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SOIL SERIES #134
Field Research in Soil Science

ACKNOWLEDGEMENTS

This 1992 edition of the soils "bluebook" compiles data collected and analyzed throughout Minnesota. Information is contributed by personnel of the University of Minnesota Department of Soil Science; by soil scientists at the Minnesota Agricultural Experiment Station branch stations at Crookston, Lamberton, Morris and Waseca, and at the Becker and Staples research farms; and by Soil and Crop area agents. Associated personnel from the Soil Conservation Service, and the Soil and Water Research group of the ARS-USDA, the Tennessee Valley Authority, and the Departments of Agriculture and Natural Resources also contribute.

The investigators also greatly appreciate the cooperation of the many farmers, agents, technical assistants, secretaries, and farm and business representatives who contribute time, land, machinery and materials which assist or enable the research this publication reports. Much of the research would not be possible without that support.

DISCLAIMERS

Some of the results reported in this publication are from 1991 experiments and should be regarded on this basis. Since most of the data is from 1991 studies only, stated conclusions may not be absolutely conclusive, and thus are not for further publication without the written consent of the individual researchers involved.

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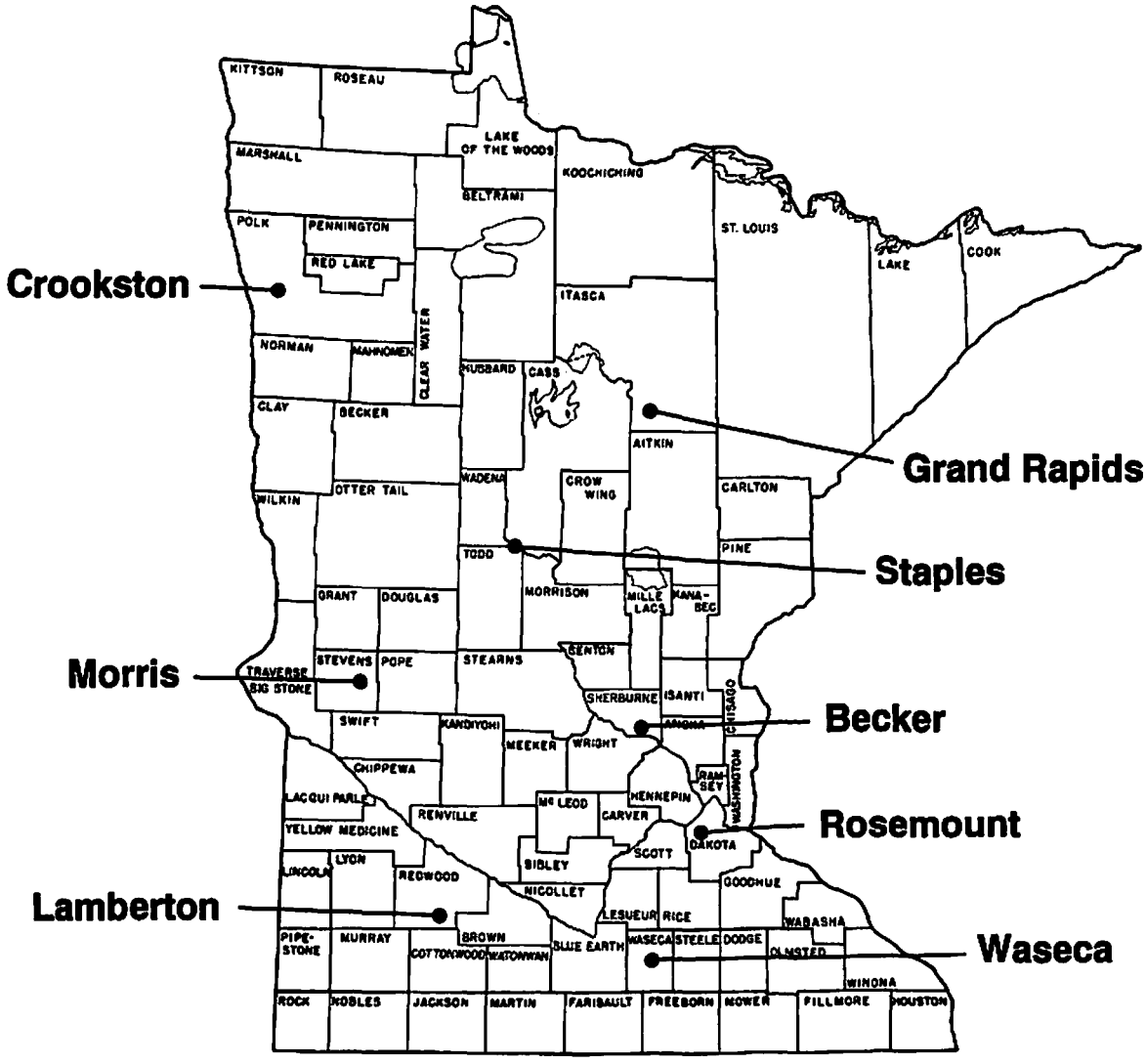

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1991 Precipitation Summary

Gregory J. Spoden[1]

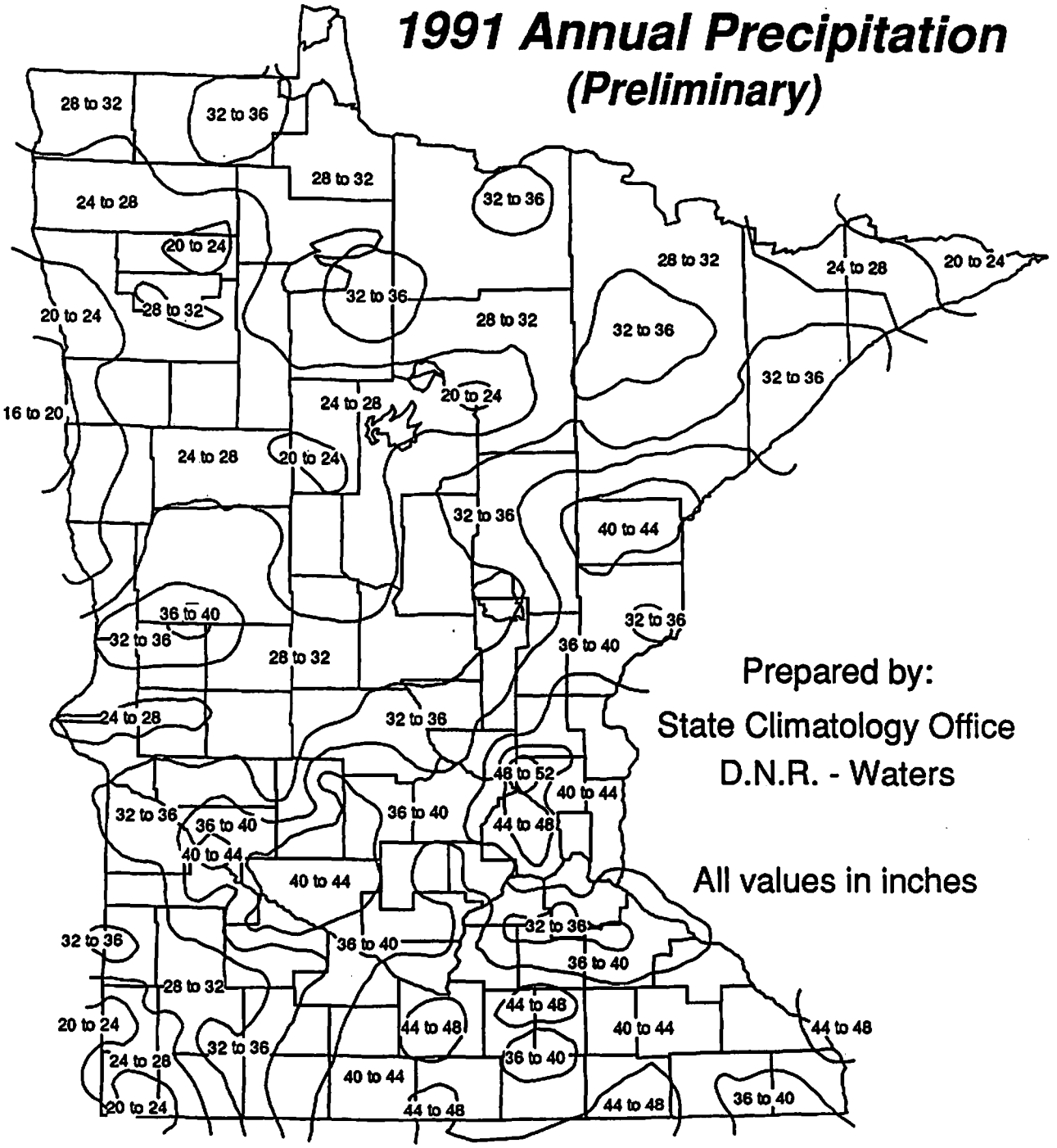
For the second consecutive year precipitation over much of Minnesota was exceptionally heavy. Annual precipitation totals of over 40 inches were common in the southern half of the state, Fig. 1 and 2. A 40 inch annual total is quite rare for most locations in Minnesota. All-time record precipitation totals were reported for several communities. Many areas exceeded the historical annual precipitation average by more than a foot. Only in isolated sections of southwestern, northwestern, north central, and northeastern Minnesota were conditions slightly drier than normal.

Much of 1991's excessive precipitation fell during April and May, creating a multitude of problems for agricultural operations. The April-May rainfall ranked in the 95th percentile for many locations. Fortunately, the month of June turned relatively dry allowing for a resumption of field activities. Extraordinarily heavy precipitation returned again in September, and with the ice and snow of November, Fig. 3.

A great deal of northwestern Minnesota received normal to above normal precipitation in 1991, Fig. 2. However, a continuation of above normal precipitation is needed in 1992 for that region of the state to rebound from five years of drought conditions. In the northwest, soil moisture reserves remain quite short in fields where longer season row crops were grown in 1991.

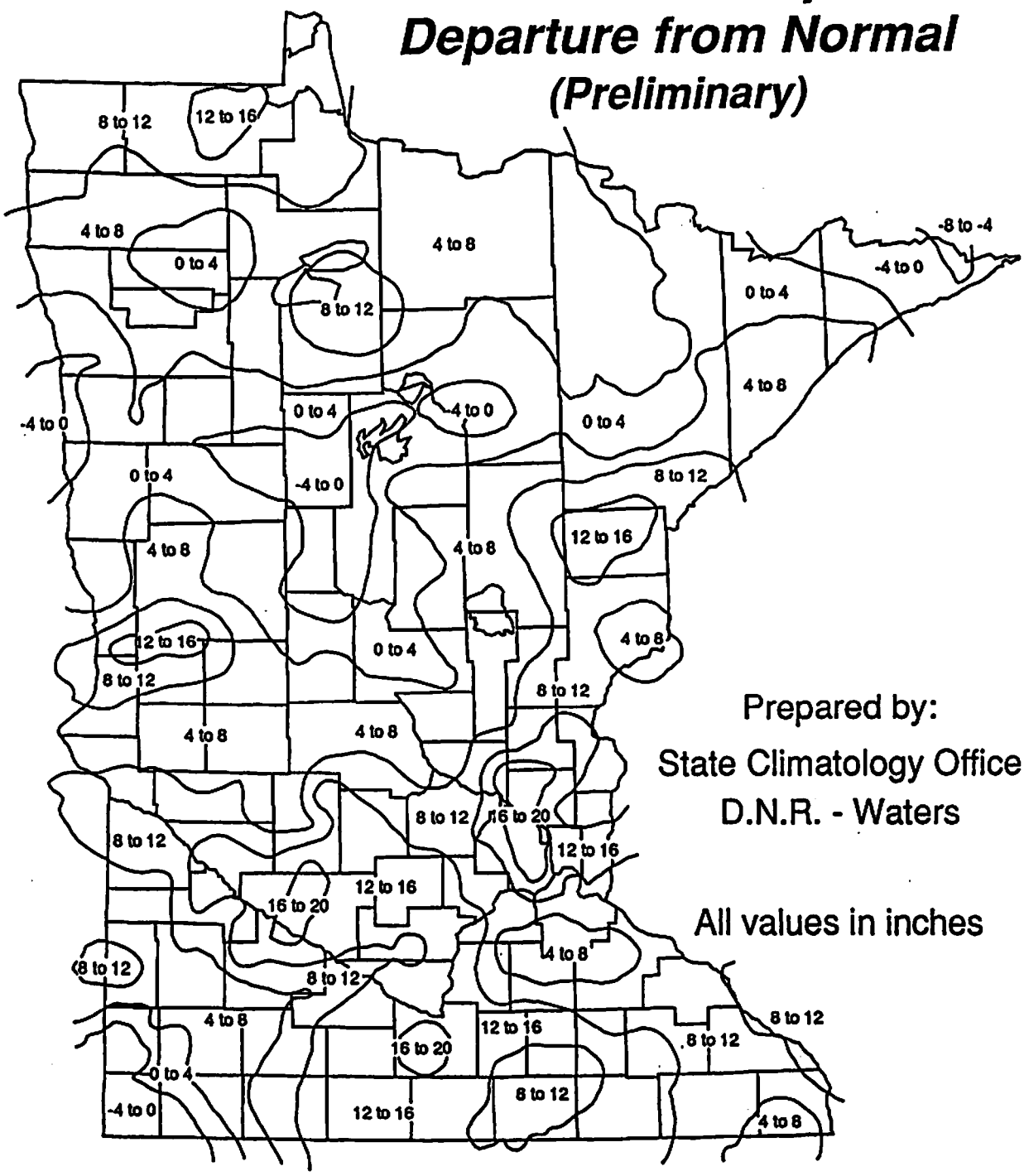
[1]Gregory J. Spoden is Assistant State Climatologist, Div. of Waters, Department of Natural Resources, State of Minnesota.

