expect the undisturbed no-till treatment to accumulate P in the surface relative to stubble mulch and plow treatments. In addition, total-P and organic-P were higher (P = 0.10) with N fertilization in the 0- to 5-cm depths than without N fertilization while the reverse occurred for soil P. Soil-P and total-P were significantly lower with N fertilization than without in the 5- to 10-cm depth and no significant differences were observed at the 10- to 20-cm depths. Thus, there appears to have been an accumulation of total and organic-P in the 0- to 5-cm depth and a depletion of soil- and total-P in the 5- to 10-cm depth resulting from

N-fertilization.

Potassium:

Stratification of extractable K with depth was observed at both sites (Table 1). Extractable K levels in the 0- to 5-cm depth were significantly higher for no-till and stubble-mulch treatments than for plow treatment at both sites. They were also significantly higher for the 5- to 10-cm depth at the native sod site. Fertilizer N had no significant effect upon extractable K levels. Extractable K accumulation in no-till surface soil layers probably resulted from release of K from crop residues which were not incorporated.

The native sod treatment has not accumulated as much K in the 0- to 5-cm layer as the no-till wheat treatment. The weight of K ha^{-1} based on soil density measurements shows the real difference is even larger. These results indicate that wheat plants under no-till cycle larger amounts of K to the surface than does native sod.

Zinc:

Zinc usually is not deficient for dryland wheat production in the Great Plains. In these studies tillage significantly affected extractable Zn in the 0- to 5-cm depth at the native sod site ($P = 0.05$) and the reseeded sod site ($P = 0.10$) (Table 1). Fertilization with N decreased extractable soil Zn in the 0- to 5-cm layer but not at deeper depths. Extractable Zn was 2 to 4 times greater at the native sod site and varied much more with depth compared to the reseeded site. Soil O.M. was about twice as great at the native sod site. The stratification of Zn at the native sod site may be due to the greater amount of Zn available for redistribution in the soil compared to soil at the reseeded sod site.

Iron, Manganese, Copper:

Usually Fe, Mn, and Cu are not deficient for dryland wheat in the Great Plains. All depths sampled at both sites (Table 1) in this study were in the adequate range for dryland crops. However, reporting the effect of long-term tillage on these nutrients may provide insights for other parts of the USA or for particular soil conditions in the Great Plains. At the native sod site, only extractable Cu was significantly decreased in the 0- to 5-cm depth by plow and stubble-mulch tillage compared to no-till and the sod treatment. The plow treatment was significantly higher in extractable Mn than the no-till treatment in the 10- to 20-cm depth, likely as a result of mixing of the soil layers with plowing. At the reseeded sod site, plow tillage significantly decreased extractable levels of Fe, Mn, and Cu at the 0- to 5-cm depth compared to no-tillage. Stubble mulch-tillage increased extractable Mn above no-till in the 5- to 10-cm depth at the reseeded sod site.

Fertilization with N (reseeded sod site only) significantly increased extractable Fe and Mn, but not Cu in the 0- to 5-cm depth. This effect in the 0- to 5-cm depth is associated with the significant decrease in soil pH that occurred with N fertilization. Extractable Mn was increased with N fertilization for the 5- to 10-cm depth while extractable Cu levels were decreased in the 10- to 20-cm depth. As indicated by a significant interaction between tillage and N-fertilizer, the largest effect on extractable Mn occurred in the 0- to 5-cm depth for the no-till treatment.

Lead, Cadmium, Nickel:

Contamination of soils and plants with Pb, Cd, and Ni, as well as other toxic metals, is reported for urban areas, near metal smelters, along roadsides, and in association with heavy industry. The remoteness of the experimental sites in this study allows evaluation of tillage and N fertilization on affects on these metals at essentially baseline levels.

Data in Table 1 indicates generally decreasing levels of extractable Pb, Cd, and Ni with increasing depth at both sites. However, levels of extractable Ni in the 10- to 20-cm depth at the reseeded sod site were higher than observed in the 5- to 10-cm depth and may be related to differences in parent material characteristics between the native and the reseeded sod site. Plow-tillage significantly decreased Pb and Ni at the native-sod site in the 0- to 5-cm and 5- to 10-cm depths compared to no-till, but increased Ni in the 10- to 20-cm depth. Extractable Pb and Cd were similarly decreased by plow tillage in the 0- to 5-cm depth as was Pb in the 5- to 10-cm depth at the reseeded sod site. Because extractable Pb, Cd, and Ni in no-till plots were not significantly different from those native grass plots at the native-sod site, long-term use of no-tillage compared to native grass is not resulting in accumulation of extractable Pb, Cd, and Ni into surface soil layers.

CONCLUSION

Results from this study show that changes in soil nutrient status can be expected if reduced tillage practices are adopted in the Great Plains. No-tillage, compared to plow-tillage, maintains fertility status of topsoil nearer to that of soil under native grass. Accumulation of crop residues at the soil surface and the associated nutrient cycling appear to be key factors in enhanced soil fertility status of Great Plains soils.

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Table 1. Soil pH, organic matter content and extractable nutrient and metal content at three soil depths as affected by tillage or tillage and fertilizer N at two sites near Sidney, NE.

NATIVE SOD

TILLAGE	DEPTH cm	FERT- kg N/ha	pH 1:1	O.M. g/kg	Soil-P	Tot-P	Org-P	K	ZN	FE mg/kg	MN	CU	PB	CD	NI
Sod	0-5	0	7.1	53.0	13.7	21.7	8.0	835	2.0	11.2	8.0	2.2	3.8	0.17	0.87
No-till	0-5	0	6.9	43.3	13.5	20.1	6.6	968	1.6	13.2	9.4	2.2	3.7	0.19	0.93
Stubble-	0-5	0	6.9	37.3	11.8	17.5	5.7	888	1.3	13.1	8.3	1.8	3.1	0.17	0.77
Plow	0-5	0	6.9	30.3	12.3	17.2	4.9	712	1.0	11.5	7.2	1.7	2.3	0.15	0.76
		LSD .05	†	5.0	NS	2.3	†	92	0.3	NS	NS	0.4	0.7	NS	0.13
Sod	5-10	0	7.2	43.7	10.2	16.0	5.8	728	1.3	11.5	7.5	2.0	3.2	0.17	0.69
No-till	5-10	0	6.9	33.3	9.4	15.6	6.2	795	1.4	13.4	8.3	2.1	3.4	0.18	0.86
Stubble-	5-10	0	6.9	35.0	10.1	15.7	5.9	749	1.3	11.4	7.3	2.0	3.2	0.18	0.79
Plow	5-10	0	7.0	28.7	10.1	15.5	5.4	678	1.1	10.9	6.3	1.9	2.6	0.15	0.74
		LSD .05	0.2	4.6	NS	NS	NS	71	NS	NS	NS	NS	0.4	NS	0.10
Sod	10-20	0	7.4	25.7	7.8	12.1	4.3	481	0.6	10.2	5.5	1.6	1.7	0.11	0.60
No-till	10-20	0	7.2	23.3	7.6	12.0	4.4	505	0.6	11.6	4.7	1.6	1.7	0.11	0.62
Stubble-	10-20	0	7.2	22.3	7.8	12.4	4.6	493	0.6	12.3	4.8	1.6	1.6	0.09	0.70
Plow	10-20	0	7.1	25.0	9.4	14.3	4.9	550	0.8	11.1	5.9	1.7	2.1	0.12	0.74
		LSD .05	0.2	NS	NS	NS	NS	NS	NS	NS	0.8	NS	NS	NS	0.06

RESEEDED SOD

TILLAGE	DEPTH cm	FERT- kg N/ha	pH 1:1	O.M. g/kg	Soil-P	Tot-P	Org-P	K	ZN	FE mg/kg	MN	CU	PB	CD	NI
No-till	0-5	0	6.7	27.0	9.0	14.2	5.2	647	0.6	11.0	3.6	1.8	2.2	0.09	0.72
Stubble-	0-5	0	6.9	24.5	8.1	12.4	4.3	614	0.4	8.6	3.1	1.5	1.8	0.08	0.64
Plow	0-5	0	7.2	18.3	8.7	12.3	3.6	568	0.4	7.6	2.8	1.6	1.6	0.08	0.68
No-till	0-5	45	6.2	30.5	9.8	16.0	6.2	639	0.5	16.6	6.6	1.8	2.4	0.11	0.81
Stubble-	0-5	45	6.4	25.5	6.6	12.5	5.9	671	0.4	12.6	4.5	1.6	2.1	0.10	0.82
Plow	0-5	45	7.1	18.5	7.1	10.6	3.5	587	0.4	9.9	3.5	1.6	1.6	0.08	0.75
		LSD .05	0.4	4.0	1.0	0.8	0.6	46	†	3.7	1.0	0.2	0.2	0.01	NS
		LSD .05	0.2	1.5	†	†	†	NS	0.1	1.7	0.6	NS	0.1	0.01	0.06
		LSD .05	NS	NS	†	1.3	NS	NS	NS	NS	0.8	NS	0.1	0.01	NS
No-till	5-10	0	7.0	18.0	7.1	10.5	3.5	558	0.4	10.0	2.2	1.6	1.8	0.08	0.61
Stubble-	5-10	0	7.0	18.5	7.8	11.5	3.7	548	0.5	10.2	2.6	1.6	1.9	0.08	0.67
Plow	5-10	0	7.3	18.5	7.3	10.7	3.4	538	0.5	8.2	2.3	1.6	1.7	0.07	0.59
No-till	5-10	45	7.0	18.3	7.1	10.5	3.4	556	0.4	10.4	2.2	1.6	1.7	0.08	0.61
Stubble-	5-10	45	6.7	18.5	5.6	9.6	4.0	563	0.4	11.4	3.0	1.5	1.9	0.07	0.75
Plow	5-10	45	7.1	18.5	5.3	9.0	3.7	549	0.4	9.1	2.6	1.6	1.7	0.07	0.70
		LSD .05	NS	NS	NS	NS	NS	NS	NS	1.4	0.4	NS	0.1	NS	NS
		LSD .05	†	NS	0.8	0.9	NS	NS	NS	NS	0.2	NS	NS	NS	0.04
		LSD .05	NS	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	†
No-till	10-20	0	7.2	16.7	4.3	7.8	3.5	503	0.4	10.6	3.5	1.3	1.7	0.06	0.78
Stubble-	10-20	0	7.0	15.8	3.2	6.6	3.4	504	0.4	10.2	3.4	1.3	1.7	0.06	0.86
Plow	10-20	0	7.4	17.0	4.2	7.6	3.4	513	0.5	8.8	3.8	1.4	1.6	0.06	0.76
No-till	10-20	45	7.0	17.0	3.8	7.4	3.6	515	0.4	10.6	3.6	1.2	1.7	0.06	0.78
Stubble-	10-20	45	7.1	15.3	2.2	5.6	3.4	528	0.4	8.0	3.4	1.2	1.6	0.05	0.83
Plow	10-20	45	7.2	16.5	3.6	7.1	3.5	511	0.4	9.1	3.9	1.3	1.6	0.06	0.82
Tillage		LSD .05	NS	NS	†	†	NS	NS	NS	†	NS	NS	NS	NS	NS
Fert-N		LSD .05	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.1	NS	NS	NS
Till*Fert		LSD .05	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† = Signigicant at p = 0.10
NS = Not Significant

FALL AND SPRING N FERTILIZATION OF DRYLAND WINTER WHEAT

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ABSTRACT

Delaying nitrogen (N) applications for winter wheat (Triticum aestivum L.) until spring gives producers more management flexibility. The primary objective of this study was to develop a spring N recommendation. The development of a spring N recommendation model allowed comparison of fall and spring N application dates. A split plot treatment arrangement was used with main and sub plots represented by fall and spring applied N, respectively. Fall and spring applied N were applied at the rate of 0, 20, 40, and 60 lb N/acre on dryland winter wheat in eastern Colorado. Spring applied N resulted in greater grain yields than fall or split applied N, regardless of N rate. Fall applied N requires 133, 118, and 103 % more N than equivalent grain yields obtained with 20, 40, and 60 lb N/acre spring applied, respectively. Fertilizer use efficiency for N rates of 20, 40, and 60 lb N/acre was 5.3, 5.3, and 5.4 lb N/bu with fall applied N and 4.0, 4.5, and 5.2 lb N/bu with spring applied N, respectively. Spring applied N was superior to fall applied N with respect to winter wheat grain yields.

INTRODUCTION

Winter wheat grain producers in eastern Colorado experience a high rate of crop failure (10-40%) due to adverse weather conditions. The opportunity in the spring to evaluate stored soil moisture and wheat stand, two important factors controlling grain yields, allows the producer to asses N needs.

Research by Goos (1980) and more recently Russell et al. (1987) conducted in eastern Colorado, concluded spring applied N to dryland winter wheat was equal or superior to fall applied N in increasing grain yields. Based on the previous researchers' conclusions, this stimulated research to develop a spring N recommendation model for winter wheat grain producers in eastern Colorado. The design of the experiment to calibrate soil and plant tissue analysis with grain yields supplements the research by Goos (1980) and Russell et al. (1987) in comparing fall and spring N application dates. The objective of this paper is to supplement and verify the work by Goos (1980) and Russell et al. (1987).

MATERIALS AND METHODS

A randomized complete block split plot design with four replications was used. Nitrogen fertilizer was fall applied to the main plots at rates of 0, 20, 40, and 60 lb N/acre. Nitrogen fertilizer was spring applied to the subplots at rates of 0, 20, 40, and 60 lb N/acre. Phosphorus (P) was applied to all the experimental sites at the rate of 60 lb P_2O_5/acre. The N fertilizer was applied as 32% urea-ammonium nitrate (UAN) or as NH_4NO_3. The semi-dwarf cultivar Vona was planted at all sites at 45 lb seed/acre.

This study was conducted for 3 years (1985-87) with grain yield measurements for nineteen locations. Thirteen of the nineteen locations responded to N fertilization. The lack of response to N at the six locations was due to high residual soil NO_3, drought, or insect damage. The results from the six locations which did not respond to N fertilization will not be used in comparing fall to spring applied N. Regression equations were developed for each N responsive location to predict grain yields at given fall and spring N rates. The predicted grain yields at a given fall and spring N rate were then averaged across all thirteen locations.

RESULTS AND DISCUSSION

The predicted grain yields are shown in Table 1 which were used to develop a regression equation describing the grain yield response surface as a function of fall and spring N rates. The components of the regression equation were:

$$\text{Yield} = 47.7 + 0.191*(\text{Fall}) + 0.281*(\text{Spring}) - 0.0000859*(\text{Fall})^2 - 0.00149*(\text{Spring})^2 - 0.00167*(\text{Fall by Spring})$$

The grain yields shown in Table 1 have been rounded to the nearest bushel; however, the regression equation which was developed was based on grain yield averages rounded to the nearest tenth of a bushel. Grain yields responded to fall and spring applied N quadratically with a significant interaction between fall and spring applied N. This model accounted for 99 % of the grain yield variation and all coefficients were significant at the .001 level. The negative interaction of the regression model implies that the grain yield attributable to N applied in a given season was decreased by N applied the other season.

Table 1. Predicted grain yields averaged over 13 locations as influenced by fall and spring N rates (1985-87).

Fall N	Spring N (lb/acre) 0	20	40	60
(lb/acre)	Grain Yield (bu/acre)			
0	48	52	57	59
20	52	56	59	61
40	55	59	61	63
60	59	62	64	64

Wheat yields with fall applied N (none in spring) and spring applied N (none in fall) are presented graphically in Figure 1. Grain yield response to fall applied N approaches a linear response while spring applied N has more curvature and exhibits a more typical quadratic response curve. Spring applied N results in greater grain yields than fall applied N regardless of the N rate used. Split application of N would result in predicted grain yields between the spring and fall response curves. The graph indicates that in no case would split application of fall and spring N give as great a yield as the same total rate applied only in the spring. However, on soils more N deficient than the soils studied, one perhaps would benefit from moderate application rates of fall N to insure good stand establishment and tillering.

The regression equation was used to calculate rates of fall applied N required to produce the same yield as a given rate of spring applied N. The calculated rates of fall applied N comparable to 20, 40, and 60 lb N/acre of spring applied N are given in Table 2. These rates were then used to calculate ratios of pounds of fall N to pounds of spring N required for given yield (Table 2). The resulting ratio is regarded as the relative efficiency of fall applied N. The ratios are graphed in Figure 2.

Tables 2. Rates of fall applied nitrogen required to produce the same wheat yields as given rates of spring applied nitrogen and relative efficiency of fall applied nitrogen.

Spring N (lb/acre)			Relative Efficiency (Fall N)/(Spring N)		
20	40	60	20	40	60
Equivalent Amounts of Fall N (lb/acre)					
27	47	62	1.3	1.2	1.0

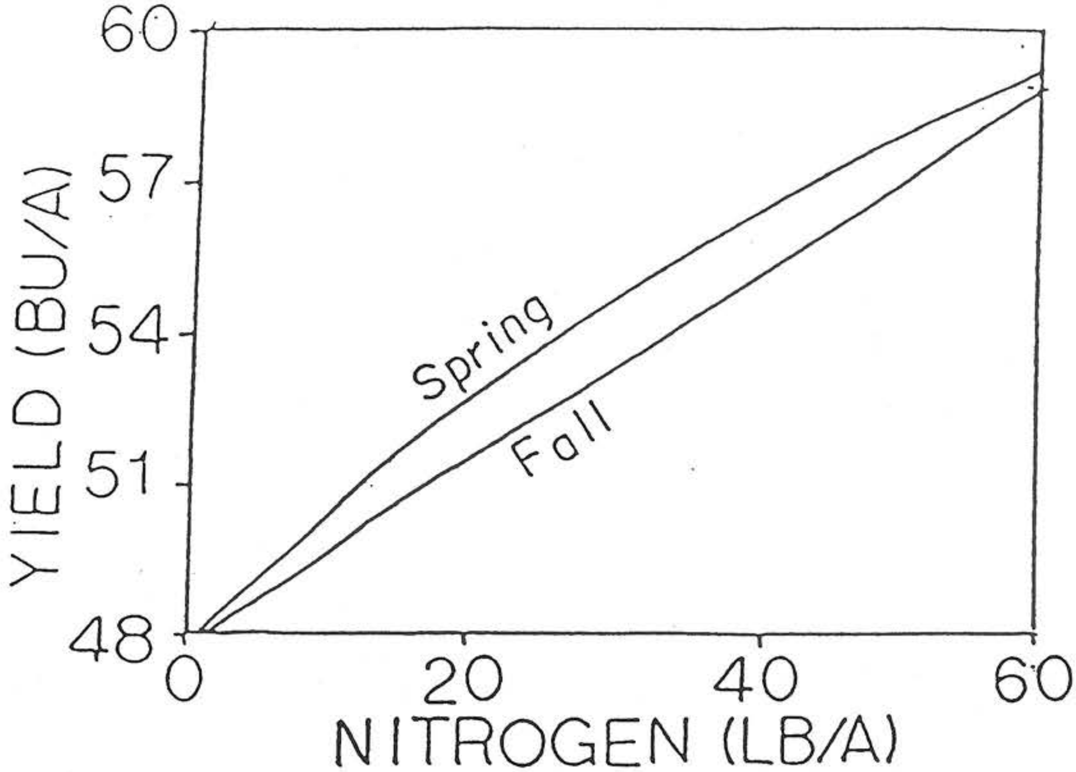

Figure 1. Predicted wheat yields as affected by time of nitrogen application (1985-87).

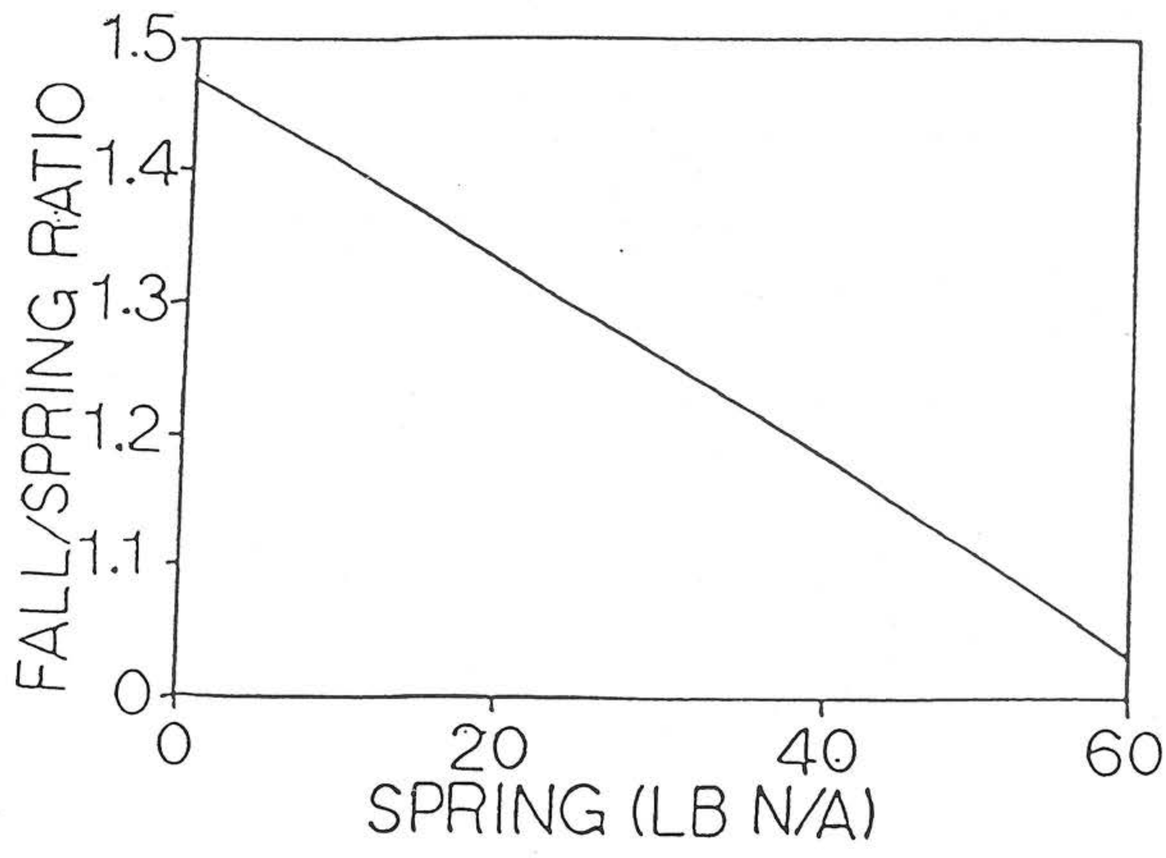

Figure 2. Pounds of fall N equivalent to spring N as a function of spring N rate.

The relative efficiency of fall applied N ranged from 1.5 to 1.0 as the spring N rate increased from 1 to 60 lb N/acre, respectively. For example, 1.3 lb of fall applied N is equivalent to one lb of spring N applied at the 20 lb N/acre rate. The line has a slight curvature which is dependent on the grain yield difference between fall and spring applied N (Figure 1). Fall applied N is more equivalent to spring applied N at higher N rates. This would be expected due to grain yield leveling off at higher N rates. Fall applied N was much less equivalent than spring applied N at lower N rates.

The relationship between fertilizer use efficiency (FUE) and N rate for fall and spring is shown in Figure 3. Fertilizer use efficiency was calculated as follows:

$$FUE = (Y_i - Y_o)/N_i$$

Where Y equals grain yield with no N applied and Y_1 is the grain yield as a result of N_i units of N. Spring applied N FUE decreased dramatically as the N rate increased. Fall applied N resulted in small FUE increases as N rates increased. FUE increased 5.3, 5.3, and 5.48 lb N/bu with fall applied N and 4.0, 4.5, and 5.2 lb N/bu with spring applied N as the N rate increased 20, 40, and 60 lb N/acre, respectively. No N rate resulted in fall and spring having equivalent FUE. Spring applied N results in the best FUE.

Spring applied N appears to be a better application date than fall applied N based on grain yields, relative efficiency, and FUE; however, economic aspects need to be considered. Anhydrous ammonia, liquid, and dry sources of N can be applied both in the fall or spring, but the cost and mode of application varies depending on season of N application. The application cost is dependent upon whether a separate agronomic operation is needed or whether the N application can be coupled with a weeding, planting, or some other conventional tillage operation. If a special application trip is needed to apply N fertilizer then the cost of application is much more expensive than when applied with a conventional tillage operation, "free ride". Nitrogen fertilization applied in the fall can have a free ride with a rod weeder, stubble mulch sweeps, planting, or some other conventional method of cultivation; however, spring applied N for winter wheat requires a specific N application operation which is not usually performed simultaneously with a tillage operation since cultivation is seldom required for a established wheat stand in the spring. Spring applied N application will cost more than fall applied N due to the additional application cost encountered; yet, this additional cost can perhaps be offset due to the higher relative efficiency realized when N fertilizer is applied in the spring.

This report compliments and supports the research conducted by Goos (1980) and Russell et al. (1987). Spring N application is more efficient and results in greater grain yields than fall applied N. Furthermore, the development of a spring N recommendation coupled with the increased grain yield benefits of spring applied N will give the grain producer much needed flexibility in N application management.

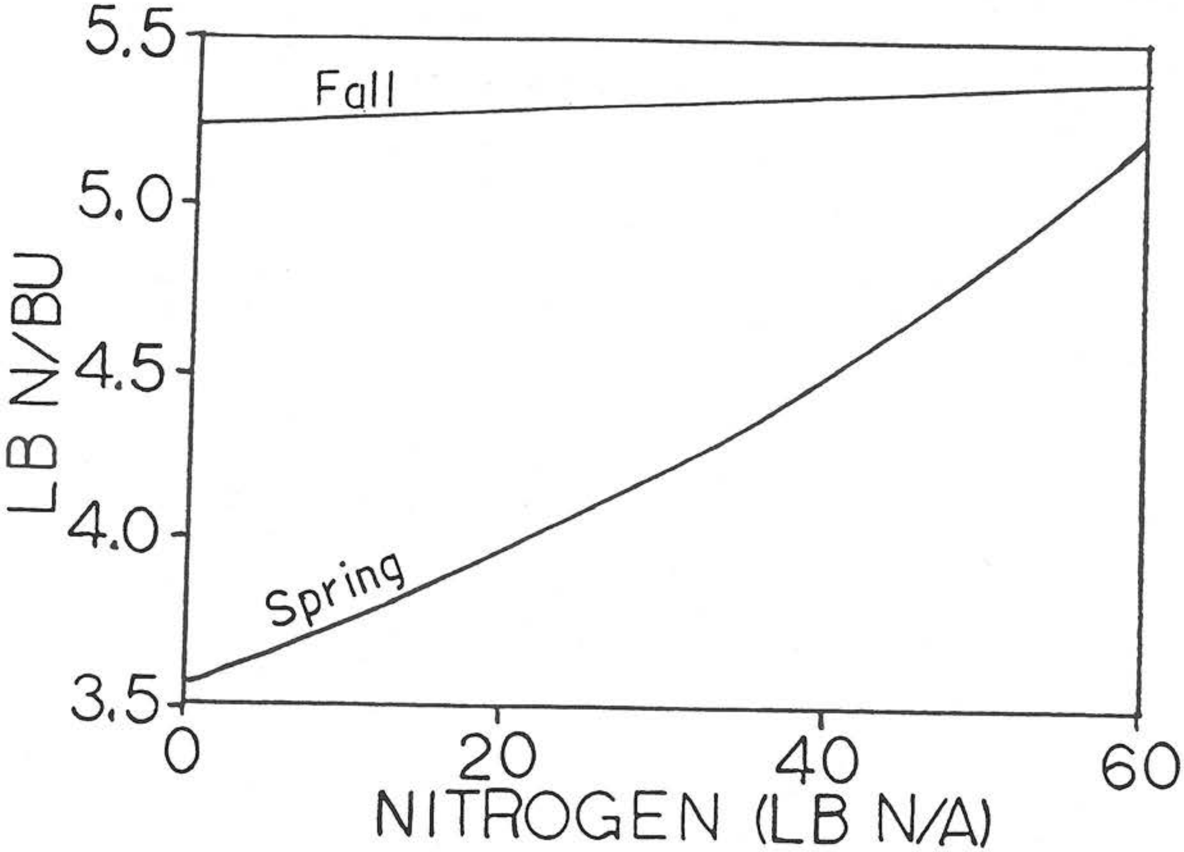

Figure 3. Relationship between fertilizer use efficiency of fall and spring N fertilizer at different N rates.

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INFLUENCE OF SURFACE SOIL ACIDITY IN SOUTH CENTRAL KANSAS ON COMMON HARD RED WINTER WHEAT AND GRAIN SORGHUM CULTIVARS

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ABSTRACT

Ten hard red winter wheat (HRWW) and eight grain sorghum cultivars commonly grown in Kansas were planted at two locations in south central Kansas where the surface pH was 4.7 (1:1 H20). KCl-extractable aluminum (Al) levels were about 90 parts per million at each location. Aluminum was not found below the 6-9 inch depth. All of the HRWW cultivars responded significantly (grain yield and/or plant population) to lime application at both locations. Wheat cultivars related to Scout 66; Newton, TAM 105, and Arkan were extremely sensitive to Al, while Hawk and Bounty 203 exhibited Al tolerance. Grain sorghum cultivars did not respond to lime application at either location. Fusarium root rot was present on the sorghum at both locations. Visual scoring on root systems in the top 6-8 inches for fusarium damage correlated well with early visual growth differences between sorghum cultivars on the check plots at the Kingman site. The full SMP lime requirement treatment only raised soil pH,s to 6.0 and not to 6.8 as projected.

OBJECTIVES

In south central Kansas where continuous wheat is often grown, isolated very low soil pH's (4.0-5.0) have been reported since the early 1980's. Nitrogen fertilization has played a key role in the development of acid soils in this region because the soil pH of pastures is usually above 6.5. However, lime experiments were initiated in 1944 at the Kingman County Experiment Station, which no longer exists, and other lime experiments were performed in the Kingman area in the early 1950's. These researchers reported that many soils in the area had an acidic surface (pH 5.4-5.8), but the subsoils were neutral or even calcareous. Thus, some soils in south central Kansas were acidic prior to the use of nitrogen fertilization. Parent material in the area primarily consists of sandstones and shale.

It is widely recognized that species differ in their tolerance to acid soils and there can be a wide range in tolerance within a given species. Since these studies sometimes involved old standard cultivars grown in nutrient solution or greenhouse experiments, field research was initiated to 1) compare several common cultivars of HRWW and grain sorghum on the acid soils in south central Kansas and 2) to determine the yield limiting factor/s associated with these acid soils. This would enable growers to make economic decisions based on the likelihood of a yield response with a particular crop or cultivar. Since liming is not a common practice in this area, there are only a few quarries and lime costs are high (from 20 to 30 dollars per ton ECC).

MATERIALS AND METHODS

Cowley County, Kansas: HRWW, 1984-85; Grain Sorghum, 1986.

A site was chosen near Udall, KS, on a Milan sandy loam soil (pH=4.7, Al=88ppm, CEC=5.3meq/100g). Soil test P was very high (Bray P1=60 ppm). The lime was applied on September 2, 1983. The lime was only incorporated to three inches the first year. A moldboard plow was used for deeper incorporation in 1985. Excessive fall moisture caused planting of ten cultivars of HRWW to be delayed until November in 1983 and 1984. Soil samples (0-3, 3-6, 6-9, and 9-12) were taken in the spring and analyzed for soil pH changes from lime application.

Eight grain sorghum cultivars were planted on June 17, 1986, where previously the wheat lime studies had been located. Furadan insecticide (one pound/acre) was applied in the furrow at planting and a Ramrod-Atrazine (2.0, 0.7 lbs/acre) herbicide mixture was sprayed immediately after planting. One hundred pounds of N (ammonium nitrate) was broadcast one week after planting. Soil samples were taken as in the wheat study and the plots were harvested (one row X 27 feet) on October 1, 1986.

Kingman County: HRWW, 1987; Grain Sorghum 1987.

Another site was chosen near Norwich, KS, on a Farnum loam soil (pH=4.7 Al=90ppm, CEC=5.7meq/100g). Soil test P levels were again very high (Bray P1=80 ppm). This study was established to compare various agricultural liming materials to pure calcium carbonate and to determine the lime response of HRWW on a heavier textured soil with a normal planting date. The lime was applied on September 18, 1985. Only one cultivar was planted the first year (data not shown). The lime was only incorporated in the top three inches the first year, and a moldboard plow was used for deeper incorporation in 1987 when three HRWW cultivars were randomized within the lime treatments. Initial soil samples were taken before lime application and again on April 16, 1987. Plant population was determined and the plots were harvested (three rows X 30 feet) with a Yanmar binder and an Almaco plot thrasher.

A grain sorghum study was initiated in the same field, but not in the exact site as the lime materials/rate study. In the previous year, the sorghum plot area had shown severe Al toxicity symptoms with Newton wheat. This site was higher in KCl-extractable Al (110ppm), lighter in texture (sandy loam, CEC=5.2meq/100g), and lower in organic matter (1.3 vs 1.6 %O.M.) than the area where the wheat study had been located. The lime treatment (6000 lbs ECC/acre) was incorporated by three tillage operations: once with a disk and twice with a chisel-springtooth on June 9, 1987. Eight sorghum cultivars were planted on June 12, 1987. Fertilizer, herbicide, insecticide, and harvesting methods were similar to those used for the sorghum lime study in Cowley County.

Four days after harvest two cultivars were selected for root observations to determine if Al toxicity symptoms were visable. TX3042 x TX2737 was chosen because early in the season it had poor growth and some plants in the check plots had purple leaves. These plants had very small root systems and a large percentage of the roots had a reddish-black color. Wheatland x TX2536 was chosen because it is the only commonly available sorghum hybrid that has consistently shown some acid soil tolerance in other regions. Ten plants (surface root systems, approximately 6-8 inches) of each cultivar per plot were removed and the roots were washed. After visual observation it was determined that fusarium root rot was present and a visual scoring system for fusarium damage was used (0=no infection and 5=very severe infection).

RESULTS AND DISCUSSION

Cowley County, KS

Grain yields for ten HRWW cultivars are reported in Table 1. There was a marked lime by cultivar interaction both years. Grain yields presented are averaged over the two years. Newton, TAM 105, and Arkan, which are closely related to Scout 66, exhibited extreme sensitivity to soluble Al. It was surprising to find HRWW cultivars grown in the Southern Great Plains with Al tolerance (Hawk and Bounty 203) because it has been observed that Al tolerant cultivars are absent from breeding populations selected on non-acid soils. Regardless of Al tolerance, the data clearly shows that all cultivars responded to lime application. Visual growth differences between sensitive and tolerant cultivars were identical both years.

After the plants emerged in the Cowley County grain sorghum study, some began to die. Examination revealed that the primary root had a reddish-black color and the secondary root system had not developed. It was thought that this was sorghum seedling blight and not Al toxicity or herbicide injury. The injury did not seem to be related to the lime treatments, but the surface pH of the high lime treatment was only 5.5 because of the prior tillage with a moldboard plow. After two weeks, it was apparent that certain plots were more affected than others, so two replications were abandoned. Final plant populations ranged from 25,000 to 31,000 plants per acre.

Visually the eight sorghum hybrids appeared to be identical on both the check and lime treated plots, showing no signs of Al or Mn toxicity. Grain yield results are presented in Table 2. None of the sorghum cultivars responded to lime application. There were significant cultivar differences with Funk's G-550 having the highest grain yield and Seedtec/Wac 652G having the lowest grain yield.

Kingman County, KS

As with many other wheat fields in south central Kansas (fall

1986) hard rains followed planting. Arkan, which has a longer coleoptile than Newton or Hawk, had the best stand. The low yields are believed to be a result of leaf diseases (tan spot and leaf rust) and not the spring freeze. Visually there were growth differences between cultivars on the check plots. Hawk had better growth than Newton or Arkan, but all three appeared to respond to lime application. However, yield measurements do not always agree with visual observations. Grain yield results are presented in Table 3. Newton and Arkan responded significantly to lime, while Hawk did not. Hawk out-yielded Newton and Arkan on the check plot despite the poor stand because of a shorter coleoptile.

Results of plant population are also presented in Table 3. Visual observations did agree with plant population data where all three cultivars responded to lime. There was not a significant lime by cultivar interaction with plant population data.

As in the previous wheat studies, disk, chisel or field cultivator tillage operations did not incorporate the lime below three inches. Nevertheless, there was an early visual response to lime in the Kingman County grain sorghum lime study. By far, TX3042 x TX2737 had the poorest growth, and it was the only hybrid with visual symptoms (purpling of the leaves). Wheatland x TX2536 and Funk's G-550 had the best early growth, but the other hybrids were not drastically different. Moisture was excellent at planting, but the multiple tillage operation for lime incorporation created a compacted layer which added to the moisture/heat stress conditions of late July. Also, compaction should enhance Al toxicity. Later a heavy rain occurred and each cultivar reacted differently to the better growing conditions. Wheatland x TX2536 initiated several additional tillers (three to four) from the growing point which resulted in late heads and reduced grain yields. Other cultivars initiated tillers from the base of the plant, and Dekalb 46 did not initiate any new tillers. These factors contributed to the somewhat poor and wide range of yields reported in Table 4. The lime main effect was not significant for grain yields; however, there was a significant lime by cultivar interaction. Grain yields of Funk's G-550 and TX3042 x TX2752 were significantly different on the 0 lime treatment but not on the lime treated plots.

Visual ratings for fusarium root damage are reported in Table 4. A rating of one to two is not uncommon with sorghum grown in Kansas. There was a significant lime by cultivar interaction between the two cultivars evaluated. Several plants of TX3042 x TX2737 had small blackish root systems, especially on the check plots. Wheatland x TX2536 had a larger more fibrous root system with a larger percentage of white roots. Fusarium damage was also present in the Cowley County sorghum lime study, but the root systems were not evaluated at the end of the season.

Soil analysis (data not shown) indicated that when soil pH was increased to 5.2, KCl-Al levels were near zero. Also, when the full SMP lime requirement rate was applied (both locations), soil pH's only approached 6.0 instead of the projected 6.8. Pure calcium carbonate was used at the Kingman location, so it seems that lime quality is not the problem. This is puzzling since the SMP method usually over estimates the lime requirement compared to the supposedly more accurate titration method.

The yield limiting factor for Scout-type HRWW appears to be Al. Poor growth (reduced tillering and/or chlorosis) has always been associated with KCl-extractable Al and visual observation of the roots (coralloid in appearance). The poor growth of grain sorghum seems to be related to root growth, but it is unclear whether or not pH or Al is involved. A greenhouse study is planned to determine if there is an interaction between fusarium and low pH. There are a few references in the older literature relating fusarium damage on corn grown in acid soils. More field studies are needed to determine whether or not grain sorghum is more tolerant of "acid" soils than the Scout-type HRWWs.

Table 1. Grain yields of HRWW in Cowley County lime study.[1,2,3]

HRWW Cultivar	Lime Rate (Lbs ECC/Acre) 0	9000	Increase to Lime
	--- bu/a ---		%
Newton	6	27	350
Tam 105	6	28	365
Arkan	10	29	190
PB 830	13	35	170
Chisolm	13	28	115
HW 1010	17	32	90
Vona	16	28	75
Centurk 78	18	31	70
Hawk	23	31	35
Bounty 203	32	42	30
HRWW AVG.	15	31	105

1 Average of two crop years.
2 Significant lime response with all cultivars both years.
3 Significant lime by cultivar interaction both years.

Table 2. Grain yields of grain sorghum in Cowley County lime study.[1,2,3]

Sorghum Cultivar	.Lime Rate (Lbs ECC/Acre). 0	9000	Increase to Lime
	- - - bu/a - - -		%
Seedtec/Wac 652G	70	88	26
RS 610	78	93	20
WheatlandxTX2536	86	92	7
TX3042xTX2737	79	81	3
TE Y101R	93	95	2
TX2752xTX430	105	102	-3
DK 41Y	91	83	-9
Funk's G-550	103	93	-10
Sorghum AVG.	88	91	3

1 One year only.
2 Nonsignificant lime by cultivar interaction.
3 Nonsignificant lime response.

Table 3. Grain yield and plant population of HRWW in Kingman County lime study.

HRWW Cultivar	.Lime Rate (Lbs ECC/Acre). 0	6000	Increase to lime
	- - - bu/a[1] - - -		%
Newton	21	30	43
Arkan	23	35	52
Hawk	30	30	0
	- - heads/2 meters[2] - -		%
Newton	95	180	90
Arkan	130	180	38
Hawk	130	160	23

1 Significant lime response and interaction.
2 Significant lime response and no interaction.

Table 4. Grain yields and fusarium ratings of grain sorghum in Kingman County lime study.[1,2]

Sorghum Cultivar	.Lime Rate (Lbs ECC/Acre). 0	6000	Increase to Lime
	bu/a or (fusarium rating)		%
TX3042xTX2737	31 (3.5)	42 (3.0)	35
Pioneer 8493	33	40	21
TX2752xTX430	55	65	I8
Dekalb 46	57	63	11
WheatlandxTX2536	41 (2.5)	45 (2.7)	10
RS 610	42	42	0
Dekalb 4IY	51	44	-14
Funk's G-550	61	50	-18
Sorghum AVG.	44	51	16

1 Nonsignificant lime response grain yield or fusarium rating.
2 Significant lime by cultivar interaction grain yield and fusarium rating.

ASSESSMENT OF AMMONIUM ACETATE AS AN INDICATOR OF SOIL K AVAILABILITY

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ABSTRACT

Results of fifteen years of field experiments on Montana soils indicate that small grains show yield response to K fertilizers, although ammonium acetate extraction indicates sufficient K. This response is theorized to be a true response to K fertilizer in a yield limiting condition. In 1988, a study was conducted by using twenty Montana soils from field locations where previous fertility studies had been conducted. Spring wheat seedlings were grown on soil columns for short periods and plants were analyzed for net K uptake. Soil K diffusion gradients were determined by measuring changes in the exchangeable K concentrations in the rhizosphere. Results of this study indicate net plant K uptake was significantly greater than soil K flux as determined by ammonium acetate, and was highly soil dependent. Soil exchangeable K was poorly correlated with plant K uptake, $R^2 = 0.372$. However, using stepwise regression, plant K uptake was correlated with % clay, diffusion gradient coefficient and cation exchange capacity, $R^2 = 0.905$. The results of both field and laboratory experiments indicate that ammonium acetate extractable K doesn't describe plant available K for small grains in Montana. The development of a new soil test for K must take into consideration major factors and processes relevant to plant available K.