Fig. 1



Data source: National Weather Service, Soil & Water Conservation Districts, DNR Forestry, Metro Mosquito Control, Back Yard Rain Gauge Network, Future Farmers of America, KSTP - TV, Deep Portage Conservation Reserve, Minnesota Association of Watersheds

Fig. 2 **1991 Annual Precipitation Departure from Normal (Preliminary)**



Prepared by:

State Climatology Office

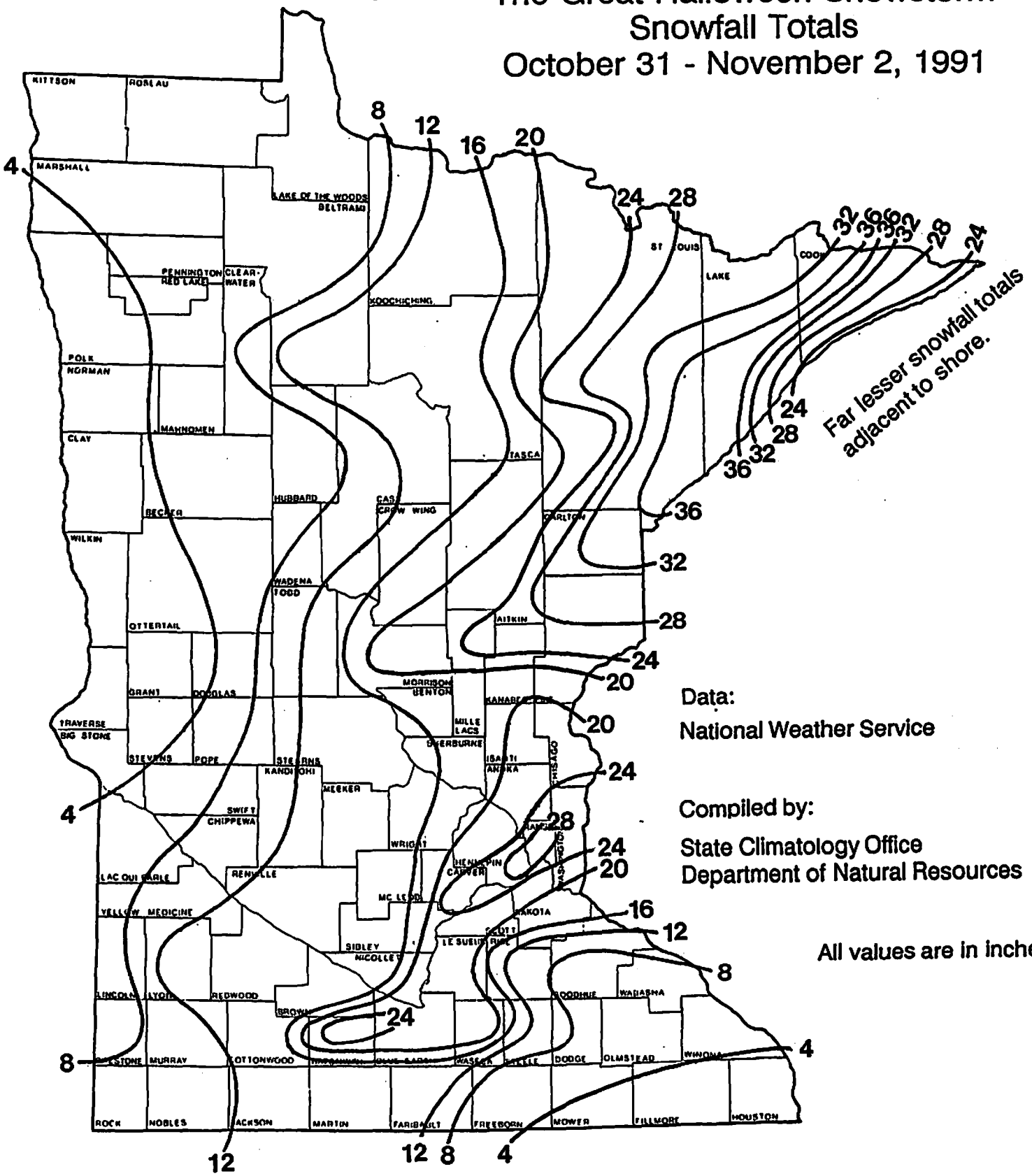
D.N.R. - Waters

All values in inches

Data source: National Weather Service, Soil & Water Conservation Districts, DNR Forestry, Metro Mosquito Control, Back Yard Rain Gauge Network, Future Farmers of America, KSTP - TV, Deep Portage Conservation Reserve, Minnesota Association of Watersheds

Fig. 3

The Great Halloween Snowstorm Snowfall Totals October 31 - November 2, 1991



ANNUAL PRECIPITATION TOTALS AT MINNESOTA AGRICULTURAL EXPERIMENT STATIONS[1]

Donald G. Baker and David L. Ruschy[2]

A brief review of the precipitation records at five Minnesota Agricultural Experiment Stations is presented.

Several of the Minnesota Agricultural Experiment Stations have precipitation records that exceed a century (Crookston, 1890 –; Morris, 1886 –;) or are approaching it (Waseca, 1915 –), Fig. 12-16. The longest of these (Morris, Fig. 14) shows a slightly positive trend over the 106 years. This was also found to be true for the Eastern Minnesota record (not shown) which dates from 1837. In contrast, the Crookston record does show an overall declining linear trend in annual precipitation amounts with a decrease of 1.9 inches in the last 102 years.

The marked increase at Waseca (Fig. 16) from 1915 to 1991 as a linear trend equals 7.9 inches, and at Morris during the same period the linear trend equals an increase of 1.7 inches. At Crookston it equals only 0.6 inches over the 1915-1991 period.

The years 1936 and 1976 stand out when a minimum total is looked for within the indicated record periods, as shown in Table 1, while the maximum occurred in several different years.

Table 1. Maximum and minimum total annual precipitation amounts and years of occurrence.

Station	Record Period	Maximum	Year	Minimum	Year
Crookston	1890-1991	32.87 in.	1941	9.97 in.	1936
Lamberton	1961-1991	40.90 in.	1968	12.48 in.	1976
Morris	1886-1991	34.10 in.	1984	9.39 in.	1976
UofM,St.Paul	1961-1991	39.30 in.	1991	14.39 in.	1976
Waseca	1915-1991	50.46 in.	1991	17.43 in.	1976

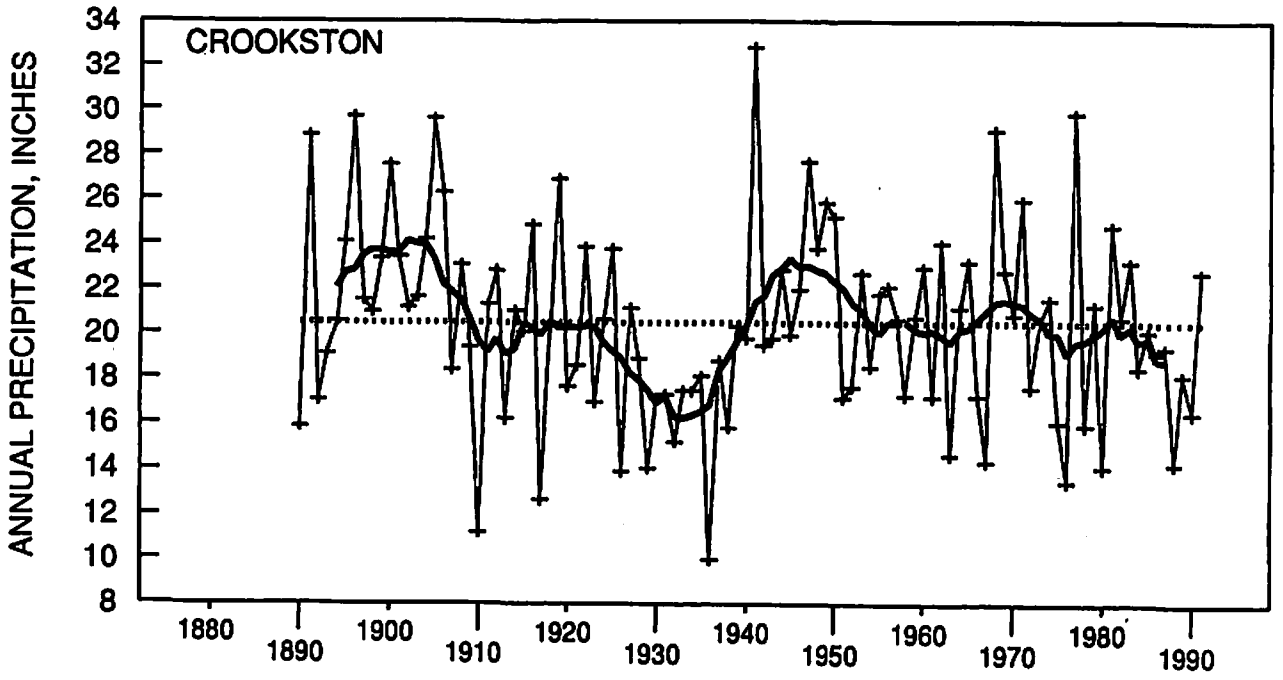


Fig. 12. Annual total precipitation and smoothed precipitation values (curved, darker line) at Crookston, 1890-1991. The dotted line represents the average value for the record.

[1]The weather stations and the individuals providing the data are supported by the Minnesota Agricultural Experiment Station as is the case for this study.

[2]Donald G. Baker and David L. Ruschy are Professor and Assistant Scientist, respectively, in the Soil Science Department, University of Minnesota, St. Paul, MN 55108.

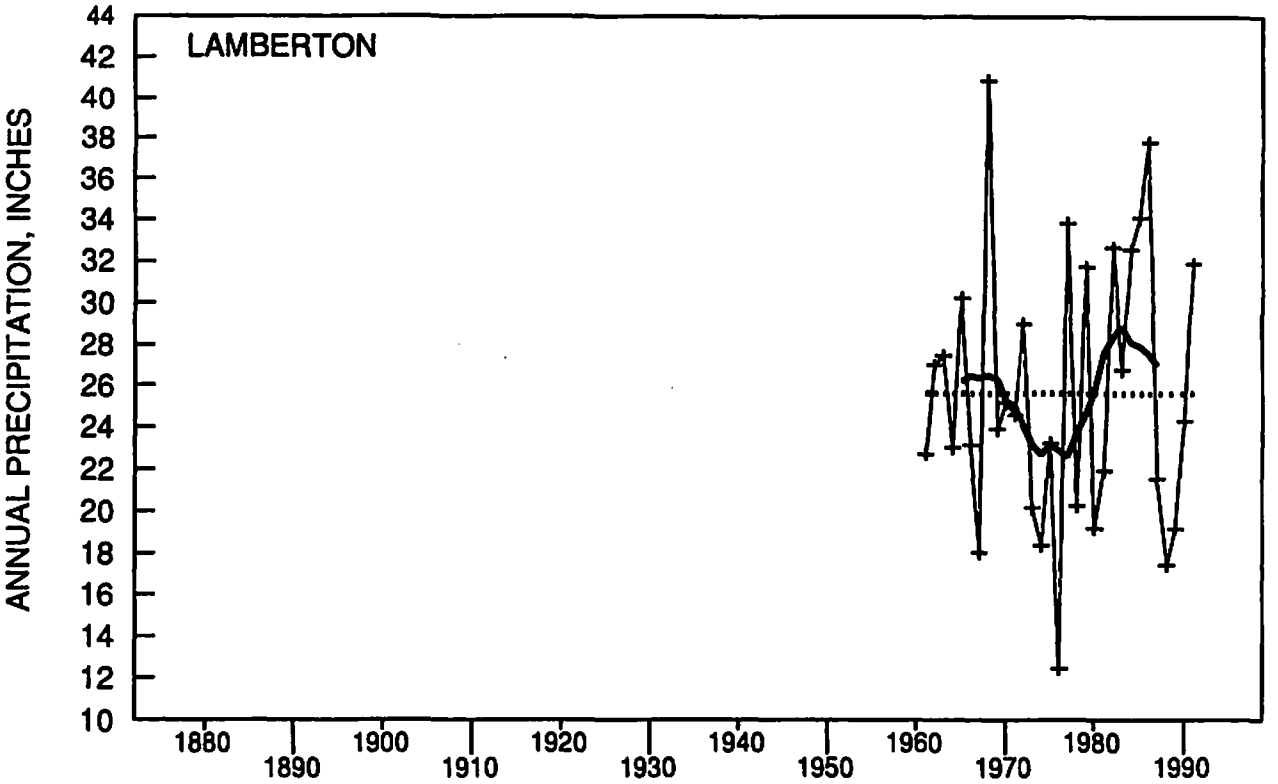


Fig. 13. Annual total precipitation and smoothed precipitation values (curved, darker line) at Lamberton, 1961-1991. The dotted line represents the average value for the record.

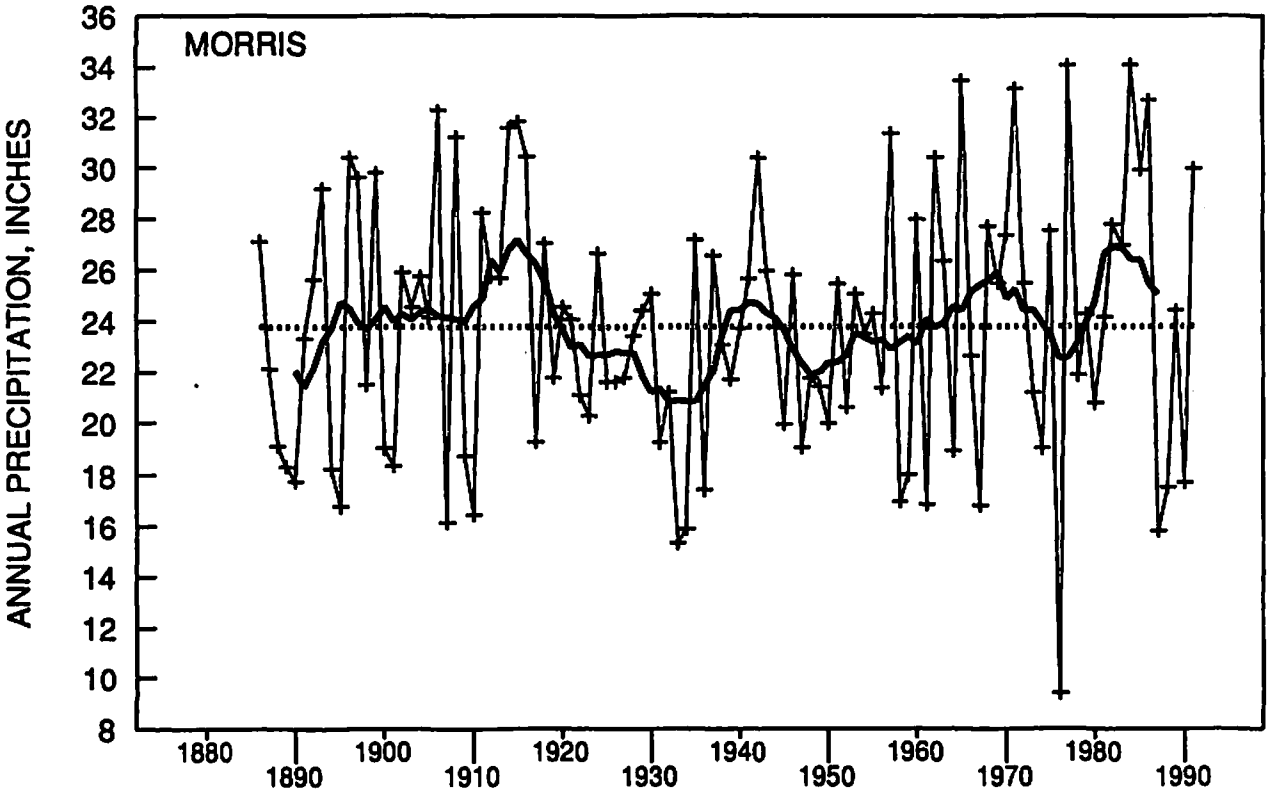


Fig. 14. Annual total precipitation and smoothed precipitation values (curved, darker line) at Morris, 1886-1991. The dotted line represents the average value for the record.

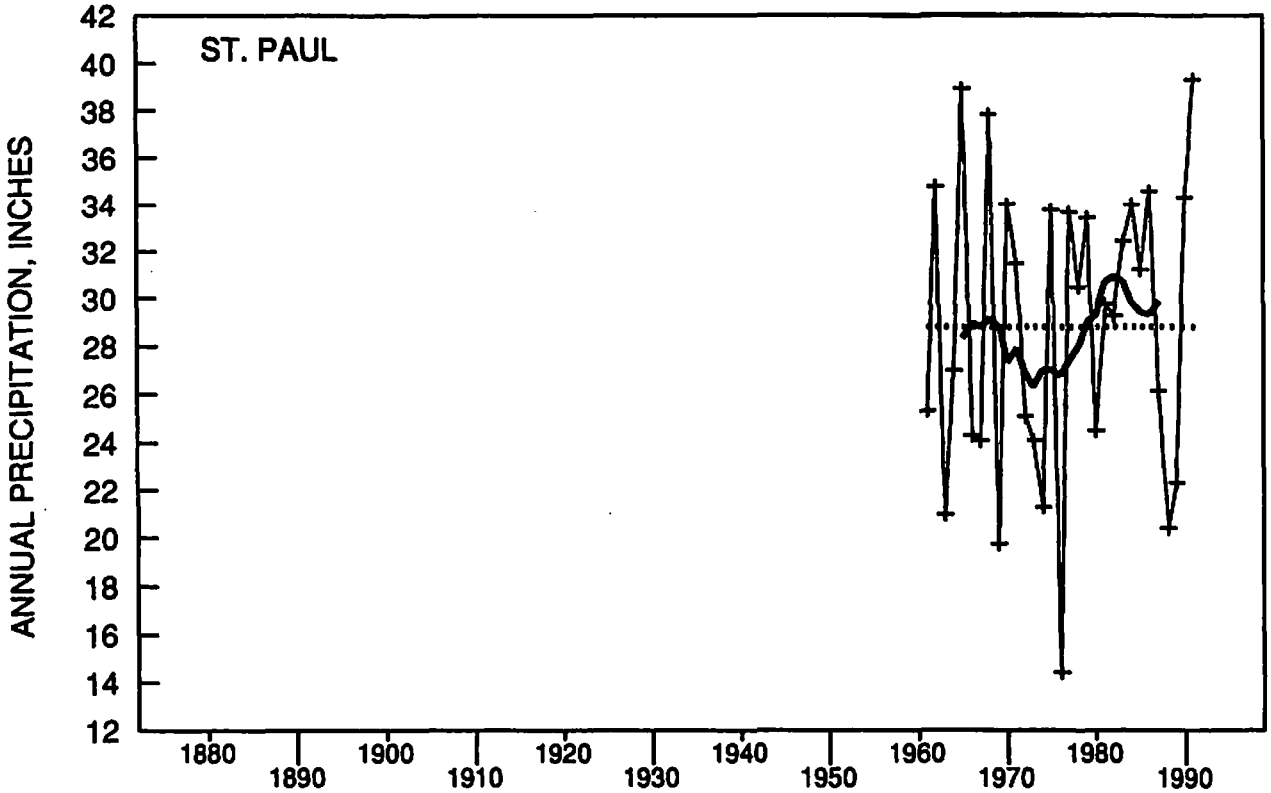


Fig. 15. Annual total precipitation and smoothed precipitation values (curved, darker line) at U of M, St. Paul, 1961-1991. The dotted line represents the average value for the record.

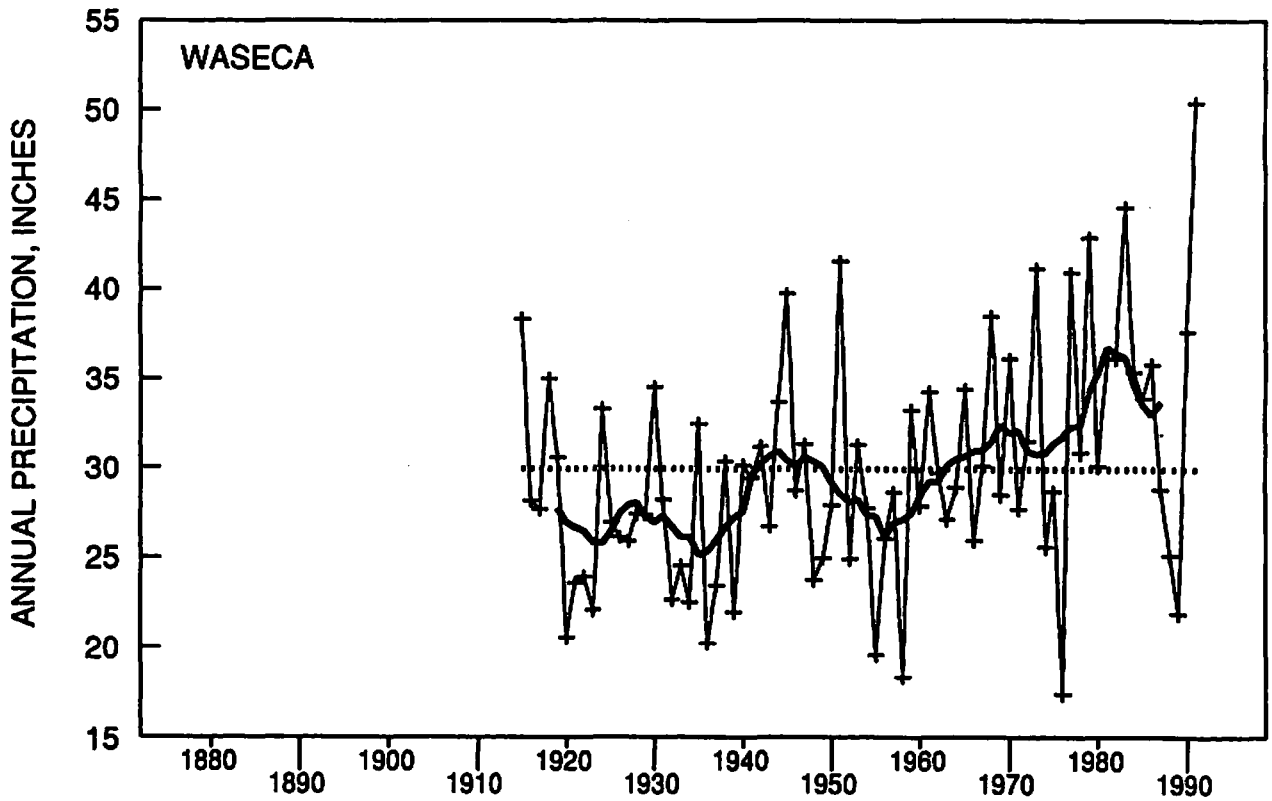


Fig. 16. Annual total precipitation and smoothed precipitation values (curved, darker line) at Waseca, 1915-1991. The dotted line represents the average value for the record.

1991 SOIL MOISTURE AT THREE SITES [1]

S. Evans, W. W. Nelson, G. Randall, D. L. Ruschy, and D. G. Baker[2]

The results of the frequent samplings of the soil moisture during the 1991 growing season are discussed.

The effect of the generally above normal precipitation, except in parts of northwestern Minnesota, are shown in Fig. 17. Lamberton, Morris, and Waseca ended the season with the October samples indicating very good moisture supplies. They certainly are sufficient to carry the crops well into the 1992 growing season. This is particularly true at Waseca where the final sampling indicates a soil that is very nearly at field capacity.

These supplies may become very important in this coming season for the indications this winter are that El Nino is back. If so, this could foretell a relatively warm and drier than average growing season.

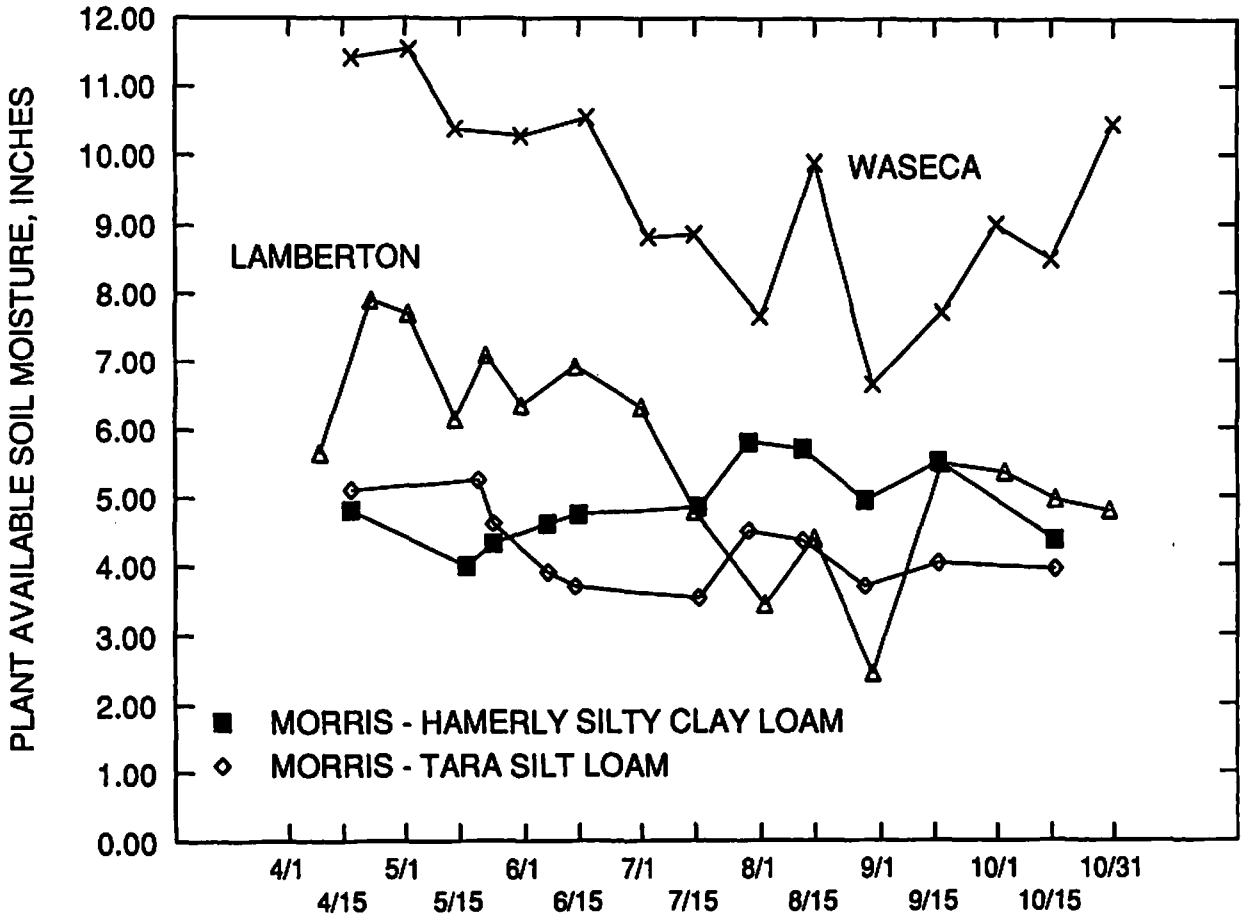


Fig. 17. Total plant available soil moisture at Lamberton, Morris, and Waseca, 1991.

[1]This long-term study is supported by the Minnesota Agricultural Experiment Station, St. Paul, and the stations at Crookston, Lamberton, Morris, and Waseca.

[2]S. Evans, Professor at Morris, W. W. Nelson, Professor at Lamberton, G. Randall, professor at Waseca, D. L. Ruschy, Asst. Scientist at St. Paul, and D. G. Baker, professor at St. Paul.

The Radiation Budget at St. Paul[1]

Donald G. Baker[2]

The incoming and outgoing short and longwave radiation fluxes are discussed and quantitative estimates are presented as to the use of the positive net radiation.

The earth is subject to four streams (technically, flux densities) of radiation. First there is the incoming solar (shortwave) radiation from the sun and sky. Its mean daily value at St. Paul is 330 cal cm^{-2} day^{-1}, Table 1. Some of this is immediately reflected back to the sky or space, the mean daily value of which is 96 cal cm^{-2}. Thus the net solar, the difference between the two, equals 234.6 cal cm^{-2} day^{-1}. The ratio of the reflected to the incoming radiation, 96/330, is the reflection coefficient or albedo. On an annual basis it equals 0.29 which means that on the average 29% of the incoming solar radiation is lost by reflection from the surface.

In addition to the two shortwave streams there are the two streams of longwave radiation, one coming in from the atmosphere and clouds and the other directed outward from the earth's surface. On an annual basis the daily average is 594 cal cm^{-2} day^{-1} coming in and 708 cal cm^{-2} day^{-1} directed upward. The difference, or net longwave, equals -114 cal cm^{-2} day^{-1}. It is noted as negative since more is leaving the earth than is directed downward.

Putting the four streams together we have the net all wave radiation (both long and short directed upward and downward) which equals 120 cal cm^{-2} day^{-1}. It will be noted, Table 1, that in November, December, January and February the net radiation is negative, while in the remaining months, March through October, it is positive. In the negative months, more energy is leaving the earth than is being received (at the point of measurement, which in this instance is St. Paul). One indication of the negative character in November-February is the decreasing temperature of these months. It is at this time that the northern hemisphere is subjected to short days and a low solar altitude resulting in low incoming solar radiation. And due to the snow cover common at this time a relatively large fraction of this already low amount is lost by reflection.

Table 1. Radiation fluxes, calories cm^{-2} day^{-1}, at St. Paul, 1979-1991.*

Month	Solar In	Solar Out	In/Out %	Net Solar	Long In	Long Out	In/Out %	Net Long	Net Radiation
Jan.	157	105	67	52	456	546	84	- 90	-38
Feb.	237	153	65	84	475	565	84	- 90	- 6
Mar.	313	124	40	190	525	628	84	-103	87
Apr.	414	89	22	325	587	719	82	-133	192
May	486	102	21	385	653	788	83	-135	250
June	537	112	21	425	721	849	85	-128	297
July	544	112	21	432	758	882	86	-124	308
Aug.	440	95	22	345	735	856	86	-120	225
Sept.	340	74	22	265	662	787	84	-125	140
Oct.	227	55	24	173	577	697	83	-120	53
Nov.	143	60	42	84	515	623	83	-108	-25
Dec.	121	73	60	49	464	566	82	-102	-54
Avg.	330	96	29	235	594	708	84	-114	120

*1 cal cm^{-2} day^{-1} = 0.48 Wm^{-2},

$\Sigma+$ = 47,468
$\Sigma-$ = 3,746
Rn = 43,722
Rn = Net Radiation

[1]This project is supported by the Minnesota Agricultural Experiment Station, St. Paul, MN 55108.

[2]Donald G. Baker is a professor in the Soil Science Department

Positive net radiation means more radiation is received than is lost. The positive net radiation is consumed by various processes and it is not "stored up", since in general a long-term balance exists between the income and the outgo of radiation. That is, the positive net radiation (Rn) is consumed in evaporation (LE), in heating the air (A), heating the soil (So), and in photosynthesis (Ph). The equation for the previous statement is:

$$Rn = LE + A + So + Ph$$

The estimate of the energy consumed in LE (evaporation) will be estimated for four periods during the year. The first will be based upon pan evaporation data. At St. Paul, this has been measured for a number of years from April 21 through October 10. This coincides approximately with the agricultural growing season. Experience suggests that with dryland (non-irrigated) farming the evapotranspiration consumes about 46% of the evaporation from a pan (Baker et al., 1979). From October 11 to the average freeze-up date of December 2 the loss is assumed to be the mean between the last pan loss (October 10 with 0.06 in day^{-1}) and the early winter loss of 0.01 in day^{-1}. This equals 0.035 in day^{-1}. The winter loss from December 3 to April 8 is estimated to be 0.014 in day^{-1} (Baker, 1972). The early spring evaporation, April 9-20, is estimated as the mean of the daily winter loss and the first pan loss, 0.01 in day^{-1} and 0.09 in day^{-1}, respectively.

An additional factor in the winter period of December 3 to April 8 that has to be considered is the sublimation of snow. This was factored into the calculation of the energy required. The estimated evaporation amounts are listed in Table 2. The total precipitation at the St. Paul campus Climatological Observatory currently averages 28.41 in. The total estimated evaporation loss of 22.12 in. and the precipitation total of 28.41 indicates a surplus of 6.29 in. This is lost as runoff and as additions to the groundwater.

Table 2. The estimated evaporation losses of water during an average year at St. Paul and the energy required in the evaporation.

Period	Evaporation	Energy Required*
April 21 - Oct. 10	17.97 in.	26,473 cal cm^{-2}
Oct. 11 - Dec. 2	1.82 in.	2,681
Dec. 3 - April 8	1.73 in.	2,900
April 9 - April 20	0.60 in.	884
Total	22.12 in.	32,938

* Energy requirements are assumed to be 580 cal g^{-1} for evaporation and an additional 80 cal g^{-1} for sublimation. It is assumed that the 1.73 in. assigned to Dec. 3 - April 8 is snow and not liquid precipitation.