OBJECTIVES

This research was initiated to provide information concerning plant available K for small grains on Montana soils. Results of field research indicate ammonium acetate has only limited usefulness at predicting plant available K. Thus to develop a more useful soil test those factors and processes important to K uptake need to be evaluated. The primary objectives of this research are: 1) determine soil K diffusion gradients and K uptake by wheat on twenty Montana soils; 2) relate K exchangeable with K uptake; and 3) identify soil physical and chemical characteristics that relate to K uptake.

MATERIALS AND METHODS

Soils representing the Ap horizon were collected from twenty locations across Montana from sites where previous fertility trials had been conducted. Soils were analyzed for physical and chemical characteristics, a selected few of which are shown in Table 1. Soils were packed into columns measuring 4.5 x 1.5 cm at a bulk density of 1.3

Table 2. Plant K uptake and soil K flux for five selected Montana soils.

	Soil Series				
	Beaverton	Edgar	Amsterdam	Creston	Kevin
Plant K Uptake umol	27.0	40.1	29.5	22.6	52.5
Soil K Flux umol	5.0	13.8	19.8	20.0	16.1
Difference	23.0	26.3	9.7	2.6	36.4

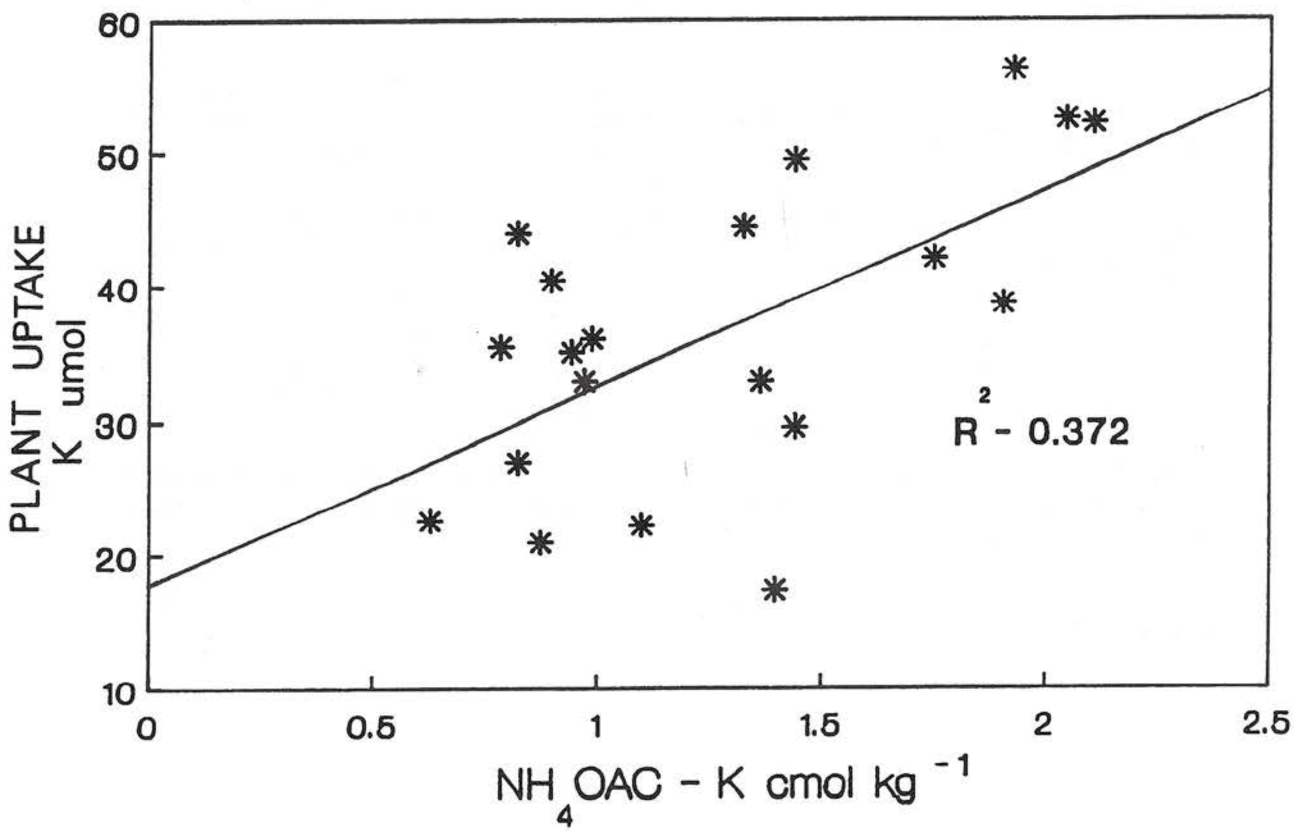

Figure 1. Correlation of wheat K uptake with ammonium acetate extractable K on twenty Montana soils.

gm cm^{-3} and placed on a moisture tension plate which was adjusted to 33 Kpa.

Table 1. Soil properties of five selected Montana soils used in K diffusion and uptake studies.

	Soil Series				
	Beaverton	Edgar	Amsterdam	Creston	Kevin
Soil type	clay loam	loam	silt loam	loam	clay loam
Soil pH	5.8	8.8	8.3	5.7	7.1
OM (%)	5.8	1.4	2.4	5.5	4.2
$CaCO_3$	0.0	0.2	5.3	0.0	0.4
K cmol(+)kg^{-1}	0.72	0.82	1.24	0.85	2.11
K (ppm)	280	322	485	332	823

Twentyfive six day old wheat seedlings supported on 325 mesh nylon screen were placed on the soil columns. This configuration permitted root hair growth, but prevented root penetration of the soil. After 98 hours, plants were analyzed for net K uptake. Soils were thin sectioned at 5 planar distances from the rhizosphere plane and were analyzed for changes in concentration in exchangeable K using ammonium acetate. Potassium concentration gradients and net soil K flux values were determined from soil thin section data.

RESULTS AND DISCUSSION

Results indicate that plant K uptake was highly soil dependent (Table 2). Potassium depletion, as measured by changes in ammonium acetate extractable K, extended into the soil approximately 5 mm. Soil K flux values, as determined from K diffusion gradients, were less than net plant K uptake in nineteen of the soils. On soil series such as the Beaverton, Edgar and Kevin, this difference is highly significant. It is our hypothesis that on these soils substantial quantities of the K absorbed by wheat root is derived from nonexchangeable K sources in close proximity of the root. Whereas at slightly greater distances wheat roots do not even use exchangeable K.

When ammonium acetate extractable K and plant K uptake were regressed against one another, a weak correlation was found, $R^2 = 0.372$ (Figure 1). These laboratory results are comparable with field results, $R^2 = 0.324$ (Skogley and Haby, 1981). This evidence clearly demonstrates that ammonium acetate is of very limited usefulness for estimating plant available K for small grains on Montana soils.

These results clearly indicate that wheat is capable of depleting soil K from nonexchangeable K sources in the near rhizosphere. In addition K uptake is directly related to the amount of K and its movement in the soil as described by the clay content and the diffusion gradient coefficient. A reliable K-soil test for small grains in Montana, therefore must consider some fraction of the nonexchangeable K as being plant available, and make adjustments for the diffusion of K through the soil.

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FERTILIZER RESPONSES IN DRYLAND CHEMICAL FALLOW AND CONTINUOUS WINTER WHEAT

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ABSTRACT

In 1984, a dryland winter wheat conservation tillage program was undertaken in Wyoming. The overall objective was to compare no-till production with conventional production practices. No-till production in chemical fallow was comparable to conventional crop-fallow production across nine large field-scale demonstrations. When 40 $\pm$ 9 lb N/A and 24 $\pm$ 7 lb P_2O_5/A were deep-banded in no-till, the advantage favored no-till by 3.4 bu/A and 1% protein. Fertilized no-till exceeded non-fertilized no-till by 6.3 bu/A and 0.9% protein across eleven demonstrations. After five continuous crop demonstrations, no-till fertilized production was 69% of the conventional crop-fallow yield.

INTRODUCTION

In 1984, it was estimated that only 14% of Wyoming's cropland was under some form of conservation tillage. This was about one-half the national average (1). To encourage conservation tillage practices, field days and tours were sponsored by the Soil Conservation Service, University of Wyoming Cooperative Extension Service and conservation districts. In addition, cost-share incentives were offered in some counties by the ASCS to stimulate interest.

A logical alternative was field demonstration of technology. This approach recognizes the importance of the field demonstration as a widely accepted method of introducing new technology. A demonstration program was initiated to compare no-till versus conventional dryland winter wheat production. The first demonstrations were established in Laramie and Platte counties in fall 1984, by the SCS, local conservation districts, University of Wyoming Extension Service and producers. Haybuster Manufacturing was also instrumental in the establishment of four seeded demonstrations by providing the use of a no-till drill. In 1985, the University of Wyoming provided a no-till drill and the personnel to expand the demonstration program throughout the dryland production regions of the state.

OBJECTIVES

This program was to demonstrate no-till farming in Wyoming through large field demonstrations. This approach allowed for the use of field-size commercially available farming equipment which greatly enhances producer application and acceptance. Specific objectives include comparisions of 1) conventional stubble mulch fallow to no-till in chemical fallow, with deep band application of fertilizer under no-till as an additional variable and 2) no-till continuous crop production with and without the supplementation of fertilizer through deep banding to to conventional stubble mulch fallow.

MATERIALS AND METHODS

No-till production was employed at all locations. Each demonstration was fine-tuned to the specific needs of the locality and the producer. Direct producer involvement was encouraged, relying heavily on the experience of the cooperator. This approach resulted in a number of atypical demonstrations based on local conditions and needs.

Two demonstrations were harvested in 1985, seven in 1986, and four in 1987 (Table 1). Demonstration comparisons were made using field strips (approx. 20 acres). Fertilizer application, which varied depending on location, was generally based on soil test information plus knowledge obtained from similar wheat production regions where no-till production had been attempted. The mean N and P application consisted of 40 $\pm$ 9 lb N/A and 24 $\pm$ 7 lb P_2O_5/A supplied as dry granular fertilizer. Unfertilized check strips, usually a drill width, were included as treatments.

Table 1. Dryland winter wheat no-tillage demonstrations in Wyoming.

Location	Type of Demonstration	Soil Characteristics	Year
Archer	Crop-fallow and continuous cropping system	sandy clay loam %O.M.: 0.5 pH: 7.4	1985-86 1986-87
Chugwater	Crop-fallow system	loam %O.M.: 0.8 pH: 7.9	1985-86 1986-87
Gillette	Crop-fallow system	clay loam %O.M.: 1.6 pH: 6.9	1985-86
Lingle	Crop-fallow and continuous cropping system	clay loam %O.M.: 1.6 pH: 7.7	1985-86 1986-87
Lusk	Crop-fallow system	sandy clay loam %O.M.: 0.5 pH: 7.8	1985-86
Pine Bluffs	Crop-fallow system	-----	1984-84
Slater	Crop-fallow and continuous cropping system	clay loam %O.M.: 1.9 pH: 7.6	1984-85 1985-86 1986-87
Spotted Horse	Crop-fallow system	sandy clay loam %O.M.: 0.9 pH: 5.8	1965-86

Variety and seeding rates varied according to producer preference. Haybuster 8000 paired row no-till hoe drills were used. These drills handled residue easily and provided banding of fertilizer 1" below and 1.5" to the side of the seed row. In 1984-85 and 1985-86 yields were obtained by subsampling strips using 10.8 sq ft subplots. Fields were divided into equal sectors, generally five, along the length of the strip with one subsample obtained at random per sector. In 1986-87 a small plot combine was used to harvest 8 by 50 foot subplots, again generally five for each treatment. Conventional yields, where possible, were obtained in a similar fashion from an adjacent strip. Protein (NIR analysis) and test weight information was obtained from local elevator. Data were subjected to statistical analysis using paired T test.

RESULTS AND DISCUSSION

Precipitation patterns can vary greatly in Wyoming from year to year. The 1984-85 growing season precipitation (Aug.-July) for southeastern Wyoming, where the majority of these demonstrations were located, averaged 12.02". In 1985-86 it was 16.47" and 15.58" in 1986-87 (3). Thus potential impact of any tillage system can not be fully assessed without the collection of information over a period of years. What may work well in a wet year may fail in a dry year. In addition, any tillage system manifests changes from year to year. The impact of these changes must be considered over the long term.

With this in mind, it is still too early to assess the overall value of no-till production compared to conventional systems for dryland winter wheat in Wyoming. The information obtained to date does, however, show good potential for no-till winter wheat production. No-till planting in chemical fallow residue produced yields and proteins comparable to conventional fallow. Across nine demonstrations combined yield from chemical and conventional fallow was 27.7 bu/A. The difference, then, may be in the economics of the fallow operation. When fertilizer is added to the chemical fallow no-till production system the advantage favors no-till by 3.5 bu/A and 1% protein (Table 2).

Table 2. Winter wheat response to conventional or no-till fertilized production in crop-fallow and continuous crop systems.

	Crop-fallow		Continuous Crop	
	bu/A	% protein	bu/A	% protein
No-till fertilized	32.6	13.0	20.7	11.9
Conventional	29.1	12.0	29.7	12.3
Difference between means	3.5	1.0	9.4	0.4
P-value	4.8%	9.1%	7.9%	---
Cases	9	7	5	4

The value of no-till deep band application of fertilizer at planting is further exemplified in comparison of no-till production with and without fertilization. Yield and protein data across years and locations were analyzed (Table 3). Production in chemical fallow across eleven demonstrations resulted in a 6.4 bu/A and 0.9% protein difference in favor of fertilization. With the six continuous crop demonstrations, there was a 10.5 bushel and 0.9% protein difference favoring fertilization. Under the current economic conditions fertilization of the no-till cropping system should be profitable in Wyoming . In fact it appears essential in continuous crop production. No-till production without fertilization resulted in a 9.4 bu/A yield when adjacent conventional areas yielded 29.7 bu/A (Table 4). The addition of fertilizer to the continuous crop no-till system in these demonstrations resulted in 20.7 bu/A, which was 69% of the conventional fallow yield (Table 2). During the 1985-86 and 1986-87 growing seasons, there was adequate precipitation. This level of continuous crop production probably will not be realized during dry years.

Table 3. No-till winter wheat response with and without fertilization under crop fallow and continuous crop systems.

	Crop-fallow		Continuous Crop	
	bu/A	% protein	bu/A	% protein
Fertilized	33.3	12.9	21.4	12.0
Non-fertilized	26.9	12.0	10.9	11.1
Difference between means	6.4	0.9	10.5	0.9
P-value	0.5%	8.4%	0.1%	---
Cases	11	8	6	4

Table 4. Winter wheat response to conventional fallow or to no-till non-fertilized production in the continuous crop system.

	Bu/A	% Protein
Conventional	29.7	12.3
No-till non-fertilized	9.4	11.1
Difference between means	20.3	1.2
P-value	1.0%	--
Cases	5	4

The results of recent rotation trials in Montana show that annual grassy weeds can become serious weed problems with continuous cropping (2). As in Montana, the proliferation of problem winter annual weeds was noteworthy in the continuous crop demonstrations. Downy brome (Bromus tectorum L.) was present in all harvested continuous crop demonstrations. The impact of this weed seemed greatest in non-fertilized areas. Deep banding of fertilizer appeared to give the wheat a competitive advantage. Somody (4) reported that the deep banding of fertilizer enhanced the competitive advantage of spring wheat over wild oat (Avena fatua L.). Perhaps a similar relationship exists between downy brome and winter wheat. A series of studies have been undertaken in Wyoming to quantify the relationship between winter wheat and downy brome to fertilizer and fertilizer placement. In addition jointed goatgrass (Aegilopsis cylindrica Host) can become a serious problem weed. One demonstration was abandoned in the third year of continuous crop production because of this weed. A new herbicide shows promise for the post emergence control of both downy brome and jointed goatgrass in winter wheat but has not yet found its way to the market place.

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NITROGEN FERTILIZATION IN RELATION TO SPRING WHEAT DEVELOPMENT STAGE

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ABSTRACT

Physical structures of the wheat plant, recognized by sight and feel, appear and develop in a consistent and orderly pattern. Although a continuum, development is sufficiently distinctive to separate into stages. Numerical designations ascribed to these stages serve as a reference in communicating information required in making decisions in which proper timing is a factor in use-efficiency and other economic aspects.***Studies conducted at the Northern Great Plains Research Laboratory provide information on N concentration and content in leaves, stems, and heads by development stage, and as well in grain from anthesis to ripe stage. This information has implications for timing of N application for beneficial yield and quality responses, peak N content in leaves and stems occurred at about flag leaf stage and anthesis, respectively. About 75% of the spike N content at kernel hard stage resulted from N translocation. Peak grain N concentration occurred about watery-ripe stage.

OBJECTIVES

Information is lacking on N concentration and content in the aerial components of hard red spring wheat at definitive stages over its life cycle. Nitrogen, because of its mobility in soils and plants, lends itself to timing management. But the plant development stages at which N supplementation can proceed beneficially is not known. The potential for loss of fertilizer N by several pathways, together with its cost, are an impetus for seeking means for improving its use-efficiency. Concerns of its loss by leaching with a concomittant increase in potential of enriching groundwater with nitrates too, are an incentive. Fertilizer N needs for optimal yield which are based on actual and anticipated water supplies (stored soil water and growing season rainfall) may need supplementation for maximum efficient use of water when water supply exceeds expectations.

The objectives were to measure N concentration and content in spring wheat leaves and stems, and, as these appeared, heads, weekly beginning at about the three-leaf to grain ripe stage, and in the grain twice weekly from anthesis to kernel ripe, and relate these to plant development stage.

MATERIALS AND METHODS

Field trials were conducted at Mandan, ND in 1981 and 1982. Each experiment consisted of all combinations of three water levels (rainfed, supplemental, and double supplemental), three fertilizer N rates (0, 40, and 105 lbs/ac), and three cultivars (Alex, Olaf, and James). Plant tissues from a 1.2 yd^2 area were cut at soil level from each treatment of one replication weekly, beginning about the three-leaf stage. Sampling was rotated among the four replications. After pollen extrusion was observed, a 3.25-foot length of row was cut about 0.5-foot above the soil level from each treatment of one replication on Tuesday and Friday of each week, until kernel ripe stage. Successive replications were sampled, but the same drill row was sampled each time. All kernels were removed from each head, composited, and counted with an electronic seed counter.

All tissues were dried at 69^oC (156^oF) and ground with a Wiley mill. The N concentration was measured by a Kjeldahl procedure. The N content (uptake) is the product of concentration and dry matter produced per appropriate unit area. All concentrations and contents are expressed on a dry-weight basis. (For greater detail, see Bauer et al., 1987a and 1987b).

Plant development stage through anthesis is based on the Haun scale (1973) and thereafter on the Feekes (Large, 1954). To facilitate computer use, the Feekes scale designations of water ripe, milky ripe, mealy ripe, kernel hard, and ripe were designated as 12.1, 13.0, 14.0, 15.0, and 18.0, respectively, for 8-leaved cultivars.

RESULTS AND DISCUSSION

Aerial plant dry matter produced increased with development stage (Fig. 1). Differences among fertilizer N and water management level treatments are largest after heading because of differences in grain yield. Although total aerial dry matter produced differs with N and water management, the percentage of the total dry matter in leaves at any development stage is similar among management levels (Fig. 2). Dry matter weight is about equally distributed between leaves and stems at the flag leaf stage. At anthesis, about 20% of the dry matter produced is in each of leaves and heads and 50% in stems.

FIGURE 1. DRY MATTER ACCUMULATION BY HARD RED SPRING WHEAT DEVELOPMENT STAGE AS A PERCENTAGE OF THE TOTAL AT KERNEL HARD STAGE.