An estimate of the energy consumed in the photosynthesis of an annual crop was made some years ago based on weekly sampling of soybeans. The whole plant including the roots was harvested. Over the 120 days growing season it was found that there was a mean daily matter increase of 15×10^{-4} g cm^{-2} day^{-1}. Assuming 4000 cal are required per gram, the total energy consumed over the season equalled 720 cal.

The energy used to heat the soil from January to July equalled 1952 calories, assuming a volumetric heat capacity of 0.51 cal cm^{-3} $°C^{-1}$. An additional 2000 calories were required to thaw the soil. A mean freezing depth of 100 cm was assumed and that ice occupied 25% of the total volume. Over a 12-month period the soil on the average will lose as much heat as was gained (that is, there is not a net heat gain or loss). Therefore, the total 3952 calories represent one-half of the heating cycle with an equal amount to be lost in the other half of the year. Thererefore, these figures are not counted in the annual heat budget.

The final result is as follows:

Annual total net radiation =		43,722 cal.
Evaporation energy =	32,938 cal	
Photosynthesis energy =	720	
Total	33,658	33,658
The difference (and the amount available to heat the air) =		10,064
Ratio energy consumed in heating the air to that consumed in evaporation =		10,064/32,938 = 0.31

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THE POSITIVE AND NEGATIVE EFFECTS OF THE RECENT "BENIGN CLIMATE"[1]

Donald G. Baker[2]

A little noticed but remarkably consistent and agriculturally favorable climatic period existed for approximately 30 years beginning in the early 1940's. The full application of technology to agriculture was delayed due to world political events (World War II and the Korean Conflict, for example) until the 1950's. From then until 1972 the interaction between this favorable climatic period and the applied technology and the enthusiasm they engendered in agricultural circles led to the inflation of the 1970's while the unexpected cessation of the "benign" climate led to the depression of the 1980's.

The period of the "benign climate" deserves special attention, since it is a good example of how pervasive and subtle (and sometimes not so subtle) the effects of climate can be. The "benign climate" has been detected in the Corn Belt region of the United States but has not been noted elsewhere to my knowledge. This is not to say that it did not occur, just that I am unaware of any study on the topic.

Before continuing with the "benign climate" story, it is important to study Fig. 1, since it illustrates the influence that the application of science and technology and their interaction with climate have had upon agriculture. The variation in annual yields about the general trend lines (the dashed lines in Fig. 1) present a rather deceiving picture. For example, it appears in Fig. 1 and 2 that severe yield depressions have occurred only in recent years. Certainly the approximately 37 and 48 bu/A yield depressions in 1976 and 1988, respectively, are unique to the record. However, these depressions can be large only because the potential yield had increased so greatly due to the interaction of science and technology with favorable climatic conditions. However, if the relative departures, expressed as percent departure from the trend lines, are viewed (Fig. 3) another picture emerges. It becomes apparent that a yield depression of 16 bu/A in 1934 (Fig. 1) compared to an expected yield of only 30 bu/A can be equally or more serious. In fact it represents a 46.6% decline (Fig. 3) which for a farmer in 1934 meant a greater loss than the 48 bu/A loss to a farmer in 1988.

The term "benign climate" is used to describe an apparently unique period in our climatic record that occurred in the recent past which had far reaching consequences, some of which only now are becoming apparent. Its discovery is an interesting story and occurred in the following way. Dr. McQuigg, the Missouri State Climatologist, and his colleagues wished to determine the effect of climate upon the yield of corn over time, as shown in Fig. 1, exclusive of the yield increases due to the application of science and technology (such as hybrid corn, commercial fertilizer and various chemicals) had upon yields (McQuigg and LeDuc, 1973). To do this the technology of 1973, the last year for which data were available for the study, was assumed in their crop yield model. Then the actual historical weather data were applied to the yield model. When this adjustment for technology was made, a most curious feature was found (Fig. 4). From the late 1930's or early 1940's until about 1971, yields of corn and soybeans were relatively high and showed less variation than any time before this period. Other evidence for this benign period in Minnesota can be found in the variation of annual temperatures, Fig. 5, and in the trend with time of the Palmer Drought Severity Index shown in Fig. 6.

The historical evidence, therefore, indicates that this feature, the "benign" period, was unique in the climatic record. And, as a unique feature, a return to the more normal years (termed "hostile" by some to contrast it with the benign period) could be expected. There were a number of people, in addition to some farmers, who overlooked the "benign climate" period as being unusual. The opinion was even expressed that technology had effectively overcome climatic influences (Thompson, 1975). This view with respect to climate versus technology has surfaced again in an article in Nature (Ausubel, 1991). From a strictly urban view an argument can be made that the climate has less effect than it once posed. This argument, at least from the urban perspective, is valid only as long as energy supplies are readily

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[1]Support for this study was provided by the Minnesota Agricultural Experiment Station and by Regional Project NC-94.

[2]Donald G. Baker is a Professor in the Soil Science Department, University of Minnesota, St. Paul, MN 55108.

available to provide the necessary heat or air conditioning. However, years like 1988 in the U.S. show the stress that can be placed upon even the most advanced civilization. From an agricultural perspective this view is difficult to support, since irrigation is successful only with adequate precipitation to replenish the source. And an artificial environment such as a glasshouse is feasible only for a relatively few crops.

There were political and technological factors that played an important part in delaying the advantages to be gained from this period until the early to mid-1950's. By then the U.S. had left the post World War II period, had more or less resolved the Korean conflict, and had entered the Eisenhower period of relative peace and prosperity. Vietnam was still on the horizon and inflation not yet a problem. Thus by the mid-1950's all of the technological advances - herbicides, pesticides, commercial fertilizers, hybrid corn, and improved machinery - were in place. For example, nitrogen fertilizer use in the U.S. increased from about 40 to 120 pounds per acre between 1960 and 1972 (Thompson, 1982).

For agriculture this period seemed to be one of ever increasing yields along with a climate, an economy, and a political scene which did not intrude. This then was a time in which an enthusiasm, a belief in an ever continuing "good life", and, indeed, a general euphoria was evident among many farmers.

This feeling of optimism and a willingness to take greater risks in terms of investments and long term goals was increasing, particularly among the younger farmers. They had not experienced the climatically and economically difficult times of the 1930's that their fathers had seen. Thus there were many farmers who were ill prepared for the time when the climate would revert, as most assuredly it would, to the more normal or "hostile" one of great variation in both precipitation and temperature. As a result, the climate, the general economy, and even the political scene were setting agriculture up for a dizzying ride, first up and then down. Unbeknownst to all but the keenest of observers was the fact that the "benign" climate was ending, and a return to the "hostile" climate of former years was commencing. The first indication of this for Minnesota farmers was the corn ear blight of 1972. Although responsibility for yield reductions in 1972 are generally attributed to the blight, this disease and its northward movement were weather induced. Next came the early frost of 1974, and then came the drought of 1976.

The "hostile" or normal climate, such as the climate experienced previous to 1940 and from 1972 on, requires greater conservatism and attention to detail than one in which the climatic conditions are both near the optimum and exhibit low variability. Such a condition permits the full expression of the applied technology. A "benign" climate can be of great profit to a good farmer, but it also "protects" the poor and careless farmer. It can be assumed that the "benign" climate lulled many a farmer, particularly those who entered farming during this period, into planning and operating as if the "benign" period was the prevailing condition. It also can be assumed that the combination of the benign climate and certain government agricultural programs helped prolong the stay of marginal farmers. Thus, the end of the "benign" period was a forerunner and precursor to the coming economic problems that would be instrumental in hastening the departure of many from farming, some of whom had been able to hang on thanks to the preceding "benign" period.

As the "benign" climate drew to a close, three related things occurred at this time that eventually brought about extremely difficult times for Corn Belt agriculture. Land prices began to rise as competition for land increased. Commodity prices too rose in concert, but not in proportion (Fig. 7), and outside interests began to pour money into farm land for both investment and speculative purposes. Poor fiscal policies of the federal government in the 1960's were beginning to bear fruit, such as the "Great Society" spending excesses at the same time as our involvement in Vietnam grew. Together they helped sow the seeds of the coming inflation. By 1982 short-term interest rates had reached at least 17% (Fig. 7). Unfortunately, many farmers failed to calculate what farm profits had to be to support such high rates of interest.

Soon to follow, and a natural culmination to these events with supporting information in hand, was the abrupt contraction in 1980 of land prices (Fig. 7). With a decrease in land values, upon which much of the bank loans for production costs and land purchases were based, less equity was available to the farmer. And with a more variable climate it meant that yields, and therefore, income, were no longer reliable.

An additional factor, as if the others were not enough, was the intrusion of politics. As the result of a very brief runup in the price of soybeans, the government in 1976 temporarily embargoed the export of beans. The results of this, though not felt immediately, meant that Japan, one of our best markets, had been cut off from its supplier. Since the U.S. could no longer be trusted as a supplier, the Japanese turned to South America as a source. The second political move to hurt American agriculture was the 1980 embargo of grain to the U.S.S.R. in response to the invasion of Afghanistan.

Thus, it is believed that climate played an extremely important but little recognized role in Corn Belt agriculture (if not in the whole U.S.) with the "benign" climate being an important, if not leading, factor in bringing about an almost unprecedented agricultural prosperity, only to be followed by a return to the more normal or "hostile" climate that led to the 1980's agricultural depression.

As a final note on this topic both relevant and interesting information is contained within Fig. 8. The upper portion is similar to Fig. 1 except it shows the mean Minnesota corn yield by decades. But for the decade of 1930-1939 the decadal mean has remained about 2 to 3 times greater than the range in the decadal yields. There is a slight indication that the range in annual yield values has decreased with time relative to the yield increases. Thus it might be inferred that technology has resulted in this suppression in the yield variation. In contrast, however, the upward trend of the standard deviation of the annual yields within each decade indicates an increasing variation with time following the decade of 1940-1949. Also, the bottom diagram shows that when the increasing size of the yields is taken into account with the coefficient of variation (the standard deviation divided by the mean) the increased variation with time remains, though it is less marked than the standard deviation. Thus, it is evident that climate, the major source of yield variation, has yet to be controlled.

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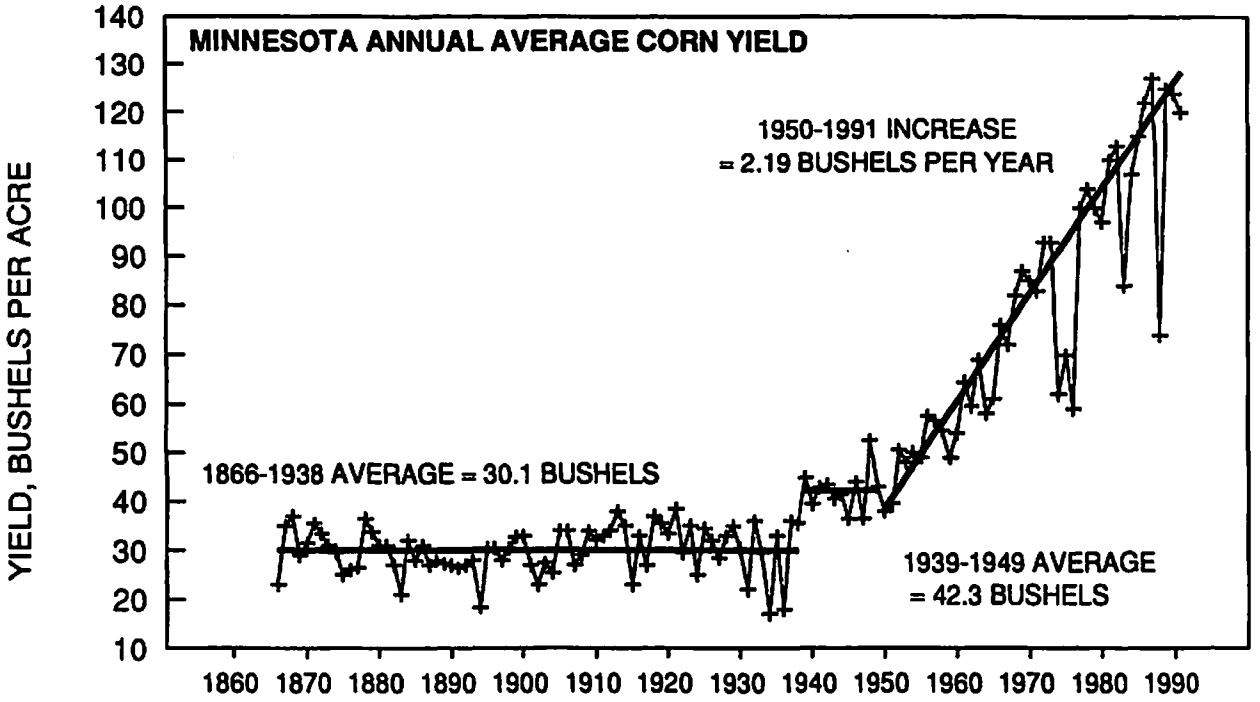

FIG. 1. Average corn yield in Minnesota. The three straight lines for 1866-1938, 1939-1949, and 1950-1991 represent the general linear trend for the respective periods. The 1950-1991 trend line was calculated exclusive of the yields for 1974, 1975, 1976, 1983, and 1988. Data are from the Minnesota Agricultural Statistics Service.

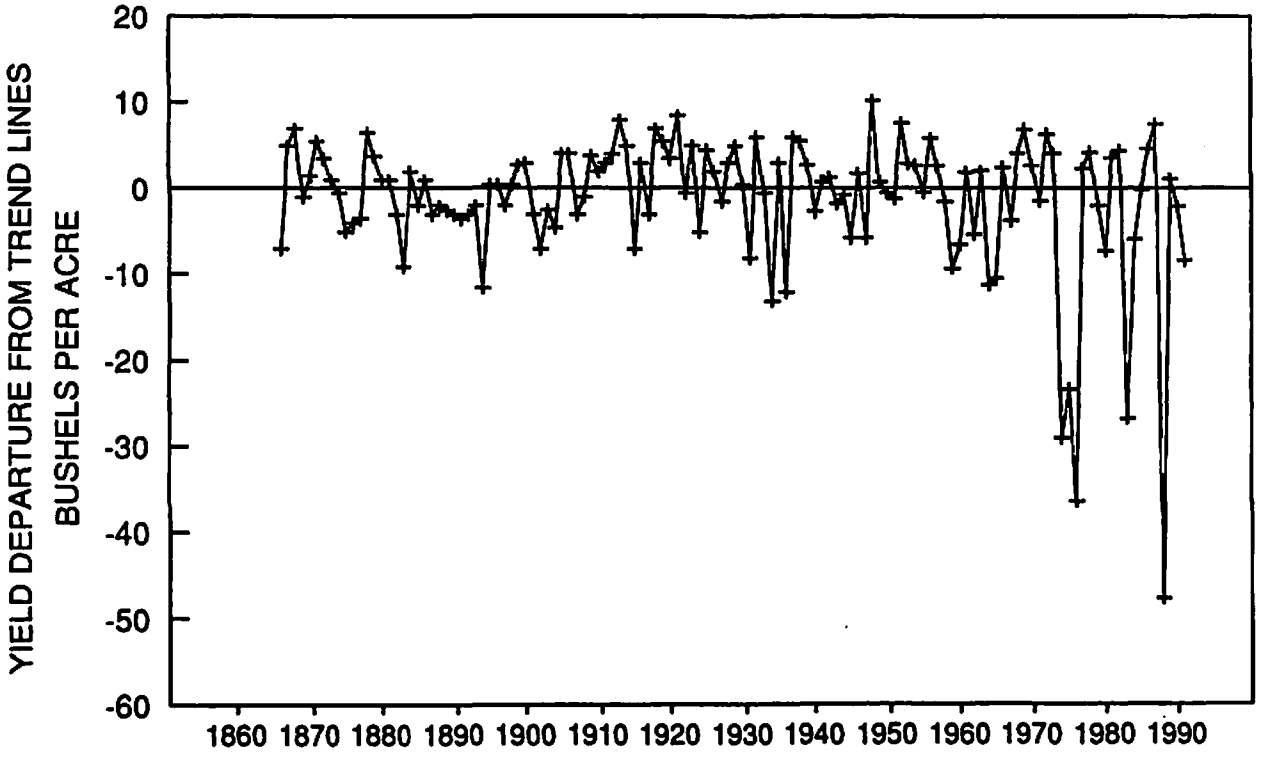

Fig. 2. The departure, in bushels per acre, of the average annual Minnesota corn yield from the general trends depicted in Fig. 1.

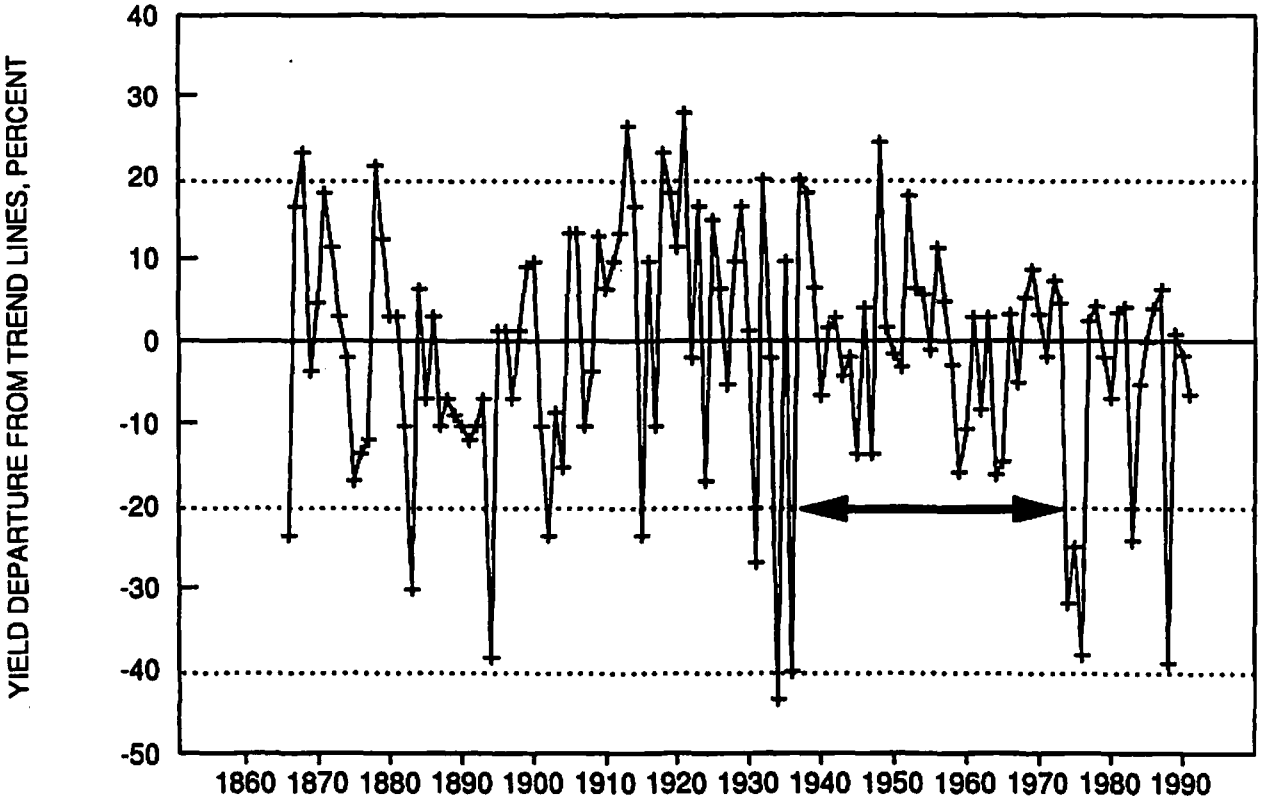

Fig. 3. The departure, in percent, of the average annual Minnesota corn yield from the general trends depicted in Fig. 1. Note that there were no departures greater than -17 percent from 1937 thru 1973.

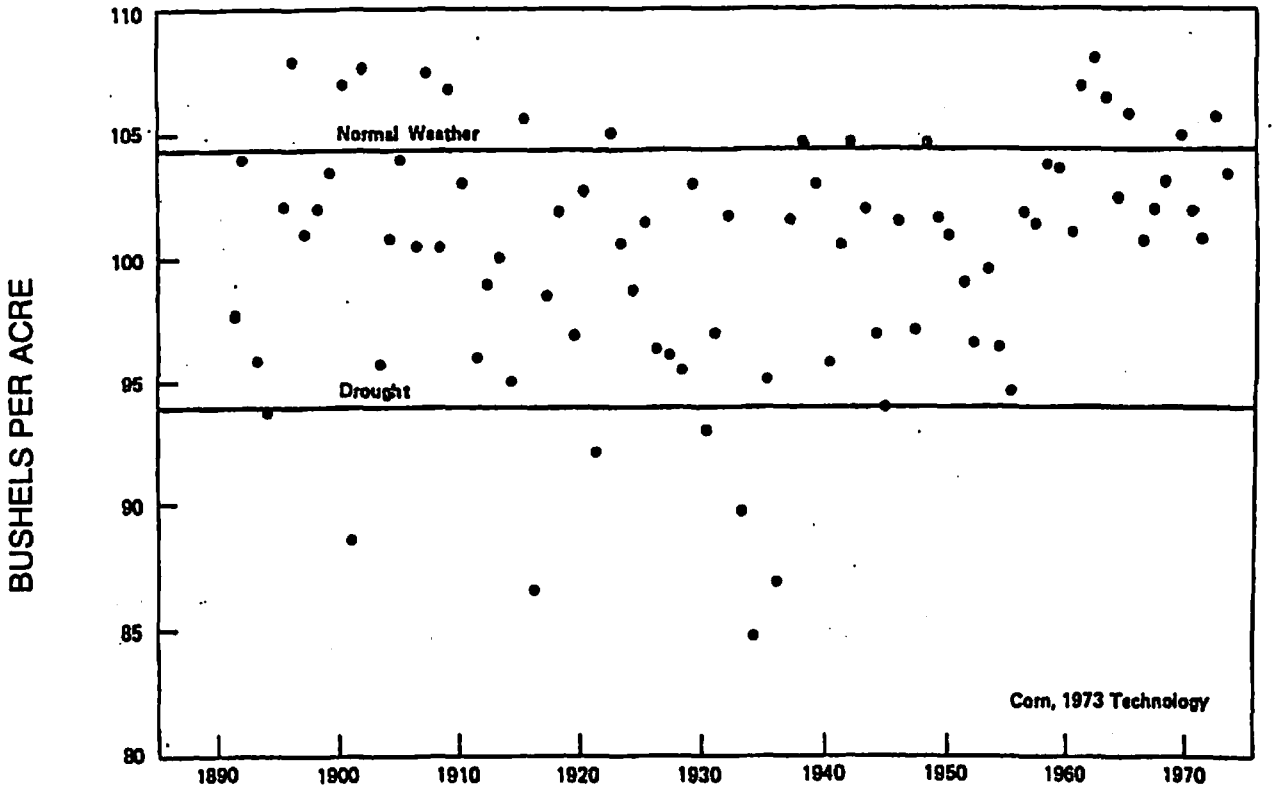

Fig. 4. Average yield of corn in five Corn Belt states assuming the technology of 1973 was available in previous years. This figure is from a study by McQuigg and LeDuc, 1973.

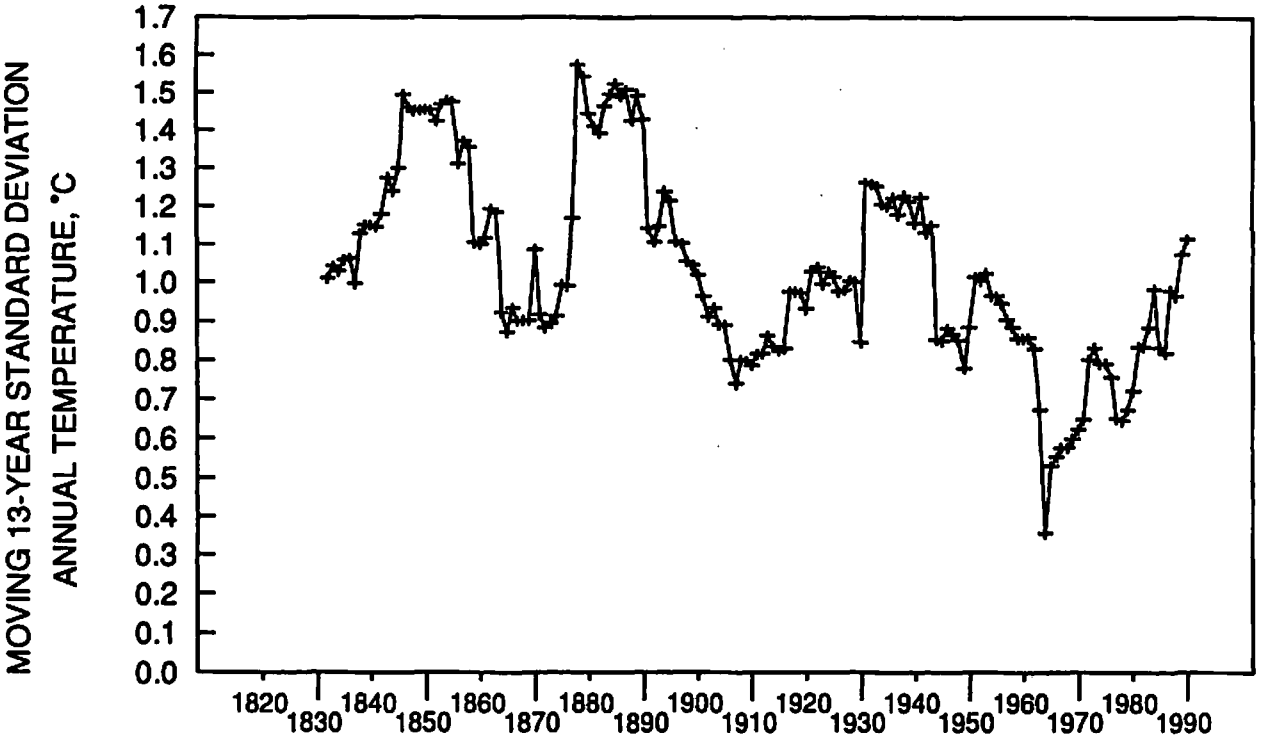

Fig. 5. The 13-year running standard deviation of the Eastern Minnesota average annual temperatures. The values are plotted at the end of the 13-year period, i.e., the 1978-1990 standard deviation is plotted at 1990.

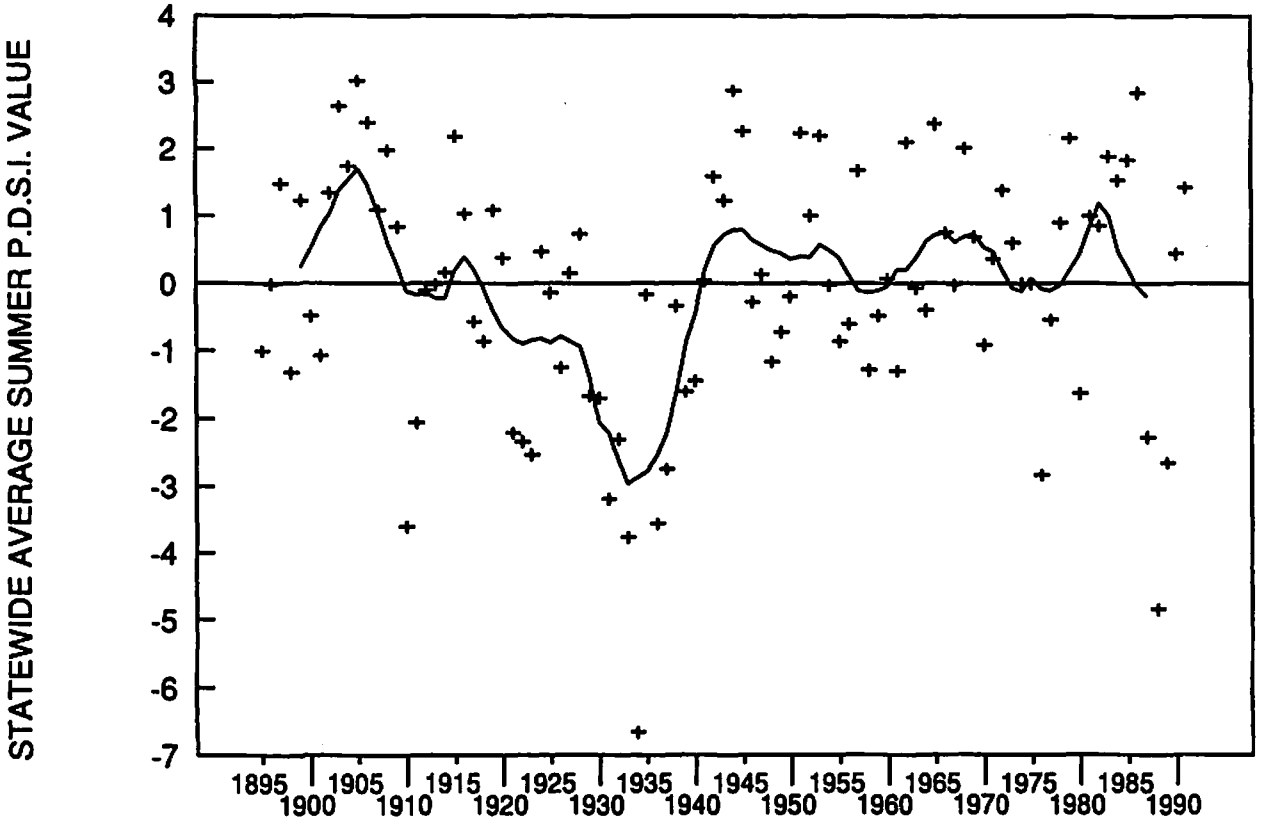

Fig. 6. Palmer Drought Severity Index average summer values (+) and smoothed values (solid line) for all climatic divisions of the state of Minnesota. The four levels of drought are: mild $\leq$ -1.0, moderate $\leq$ -2.0, severe $\leq$ -3.0, and extreme $\leq$ -4.0. Notice the absence of severe ($\leq$ -3.0) and extreme ($\leq$ -4.0) drought between 1941-1975. (Updated from Swerman et al., 1987).