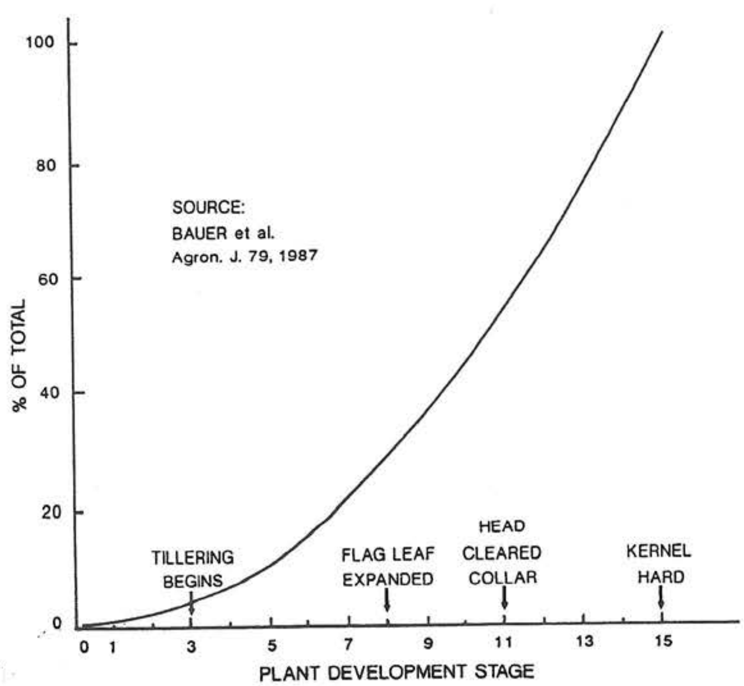
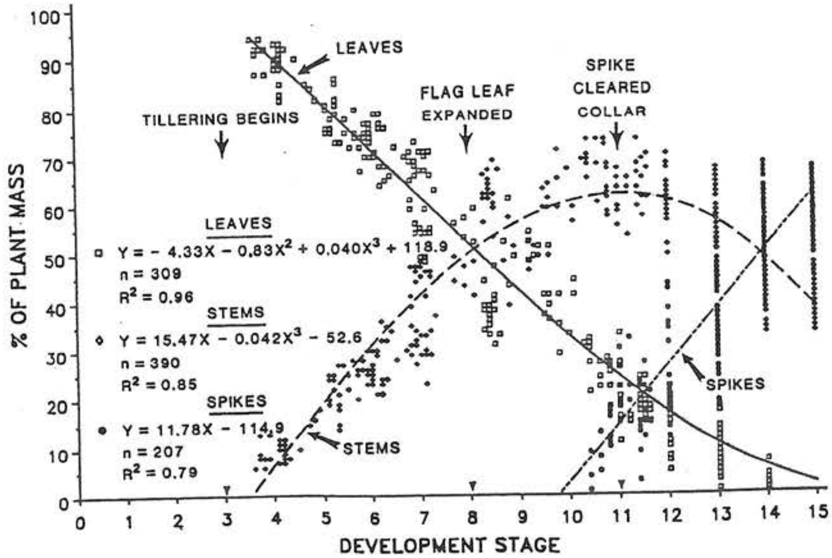


Figure 2. Percent of plant mass of Alex-Olaf spring wheat in leaves (□), stems (◊), and heads (●) in relation to development stage, 1981-1982. Values are from all combinations of 3 fertilizer N and 3 water levels.



Nitrogen (N) concentration in leaves decreased linearly at about 0.293% for each unit increase in development stage (Fig. 3), from an initial concentration of about 7.0%. In stems the decline is most rapid during their most rapid development period. After heading, the decline in N concentration of stems is about half that of leaf N. Head N concentration increases with development stage, but slightly.

Nitrogen concentration in plant parts can vary with available soil N supply. (This is at least part of the reason for the deviation from regression in Fig. 8). But, irrespective of available N supply, N concentration in leaves and stems declined with development stage.

The amount of available soil N affects the growth of the plant (not the development, however) resulting in differences in extent of tillering, size of leaves, etc. among treatments. Because of more plant growth, the N concentration in the plant grown in soil supplied with larger amounts of available N is not necessarily higher than in plants with less growth.

Peak N content (uptake) in leaves occurred at about flag leaf extension (Haun stage 9.0) and in stems at about anthesis (Fig. 4). The combined peak N content in leaves and stems in these trials, about 87 lbs/ac, was about 9 lbs/ac less than the total in the head at ripe stage. Of the total N content of leaves and stems, about 13 lbs/ac were still present in these tissues at grain ripe stage. Hence, about 75% of the head N content at ripe stage was translocated from leaves and stems. (The average grain yield in these trials was about 50 bu/ac, dry weight).

Figure 3. Nitrogen concentration in leaves (□), stems (◊), and heads (●) of Alex-Olaf spring wheat in relation to development stage. Values are for all 3 fertilizer N and 3 water levels.

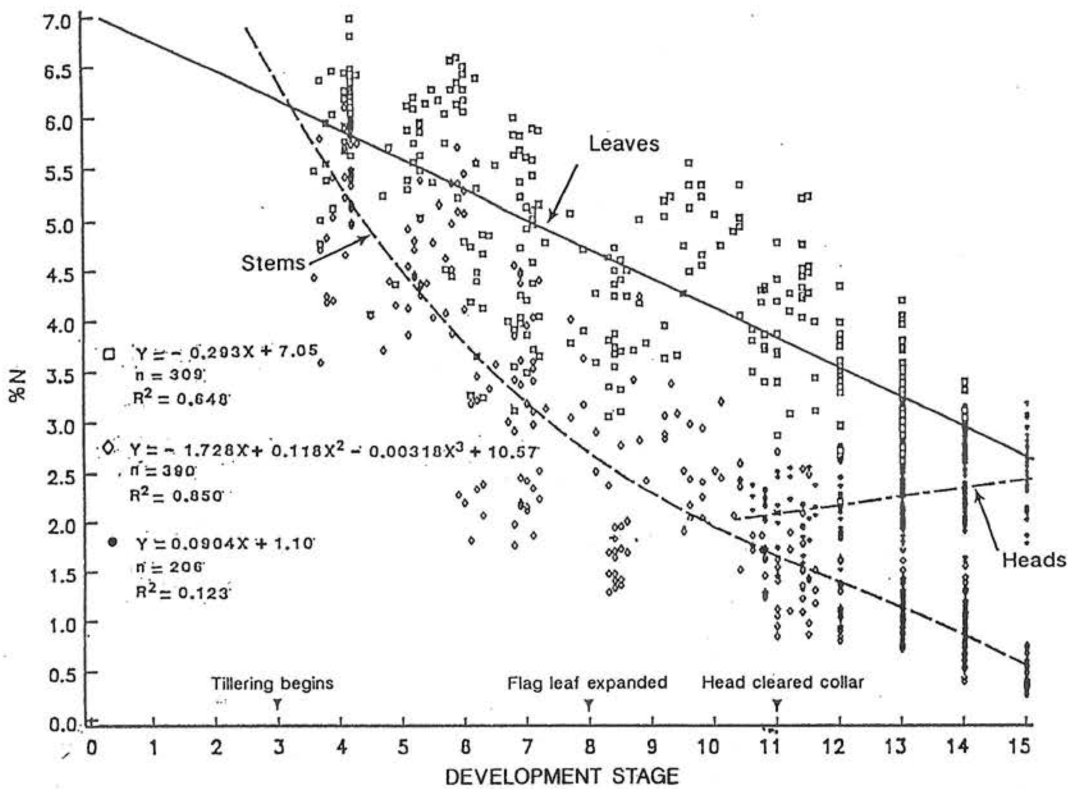
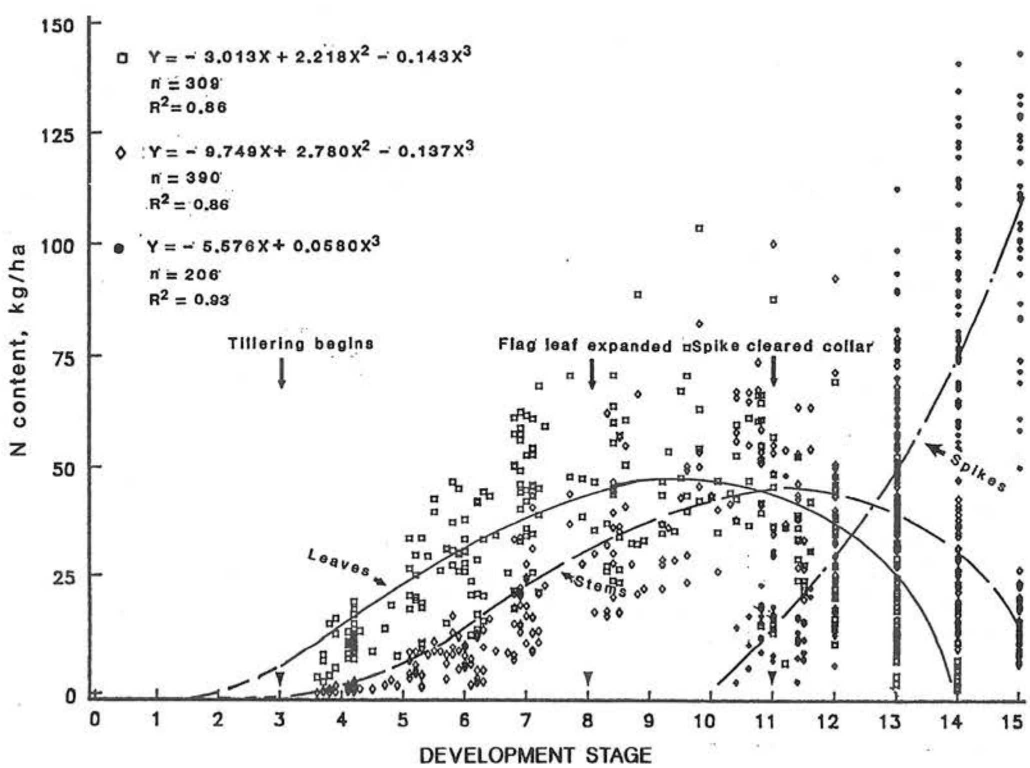


Figure 4. Nitrogen content in leaves (□), stems (◊), and spikes (●) of Alex-Olaf spring wheat in relation to plant development stage, 1981–1982.



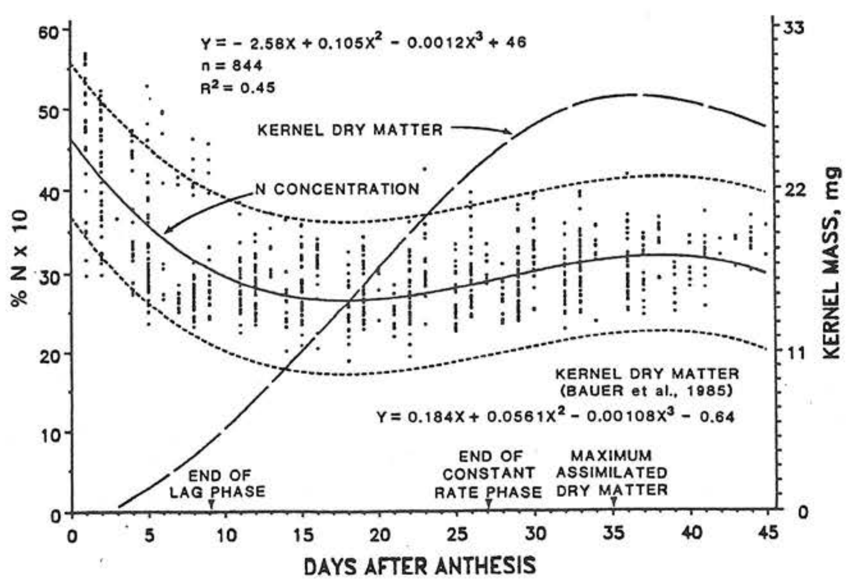
In cases of impending N deficiency during grain filling, it appears that fertilizer N needed for yield maximization should be supplied before the flag leaf stage. Note from Fig. 2 that leaves make up about 50% of the total plant weight at this stage and then decline rapidly. Note also in Fig. 3 that N concentration is higher in leaves than the stem (the other source of N translocated to the head), and therefore is the source of largest supply available for translocation.

Peak N concentration in grain occurred within the first 4 to 5 days after anthesis (Fig. 5). The near constant concentration from DAY 10 to DAY 25 (after anthesis) corresponds to the constant-rate phase of grain filling (Bauer et al., 1985). The grain N concentration increased very little during the post constant-rate phase. Likely, the final N (protein} concentration is determined at this time.

How late available N can be applied in the plant development cycle to increase grain protein cannot be precisely determined from these studies. Considering the relatively short period of the constant-rate phase of grain filling (about 18 days), assuring that the necessary supply of N be supplied prior to anthesis appears essential.

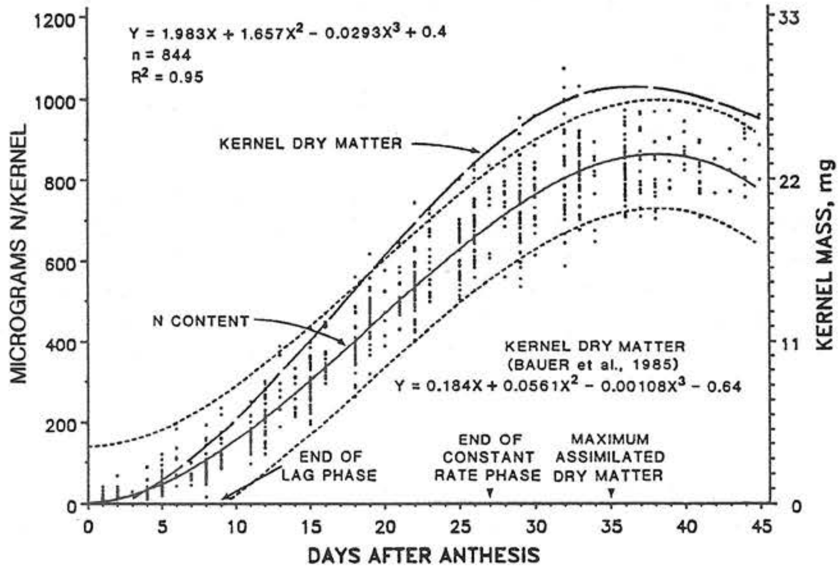
If 3.25% grain N concentration (dry basis) at harvest is an acceptable level (16.3% protein at 12% water concentration), as expressed by the regression (Fig. 5), it would appear that the N concentration exhibited in various plant parts, as expressed by the regression equation, could be considered the "critical" N concentrations at the specific development stage to achieve this grain protein level.

Figure 5. Regression with 95% confidence limits of days after anthesis and N concentration in grain of hard red spring wheat, trials 79F, 81F, 82F,81NF, and 82NF. (Regression of kernel dry matter assimilation from Bauer et al., 1985 is included.)



Peak N content in grain occurred at maximum assimilated grain dry matter (Fig. 6) and for several days thereafter. The most rapid N uptake occurred during the constant-rate phase of grain filling. Note that N uptake in the grain closely parallels grain dry matter accumulation.

Figure 6. Regression with 95% confidence limits of days after anthesis and N content in grain of hard red spring wheat, trials 79F, 81F,82F, 81NF, and 82NF. (Regression of kernel dry matter assimilation from Bauer et al., 1985 is included.)



The rate of N uptake on a daily basis can be estimated for the data in Fig. 6 for different crop yields and wheats of different kernel weights. Assuming the 850 micrograms N/kernel were taken up uniformly over the 35-day period from anthesis to maximum assimilated grain dry matter, a 50 bu/ac wheat crop with 32 mg final kernel weight would accumulate N in the grain at a rate of about 2.3 lbs N/ac/day.

SUMMARY

The nitrogen needed to optimize spring wheat yields needs to be adjusted to match the water component potential. The water component especially can change during the growing season, and consequently change the yield potential. In many cases, to achieve the potential yield may require additional fertilizer N input.

Information about nitrogen (N) distribution in the wheat plant at different stages has implications for timing of fertilizer N applications to prevent deficiency, and also may indicate whether additional N will increase grain yield or grain protein. Further, timing of fertilizer N to coincide with plant N needs may improve use efficiency.

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PROJECTS

1. Timing of Nitrogen Application to Spring Wheat

   Objective: Measure effect of nitrogen application by plant development stage on tissue nitrogen concentration and content, grain yield, and quality factors.

   Personnel: A. Bauer, A. L. Black, Technicians

(ONE YEARS' RESULTS OF THIS STUDY WILL BE DISCUSSED AT THIS WORKSHOP)

2. Conservation Tillage - Cropping Systems

   Objective: Measure effect of nitrogen rates on yield and quality factors of spring wheat, winter wheat, sunflowers, and corn in relation to residue management systems.
   Personnel: A. L. Black, J. M. Krupinsky, A. Bauer, Technicians

TILLAGE, CROP HISTORY, AND FERTILIZER PLACEMENT EFFECTS ON WHEAT YIELD AND QUALITY

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ABSTRACT

A two-year experiment was carried out to determine significance of precise placement, deep-banded fertilizer for maximizing cereal grain production in conservation tillage systems in Montana. The experiment, replicated in modified forms at 21 locations in 1986 and 1987, included winter and spring wheat and barley. Conventional, surface-applied (top-dressing) fertilization practices were compared to deep-banding in till-plant and no-till residue management systems. Fertilizer treatments included a check (no fertilizer), deep-band, pre-plant broadcast without incorporation, and deep-band at 1.5 times the recommended fertilizer rate. No-till yield averaged 30.7 bushels per acre while till-plant average yield was 27.4 bushels per acre. Deep-banding fertilizer resulted in an 8.3 bushels per acre yield increase over the average check treatment; deep-band yield was 3.4 bushels per acre greater than the broadcast fertilizer treatment. Grain test weight was not consistently affected by either tillage method or fertilizer placement strategy. No-till test weight was slightly greater than till plant test weight. Maximum response (benefit) to deep-banding occurred when pre-plant soil test nitrogen levels were relatively low, while no benefit to any fertilizer placement strategy was measured when soil test nitrogen level was relatively high. Surprisingly, the average pre-plant soil test nitrogen level (for 21 sites) was 52 lbs/acre. Results of this study indicate that deep-banding fertilizer will result in a 3-4 bushel/acre increase in yield over conventional fertilizer placement methods in dryland grain producing areas of Montana.

OBJECTIVES

Conservation tillage, residue management to reduce or prevent erosion, has become a mandated practice on millions of acres of erodible soil in the United States, as a result of the 1985 Farm Bill. Many farmers are already practicing conservation tillage, due in part to new or modified planting equipment, improved fertilizer strategies, and flexible crop rotations. However, for those farmers now being directed to adopt conservation tillage, many questions still remain unanswered.

Fertilizer constitutes a significant variable expense for most farmers. Dryland small grain farmers in Montana sometimes question the value and efficiency of applied fertilizer. Reports of improved fertilizer use efficiency as a result of "paired" row seed placement and deep-banding fertilizer have added more uncertainty to the fertilization issue. Dryland small grain farmers in Montana would like clarification about reported benefits of precise fertilizer placement. A multi-site, multi-year, replicated experiment was initiated to determine the effect of tillage, planting method and precise placement, deep-banded fertilizer on dryland cereal grain yields in conservation tillage systems in Montana.

MATERIALS AND METHODS

With financial assistance from the Potash and Phosphorus Institute (PPI), a multi-site, two-year research project was initiated. Crops included spring wheat, barley, and winter wheat. Twenty-one replicated, randomized block experiments were established (Figure 1). Northeast and north central Montana constitute the principle grain-producing regions of Montana.

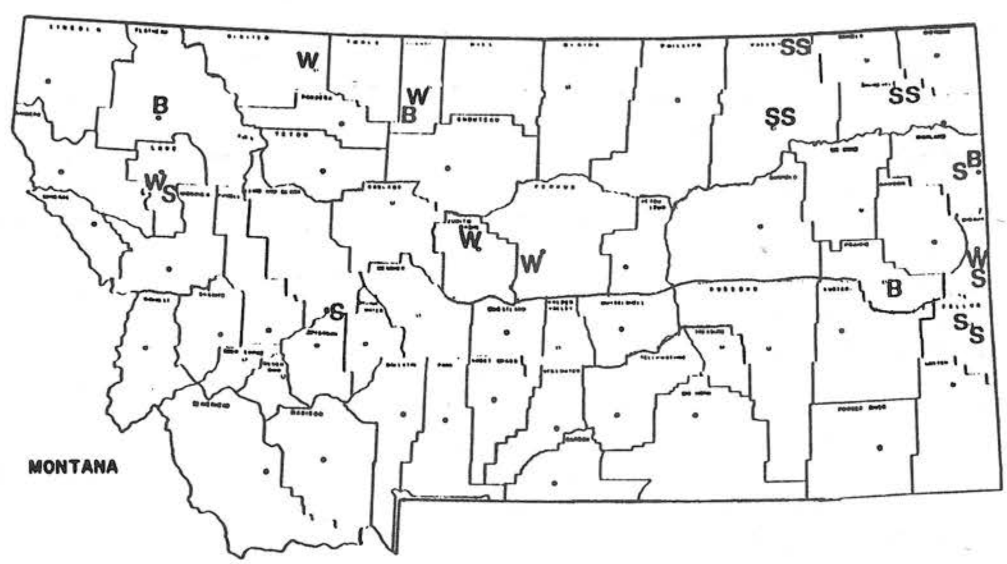

Figure 1. Location of fertilizer placement/tillage method comparison trials, 1986-87; s = spring wheat, b = barley, w = winter wheat. Montana CES and PPI cooperating.

The study was initially intended to compare broadcast and deep-banding fertilizer placement under no-till and conventional till or till plant. Subsequently, the design was modified to determine the best fertilizer strategy for no-till (Table 1). The field design consisted of either 3 or 4 replicated, randomized blocks.

Table 1. Summary of treatment comparisons of 1986-87 small grain trials.

Treatment *	Spring 1986	Fall 1986	Spring 1987
No till			
Check (no fertilizer)	x	x	x
Broadcast fertilizer	x	x	x
Deep band fertilizer	x	x	x
Deep band 1.5 x fertilizer	x	x	x
Till plant			
Check (no fertilizer)	x	x	
Broadcast fertilizer	x		
Broadcast + inc. fertilizer	x	x	
Deep band fertilizer	x	x	
Deep band 1.5 x fertilizer	x	x	
Number of locations	6	6	9

* Fertilizer included N, P, K, and S at rates determined from pre-plant soil test values, anticipated yield potential, and projected crop response to applied fertilizer; same fertilizer rate applied to all treatments but check and 1.5x.