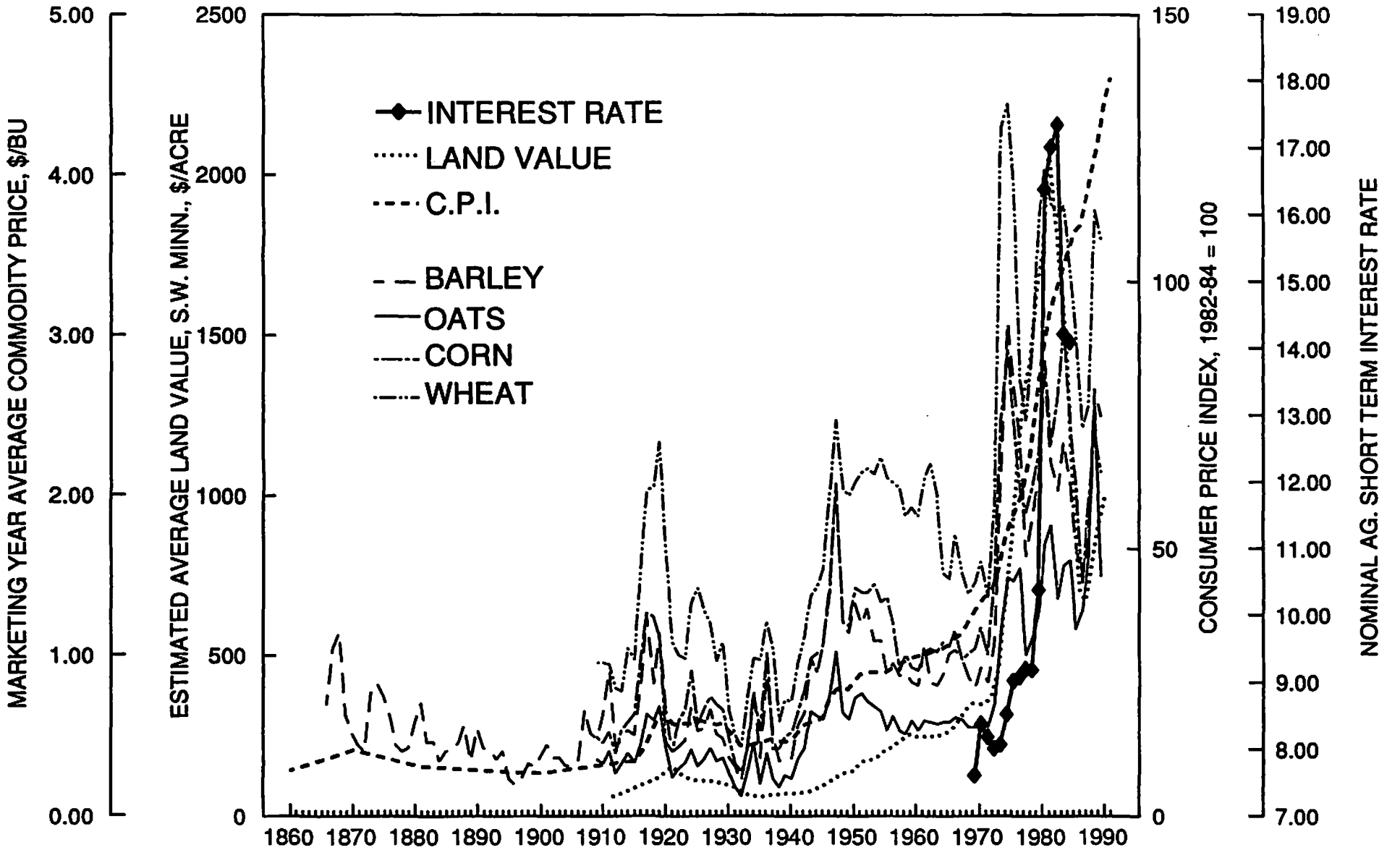

Fig. 7. Trend of consumer price index, agricultural commodity prices, nominal agricultural short term interest rates, and estimated average land value in southwestern Minnesota. Data courtesy of P. Raup and S.C. Stevens, Ag. Econ. Dept., Univ. of Minn., St. Paul, and the Minnesota Agricultural Statistics Service.

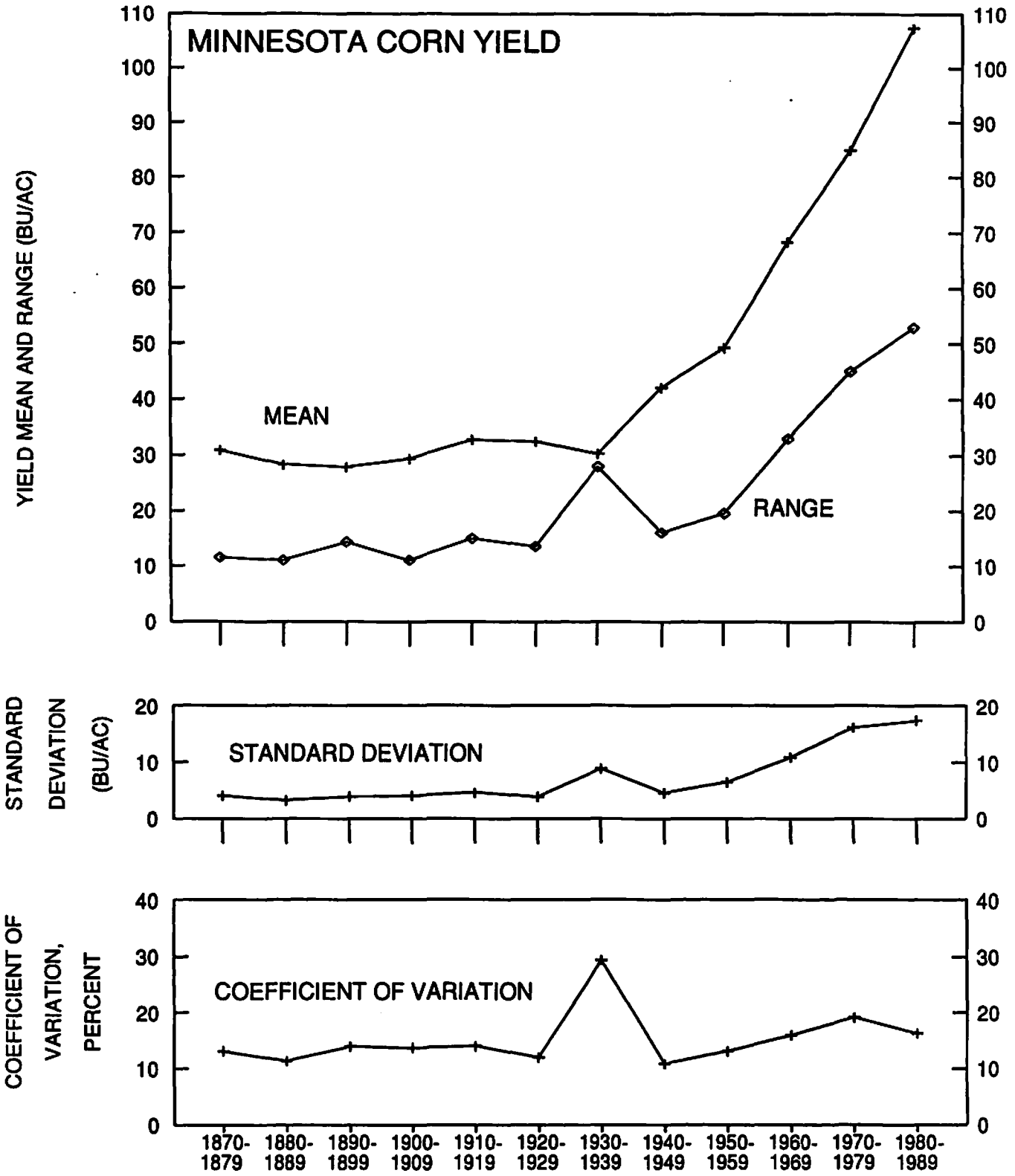

Fig. 8. The average yield of corn in Minnesota by decade with the range of annual yields within each decade (upper figure). The standard deviation of the annual yields within each decade (middle figure). The coefficient of variation of the annual yields within each decade (lower figure). (Original data are from the Minnesota Agricultural Statistics Service).

Climate Change and the Greenhouse Warming[1]

Donald G. Baker[2]

The changes that might occur to the world's climate resulting from the increase of CO_2 and similarly behaving gases in the atmosphere continues to cause concern and public comment. The latest news is that the aerosols introduced into the atmosphere by the eruption of Mount Pinotuba in the Philippines may well cause a cooling of the atmosphere (Charlson et al., 1992). The cooling is indicated by the same models used to estimate the warming by CO_2. It is expected that the cooling will equal in magnitude the warming that occurred over the last century. A principal effect of the aerosols is to decrease the incoming solar radiation. However, once the aerosols have settled out of the atmosphere it is expected that the warming will continue.

A second item of interest relative to a global climate change is that maximum and minimum temperatures have not been increasing equally. Recent analysis of temperature records in both the U.S. and the U.S.S.R. indicate an inequality in the warming. This has been termed an "asymmetric" warming (Karl et al., 1991). As a result we have looked at some Minnesota records which demonstrate this. See Fig. 9. and 10. Over the 98 year record period the linear trend increase of the minimum temperatures has amounted to 2.7°F compared to only 0.8°F for the maximum temperatures. Such a disparity between the two temperatures has not been indicated by the climate models, nor is it to be expected physically as a result of a CO_2-caused warming. Rather it appears to be due to an increase in cloud cover. A conclusion reached in the study by Karl et al. (1991) is that the Northern Hemisphere is being "significantly affected by factors unrelated to an enhanced anthropogenically - induced greenhouse effect".

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[1]A continuing study of Minnesota's climatological records is supported by the Minnesota Agricultural Experiment Station, St. Paul, MN 55108.

[2]Donald G. Baker is a professor in the Soil Science Department.

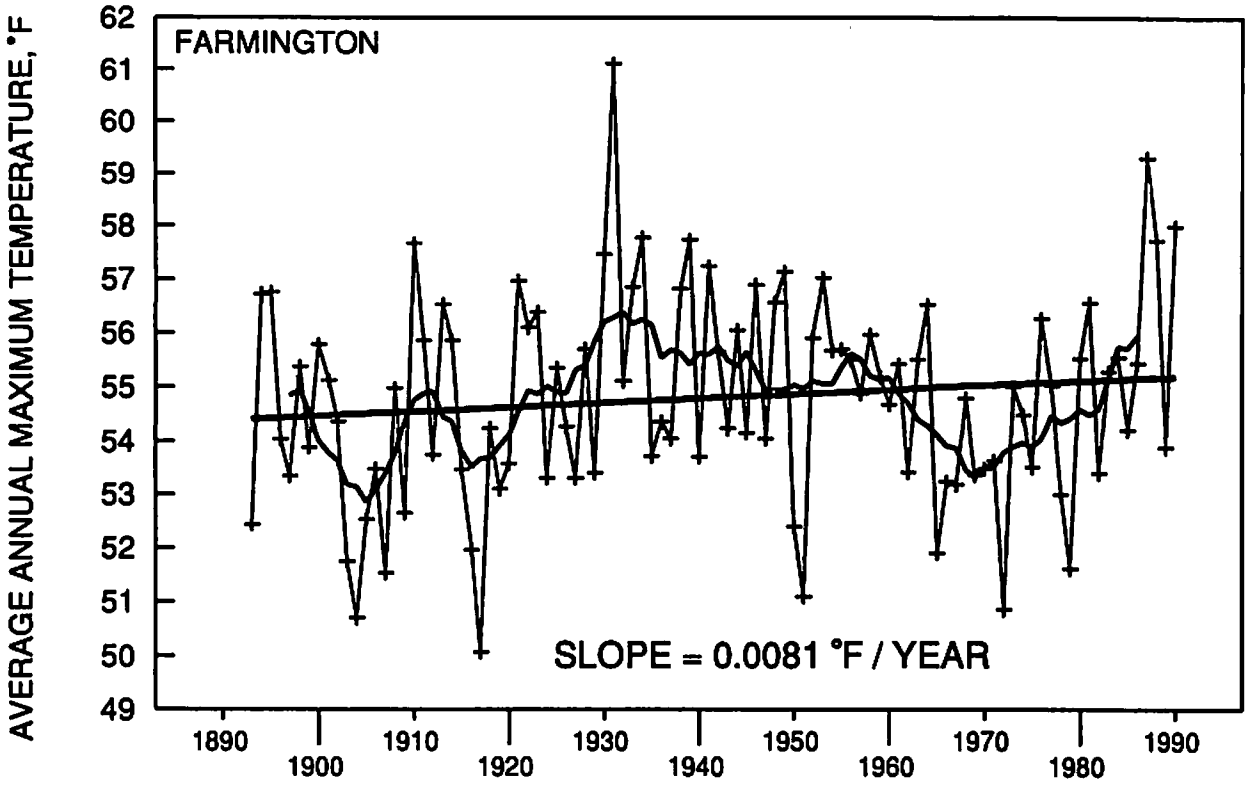

Fig. 9. Average annual maximum temperatures at Farmington 3NW, MN, 1893-1990. The smoothed data are shown and also the linear trend which has an increase of 0.0081 °F per year. This increase is not statistically significant.

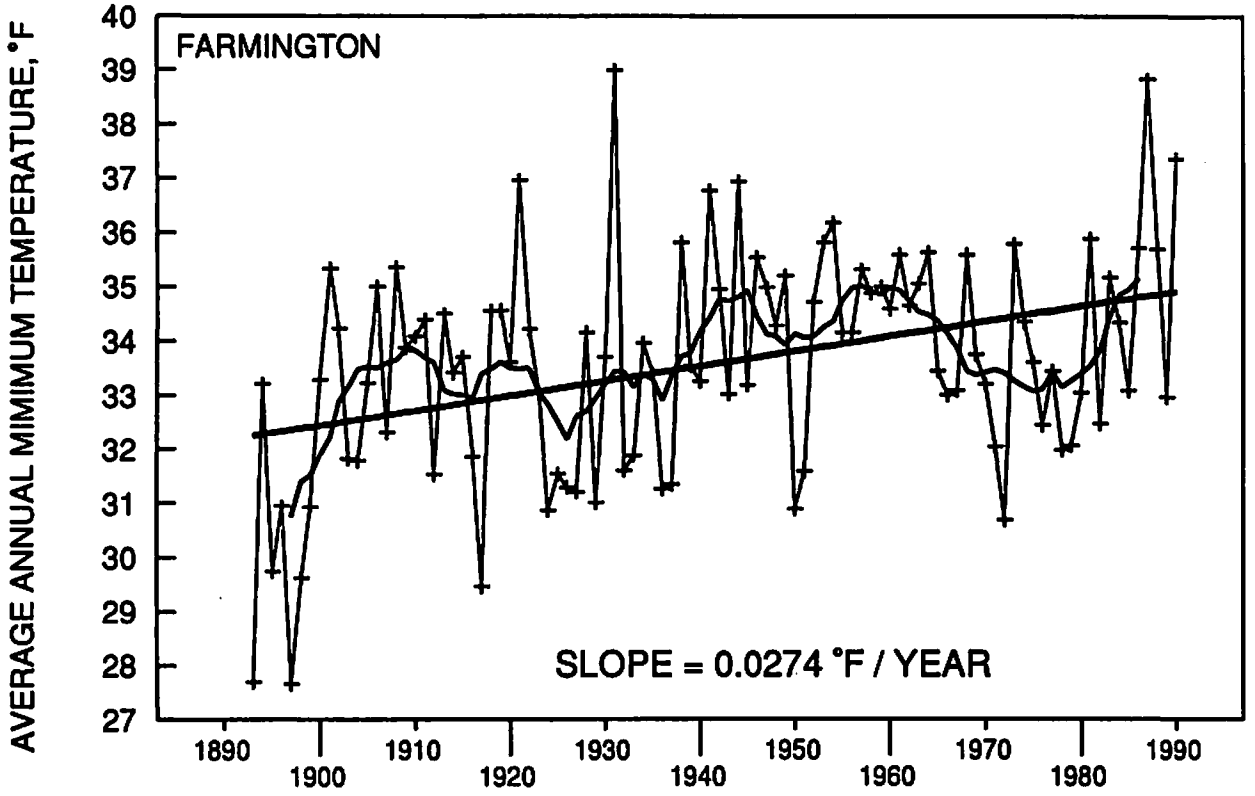

Fig. 10. Average annual minimum temperatures at Farmington 3NW, MN, 1893-1990. The smoothed data are shown and also the linear trend which has an increase of 0.0274 °F per year. This increase is statistically significant.

THE INVERSE RELATIONSHIP BETWEEN TEMPERATURE AND PRECIPITATION[1]

Donald G. Baker and David L. Ruschy[2]

The inverse relationship between temperature and precipitation in Minnesota is discussed and an explanation is provided.

An interesting inverse relationship exists between air temperature and precipitation amounts when viewed on a long term basis, Fig. 11. Precipitation periods are accompanied by cloud cover which, of course, obscures the sun and decreases solar heating. At the same time evaporation of this precipitation from the earth's surface consumes great amounts of energy, which otherwise would have resulted in higher air and soil temperatures.

Due to the much greater solar input during the warmer half of the year (March 22 to September 21), a reduction of the energy input with a cloud cover has a greater effect than in the colder half of the year. In fact the cloud cover effect upon air temperatures is different in the two periods; cooler temperatures result in the warmer half and warmer temperatures in the cooler half. In the latter case due to the longer nights the clouds are more important as blankets and keep the earth from cooling.

The decreased solar input in the warmer half of the year due to a cloud cover plus the much greater evaporation that occurs in the same period act together to overwhelm any warmer temperatures occurring due to a cloud cover in the September 22 to March 21 period.

Because of the variation in cloudiness and precipitation within any one year, or even a few years, a long term view such as the 30-year running mean depicted in Fig. 11 is required to make the inverse relationship so evident.

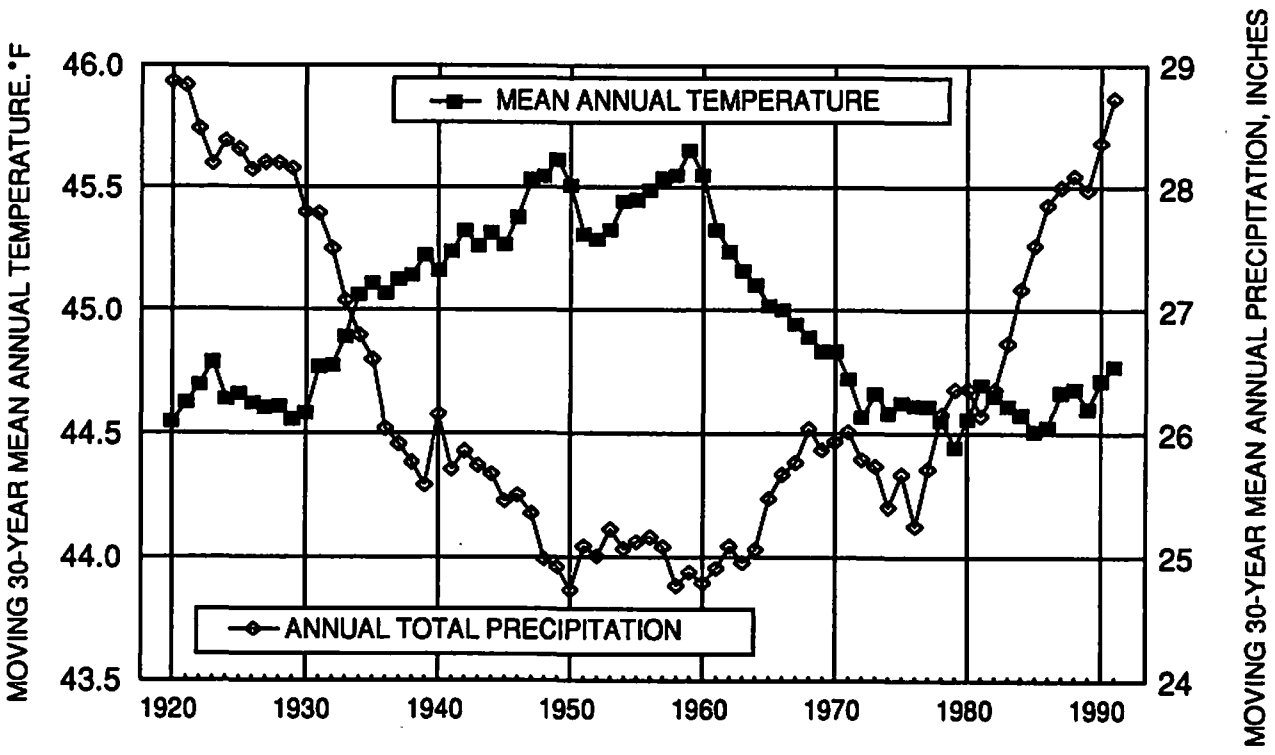

Fig 11. The moving 30-year average annual temperature and annual total precipitation at Minneapolis - St. Paul, 1891-1991.

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[1]This study was supported by the Minnesota Agricultural Experiment Station.

[2]Donald G. Baker and David L. Ruschy are Professor and Assistant Scientist, respectively, at the Soil Science Department, University of Minnesota, St. Paul, MN 55108.

CALCIUM NITRATE AS A SOURCE OF CALCIUM AND NITROGEN FOR POTATO PRODUCTION[1]

Carl Rosen, Dave Birong, Duane Preston, and Roger Hanson[2]

ABSTRACT: Two field experiments, were conducted to evaluate the effects of calcium nitrate as a calcium and nitrogen source for potato production. At Becker, MN under irrigated conditions using the cultivar 'Russet Burbank', total yields obtained when calcium nitrate was provided were similar to those when only urea was used. Calcium nitrate increased calcium concentrations in leaf tissue, but did not significantly affect tuber skin or flesh calcium. At Grand Forks, ND under nonirrigated conditions using the cultivar 'Norchip', nitrogen supplied either as urea or calcium nitrate tended to increase potato yield over yields obtained in the control plot. Calcium nitrate had no effect on calcium concentrations in leaf or tuber tissue.

Calcium is a nutrient that has been implicated in improved storage qualities of potatoes. Yield increases have also been reported with calcium applications when potatoes are grown on low Ca soils. One of the most readily available forms of calcium is calcium nitrate; however, the effect of this calcium source on potato production in Minnesota has not been evaluated. The objective of this research was to determine the effects of calcium nitrate on potato yield, nutrient composition, and tuber quality under irrigated and nonirrigated conditions.

PROCEDURES:

Field experiments were conducted at two locations: the Sand Plains Research Farm in Becker, MN under irrigation and the Potato Research Farm in Grand Forks, ND. Procedures varied with each location will be discussed separately.

Sand Plains Research Farm, Becker, MN: The soil at this location is classified as a Hubbard loamy sand and had the following soil test values prior to planting (0-6"): pH - 5.8; Organic Matter - 3%; Bray P1 - 24 ppm; NH_4OAc K, Ca, Mg - 61, 455, 75 ppm, respectively; 2N KCl nitrate-N - 20 lb/A. The previous crop was rye. The cultivar 'Russet Burbank' was planted April 19, 1991. Prior to planting, 200 lbs 0-0-60/A and 200 lbs 0-0-22/A were broadcast and incorporated over the entire field. At planting, all plots received 750 lb 8-10-30 as a band with urea as the N source. There were six treatments arranged in a randomized complete block design with four replications. The six treatments were:

	Time of application				
Treatment No.	Planting	Emergence	Hilling	3 weeks post hilling	6 weeks post hilling
	N rate (lb/A) and source				
1.	60 Urea	75 Urea	75 Urea	0	0
2.	60 Urea	75 Urea	75 Ca Nit	0	0
3.	60 Urea	75 Ca Nit	75 Urea	0	0
4.	60 Urea	75 Ca Nit	75 Ca Nit	0	0
5.	60 Urea	30 Urea	35 Urea	35 Urea	35 Urea
6.	60 Urea	30 Urea	35 Ca Nit	35 Ca Nit	35 Ca Nit

The N application at emergence was on May 24 and the hilling application was on June 7. Irrigation was supplied according tho the checkbook method. Leaf samples were collected on June 21 and August 2 for nutrient analyses. Plots were harvested on September 4 and tubers were separated according to size. Subsamples of tubers were also collected for specific gravity determinations and nutrient analyses.

Potato Research Farm, Grand Forks, ND: The soil at this location is classified as a Nutley/Aberdeen silty clay loam and had the following soil test results (0-6"): pH - 7.8; Organic Matter - 3.3%; Bray P1 - 7 ppm; NH_4OAc K, Ca, Mg - 114, 5315, 788 ppm, respectively; 2N KCl nitrate-N - 70 lb/A. The cultivar 'Norchip' was planted May 22, 1991. There were five treatments :

1. Control (no nitrogen applied)
2. 75 lb N/A as urea at planting
3. 75 lb N/A as calcium nitrate at planting
4. 75 lb N/A as urea at planting and 75 lb N/A as urea at hilling
5. 75 lb N/A as urea at planting and 75 lb N/A as calcium nitrate at hilling

[1] Funding for this project was provided by WGM/Hydro.

[2] Extension Soil Scientist, Junior Scientist, Dept. of Soil Science, Area Agent and Potato Research Station Supervisor, Grand Forks, ND.

Prior to planting, 75 lbs/A 0-46-0 and 50 lb/A 0-0-60 were broadcast and incorporated. Nitrogen applied at planting was broadcast and incorporated. Nitrogen applied at hilling was sidedressed and then incorporated into the hill. All plots were hilled June 26. The experimental design was a randomized complete block with six replications. Leaf samples were collected on June 26 for nutrient analyses. Tubers were harvested September 26, 1991 and sorted according to size. Subsamples of tubers were collected at harvest for specific gravity determinations and elemental analyses.

Total leaf nitrogen was determined using Kjeldahl procedures (with nitrate reduction) and calcium in leaf and tuber tissue was determined on ashed samples using ICP techniques.

RESULTS:

Becker, MN: All treatments tested resulted in similar total potato yields (Table 1). The calcium nitrate treatment applied only at hilling (treatment 2), resulted in significantly more 3-7 oz size potatoes and less 7-14 oz potatoes compared to the urea treatment at similar application times (treatment 1). Reasons for this apparent shift in size distribution with calcium nitrate at hilling are not clear since the other treatments with calcium nitrate resulted in similar size distributions as the all urea treatments. Specific gravity was similar for all treatments tested. Leaf concentrations of nitrogen at the first planting date were lower when calcium nitrate was used at hilling and emergence compared to the all urea treatments (Table 2). At both sampling dates, elevated leaf calcium concentrations were detected when calcium nitrate was applied at the hilling stage, but not when applied at emergence or in lower application rates post hilling. Leaf nitrogen at the second sampling date was highest when calcium nitrate was applied in three 35 lb N/A doses starting at hilling. Tuber skin calcium concentrations were 4-5 times higher than calcium concentrations in tuber flesh (Table 3). Calcium nitrate did not significantly increase tuber calcium concentrations in skin or flesh compared to urea; however, there was a slight trend for higher calcium levels in tuber skin when calcium nitrate was applied at post hilling or once at emergence. No trends due to calcium nitrate treatment were observed in tuber flesh calcium levels.

Grand Forks, ND: Statistically, only the urea treatment at 150 lb N/A was higher than the zero N control (Table 4). However, all treatments receiving 75 or 150 lb N/A resulted in at least 30 cwt/A more than the control. Nitrogen application, whether from urea or calcium nitrate, tended to result in larger tubers. For the greater than 3.5" size category, the urea treatment at 75 lb N/A was the only treatment to result in significantly greater yield than the control treatment. Specific gravity was not affected by the nitrogen treatments. Leaf nitrogen and calcium concentrations were not affected by treatment, although there was a trend for lower leaf nitrogen in the control treatment (Table 5). It should be pointed out that leaf samples were collected just before the hilling N application and therefore do not reflect nitrogen applied at hilling. Calcium concentrations in tuber skin and flesh were not affected by either of the nitrogen sources (Table 6).

Table 1. Comparative effects of calcium nitrate and urea on 'Russet Burbank' potato yield and specific gravity. (Becker, 1991).

Treatment											
Time of application						Tuber size					Specific
Planting	Emergence	Hilling	3wk PH[1]	6wk PH	Knobs	<3 oz	3-7 oz	7-14 oz	<14 oz	Total	Gravity
N rate (lb N/A) and source[2]					cwt/A						
60 U	75 U	75 U	0	0	32.5	26.0	213.5	193.2	16.0	481.2	1.0855
60 U	75 U	75 C	0	0	36.5	30.9	294.0	126.7	14.7	502.7	1.0870
60 U	75 C	75 U	0	0	27.3	23.5	240.5	172.4	11.7	475.4	1.0853
60 U	75 C	75 C	0	0	25.9	25.0	268.2	148.7	18.2	486.0	1.0878
60 U	30 U	35 U	35 U	35 U	23.7	39.0	234.8	168.8	14.0	480.3	1.0863
60 U	30 U	35 C	35 C	35 C	17.8	27.5	241.0	178.7	20.2	480.3	1.0848
Significance					NS	NS	*	*	NS	NS	NS
LSD (5% level)					--	--	51.2	54.2	--	--	--

NS = nonsignificant, * = significant at the 5% level.
[1]wk PH = weeks post hilling
[2]U = urea, C = calcium nitrate

Table 2. Comparative effects of calcium nitrate and urea on total nitrogen and calcium concentrations in leaves (petiole + leaflets) sampled June 21 and August 2. (Becker, 1991).

Treatment					Sampling Date			
Time of application					June 21		August 2	
Planting	Emergence	Hilling	3wk PH[1]	6wk PH	Nitrogen	Calcium	Nitrogen	Calcium
N rate (lb N/A) and source[2]					% dry weight			
60 U	75 U	75 U	0	0	5.72	0.70	4.88	0.88
60 U	75 U	75 C	0	0	5.43	1.04	4.48	1.07
60 U	75 C	75 U	0	0	5.67	0.81	4.95	0.72
60 U	75 C	75 C	0	0	4.95	1.15	4.43	1.07
60 U	30 U	35 U	35 U	35 U	5.53	0.97	5.11	0.71
60 U	30 U	35 C	35 C	35 C	5.22	0.95	5.53	0.64
Significance					*	*	**	*
LSD (5% level)					0.54	0.41	0.54	0.35

* = significant at the 5% level, ** = significant at the 1% level.
[1]wk PH = weeks post hilling
[2]U = urea, C = calcium nitrate

Table 3. Comparative effects of calcium nitrate and urea on calcium concentrations in tuber skin and flesh at harvest. (Becker, 1991).

Treatment					Calcium concentration	
Time of application					Skin	Flesh
Planting	Emergence	Hilling	3wk PH[1]	6wk PH		
N rate (lb N/A) and source[2]					ppm dry weight	
60 U	75 U	75 U	0	0	940	234
60 U	75 U	75 C	0	0	869	192
60 U	75 C	75 U	0	0	1017	181
60 U	75 C	75 C	0	0	889	225
60 U	30 U	35 U	35 U	35 U	873	228
60 U	30 U	35 C	35 C	35 C	1128	227
Significance					NS	NS

NS = nonsignificant
[1]wk PH = weeks post hilling
[2]U = urea, C = calcium nitrate

Table 4. Comparative effects of calcium nitrate and urea on 'Norchip' potato yield and specific gravity. (Grand Forks, 1991).

Treatment: Time of application: Planting	Hilling	Tuber Size: < 1"	1-2"	2-3.5"	> 3.5"	Total	Specific Gravity
N rate (lb N/A) and source[1]		cwt/A					
0	0	20.6	65.9	137.0	7.5	231.0	1.0936
75 U	0	26.4	67.6	146.4	20.8	261.1	1.0918
75 C	0	25.3	69.3	155.5	15.3	265.5	1.0906
75 U	75 U	24.4	69.5	167.1	17.3	278.2	1.0933
75 U	75 C	23.3	63.8	164.7	13.9	265.7	1.0928
Significance		NS	NS	NS	*	*	NS
LSD (5% level)		--	--	--	9.5	37.0	--

NS = Nonsignificant, * = significant at the 5% level.
[1]U = urea, C = calcium nitrate

Table 5. Comparative effects of calcium nitrate and urea on total nitrogen and calcium concentrations in potato leaves (petioles + leaflets) sampled June 26. (Grand Forks, 1991).