An additional treatment was included where the recommended fertilizer rate was increased 50%. Two "split" fertilizer treatments were included in 1987 to investigate the effect of deep-band + broadcast combinations.

Each experiment was located in a "cooperating" farmer field. Sites were selected where farmers were presently practicing conservation tillage and study areas were specifically located within cropped fields, to insure adequate buffer and surrounding crop area to allow for "representative" field conditions. Yield potential for each site was estimated and an appropriate fertilizer rate determined, using pre-plant soil test results, cooperator records and recommendations, rainfall probabilities, county yield statistics, and established plant-available water-yield models for Montana.

The 1986 spring planting was completed using cooperator-owned no-till drills, with exception of the Liberty site, where an experimental drill was used. Cooperator drills were either Haybuster or Yielder. All 1986 winter wheat and 1987 spring wheat experiments were planted with dealer or conservation district Haybuster, no-till hoe drills, equipped with 5" x 15" fixed position paired row hoes. This drill allowed for "deep band" placement of all fertilizer approximately 2 1/2" between and 2" below the paired rows.

Each plot consisted of a minimum of 1 drill pass, 200′ in length. At each site, the drill was calibrated to insure proper seeding rate. Prior to planting each treatment, the drill was cleaned of fertilizer, appropriate fertilizer blend was placed in the drill, and the drill was calibrated to insure appropriate fertilizing rate.

Variety and seeding rate were kept constant for all treatments at a given site. In most instances, the cooperating farmer and participating county agent provided necessary weed control. Plots were harvested at maturity, using a small-plot research combine. Grain samples were cleaned and weighed to determine yield, test weight, and other physical characteristics. Additional analyses were conducted to determine protein, grain quality and baking characteristics.

RESULTS AND DISCUSSION

The 1986 spring grain and 1986 winter wheat experiments were established with essentially the same experimental design throughout. Minor changes in design were made between spring and fall experiments, i.e., the surface broadcast, non-incorporated till plant treatment was deleted from the fall 1986 winter wheat trials. The experiment was substantially modified prior to the 1987 season, eliminating the till plant component; only no-till planting was evaluated in 1987.

Tables 2, 3, and 4 include average yield by location for composite check, deep-band, and broadcast treatments for 1986 and 1987. In addition, comparisons of average no-till and till plant yields for all 1986 experiments are presented. Pre-plant soil test nitrogen levels are also presented.

Four 1986 spring grain sites responded favorably to fertilizer additions: Prairie, Richland, Flathead, and Lake. Drought and excessive grasshopper damage limited yield at Liberty and Roosevelt sites. In addition, significant yield losses due to grasshopper damage were observed at Prairie and Richland sites (Table 2). Average 1986 spring grain yield was increased 3-8 bushels per acre by fertilizer additions. Composite no-till average was 33 bushels per acre, while the composite till plant and check treatments were 28.3 and 25.1 bushels per acre, respectively. The average no-till and till plant yields represent all fertilizer placement methods and check treatment averages. Comparing only deep band with broadcast, there was no observable yield difference due to fertilizer placement method. This is reflected in the average yield of 34.2 and 34.3 bushels per acre for deep band and broadcast, respectively.

Table 2. Summary of 1986 no till and till plant spring grain yields, as affected by precise fertilizer placement and soil test nitrogen level.

	Prairie	Richland	Flathead**	Liberty	Roosevelt	Lake**	Average
			- Location -				
Crop	b	b	b	b	sw	sw	
Soil Test N (#/ac)	11	47	52	15	54	68	41
			- Yield (bu/ac) -				
Check	8.1	54.6	57.8	12.7	12.1	5.5	25.1
No till*	19.9	63.9	71.4	7.7	13.0	22.1	33.0
Conv. till*	18.5	54.4	59.1	13.8	11.9	12.3	28.3
Deep band	24.6	59.2	76.3	8.0	12.9	24.0	34.2
Broadcast	21.4	60.6	78.4	11.1	12.8	21.8	34.3

* Average of all fertilized no till treatments or all fertilizer conventional tillage treatments; b = barley, sw = spring wheat.
** Irrigated site.

Winter wheat responses to tillage method were less dramatic than spring grain response (Table 3), although the winter wheat plantings responded more to fertilizer placement method. Average response to fertilizer addition was 11-16 bushels per acre. Deep band fertilizer placement resulted in approximately a bushel per acre yield increase above broadcast placement and 15.7 bushels per acre more than the average check treatment. In five of the six 1986 winter wheat experiments, deep banding resulted in a significant yield improvement over broadcasting. Grain yield at the Liberty site was again limited by plant-available water.

Table 3. Summary of 1986 no till and till plant winter wheat grain yields, as affected by precise fertilizer placement and soil test nitrogen level.

	Glacier	Fergus	Judith Basin	Liberty	Lake**	Wibaux	Average
			- Location -				
Soil Test N (#/ac)	44	1	108	100	60	20	56
			- Yield (bu/ac) -				
Check	20.8	11.5	32.6	8.1	41.1	22.4	22.8
No till*	23.0	41.9	35.9	9.7	79.7	34.1	35.8
Conv. till*	20.9	44.4	33.5	8.8	82.9	28.6	34.3
Deep band	22.6	49.6	36.4	10.3	76.0	35.3	38.4
Broadcast	19.8	29.2	33.2	8.9	77.4	31.1	33.3

* Average of all fertilized no till treatments or all fertilizer conventional tillage treatments.
** Irrigated site.

The 1987 experiments evaluated significance of fertilizer placement in both summer-fallow and no-till recrop rotations. Side-by-side comparisons of summer-fallow vs. no-till recrop were made at Valley South (S) and North (N) and Fallon (Table 4). In anticipation of these comparisons, and based on 1986 and previous study results, till-plant seeding operations were not evaluated in 1987. With exception of the Valley-S-recrop and Fallon-recrop site, pre-plant soil test nitrogen levels were relatively high, i.e., > 40 pounds per acre. Only at the Valley-S-recrop site, where pre-plant test nitrogen was low, was a significant response to fertilizer measured. Yield of all treatments was limited at the Roosevelt and Fallon-recrop sites by inadequate plant-available water. Average response across all 1987 trials indicated only a 3 bushel per acre response to fertilizer additions and no response to fertilizer placement.

Table 4. Summary of 1987 no-till spring wheat yields as affected by precise fertilizer placement and soil test nitrogen level.

					- Location -					
		Valley - S*			Fallon		Valley-N			
	Roosevelt	#1-R	#2-SF	Richland	#1-R	#2-SF	#1-R	#2-SF	Wibaux	Average
Soil Test N (#/ac)	40	10	54	95	22	55	42	124	86	59
					- Yield (bu/ac) -					
Check	19.5	11.7	33.2	43.5	12.6	36.0	23.0	38.2	36.3	28.2
No till				**						
Deep band	17.2	28.3	31.1	50.8	11.2	39.0	23.3	42.0	38.3	31.2
Broadcast	21.2	23.3	33.0	48.1	11.8	36.9	23.7	43.6	41.4	31.4

* R = recropped; SF = Summerfallow site.
** Irrigated site.

Table 5 is a composite summary of responses from all 21 study sites. No till yield was approximately 3.5 bushels per acre greater than till-plant. We speculate that this difference was due to differences in stand establishment between the no-till and till plant treatments, although population measurements were not made to substantiate this hypothesis. Average response to broadcast fertilization was approximately five bushels per acre (over check treatment) while response to deep-banding was approximately eight bushels per acre. This latter response represents a 34% yield improvement above the check treatment yield and a 10% improvement over the broadcast fertilizer practice.

The 1986-87 winter wheat experiments offer opportunity to evaluate the significance of several different fertilizer placement strategies, in both no-till and till plant cropping systems (Table 6). Average pre-plant soil test nitrogen level was 56 pounds per acre, while the average rate of applied nitrogen was 65 pounds per acre and the average check treatment yield was 22.8 bushels per acre. The deep band x 1.5 (increased fertilizer rate to 1.5 times recommended) was included to investigate the potential yield gain that might be realized from additional moisture conservation in no-till. Increasing the deep-band fertilizer rate in no-till resulted in a yield decrease (compared to the recommended rate) at all but the irrigated site, i.e., Lake. It is our opinion that the greater deep band fertilizer rate (at 1.5x) resulted in excessive, early-season vegetative growth, beyond the capacity to be supported by plant-available water at all but the irrigated site.

Table 5. Summary of 1986-87 yield responses to tillage method and fertilizer placement strategy, all sites combined.

	- Grain yield, bushels/acre -				
	1986	1986	1986	1987	
Treatment	Barley	Spring wheat	Winter wheat	Spring wheat	Average
No till	41.5	17.2	33.7	30.3	30.7
Till plant	38.8	11.7	31.6	--	27.4
Check	36.4	9.0	22.8	28.2	24.1
Deep band	42.8	16.5	39.0	31.2	32.4
Broadcast	39.0	14.5	31.1	31.4	29.0

Table 6. Winter wheat response to tillage and fertilizer placement method.

	Glacier	Fergus	Judith Basin	Liberty	Lake	Wibaux	Average
Soil Text N (#/ac)	44	1	108	10	60	20	56
N applied (#/ac)	33	119	0	88	110	41	65
Check yield (bu/ac)	20.8	11.5	32.6	8.1	41.1	22.4	22.8
No Till							
Check	22.1	13.1	36.6	8.5	49.8	20.3	25.1
Broadcast	19.3	28.3	34.4	10.2	75.3	34.8	33.7
Deep band	25.5	50.7	39.8	11.0	70.4	36.3	39.0
Deep band x 1.5	24.3	46.6	33.5	8.0	93.3	34.8	40.1
Till Plant							
Check	19.4	9.8	28.9	7.7	32.4	24.5	20.5
Broadcast	20.3	30.1	32.0	7.6	79.5	27.4	32.8
Deep band	19.7	48.5	33.0	9.6	81.5	34.3	37.8
Deep band x 1.5	22.7	54.7	35.5	9.3	87.7	25.1	39.2
Average Response	1.2	31.7	2.1	1.2	28.9	9.7	14.3

Conversely no-till deep-band placement, with exception of the irrigated Lake site, resulted in a significant yield increase over the check and broadcast treatments. In both no-till and till-plant tillage systems, deep-banding fertilizer at the same rate as broadcasting resulted in a 5-6 bushel per acre yield increase.

The 1987 experiments compared both fertilizer placement strategy and previous crop history effects on yield and grain quality. Side-by-side comparisons of crop-summer fallow and annual crop rotations were made. In addition, several other fertilizer placement strategies were considered, including combined deep banding with broadcasting. Results of these comparisons are summarized in Table 7.

No response to fertilizer placement method was measured in the crop-summer fallow cropping sequence. Average response to fertilizer addition was only 3 bushel per acre. No advantage to deep-band or split (deep-band plus top-dress combination) placement was measured. No yield increase was obtained as a result of increasing the applied fertilizer rate by 50%. Average recrop yield was approximately 50% of the yield following summer fallow, reinforcing the contribution of summer fallowing as a moisture storage method. Response to fertilizer addition was only 3 bushels per acre, while response to method of fertilizer placement, i.e., broadcast, deep-band, or split, was non-significant. A slight yield increase due to deep banding 1.5 x the recommended rate in the recrop system was observed.

Table 7. Summary of 1987 spring wheat yields, as affected by cropping history and no-till fertilizer placement method.

	- Location/Yield, (bu/ac) -				
Treatment	Valley-South	Richland	Fallon	Valley-North	Wibaux	Average
Check	33.2	43.5	36.0	38.2	36.3	37.4
Broadcast	33.0	48.1	36.9	43.6	41.4	40.6
Deep band	31.1	50.8	39.0	42.0	41.4	40.9
Deep band P + 10N	33.4	49.3	38.7	38.6	37.5	39.5
Deep band All + 10N	34.8	46.2	38.7	43.0	39.1	40.4
Broadcast x 1.5	33.5	47.2	37.8	43.9	40.1	40.5
Deep band x 1.5	33.9	49.1	38.4	38.1	42.7	40.4
LSD	1.7	5.6	3.1	4.9	6.1	

Treatment	Roosevelt	Valley-South	Fallon	Valley-North	Average
Check	19.5	11.7	12.6	23.0	16.7
Broadcast	21.2	23.3	11.8	23.7	20.0
Deep band	17.2	28.3	11.2	23.3	20.0
Deep band P + 10N	21.2	23.1	10.3	23.6	19.6
Deep band All + 10N	20.2	22.7	11.4	25.0	19.8
Broadcast x 1.5	19.9	22.7	11.6	23.1	19.3
Deep band x 1.5	22.3	24.8	13.3	24.6	21.3
LSD	4.0	1.8	1.4	3.5	

Quality factors, including protein, test weight, milling, and baking characteristics will be available at a later date. At the present time, only limited data about test weight are available. Preliminary observations indicate that fertilizer placement methods may significantly affect protein, milling, and baking qualities. Table 8 is a summary of test weight data from 1986 experiments. Average test weight of fertilized barley was less than that of check treatments. In addition, slight reductions in test weight occurred as a result of deep-banding, especially at rates above the recommended fertilizer level. Conversely, deep banding resulted in slightly greater spring wheat test weights than check treatments and no observably consistent changes in winter wheat test weight. Average test weight of no-till treatments was consistently greater than average test weight of till plant.

Table 8. Average test weight for 1986 crops, as affected by tillage method and fertilizer placement strategy.

	Test weight (lb/bu)		
Treatment	Barley	Spring Wheat	Winter Wheat
No Till			
Check	48.9	60.9	59.2
Broadcast	47.7	61.2	59.5
Deep band	46.6	61.2	59.6
Deep band x 1.5	45.9	61.6	59.5
Till Plant			
Check	48.9	57.9	59.4
Broadcast	46.6	59.1	59.3
Brodcast + inc.	46.4	59.9	--
Deep band	46.5	59.1	59.2
Deep band x 1.5	46.3	58.6	59.1
Average No Till	47.3	61.2	59.5
Average Till Plant	47.0	58.9	59.3

SUMMARY

A two-year, multi-site experiment was conducted at 21 locations in northeast and north central Montana during 1986 and 1987. Tillage methods compared were spring till-plant and no-till. Crops included spring wheat, barley, and winter wheat. Fertilizer treatments were modified slightly during the two-year study, but all experiments included check (no fertilizer), deep-band fertilizer placement (in one-pass seeding operations), and surface broadcast fertilizer placement (with or without pre-plant incorporation).

Results of grain yield and crop quality measurements indicate that:

- average no-till yields were approximately six bushels per acre greater than till-plant yields;
- deep-band fertilizer placement midway below and between 5"-spaced paired rows resulted in an average yield approximately 3-4 bushels per acre greater than surface broadcast fertilizer treatment yields;
- no consistent effects of fertilizer placement method on test weight were observed, although test weight appeared to be greater where fertilizer placement method resulted in increased fertilizer use efficiency.

SNOW TRAPPING AND NITROGEN MANAGEMENT FOR ZERO TILLED SPRING WHEAT IN SOUTHWESTERN SASKATCHEWAN

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ABSTRACT

The results to date show that the feasibility of stubble cropping in the Brown soil zone of western Canada can be improved if tall stubble trap strips are used for trapping snow. The average advantage in conserved soil water for tall stubble compared to short stubble was 0.5 in. This is only 25% of that usually conserved by summerfallowing. Although the snow is often trapped, getting the meltwater to enter the soil is still a major problem. Much of the meltwater is lost through runoff due to rapid thaw of the snowpack during Chinooks. The use of zero tillage management may be causing an increase in the rate of water infiltration into the soil, but more research is needed to explore this and to develop alternative ways to enhance meltwater infiltration. The higher spring soil moisture reserves in tall compared to short stubble were translated into higher grain yields and higher net returns in years with limited rainfall. The economic benefit of snow trapping averaged 6-9 $/ac in dry years and 2-3 $/ac in years with average rainfall, but there was no benefit in wet years. Yields were increased by N fertilizer rates up to 88 lb/ac in years of favorable moisture; but, in dry years there was no yield response to fertilizer N irrespective of time, method, or rate of application. But, net returns were generally highest for fall application of fertilizer N and for the broadcasting method of N placement, directly reflecting the lowest cost method of fertilizer management. In years with average or better rainfall, yields were generally higher for spring than for fall applied N, and for banded than for broadcast N. In contrast, net returns in these years were little affected by the fertilizer management system used.

OBJECTIVES

Successful crop production in the semiarid Brown soil zone of western Canada requires adapting to low and variable amounts of water. Potential evapotranspiration normally exceeds growing season rainfall, thus a severe water shortage for plants develops unless an ample reserve of soil water is stored before planting (Nicholaichuk 1984). Approximately 30% of the total precipitation received in this area comes as snow, and under conventional summerfallowing practices much of it is blown off the field and lost. It is imperative that we attempt to conserve as much of this water as possible and that the conserved water be used efficiently.

This paper reports on 6 years of results from an ongoing study to determine the influence of alternative snow and fertilizer management systems on winter precipitation conserved, grain yields, and on economic returns for spring wheat grown continuously using zero tillage management at Swift Current, Saskatchewan.

MATERIALS AND METHODS

The experiment was initiated at the Swift Current Research Station in 1982 on a Swinton silty loam soil (Ayres et al. 1985), an Aridic Haploborall. It was composed of four 6 ac replicates, each split into two main stubble height treatments: a uniform short stubble (6-8 in high) and a tall-short stubble treatment (hereafter called tall stubble) (Campbell et al. 1986). The tall stubble plots were created with a deflector attachment mounted on a self-propelled swather (Dyck et al. 1982) and consisted of one strip of standing stubble about 16-24 in tall by 12 in wide every width of the swather (18 ft) and running in a perpendicular direction to the prevailing winds; the remainder of the 18 ft area was cut at the standard height.

Each stubble height treatment was divided equally and randomly into three year-subplots which allowed the experiment to be moved yearly so as to minimize residual effects of fertilizer. The test-year subplots were divided into four N fertilizer (urea) sub-subplots. In first year the N fertilizer rates were 22, 44, 88, and 132 lb/ac. In subsequent years the 132 lb/ac N rate was changed to 66 lb/ac. Each N fertilizer rate treatment was divided into two sub-sub-subplots which compared broadcast application to banding at 5-6 in depth on a 12 in spacing. There was a further split which allowed comparison of fall versus spring application of N. All test-year plots received blanket applications of P, K, and S to remove any deficiencies in these nutrients. The year-plots not under test (hereafter called filler plots) received 25 lb/ac N and P_2O_5 fertilizer applied with the seed.

Plots were planted to Canuck spring wheat in early May of each year using a zero-till offset disc drill without seedbed preparation. At harvest each year the test-plots were trimmed to a constant size and a small combine was used to thresh grain samples taken perpendicular to the trap strips and to the direction of seeding.

Each replicate was staked in the fall to facilitate soil and snow sampling at the same points each time of measurement as described by Campbell et al. (1986). Soil cores were taken in fall (usually late September) and spring (usually early May) close to each stake for soil moisture, NO_3-N, and $NaHCO_3$-P determinations in the 0-6, 6-12, 12-24, 24-36, and 36-48 in depths. Snow surveys were taken whenever there was a significant change in the snow pack. Growing season rainfall, air temperatures, and wind speeds were recorded at a meteorological station located 0.3 mi to the east of the test site.

The economic optimum rates of N fertilizer and the associated net returns for each method and time of N placement were calculated for a range of wheat prices and fertilizer costs. Multiple regression was used to relate yields for each fertilizer management treatment to total available N at time of planting (i.e., soil test NO_3-N in 0-24 in depth plus applied N fertilizer). For this purpose, the data were arbitrarily separated into dry years (1984 and 1985), normal years (1983 and 1987), and wet years (1982 and 1986) and second degree polynomial relationships (regressed through the origin) were determined. The first derivative of the relationships were solved for rates of total available N that maximized physical yields and for rates that maximized net returns at various fertilizer N cost/wheat price ratios. In the analysis, emphasis was placed on the assumed higher cost of N fertilizer and farm labor in the spring compared to fall, the higher costs for energy and equipment ownership for banding compared to broadcasting fertilizer, and the interest charges on operating capital (Table 1).

Table 1.Summary of Economic Assumptions

Item	Cost	Units
Farm Labor - Fall	6.	$/h
- Spring	12.	$/h
Fertilizer N Cost - Fall	0.85	index
- Spring	1.00	index
Banding - variable plus fixed cost	5.92	$/ac
- labor required	0.08	h/ac
Broadcasting - variable plus fixed cost	1.46	$/ac
- labor required	0.05	h/ac
Interest Rate	10.	%

RESULTS AND DISCUSSION

Precipitation and Weather Conditions

The weather during the 6 years of study reinforced the historical pattern of extreme variability. Precipitation received between fall and spring soil sampling averaged 3.7 in and ranged from 2.5 to 5.2 in. Growing season (May-July) rainfall in the years 1982 to 1987 respectively were 9.6, 7.3, 3.9, 2.9, 8.1, and 5.1 in. These compare to our long-term (99 yr) mean growing season rainfall of 6.5 in. Growing season air temperatures and wind speeds in the dry years were much above average resulting in severe moisture stress for growing plants (data not shown).

Moisture Conservation

Each year, significantly more snow was trapped in tall than in short stubble treatments. Further, the snow trapped was observed to persist in the tall stubble areas for days after it had disappeared from short stubble areas during periods of warm Chinook winds. The water equivalent of snow trapped in the tall stubble treatments averaged 3.4 in or 92% of the fall to spring precipitation received, and 1.8 in or 49% of the fall to spring precipitation received in short stubble treatments (Table 2). It was greater than the actual precipitation received during the fall to winter period for the tall stubble treatments in 1983-84 and 1985-86. In contrast, the water equivalent of snow trapped on short stubble areas was below the level of fall to spring precipitation received in all years, reflecting the greater snow loss through blowoff. One problem foreseen for this snow trapping technique in the Brown soil zone is that in dry years restricted soil water supply when stubble cropping will result in insufficient stubble height for construction of adequate snow trap strips.

The extra water conserved in tall stubble compared to short stubble areas averaged 0.5 in (1.7 vs 1.2 in) in the top 48 in of soil depth and varied from -0.3 in in 1985-86 to 1.1 in in 1984-85 (Table 2). These results are similar to those reported by Nicholaichuk (1980) and Kachanoski (1985), but are substantially below the extra 1.8 in of

Table 2. Conservation and Efficiency of Intake of Fall and Winter Precipitation

Season	Precipitation Fall to Spring	Water in Snow Trapped		Water Conserved		Advantage of Tall stubble	Efficiency of Precipitation Intake	
		Tall	Short	Tall	Short		Tall	Short
	(in)						(%)	
1981-82	5.2	3.8	1.7	1.9	1.5	0.4	37	29
1982-83	3.7	1.6	1.3	1.2	1.0	0.2	32	27
1983-84	2.7	2.7	1.1	1.8	0.8	1.0	67	30
1984-85	5.2	4.8	2.4	3.3	2.2	1.1	63	42
1985-86	2.5	3.9	2.4	0.3	0.6	-0.3	12	24
1986-87	3.0	ND	ND	1.7	1.3	0.4	57	43
Mean	4.7	3.4	1.8	1.7	1.2	0.5	45	33
Stubble (Ht)		**		*		--	**	
Year (yr)		**		**		*	**	
Ht x yr		**		NS		--	*	

*, ** Significant at P<0.05 and at P<0.01, respectively; NS, not significant.

available soil moisture by which fallow fields generally exceed stubble fields in the Brown soil zone (de Jong and Steppuhn 1983; Campbell et al. 1987b). The efficiency of meltwater intake averaged 45% for tall stubble and 33% for short stubble. The efficiency of short stubble is similar to that reported for this system in the past (Campbell et al. 1987b). The high efficiency of meltwater intake in 1983-84, 1984-85, and 1986-87 was due to a combination of factors including the relatively dry soil conditions in the fall, few Chinook winds during winter which minimized the formation of ice layers at or near the soil surface, and slow spring melting of the snowpack. In contrast, the particularly low efficiency of meltwater intake in 1985-86 was due to thawing and refreezing of meltwater in the warmer than usual winter which formed ice layers that sealed the soil surface, and a rapid thaw and runoff in late winter as a result of a sudden Chinook. Significant runoff losses of meltwater also occurred in the first two years of the study as a result of rapid spring melting of the snowpack. These results highlight a second problem with snow trapping: that of obtaining good infiltration of meltwater during periods of rapid thaw by Chinook winds, especially when soil moisture is high going into the winter period (de Jong and Steppuhn 1983).

Effect of Stubble Height and N Fertilizer on Spring Wheat Yields

Wheat yields were directly related (r=0.90) to the level of growing season rainfall. In years of favorable moisture, yields were increased by application of N fertilizer (Table 3); maximum yields in these years were obtained at N fertilizer rates of 66-84 lb/ac. At these rates of N fertilizer, yields were often 70-100% higher than those obtained on the filler plot areas which received only 25 lb/ac of fertilizer N. In dry years, crop yields were unaffected by N fertilizer, and test plot yields were generally lower than those obtained on filler plots (data not shown). This latter effect occurred because the higher rates of N fertilizer stimulated rapid and lush early growth of the wheat plants which utilized all of the available soil water and the plants became completely desiccated before the scant summer rains came. In contrast, plants receiving lower rates of N fertilizer grew more slowly and utilized less water and were able to use summer rains more efficiently. This problem of little yield response or of depressing crop yields by application of moderately high rates of N fertilizer is not uncommon with stubble cropping in the Brown soil zone, and since drought can be expected as a rule rather than an exception, care must be taken not to over-fertilize.

Table 3. Soil N and Effect of Stubble Height and N Fertilizer on Wheat Yields+

Year	Soil NO_3 -N (0-24 in)	Stubble Height	Fertilizer N Rate (lb/ac)++ 22	44	66	88	Mean
	(lb/ac)		(bu/ac)				
1982	23	Tall	29.9	33.1	(34.9)^	36.9	33.7
		Short	27.0	30.8	(35.8)^	39.6	33.3
1983	12	Tall	20.8	24.3	29.3	29.6	26.0
		Short	20.2	24.2	24.5	28.2	24.3
1984	13	Tall	9.7	8.7	10.6	10.7	9.9
		Short	7.3	6.8	6.5	7.1	6.9
1985	22	Tall	11.7	10.2	8.1	9.6	9.9
		Short	8.2	7.6	7.8	6.9	7.6
1986	44	Tall	39.2	38.8	42.1	41.5	40.4
		Short	37.6	39.0	38.8	40.0	38.8
1987	21	Tall	17.3	19.7	21.6	23.6	20.6
		Short	19.2	20.6	22.3	22.8	21.2
1982-87	23	Tall	21.4	22.5	24.4	25.3	23.4
		Short	19.9	21.5	22.6	24.1	22.0
		Mean	20.7	22.0	23.5	24.7	22.7

\+ Values are averaged over time and method of N application.
++ Main effects (year, stubble height and N fertilizer) were significant ($P<0.05$) as were several interactions.
^ Estimates based on missing plot techniques.

In 4 of 6 years, yields were higher ($P<0.05$) on tall stubble than on short stubble (Table 3). The overall yield advantage of tall stubble averaged 1.4 bu/ac or about 6% more, and was particularly significant in years of low growing season rainfall. However, the extra moisture conserved by tall stubble cannot account for the yield difference between stubble heights in some years (e.g., 1984). We believe that the zero till-trap strip combination may also be increasing yield by reducing evapotranspiration through reduced wind speeds near the soil surface. In 1982 a significant ($P<0.05$) interaction between N rate and stubble height on grain yield was observed; at low N rates tall stubble yielded more than short stubble, while at high N rates the converse was true. This was explained in terms of differences in rates of soil water use and the timing of growing season rainfall (Campbell et al. 1986).

The effect of timing and method of N application on grain yields varied with the year (Table 4). During the two dry years there was no effect of either method of N placement nor time of N application on yield. In contrast, in the wettest year (1982), spring banded N gave the highest yields and fall broadcast gave the lowest yields. Yields for spring banded treatments were thus 17% (5.2 bu/ac) greater than for fall broadcast treatments in this year. In 1983, a year with average rainfall, all fertilizer management systems except fall broadcast N gave similar yields; fall broadcast N gave 2.2 to 4.1 bu/ac less yield than the other treatments. In 1986 and 1987, there was no effect of time of N application, but yields averaged 1.0 and 3.6 bu/ac higher in the respective years for banded compared to broadcast N. When averaged over years, the overall relative responses to the N management systems were rated 100, 97 , 95, and 90 for spring band, fall band, spring broadcast, and fall broadcast, respectively. This compares to rating of 100, 100, 83, and 75 for the same fertilizer management systems reported for the dry regions of Alberta (Penny 1985).

Optimum Available N Levels and Effects of Fertilizer Management on Net Returns

The economic optimum levels of total available N were lower than those which maximized grain yields; they increased as the level of total available water increased, and decreased as the ratio of N fertilizer cost to wheat price increased (Table 5). In dry years, the optimum total available N levels averaged 5 to 10 lb/ac higher on tall than on short stubble because of the greater available soil moisture, and were similar regardless of time or method of N application used. In years of average moisture, the optimal N levels were often higher for tall than for short stubble, for fall than for spring application of N, and for band than for broadcast. In wet years, optimum available N levels were higher for broadcast compared to band application; no other factors were significant.

Net returns (i.e., revenue above the cost of fertilizer and fertilizer application) averaged 6-9 $/ac higher on tall stubble than on short stubble in dry years, but only 2-3 $/ac higher in years with average rainfall and no difference in wet years (Table 6). In dry years, broadcast application of N was more profitable than banding irrespective of time of application. But, in years of average moisture, fall broadcasting provided the lowest net return, while in wet years net returns were generally similar for all fertilizer management systems.

Soil Quality and Weeds

Although space and time do not allow details, it should be noted that biological and biochemical measurements made on these plots reveal a significant improvement in soil quality and soil physical properties due to the use of zero tillage (Campbell et al. 1987a). We believe that this is contributing to an improvement in efficiency of meltwater intake with time. However, we have also found that after only 6 years of zero tillage, perennial grassy weeds have become a serious problem.

Table 4. Effect of Time and Method of N Placement on Yield+

Year	Method of^ Placement	Time of Application++ Fall	Spring	Mean
		---------- (bu/ac) ----------		
1982	Band	34.0	35.5	34.8
	Broadcast	30.3	34.1	32.2
1983	Band	25.0	26.0	25.9
	Broadcast	22.8	25.9	24.3
1984	Band	8.4	8.5	8.5
	Broadcast	8.4	8.3	8.4
1985	Band	8.8	8.7	8.8
	Broadcast	9.0	8.4	8.7
1986	Band	40.3	40.0	40.1
	Broadcast	39.7	38.5	39.1
1987	Band	22.4	23.0	22.7
	Broadcast	18.8	19.4	19.1
1982-87	Band	23.2	23.8	23.5
	Broadcast	21.5	22.5	22.0
	Mean	22.3	23.1	22.7

\+ Values are averaged across stubble height and rates of fertilizer.

^ All main effects and several of the second and third order interactions were highly significant.

++ In 1985 these treatments were early-April and mid-May because early arrival of winter prevented a fall application.

Table 5. Economic Optimum Levels of Total Available N+

Stubble Height/Time/Method	Maximum++ Yield	Fertilizer N Cost/Wheat Price^ 0.05	0.075	0.10	0.125
				(lb/ac)	
Dry Years					
Tall - Fall & Spring					
- Band & Broadcast	75	63	56	50	43
Short - Fall & Spring					
- Band & Broadcast	74	57	49	40	32
Normal Years					
Tall - Fall - Band	99	90	86	82	77
- Broadcast	95	86	81	76	72
- Spring - Band	83	77	73	70	67
- Broadcast	81	75	71	68	65
Short - Fall - Band	85	78	75	71	68
- Broadcast	87	79	76	70	67
- Spring - Band	86	80	76	73	70
- Broadcast	81	74	71	68	65
Wet Years					
Tall & Short - Fall & Spring					
- Band	107	100	97	93	90
Tall & Short - Fall & Spring					
- Broadcast	113	105	101	97	93

\+ Includes soil test NO_3-N (0-24 in depth) plus applied fertilizer N.
++ Level of total soil N which maximizes yield.
^ N fertilizer cost measured in $/lb and wheat price in $/bu.

Table 6. Effect of Changes in Wheat Price and Fertilizer Costs on Net Returns+

Stubble Height/Time/ Method			Wheat Price = \$2.50/bu N Fertilizer Cost (\$/lb)^ 0.15	0.20	0.25	Wheat Price = \$3.25/bu N Fertilizer Cost (\$/lb)^ 0.15	0.20	0.25
			(\$/ac)					
Dry Years								
Tall	- Fall	- Band	11	8	6	19	16	13
		- Broadcast	16	13	11	24	21	18
	- Spring	- Band	10	7	4	18	15	12
		- Broadcast	15	12	11	23	20	17
Short	- Fall	- Band	4	2	0	10	7	5
		- Broadcast	9	7	5	15	12	10
	- Spring	- Band	3	1	-2	9	6	3
		- Broadcast	8	6	3	14	11	8
Normal Years								
Tall	- Fall	- Band	51	46	42	72	67	63
		- Broadcast	45	41	38	63	59	55
	- Spring	- Band	50	46	42	71	67	63
		- Broadcast	50	46	42	69	65	61
Short	- Fall	- Band	46	42	39	65	62	58
		- Broadcast	45	41	38	62	58	55
	- Spring	- Band	50	46	42	70	66	62
		- Broadcast	48	45	41	67	63	59
Wet Years								
Tall	- Fall	- Band	81	77	72	112	107	103
&		- Broadcast	82	77	72	111	106	101
Short	- Spring	- Band	80	74	70	110	105	100
		- Broadcast	80	75	69	109	104	99

\+ Income above the cost of fertilizer and fertilizer application.
^ N fertilizer cost in spring; fall fertilizer N costs are 85% of spring.

CONCLUSIONS

1. We have only been able to conserve 0.5 in of extra water instead of the 2 in that we had hoped for. However, it appears that this conserved water may be more efficiently used than that stored in fallow.

2. Yield analysis shows clearly that broadcasting N in the fall is the worst scenario of the band-broadcast-fall-spring application combinations, but the economic analysis suggests that this may well

be the best scenario. The economic picture for banding fertilizer would improve if it could be combined with another field operation, or if zero-till seeding equipment capable of banding fertilizer separate from the seed would become readily available.

3. Although not discussed in detail here, an improvement in soil quality associated with the snow and fertilizer managed zero till system may be one of its greatest advantages.

4. Perennial grassy weeds present the greatest drawback to this cropping system.

ACKNOWLEDGMENT

The authors acknowledge the financial assistance of the Potash and Phosphate Institute of Canada and the following companies for donation of fertilizers and herbicides: Hoechst Canada Inc., Simplot Chemical Co. Ltd., Saskatchewan Wheat Pool, Cominco Ltd., and Monsanto, Canada, Inc.

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MANURE/SEWAGE SLUDGE EFFECTS ON MICRONUTRIENTS

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ABSTRACT

Micronutrients iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn) can be problems on high pH, calcareous soils. Many acres of potential micronutrient problem soils are found in the midwest to western U.S.. Animal and human manures have been recognized for centuries as valuable fertilizers but are becoming more recently appreciated for their micronutrient benefit. Many micronutrient sensitive plants (especially for Fe and Zn) have been corrected with the use of manure and especially sewage sludge. Sewage sludge has been shown to be longer lasting (Minimum of 5 times longer) than dairy manure on severe sorghum iron deficiency. Sludge also significantly increased soil Zn, Cu, Mn and P to more sufficient levels. Sewage sludge may be considered an alternative micronutrient source on calcareous high pH soil if federal and state guidelines are followed.

OBJECTIVES

Published estimates indicate more than 4.9 million hectare of arable land in 22 states, mainly in midwestern to western United States, are iron (Fe) deficient for plants (Mordvedt, 1975), Zinc (ZN), copper (Cu), and manganese (Mn) are also often associated with calcareous, high pH soils of the midwest to western US. The correction of the micronutrient deficiencies especially iron are more often accomplished with foliar sprays of the micronutrients. Soil applications of available micronutrient salts and chelates are generally considered less efficient than foliar applications and often do not correct deficiencies.

The objective of this review is to demonstrate the efficiency of using manure and sewage sludge as long lasting soil applied micronutrient sources. Manure and sewage sludge are especially interesting under circumstances where foliar sprays or other of the common micronutrient fertilizers either cannot be used, do not work, or are too expensive.

MATERIALS AND METHODS

A 5 year experiment was conducted to determine the effect of manure and sewage sludge on grain sorghum yield and soil chemical composition (McCaslin et al., 1987). A randomized complete block with four replications of three treatments on the Holloman soil(fine-loamy, gypsic thermic, shallow Typic Torriorthent) pH 7.8 was used. The three treatments were fertilized check (no sludge or manure), sludge at 40 tons/acre, and manure at 40 tons/acre (both on a dry weight basis). The sludge and manure was surface applied April, 1980 and plowed in to approximately 10 inches depth. No additional sludge was applied until Spring 1984 when an additional 40 tons/acre was reapplied to half of each sludge plot. Approximately 50 lbs N/acre and 7 lbs P/acre as urea and triple-superphosphate, respectively, were broadcast annually to the experiment and disked in prior to planting. These were the only nutrients applied to the check plots and represent approximate recommended rates for maximum grain sorghum yield. Each of the 12 plots were approximately 30 ft square with sorghum planted in approximately 40 inch rows.

RESULTS AND DISCUSSION

Grain yield for the 5 year sorghum experiment shows the fertilized check treatment produced little or no grain in any of the 5 years (Table 1). The manure treatment produced a moderate yield in 1980, but was no better than the check in the remaining 4 years. The sludge treatment gave good results for all 5 years. It is interesting that the sludge reapplied in 1984 gave similar yield as the residual from 1980. The correction of iron deficiency was still sufficient five croppings after application (McCaslin et al., 1987).

Table 1. Sorghum yield for 1980 through 1984 (McCaslin et al., 1987).

Treatment	1980	1981	1982	1983	1984
Tons/A	lbs/A				
Check	280a*	120b	290b	18b	14b
Manure 40	1490b	175b	302b	9b	17b
IRSS 40	2980c	1700a	1440a	1532a	2800a
IRSS R 40	+	+	+	+	2700a

* = Means within columns followed by the same letter are not significantly different (P<0.05) by orthoganol contrast.
+ = Not possible to collect data.
IRSS R = Sludge reapplied to half of each sludge plot in 1984 only.

Fertilized check plots had DTPA extractable/Fe below the approximate 4.5 ppm critical level (Lindsay and Norvell, 1978) throughout the study, indicative of the poor growth on these plots (Table 2). The manure treatment had DTPA Fe above the soil critical level only in 1980, which is also indicative of the 1980 yield level. The sludge treatment Fe levels were above the critical level for all 5 years of the experiment. Sludge reapplication in 1984 significantly increased DTPA extractable Fe. However, the residual level was sufficient for maximum growth under the conditions of this experiment. The data suggest that the residual effect of the sludge would last for more than 5 years (McCaslin et al., 1987).

Table 2. DTPA extractable soil Fe and Zn from 1980 to 1984.

Treatment	1980	1981	1982	1983	1984
Tons/A			ppm		
			Fe		
Check	2c*	2b	2b	2b	3b
Manure 40	5b	3b	3b	2b	2b
IRSS 40	9a	6a	6a	5a	5a
IRSS R 40	+	+	+	+	8a
			Zn		
Check	0.6b	0.6b	0.5b	0.5b	0.5c
Manure 40	0.7b	0.6b	0.5b	0.5b	0.5c
IRSS 40	8.8a	6.8a	4.8a	3.0a	3.0b
IRSS R 40	+	+	+	+	9.6a

* = Means within columns and element followed by the same letter are not significantly different ($P<0.05$) by orthoganol contrast.
+ = Not possible to collect data.
IRSS R = Sludge reapplied to half of each sludge plot in 1984 only.

DTPA extractable Zn was near the critical level of 0.6 ppm (Lindsay and Norvell, 1978) in all the years for the manure and fertilized check treatments (Table 2). Sludge treatments were well above the the critical level in all years, and reapplication of sludge in 1984 resulted in a significant increase in extractable Zn over the residual. The sludge is an effective Zn source, and data suggest that the residual sludge effect would continue for more than 5 years.

Levels of NaHC03 extractable P (McCaslin et al., 1987) indicate that check treatments remained between the low boundaries (8-16 ppm) where sorghum might show a response (Olsen et al., 1954). The manure and IRSS treatments increased extractable P above the 16 ppm level. The soil data indicate that the sludge and manure are also a good P source and that residual soil P effects would last at least 5 years. Manganese and Cu soils levels were increased to more sufficient levels and maintained at higher levels throughout the study. However, all levels were sufficient for sorghum growth.

The yield and soil test Fe, Zn, data presented (Plus other data such as McCaslin and O'Connor, 1982 and unpublished data) demonstrate how effective manure and especially sewage sludge can be at supplying micronutrients and P to deficient soils. The soil application can also have long lasting residual effects. When manure and sludge are applied on the basis of correcting micronutrient deficiencies then nitrogen, potassium and other nutrients would need to be applied as needed. Federal and state guidelines for sludge use have to be observed. As a guideline, for the sludge used in this study, it could be applied at the rate equivalent to the maximum annual sludge cadmium application rate of

0.45 lbs Cd /A/year suggested by the U.S. Environmental Protection Agency (1983) for food chain crops and sorghum iron deficiency could still be corrected for 3 to 5 years following the one application. Manure and sludge can be an option to consider on high pH, calcareous soils deficient in micronutrients and phosphorus.

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OTHER FERTILITY RELATED RESEARCH PROJECTS AT NEW MEXICO STATE UNIVERSITY

A. Projects being conducted by Dr. Neal B. Christensen, NMSU Agricultural Science Center, Star Route Box 77,Clovis NM, 88101.

1. N and P rate and placement studies in irrigated wheat and sorghum under a high residue management system. This study will evaluate the effects of N and P applied with the seed, below seed, and between and below seed in paired rows of an irrigated wheat-sorghum-fallow rotation.

2. N and P rate and placement in dryland wheat and sorghum under a high residue management system. This study will evaluate N and P rates placed with and below the seeds of a dryland wheat-wheat-sorghum-fallow rotation.

3. Acid based fertilizer trials in dryland and irrigated sorghum. This study will evaluate differences between neutral and acid based fertilizer rates in sorghum grown on calcareous soils.

B. Projects being conducted by Dr. Greg Weiler, NMSU Agricultural Science Center, P.O. Box 1018, Farmington NM 87401.

1. Foliar application of nutrients to Navajo pinto and Viva pink beans. This study will evaluate foliar applications of N,P,K and chelate versus sulfate forms of foliar applied Zn,Fe,Cu, and Mn.

2. Soil application of sulfur to corn. This study will evaluate the effect of sulfur rates on the yield of grain.

3. Yield of corn by N rate. This study will help determine the maximum N rate for corn grown on sandy soils in the Farmington area.

4. Timing of nitrogen applications to three varieties of onions. This study will determine if nitrogen applied toward the end of the season effects storability, neck size, and percent marketable onions.

5. Potassium and magnesium applications to russet burbank potatoes, four winter wheat varieties, one barley and alfalfa. This study will determine if there is a yield response to these nutrients since they are found in low levels toward the end of the growing season.

C. Cooperative project between B. D. McCaslin, Greg Weiler New Mexico State University address given above and Merlin Dillon, Gary D. Franc of Colorado State University, San Luis Valley Research Center, 0249 East Rd. 9 North, Center, CO 81152. Sulfuric acid application to a wheat potato rotation. This study will examine the effects of sulfuric acid application on soil, and yield of the crops. Acid being used is from a coal powered electrical generation plant.

D. Cooperative project between B. D. McCaslin and Bill Melton address given above. Breeding alfalfa for increased phosphorus concentration in the forage. The project objective is to determine if breeding procedores can produce alfalfa populations with increased phosphorus concentrations in the forage at any given levels of soil phosphorus. Then develop the populations.

PHYTOAVAILABILITY SOIL TEST

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ABSTRACT

Contemporary soil tests are based on philosophies and procedures developed 30 to 40 years ago. The standard approach is to extract a representative sample of soil with specific chemical solution, determine the level of nutrient extracted, correlate that level of extracted nutrient to crop response as demonstrated by field experimentation, and finally recommend an application of fertilizer for a specific crop to be grown on the field represented by the soil sample. Soil tests conducted in this manner provide only an "index" of true nutrient availability. Although this approach continues to be highly useful, only minor changes have been made over the years despite huge technological and scientific advances in laboratory equipment and knowledge concerning processes controlling nutrient availability in soils. Also, attempts to "standardize" soil test methods have been only partially successful; in many instances contemporary soil tests simply don't work.

We propose to modernize soil testing with a new process that complements high technology farming. The extraction actually simulates nutrient uptake by plant roots, and the suggested approach will not require more time than present procedures. The extracted nutrients are rapidly and accurately analyzed on modern laboratory equipment to provide a better indication of amounts and kinds of fertilizers required for efficient crop production. Not only will the extraction process be more biologically realistic, but the entire soil test operation will be simplified. Moreover, the procedure would be adaptable for most nutrients and for soils of nearly all kinds, worldwide. Because the extraction process is one which simulates the action of plant roots in absorbing nutrients, we have named the new approach Phytoavailability Soil Test (PST).

INTRODUCTION

Current soil tests are of limited accuracy, leaving much room for improvement by the application of modern technology and more recent scientific advances. For example, Dr. T.R. Peck, University of Illinois (as reported in the Spring, 1987 issue of "Better Crops" magazine) estimates that the "scale of reliability, usefulness, and cost effectiveness of soil tests" ranges from 85 percent for phosphorus, 80 percent for potassium, and 40 percent for sulfur, at their best level of performance. Certain micro nutrient soil tests were given a rating of only 10 to 30 percent. Thus, it can be seen that development of a simple, improved soil test could certainly increase the efficiency of fertilizer management and crop production.

Farm management techniques that will improve fertilizer use efficiency require the development of accurate soil tests for precise fertilizer recommendations. Also, specific management requirements for each soil type will have to be identified. Research is currently being conducted at MSU on a project entitled "Farm Soils, Not Fields" to demonstrate how production efficiency can be increased by managing each soil according to its fertility status and its production potential. Fertilizer application recommendations are generally based on both yield goals as a function of the field's capability and on test results from a composite soil sample. The resultant field-averaged fertilizer application rates will over-fertilize parts of the field and under-fertilize other parts. Fertilizing soils, not fields will reduce fertilizer waste, water contamination from over-fertilization, and reduce instances of under-fertilization. Soils experts from other areas of the country have estimated that 30 to 50 percent of America's fields have enough soil variation to economically fertilize each soil separately. In Montana, with the large scale of farming and large fields, the percentage of fields that would likely benefit from this approach is probably even greater. We believe that many opportunities exist for applying this technology in Montana and the region. This type of innovation in farming can greatly increase the profit potential for producers who properly use it.

To gain maximum benefits from this type of management refinement, it will be necessary to better predict fertilizer needed on each soil type. Development of the PST will provide this additional tool. It will promote acceptance of new, more efficient farming technologies of all kinds. Of course, a more accurate soil test will help improve fertilizer use efficiency under current production methods as well. Furthermore, we feel the approach can be developed to address problems related to impacts of fertilizers on the environment, or other environmental quality aspects.

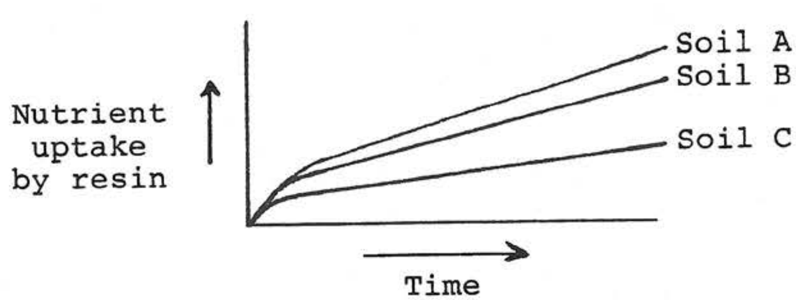
PST - What is it?

Nutrients come into contact with plant roots by three processes. First, roots expand and grow into contact with increasing amounts of soil. However, only a small fraction of the soil volume (less than 5%) is ever contacted by the root. Thus, this process accounts for only a small portion of nutrients which are present at the absorbing surfaces of crop roots. Second, dissolved nutrients are swept to the root in the water which plants absorb. This process, called "mass flow," can account for a large portion of certain nutrients (e.g., nitrate) which contact root surfaces. However, the major portion of most nutrients move to root surfaces by the third process, "diffusion." Diffusion is the mechanism whereby nutrients migrate to the depletion zone near the root in order to maintain the solution equilibrium level. A soil test extraction process which measures diffusion, and also provides the level of soil solution nutrient concentration, will theoretically provide information which directly relates to each soil's capacity to supply nutrients to plant roots in a manner similar to what occurs under field conditions. This differs greatly from single-extract chemical procedures, which provide only an "index" of nutrient availability based on the "extractability" of specific elements in the particular chemical solution employed. Thus, being a "process" which simulates nutrient supply and uptake by plant roots, the PST approach should improve our ability to separate soils based on their capacity to sustain nutrient uptake by crops.

PST - How does it work?

The approach being developed is based on use of ion-exchange resins to extract nutrients. A portion of mixed cation-anion resins, enclosed in a mesh bag, is placed in a soil sample which has been wetted to "saturation" conditions. The sample container is capped and set aside for a prescribed period to allow extraction to occur. The resin bag extractor functions as a "sink," absorbing nutrients as they diffuse toward its surface (where solution concentration would be near zero due to the large exchange capacity of the resin). The resin would give off $H+$ and $OH-$ (or whatever the initial saturation ions were) in exchange for the nutrients adsorbed. Again, this is similar to what plant roots do while absorbing nutrients. At the end of the extraction period, the quantity of each nutrient accumulated in the resin extractor would be dependent upon the initial level of that nutrient in the soil solution, and its rate of diffusion to the resin sink. To determine the quantity of nutrients adsorbed, the resin bag is removed from the soil sample, rinsed with pure water to remove any soil particles, and immediately extracted with a strong acid, or other appropriate solution. Concentrations of all nutrients of interest can then be analyzed with modern equipment using only this one extract solution.

Preliminary results have shown that the proposed approach has definite promise and will function according to theoretical considerations. Placement of a mesh bag containing 5 ml of mixed cation-anion resin into a sample of moist soil has shown a typical uptake vs time curve for each of P, K, and S as shown below:



The differences between soils relate to "quantity" of nutrient uptake (magnitude of extracted nutrient) and "rate" of nutrient supply over time (the slope of the line). These factors for each soil will characterize its nutrient supply capabilities and will allow for more precise and efficient fertilizer recommendations on a soil by soil basis. Although results have only been obtained for P, K, and S, the procedure should be equally useful for all nutrients, including micronutrients. Furthermore, it should allow the determination of plant available characteristics of many environmental contaminants which might be detrimental to plant growth.

PST - Disadvantage/Advantage

The "good news - bad news" for PST is heavily weighted toward the "good." The only major disadvantage we have identified to date, is being able to standardize the "saturation" condition of the sample prior to insertion of the resin bag. Some training/experience may be necessary so that whoever takes the soil sample and initiates the extraction can do this consistently. It is generally no problem with course or medium textured soils, but is more difficult on soils high in expanding-type clays. This is of some concern because, to minimize the lab turn-around time, we anticipate the initiation of the extraction process (by means of a "kit" provided) immediately after the soil sample is taken and before sending the sample to the lab. In this way, the mailing time can be utilized as part of the extraction period. Other problems relate to temperature and time standardization, but simple solutions to these problems can be devised. It may also be necessary to correlate certain aspects of the new soil test approach with new field results, rather than being able to correlate against existing soil test methods. This, however, may be a real advantage rather than a disadvantage, if it provides for more accurate results.

Many advantages for the PST approach can be mentioned. Currently soil samples must be dried, pulverized, weighed or measured, and then extracted with one or more chemical solutions before the extracts are analyzed for specific nutrients. Small differences in any of these steps (e.g., temperature or duration of drying, speed or length of extraction, soil to extractant ratio, etc.) will normally cause differences in amounts of specific nutrients extracted and subsequently analyzed. The PST procedure will eliminate most of these steps, and hence remove them as potential sources of error, or as causes for the lack of standardization. At the same time, it will allow analysis of several nutrients with one extraction. And, because it will work on virtually all kinds of soils, the procedure can be truly "standardized" for use in any region. The extractor will take up all nutrients of interest in a manner which reflects the true capacity of a soil to continuously supply nutrients over time.

We feel that the improved soil test can be offered at or below current costs. The cost of kits for extraction should be more than offset by reducing the number of steps and amounts of chemicals currently required. Improvements in accuracy without an attendant increase in costs could also increase the general use of soil testing. Current under-utilization of soil testing in this country is suggested by data on numbers of soils tested annually. There are approximately 3.5 million soil samples tested annually in the U.S., as compared to more than 27 million tested each year in the Soviet Union through its state-owned laboratories. Thus, the potential for increased fertilizer use efficiency is tremendous merely by increasing the use of soil testing to a level more appropriate for U.S. agriculture. Furthermore, if farm management is done according to soil type, more intensive soil testing will be mandatory. If the innovations and use of high technology prove to be as economical as current results indicate, increases in agricultural efficiency, profits, and competitiveness will be realized.

PST - Some typical results

A typical example of PST potential is illustrated by the following sulfur experiment. A growth chamber fertilizer rate experiment was conducted using seven different Montana soils with Pondera spring wheat as the crop. Treatment rates of actual sulfur in the form of dissolved gypsum were 0, 15, 30, 60, and 120 kg/ha with four replications. Plants were harvested at heading and dry matter yield was used as the response variable.

To evaluate PST as a soil test the third day of equilibration concentration of sulfur by PST was used, as well as the extract concentration of sulfur by the standard ammonium acetate turbidimetric soil test in use today. Both extract concentrations were determined by ICP analysis.

The single data point of three days for PST was chosen because it is a function of both the magnitude (phytoavailable quantity) and the slope of the line (diffusion rate of the soil) constructed by time-phase sampling. The graph of sulfur concentration over seven days of time phase sampling shows the sensitivity of PST to the independent character of each soil with respect to sulfur supply and the validity of a single time point (three days) to express this (Figure 1).

The correlation between the PST and standard soil test concentrations shows there is no relationship between the two tests (Figure 2). This does not indicate that either test is better. It does indicate the two tests are entirely different with respect to the amount of sulfur they retrieve from the soil.

The results clearly indicate that PST is a reliable predictor of fertilizer response and that the current standard test is not reliable. The final step in the process of evaluation will be to work out an algorithm which assigns a workably specific amount of fertilizer sulfur needed per acre based on a particular PST value. This will require correlations involving field fertility experiments.

FIGURE 1 : SOILS

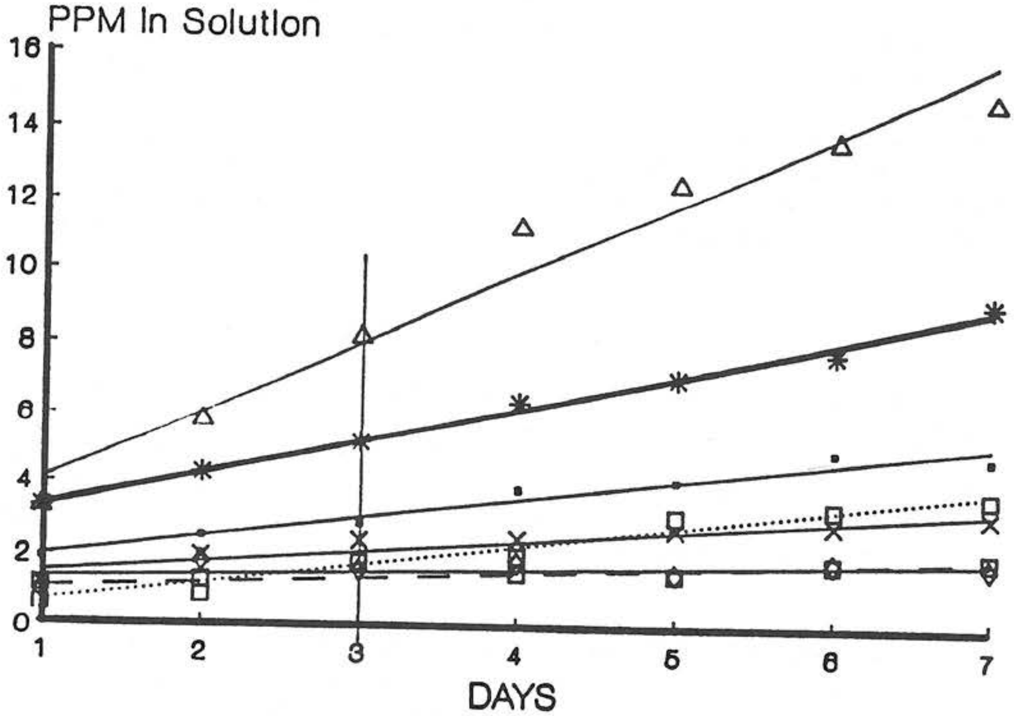


FIGURE 2 : STD VS PST

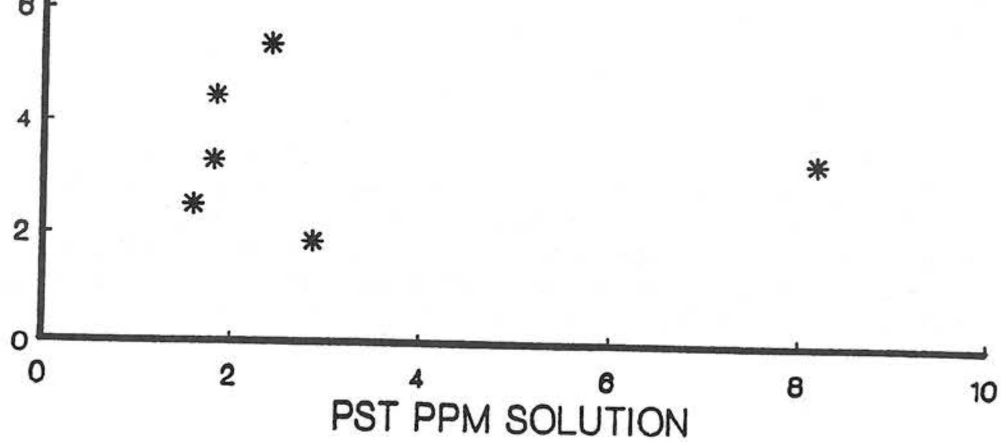


FIGURE 3 : STD VS YIELD

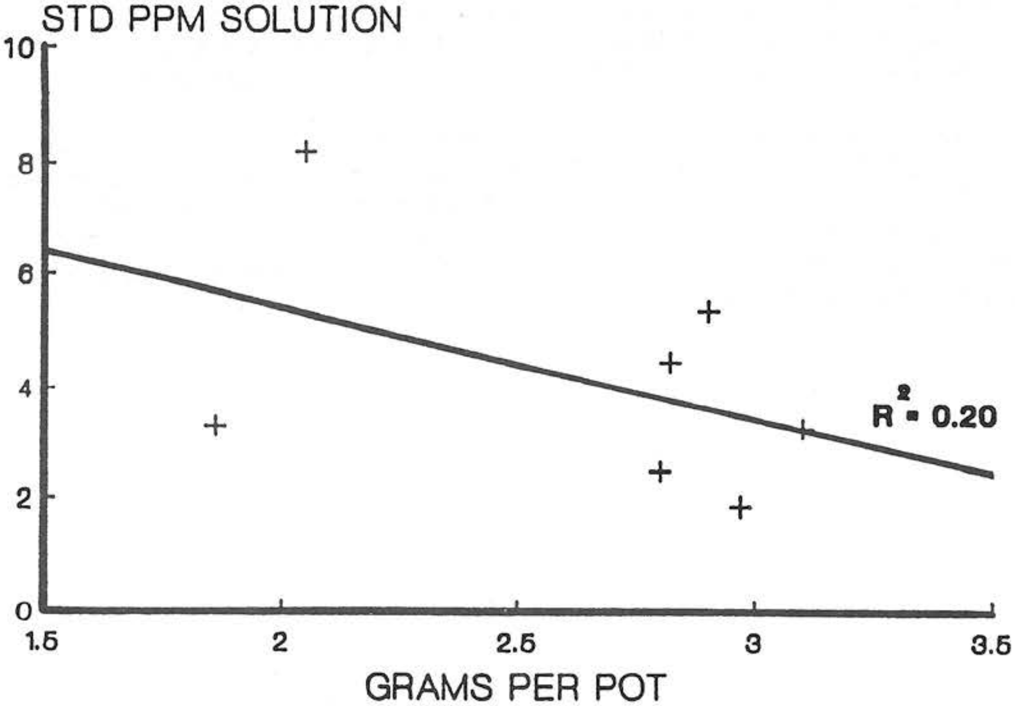
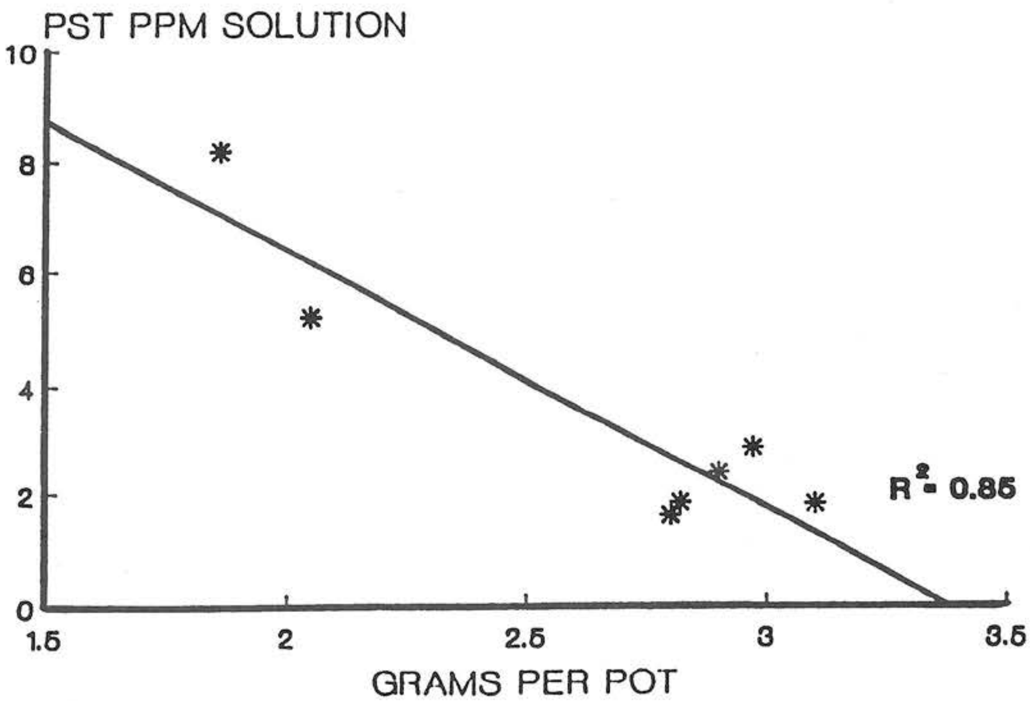


FIGURE 4 : PST VS YIELD



The stepwise evaluation process illustrated by the sulfur example has been followed for phosphorus and potassium with similar results of improved prediction of fertilizer response. This research shows that the supply rate of the nutrient to the plant root is a critical component for accurately predicting fertilizer requirements.

The appropriate way to determine which test is a reliable predictor of crop response to fertilizer is to correlate each test to dry matter yield from one of the treatments of added sulfur. The following graphs illustrate the relationship between soil test concentration and yield at the first level of added sulfur fertilizer, 15 kg/ha (Figures 3 and 4).

THE COPPER FERTILITY OF ALBERTA SOILS

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ABSTRACT

DTPA-extractable Cu levels in soil samples submitted by farmers for micronutrient analysis and from fields previously diagnosed with stem melanosis of wheat (a disease associated with Cu deficiency) were used to indicate the extent and distribution of Cu deficient soils in Alberta. Using a critical level of 0.6 ppm, 29% of the farm samples and 55% of the samples from fields previously diagnosed with stem melanosis were marginal to low in Cu. Organic and sandy soils were more frequently low in Cu than heavier textured soils. In a field experiment with barley on a Dark Grey Chernozemic soil containing 0.7 ppm DTPA-extractable Cu, visual symptoms of Cu deficiency were observed and Cu fertilization significantly increased the bushel weight, 1000 kernal weight, and markedly reduced the percentage of thin kernals.

BACKGROUND AND OBJECTIVES

Limited research has been conducted in Alberta to determine the extent of Cu deficiency. Cu deficiency in organic soils was first reported in Alberta by D.R. Walker (unpublished results, 1965). Because of the small acreage of cultivated organic soils, there was little interest in this problem until recent reports of Cu deficiency on mineral soil in Saskatchewan. Kruger et al. (1985) and Karamanos et al. (1986) estimated that soils prone to Cu deficiency occupy up to one million acres in that province. The soils were described as primarily fine sandy textured Transitional Degraded Black and Wooded Calcareous; and Grey and Brownish-Grey Podzolic soils. They estimated a "critical" DTPA extractable Cu level (Lindsay and Norvell, 1978) of 0.4 ppm, double a previous estimate of 0.2 ppm.

Piening and MacPherson (1985), observed that Park wheat (a hard red spring variety developed for the Parkland region of the northern plains) exhibited melanism; a brown discoloration of the peduncle and rachis. They identified the disease as stem melanosis, caused by the bacterium <u>Pseudomonas</u> <u>cichorii</u>. Subsequently in 1987, Piening et al. reported that stem melanosis was often found to be associated with Cu deficient soils. This suggested that Cu deficiency may occur on a significant acreage of mineral soils in Alberta.

The objectives of this ongoing study are to obtain information on the extent and distribution of Cu deficient soils. This will be obtained from soil test summaries and surveys, and field experiments to determine crop response to Cu fertilization and establish critical soil test levels for various soils and crops.

MATERIALS AND METHODS

Soil Test Summary

Data from soil samples submitted by farmers to the provincial Agricultural Soil and Animal Nutrition Laboratory in 1986-87 requesting micronutrient analyses were summarized to determine mean values and frequency distribution by soil-climatic area and textural class. The samples represented approximately 250 fields on which DTPA-extractable Cu (Linsay and Norvell, 1978) was determined.

Sampling Survey

Based on the association between stem melanosis of wheat and Cu deficiency noted by Piening et al. (1987), 21 fields were sampled where the stem melanosis disease was previously diagnosed. Fifty eight samples (2 to 4 samples per field) were analyzed to examine spacial variability of Cu and the relationship between stem melanosis and Cu deficiency.

Field Experiments

Field experiments are underway to measure crop response to Cu fertilization and to calibrate soil tests. The first experiment, established in 1987, was located in the Parkland region of west central Alberta on a soil described in Table 1. The site was chosen because of visual Cu deficiency symptoms on barley and apparent response to copper sulphate in a strip trial the previous year. The experiment was a randomized complete block design with four replicates. The treatments were: 1) control; 2) 5 lb/ac Cu as $CuSO_4 \cdot 5H_2O$; 3) 10 lb/ac Cu as $CuSO_4 \cdot 5H_2O$; 4) 5 lb/ac Cu as $CuSO_4 \cdot 5H_2O$ plus 0.25 lb/ac Cu as Cu-chelate foliar applied at FEEKES 10.1; 5) 0.25 lb/ac Cu as Cu-chelate foliar applied at FEEKES 10.1; 6) 10 lb/ac Cu as $CuSO_4 \cdot 5H_2O$ plus foliar Mn; 7) 5 lb/ac Cu as a commercial granular fertilizer (15% Cu). The $CuSO_4 \cdot 5H_2O$ and granular Cu fertilizer were broadcast and incorporated one week prior to seeding barley (var. Leduc). A basal application of N, P, K and S was applied to all treatments. The treatment size was 8' x 22'; with a 4' untreated guard between each treatment. At maturity, the above ground plant material from a 15 ft^2 area was harvested for determination of total yield, grain yield and quality.

Table 1. Description of the soil at the experimental site.

Soil Classification	Depth	Texture Sand	Silt	Clay	pH	Organic Matter	DTPA Extractable Cu
	cm	------%-------				%	ppm
Dark Grey Chernozem developed on pitted	0-15	46	38	16	5.9	7.6	0.7(0.6-0.8)*
deltaic material (LL to FSL)	15-30	42	29	19	6.4	5.4	0.8

(   ) * range of 4 replicates

RESULTS AND DISCUSSION

Soil Test Summary

Based on the 1987 field experiment, observations of Cu deficiency and soil analyses, the soil test results from farm samples were categorized as; marginal to deficient ($\leq$ 0.6 ppm) and adequate (> 0.6 ppm) in DTPA-extractable Cu. The percentage of samples testing marginal to deficient in Cu by soil-climatic area and textural class are shown in Tables 2 and 3. Because of the limited number of samples, the province was divided into only four general soil-climatic regions.

Table 2. Distribution of DTPA-extractable Cu levels by soil-climatic region.

	Region	No. of Samples	DTPA-extractable Cu ($\leq$ 0.6 ppm)
			%
1.	Southern Alberta-dominantly Brown and Dark Brown Chernozemic soils	36	3
2.	East Central and NE Region-dominantly Thin Black Transitional and Grey soils	23	17
3.	West Central and NW Region-Black, Transitional and Grey soils.	119	44
4.	Peace River Region-Transitional and Grey soils	44	27
	Total - Province	222	31

Micronutrient analyses are not done routinely but by specific request of the farmer at additional cost. Because farmers who suspect a micronutrient problem are more likely to request these analyses, the proportion of samples with low levels of Cu in this summary (31%) is likely greater than the proportion of farmland low in available Cu (Table 2). Nonetheless, the summary provides a preliminary indication of Cu levels and their distribution.

The largest acreage of cultivated organic soils occurs in region 3 so the data were further examined to determine the influence of organic soils on the percentage of low Cu levels in this region. Organic soils comprised 42 of the 119 samples from the region with 48 percent of the organic soils and 41 percent of the mineral soils testing in the low to marginal category ($\leq$ 0.6 ppm).

A total of 256 samples were categorized into organic soils and two broad textural classes (Table 3). The results show that organic and lighter textured mineral soils have lower levels of DTPA-extractable Cu than heavier textured soils.

Table 3. Distribution of DTPA-extractable Cu levels by soil texture and type.

Textural Class* or Type	No. of Samples	DTPA-extractable Cu ($\leq$ 0.6 ppm)
		%
Sandy loam and loam	156	27
Clay loam or heavier (> 25% clay)	31	16
Organic (> 30% OM)	69	41
Total	256	29

*Based on hand texture determined as part of routine soil analyses.

<u>Sampling Survey</u>

A total of 58 composite soil samples were taken from 21 fields where stem melanosis or a disease of similar appearance had been diagnosed. The results (Table 4) show a high percentage with low Cu levels and a strong influence of soil texture. A majority of the fields in this survey were from region 2 as described in Table 2.

Table 4. Distribution of DTPA-extractable Cu levels in soil samples from 21 fields with a suspected history of stem melanosis.

Textural Class or Type	No. of Samples	DTPA-extractable Cu ($\leq$ 0.6 ppm)
		%
Sandy loam and loamy sand	48	67
Loam	10	0
Total Samples	58	55

Field Experiment

The results of the field experiment (Table 5) show significant effects of Cu fertilization on quality but not on yield. A larger yield increase from the Cu treatments was expected because marked Cu deficiency symptoms were evident in the control plots and in the adjacent farmer's crop. Lodging, and the spatial variability of Cu deficiency described by Kruger et al. (1985) were factors that may have contributed to the lack of significant yield response. The poor response to Cu, relative to observed treatments differences during the growing season may have resulted from above normal rainfall in late July and August, and a longer than normal growing season. Graham and Nambiar (1981) reported that Cu deficiency symptoms include excessive tillering and delayed maturity, and that Cu deficiency symptoms were generally more severe in dry seasons. Late tillering was observed in the control treatments and with above normal rainfall in late July and August, those tillers apparently contributed to both dry matter and grain yield.

Table 5. Effect of soil and foliar applied Cu fertilization on yield and quality of Leduc barley in 1987.

Fertilizer Treatment	Yield: Straw	Yield: Grain	Quality: Bu. wt.	Quality: 1000 Kernal wt.	Quality: Thin Kernals
	(cwt/ac)	(bu/ac)	(lb/bu)	(gm)	(%)
1. Control	43.4	91.7	43.4	34.4	49.4
2. 5 lb/ac Cu ($CuSO_4 \cdot 5H_2O$)	41.8	96.6	45.6	39.2	23.4
3. 10 lb/ac Cu ($CuSO_4 \cdot 5H_2O$)	43.4	96.3	46.8	39.3	21.3
4. 5 lb/ac Cu ($CuSO_4 \cdot 5H_2O$) plus foliar Cu	42.8	100.4	46.8	40.0	19.2
5. 0.25 Cu (foliar)	39.8	86.9	46.4	35.5	34.8
6. 10 lb/ac Cu ($CuSO_4 \cdot 5H_2O$) plus foliar Mn	42.2	103.3	48.9	40.4	16.2
7. 5 lb/ac Cu (granular fertilizer 15%)	44.2	103.3	46.3	40.4	21.0
LSD (0.05)	NS	NS	1.6	2.8	9.7

All of the soil applied Cu treatments had similar effects on grain quality. Foliar applied Cu-chelate produced lower 1000 kernal weights and higher percent thins than the soil applied Cu treatments. Karamanos et al. (1986) reported that response to foliar applications of Cu were more erratic than soil application.

Although significant yield response to Cu fertilization was not obtained in this experiment, it was evident from observation of Cu deficiency symptoms and the significant effect of Cu treatments on quality that Cu deficiency affected the growth of barley on the experimental site and in the adjacent field. The most notable aspects of this experiment are; 1) the growth of barley was affected by Cu deficiency on a soil with a DTPA-extractable Cu level of 0.7 (0.6-0.8) ppm which is above the critical level for cereals reported by Kruger et al. (1985) and Karamanos et al. (1986); and 2) grain quality measurements, particularly percent thins may be more discriminating than grain yield for detecting response to Cu fertilization in field experiments.

The relatively high DTPA-extractable Cu level at which Cu-deficiency was observed may be due to the high level of soil organic matter (7.6%). Organic matter has been reported to play a major role in controlling the availability of Cu to plants (Stevenson and Ardakani, 1972). Brennan et al. (1986) reported that the level of ammonium oxalate-extractable Cu required for maximum yield of wheat on soils with 0.87 and 3.67% organic carbon was 0.4 ug/g and 0.8 to 1.0 ug/g respectively.

The results of the research to date do not provide a basis on which to estimate the extent of Cu deficiency for small grain production in Alberta. The results do however show that; 1) a relatively high percentage of farm samples on which micronutrient analyses were requested tested marginal to low in Cu; 2) a high percentage of fields previously diagnosed with stem melanosis of wheat have marginal to low levels of Cu; and 3) Cu levels in the marginal to low range occur more frequently on organic and sandy soils than on heavier textured soils.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of L. Kryzanowski, Agricultural Soil and Animal Nutrition Lab and extension staff of Alberta Agriculture.

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SOIL FERTILITY RESEARCH IN ALBERTA

(note: for brevity some projects are grouped and shown as a list of key words)

1. Nitrogen transformations and N uptake by crops - the influence of zero and conventional tillage, crop residues, soil temperatures and moisture; N fertilizer - time and method of placement, bands, nests, denitrification of soil and fertilizer N. M. Nyborg, D.J. Heaney and D.S. Chanasyk, Soil Department, University of Alberta, Edmonton; S.S. Malhi, Agriculture Canada, Lacombe and E.D. Solberg, Alberta Agriculture, Edmonton.

2. Oxidation of S and S-bentonite fertilizers, influence of rain drops and freezing and thawing on dispersion of S-bentonite pellets. H.H. Janzen, Agriculture Canada, Lethbridge; R.E. Karamanos, Esso Chemicals, Lethbridge; and E.D. Solberg, Alberta Agriculture, Edmonton.

3. Intensive Crop Management systems and nutrient requirements for maximum economic yield - nutrients, fungicides, growth regulators. D.C. Penney, E.D. Solberg, J. Helm and R.H. McKenzie, Alberta Agriculture, Edmonton, Lacombe, and Lethbridge.

4. Phosphorus placement for zero and conventional tillage. J.A. Robertson and K.W. Domier, Department of Soil Science and Agriculture Engineering respectively, University of Alberta, Edmonton.

5. Recovery of biologically fixed nitrogen in grain legume residues by wheat. H.H. Janzen and J.B. Bole, Agriculture Canada, Lethbridge.

6. Straw, water management, nitrogen efficiency, fertigation. J.M. Carefoot, Agriculture Canada, Lethbridge.

7. Chlorine: a possible deficient nutrient in Alberta soils. J.A. Robertson, Department of Soil Science, University of Alberta; D.C. Penney, Alberta Agriculture, Edmonton.

8. Long - term effects of fertilizers and crop rotations on the Breton Plots. J.A. Robertson et al. Department of Soil Science, University of Alberta, Edmonton.

A PROGRAM FOR INTENSIVE COTTON MANAGEMENT EDUCATION

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ABSTRACT

Cotton is the main cash crop on the Texas High Plains. During the 1970 to 1980 period, yields declined steadily, commodity prices were generally depressed and production costs increased markedly. Dryland lint yields currently average about 250 pounds per acre and irrigated yields about 375 pounds per acre. Through full utilization of available technology, average production levels of 400 to 475 pounds per acre dryland and 720 to 950 pounds per acre irrigated are thought to be attainable. Rapid, systematic adoption of viable new technology by producers is essential for attainment of such production levels and for a healthy cotton industry on the Texas High Plains. A committee composed of representatives from private and public institutions was formed to develop production management guides based on the latest "best practice" technology. An innovative audio-visual approach is being developed to facilitate the transfer and adoption of this technology.

OBJECTIVES

During the past 10 years, U. S. cotton yields have remained essentially static. Moderate yield increases in some production regions have been noted but these have been offset by steady yield declines in other areas. For example, per acre yields on the Texas High Plains have decreased approximately 10 pounds per acre per year for the last decade. In this same time period, production costs have increased markedly, while commodity prices have been generally depressed. The result has been a sustained loss in profitability for cotton production.

Depending on government programs, profitability of alternate crops, and weather factors, cotton is planted on 2.5 to 4.5 million acres on the Texas High Plains annually. About 60-percent of this acreage is dryland and 40-percent can be irrigated to some extent. Dryland lint yields average approximately 250 pounds per acre whereas irrigated yields average about 375 pounds per acre. Potential yields are substantially higher than the average yield levels. Through full utilization of available technology, average production levels of 400 to 475 pounds per acre dryland and 720 to 950 pounds per acre irrigated are thought to be attainable.

The major limitations to cotton production on the Texas High Plains are available water, temperature (short growing season), soil fertility (mainly N and P), abiotic factors (wind, blowing sand, hail, etc.) and biotic factors (diseases, weeds, insects). Numerous research studies have provided a large data base for specific aspects of cotton production. More recently, systems oriented research studies have been implemented to refine current "best practice" production-management methods. The focus of these studies is to develop cotton production systems which minimize environmental limitations and simultaneously optimize returns from inputs such as fertilizers, irrigation water and pesticides.

Rapid, systematic adoption of viable new technology by producers is essential for a healthy cotton industry on the Texas High Plains. Educational programs are needed to create an awareness among growers of new and better management methods. The Cooperative Extension Service has and continues to provide timely information and training to producers as well as representatives of agri-businesses (i.e. fertilizer dealers, seedsmen, farm store operators, ginners, etc.) who impact on grower decision making. Needs exist, however, for new communication techniques to complement the more traditional means of introducing new technology to growers.

In 1985, a joint project was initiated by the Foundation for Agronomic Research and representatives of the Texas Agricultural Experiment Station, Texas Tech University and the Texas Agricultural Extension Service to develop an educational program intended to help re-establish an acceptable level of profitability to cotton production on the Texas High Plains. The major objectives of this project are to:

1. Compile a comprehensive cotton production management guide comparing "best practice" technology with conventional production methods.

2. Develop a videotape library of cotton production practices for educational and historical purposes.

3. Use an innovative audio-visual approach to facilitate the transfer and adoption of cost effective cotton production-management technology by Texas High Plains producers.

Two years (1986 and 1987) were allotted for the development of the production guide, videotaping conventional and improved cotton production practices and developing a 30 to 40 minute videotape presentation describing optimal production systems.

MATERIALS AND METHODS

The project officially began in February, 1986. Because of the assigned time frame, the decision was made to develop the production guides and videotape seasonal farming activities simultaneously. This is in contrast to the usual approach of videotaping subject matter to compliment a prepared script.

To direct and monitor the development of the production-management guide and field videotaping activities, a 10-member committee was formed. This group met periodically to review videotape footage, note apparent omissions and suggest shooting schedules and topics for coming weeks. Committee members in cooperation with various research and Extension scientists were requested to prepare scripts (production guidelines) comparing traditional methods with the best available technology for the following production practices:

- Tillage
- Crop development-management
- Seed selection - testing - planting
- Pest management (weeds, insects, diseases)
- Soil testing - crop fertilization
- Water management - irrigation
- Crop termination - harvesting - field storage.

Drafts of the scripts were reviewed by committee members as they become available and edited for use in the overall videotape presentation.

Videotaping activities began in February of 1986. Grant support from the Foundation for Agronomic Research was used to retain the services of the Texas Tech University News and Publications department. A Video-Broadcasting specialist was assigned to the project to actually video-tape field activities and coordinate the development of the audio-visual presentation. In 1986, field trips were made on a weekly or bi-weekly basis to videotape seasonal operations on numerous commercial farms and at various research locations. Some videotaping of selected farm operations and on-site interviews with producers was also done in 1987.

The scripts describing individual segments of cotton production were used to develop a narrative for the final audio-visual presentation. Videotape footage as well as slides and illustrations are being used to support the narrative. The audio is being done by a professional broadcaster and incorporates interviews with producers, scientists and industry representatives.

Short (2 to 10 minute) audio-visual segments describing specific production practices (i.e. cotton fertilization) will be prepared following completion of the master presentations.

RESULTS AND DISCUSSION

Completion of the project will exceed the projected time frame by several months. Personnel changes, delays in script preparation and editing and a host of other factors combined to break the continuity needed to finish the project on schedule. To maintain continuity in a project of this nature, two components are essential: a knowledgeable individual who can direct his full attention to the project and a master script to direct the videotaping and editing activities.

A requirement of the project was that the final audio-visual presentation review the total cotton production system. Professional educators suggest that in order to keep from overwhelming the audience, the length of such a presentation should be limited to 30 or 40-minutes. This is hardly adequate time to teach the subject matter involved. Consequently, the master presentation is structured more toward creating awareness of technology that can improve profitability. Follow-up programs will be needed to provide comprehensive instruction on specific production technology. These can be provided by conventional teaching methods or with audio-visual presentations developed specifically for this purpose.

To develop a quality 30 to 40 minute presentation for today's clientele requires a great deal of preparation. Extensive editing is required to keep the presentation from being just a review of cotton production practices on the one hand and an extremely detailed, fast moving but dull lecture on the other. Viewers expect the same quality in training films that they are accustomed to viewing on commercial television. Concerted efforts are being made to insure the audio-visual presentation under development will provide timely production information to High Plains cotton producers in a manner that will stimulate interest and encourage adoption of cost-effective technology.

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1988 Great Plains Soil Fertility Workshop

EVALUATION

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1. Should the word 'WORKSHOP' in the title be replaced with another more appropriate term (i.e. Symposium, Conference, etc.)?

   YES____ NO____

2. If you said yes, how would you change the title?

3. Meeting length (1.5 days)? About right____ Too long____ Too short____

4. Speaker time (20-25 minutes)? About right____ Too long____ Too Short____

5. Was adequate time provided for discussion? YES____ NO____

6. Should Poster Papers be included in this meeting? YES____ NO____

7. Should more time be given for the Poster Session? YES____ NO____

8. Do you favor 'dinner on your own' or 'dinner as a group' for Monday evening? ON YOU OWN____ AS A GROUP____

9. Do you prefer 'continental' or 'full-course' breakfasts?
   CONTINENTAL____ FULL-COURSE____

10. What topics or speakers would you recommend for future meetings?

    a.

    b.

    c.

    d.

    e.

11. Please suggest improvements for the Proceedings.

12. General comments/recommendations. (use the back for more space)