Treatment: Time of application: Planting	Hilling	Nutrient Concentration: Nitrogen	Calcium
N rate (lb N/A) and source[1]		% dry weight	
0	0	4.29	1.95
75 U	0	4.49	2.00
75 C	0	4.73	1.97
75 U	75 U	5.10	1.94
75 U	75 C	4.70	2.08
Significance		++	NS
LSD (0.10)		0.71	--

NS = Nonsignificant, ++ significant at 10%.
[1]U = urea, C = calcium nitrate

Table 6. Comparative effects of calcium nitrate and urea on calcium concentrations in tuber skin and flesh at harvest. (Grand Forks, 1991).

Treatment: Time of application: Planting	Hilling	Calcium Concentration: Skin	Flesh
N rate (lb N/A) and source[1]		ppm dry weight	
0	0	1428	226
75 U	0	1287	228
75 C	0	1385	213
75 U	75 U	1485	234
75 U	75 C	1476	212
Significance		NS	NS

NS = Nonsignificant
[1]U = urea, C = calcium nitrate

NITROGEN FERTILIZATION STUDIES ON IRRIGATED POTATOES: NITROGEN USE, SOIL NITRATE MOVEMENT, AND PETIOLE SAP NITRATE ANALYSIS FOR PREDICTING NITROGEN NEEDS[1]

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Potatoes grown on sandy soils under irrigation are usually provided with high rates of nitrogen (N) to promote growth and yield. Concern about ground water quality, however, has raised questions about the fate of N applied to potatoes on irrigated soils. In part, this concern is due to the fact that potatoes have a relatively shallow root system, yet require relatively high rates of N to maintain profitable production. Proper N management is critical to minimize losses of N from the root zone and maintain yields. The objectives of this study were to characterize the pattern of soil nitrate-N movement during irrigated potato production under defined management regimes and to develop diagnostic tools for quick and accurate prediction of the need for N by potato during the growing season.

EXPERIMENTAL PROCEDURES

The experiment was conducted in Becker, MN at the Sand Plain Research Farm. The soil is a Hubbard loamy sand. The previous crop was rye. Selected soil chemical properties prior to planting were as follows (0-6"): pH, 6.7; organic matter, 2.5%; phosphorus, 36 ppm; potassium, 98 ppm; sulfur, 1 ppm. Residual nitrate-N in the top 3 feet of soil was 26 lb/A. Prior to planting, 200 lbs/A 0-0-22 and 200 lbs/A 0-0-60 were broadcast and incorporated. Russet Burbank "B" size potatoes were planted May 3, 1991 at a spacing of 36" between rows and 10" within the row. Phosphate (0-46-0) and potash (0-0-60) fertilizer were applied in the band at planting at a rate of 80 lb P_2O_5/A and 200 lb K_2O/A to all plots. The fertilizer was banded 3" to each side and 2" below the tuber. Individual plot size consisted of six, 30 ft rows. The middle two rows (3 and 4) were harvest rows and rows 2 and 5 were sample rows. Ten treatments were tested to evaluate the effects of various N management practices on potato productivity, N use/uptake, soil nitrate movement, and petiole N status during the course of the season.

The 10 specific treatments were as follows:

		N Application Rate (lb N/A)			
	N Source	Planting	Emergence	Hilling	Post-Hilling
1)	Control	0	0	0	0
2)	Ammonium nitrate	0	120	120	0
3)	Ammonium nitrate	40	100	100	0
4)	Ammonium nitrate	80	80	80	0
5)	Ammonium nitrate	120	60	60	0
6)	Ammonium nitrate	80	80	0	0
7)	Slow Release[1]	80	80	0	0
8)	Ammonium nitrate	40	40	40	0
9)	Ammonium nitrate	40	40	40	based on sap test
10)	Urea	80	80	80	0

[1]Slow release fertilizer was Nutralene (40-0-0).

Nitrogen applied at planting was banded with the P and K fertilizer. Nitrogen applied at emergence (May 31) was banded 1" deep and 8" from each side of the plant. At hilling (June 13), the N fertilizer was sidedressed on the surface on either side of the plant and then incorporated during the hilling process. Post-hilling applications to treatment #9 were applied on June 21 and July 16. Applications were made by broadcasting ammonium nitrate over the plot by hand and then irrigating in. The June 21 application could have been delayed about one week. It should have been applied when the sap nitrate-N was about 1300 ppm. The July 16 application was based on a critical sap value of 900 ppm.

The experimental design was a randomized complete block with 4 replications. Rainfall was supplemented with overhead irrigation to supply water needs according to the checkbook method. Rainfall during the growing season totaled 31.6 inches and was supplemented with 10 inches of irrigation. The nitrate-N concentration in the irrigation water averaged 7 ppm. Given that 10 inches of irrigation were applied, approximately 16 lbs of additional N was provided with the irrigation water. Figure 1 shows the weekly precipitation (rainfall + irrigation) through the growing season.

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Recently matured potato leaves (4th leaf from the growing terminal) were collected every 10-14 days starting one day before hilling for nitrate-N determinations. Thirty leaves were collected from each plot. Leaflets were removed, half of the petioles were crushed with a Hach press, and the remaining petioles were dried in an oven at 140°F. The expressed sap was immediately frozen until analyses could be performed.

Two instruments designed for quick tests were compared: the Hach nitrate electrode and the Horiba/Cardy nitrate electrode. In addition to the quick test procedures, nitrate in sap and nitrate in dried petioles were determined conductimetrically using a Wescan nitrogen analyzer.

Specific methods for analyses were as follows:

Hach Test - The instrument was calibrated using two standard solutions. One ml of expressed sap was mixed with 25 ml of 0.075 molar aluminum sulfate solution. The electrode was immersed into the solution and a reading was recorded. The reading was related to concentration of nitrate-N in the sap by using a standard curve.

Horiba/Cardy Test - The instrument was calibrated using two standard solutions. One half ml of expressed sap was mixed with 2.0 ml of 0.075 molar aluminum sulfate solution. A few drops of the mixture were placed on the electrode and a direct reading of concentration was recorded. NOTE: Determination of nitrate in nondiluted sap was also attempted; however, the readings obtained were consistently higher than the other methods. Dilution with aluminum sulfate gave more realistic values and the instrument seemed to be more stable.

Wescan Sap Test - The instrument was calibrated using five standard solutions. One ml of expressed sap was mixed with water to a volume of 100 ml in a volumetric flask. Diluted solutions were run through the instrument and the reading recorded was related to the concentration of nitrate-N in the sap using a standard curve.

Wescan Petiole Nitrate Test - The instrumental set up was the same as for the sap test. Dried petioles were ground and 0.1 g of ground tissue was weighed and mixed with 20 ml of water. Samples were shaken for 30 minutes and then filtered. The reading recorded was related to concentration of nitrate-N in dried tissue using a standard curve.

Nitrate-N was determined in soil samples collected at hilling and two days before harvest. The samples at hilling were collected in the row to a depth of one foot. Samples collected at harvest consisted of 3 cores from an individual plot taken to a depth of 3 feet at 1 foot increments. Two samples at each depth were collected from each plot: one from between rows and the other within rows. All samples were brought back to the lab and air dried. Nitrate and ammonium were extracted with 2 N KCl using a 5 g to 25 ml soil:extractant ratio. For the hilling samples, results are expressed as ppm nitrate-N or ammonium-N. For the harvest samples, results are expressed as pounds of nitrate-N or ammonium-N using the convention ppm X 2 = lb/A for a 6" furrow slice. Bulk density of each sampling depth was not determined, so lb/A values should be considered approximate. To calculate lbs nitrate-N/A, it was assumed that half the field was 'within row' and the other half 'between row'.

Suction tubes, consisting of a porous ceramic cup and 1.5" diameter PVC ubes were installed one week after planting in the row at 2.5 and 4.5 ft depths. Nitrate-N in soil water was determined in samples collected every 1-2 weeks from the suction tubes.

Two plants from the sample row from each plot were harvested every two weeks starting one week before hilling. Samples were dried and weighed to determine dry weight accumulation through the season. Samples were ground and total N was determined using the salicylic Kjeldahl method. At harvest, vines were cut and weighed one week prior to harvest. Potatoes were mechanically harvested on September 12. Subsamples of vines and tubers were collected to determine dry matter and N accumulation using methods describe above for the two plant samples.

RESULTS

Rainfall and Soil Nitrate Movement. Weekly precipitation over the course of the season is presented in Figure 1. Rainfall was excessive from planting to emergence with nearly 7 inches falling during this time period. June and July were also well above normal in rainfall events.

Seasonal nitrate-N concentrations in soil water extracted with the suction tubes at depths of 2.5' and 4.5' for each treatment are shown in Figures 2 to 11. Although nitrate-N in the soil water was measured, these numbers do not represent the concentration of nitrate in the ground water. Nor do they indicate the amount of nitrate lost to the ground water. The only way these data can be interpreted is in a more qualitative

sense. That is, a higher peak for one treatment compared to another at a given time, indicates that losses of nitrate were relatively greater, but does not indicate how much greater. These data, therefore, can be used to determine which treatments minimized nitrate movement out of the root zone.

The control treatment where no fertilizer N was applied, had basically background concentrations of nitrate-N (1-20 ppm). A noticeable feature of all treatments was that between 12 and 18 weeks after planting nitrate-N concentrations were very low and then increased 18 weeks after planting. The period of 12-18 weeks after planting follows the period of rapid N uptake by the potato plant. The increase after 18 weeks corresponds to the period after harvest and may represent a slight flush of nitrate following breakdown of vines.

Starter N fertilizer had dramatic effects on nitrate movement (Figures 3 to 6). The 120 lb N/A starter fertilizer rate had the highest concentrations of Nitrate-N in the soil water compared to the other treatments. Delaying application of N to the emergence stage significantly reduced nitrate movement during the growing season even though the same total amount of N was applied. The significant movement of N corresponded to the 4 inches of rain that occurred at the end of May.

Slow release N fertilizer reduced nitrate movement compared to ammonium nitrate (Figures 7 vs. 8). The use of urea also reduced nitrate movement compared to ammonium nitrate (Figures 11 vs. 5). Most of the differences in nitrate movement occurred at the beginning of the growing season. These results suggest that in terms of potential N losses, fertilizer N used at planting should be in the ammonium form rather than nitrate form. Post-hilling applications of N did not result in increased losses of N (Figures 9 vs. 10). Even though more N was applied in the post-hilling treatment, it was applied at a time when the plant could use it.

Extractable nitrate-N and ammonium-N in the top foot of soil one day before hilling did not provide useful data for adjusting N fertilizer rates at hilling (Table 5). That is, there were not enough differences in the concentrations due to treatment to base any recommendations. By the end of the season, nitrate-N was basically at background levels (Table 6).

Tuber Yield, Specific Gravity, and Vine Yield. The effects of the various N treatments on tuber yield, specific gravity, and vine yield are presented in Table 1. Total yield increased with N rate with most of the yield increase occurring between the control treatment and 120 lb N/A. The 7-14 oz tuber size increased significantly with N rate. Vine yield also increased with increasing N rate. Specific gravity of tubers from the control treatment was lower than in the those receiving N. Starter N had no significant effect on total tuber yield, but higher rates of N tended to increase knobby tubers. Higher starter N rates resulted in lower vine yield at harvest. Specific gravity increased with increasing starter N rates. At similar N rates and timing of application, there was little difference between urea and ammonium nitrate on vine and tuber yields. Specific gravity was slightly lower when urea was used. Vine and tuber yields and specific gravity with slow release N were similar to those obtained with ammonium nitrate. The post hilling N application treatment resulted in 200 lb N/A (120 lb N/A before hilling and 80 lb N/A after hilling. Additional N after hilling increased tuber size and vine yield compared to the 120 lb N/A rate, but was not significantly different in tuber size and vine yield from the 240 lb N/A rate. Specific gravity, however, was significantly lower when post-hilling N applications were used.

Tuber number per plant over the course of the season is presented in Table 2. Although some initial effects on tuber number per plant were detected two weeks after hilling, no differences due to N management were detected by the time of harvest. Because of small sample size (two plants per plot), variability was high and, therefore these data should be interpreted with some caution.

Dry Matter and Nitrogen Accumulation. Dry matter accumulation and N content of vines, tubers, and roots through the growing season for each treatment are provided in Figures 12 to 21. Tuber bulking started at about 8 weeks after planting and continued in a linear manner until harvest. Nitrogen accumulation in the tubers followed the general pattern of dry matter accumulation. Dry weight accumulation in vines reached a peak between 6 and 8 weeks after planting and then leveled off or declined for most treatments. Nitrogen accumulation also peaked between 6 and 8 weeks after planting, but then declined dramatically after this time. Vines reached maximum dry weight and N accumulation about two weeks earlier when N was limiting. The peak in vine dry weight and N accumulation were delayed by two weeks when urea or post-hilling applications of N were applied.

Dry matter and N accumulation, as well as concentrations of N in vine and tuber at harvest, are presented in Table 3. As expected, dry weight and N accumulation increased with increasing N rate. High rates of N in the starter reduced N recovery by the plant due to losses during the May rainfall period. However, dry matter accumulation increased in tubers and decreased in vines with increasing N in the starter. These results suggest that a longer season was needed for the treatment where N application was delayed until emergence. The results also suggest that N rates lower than 240 lb N/A could have been used to achieve the

same yield. Highest N recovery and highest N concentrations in tubers and vines were obtained with the post-hilling N treatment.

Nitrate-N Concentrations in Petiole Samples. The N status of the plant every 10-14 days starting one day before hilling, as measured by conventional petiole analysis and sap analysis, is presented in Table 4. On the first sampling date, sap analysis seemed to detect more subtle differences in nitrate status of the petiole compared to conventional analysis. In all methods of analysis, differences due to N rate were apparent. Differences due to starter N rate and N source were detected with the sap tests, but not the conventional petiole analysis. The two electrode methods were fairly consistent in nitrate readings, while the Wescan method gave consistently lower readings. At later sampling dates, the differences among the three methods for sap analysis were not as great. By the July 1 sampling date, differences due to starter N, N rate, N source and post-hilling N applications were apparent using all methods of analysis.

Linear correlations between the sap nitrate analysis and conventional nitrate analysis are presented in Figures 22, 23, and 24. All R^2 values were above 0.900, indicating a strong relationship between sap analysis and conventional petiole analysis. From looking at the data, a better fit might be obtained using a curvilinear fit and should be investigated in the future. For the time being, however, sap values can be inserted in the linear equation to determine whether nitrate-N levels are in an adequate range as predicted from conventional analysis. Overall, the sap test does seem to be useful for determining and predicting N needs for irrigated potatoes.

SUMMARY

The 1991 season at Becker was ideal for evaluating N losses because of excessive rainfall in May and June. Nitrogen source, rate, and management significantly affected nitrate losses under irrigated potatoes. Greatest losses were observed when N was applied early before emergence. Use of urea and slow release N minimized N losses compared to ammonium nitrate. Post-hilling applications of N also reduced N losses compared to similar rates of N applied before hilling. Potato yield was primarily affected by N rate. The greatest yield increase was obtained between the 0 and 120 lb N/A increment. Petiole sap nitrate tests using portable nitrate electrodes appear to have promise for determining and predicting N needs for irrigated potatoes.

Table 1. Effect of nitrogen treatments on fresh weight of vines and tubers. Becker, MN.

Treatment			Fresh weight							Specific
			Vines	Knobs	<3 oz	3-7 oz	7-14 oz	>14 oz	Total	Gravity
	N source	N timing	Tons/A	cwt/A						
1.	Control	(0 N/A)	1.78	16.8	40.7	195.4	83.6	2.8	339.3	1.0845
2.	(34-0-0)	(0,120,120)[1]	8.08	21.8	38.6	210.0	188.8	11.9	471.1	1.0850
3.	(34-0-0)	(40,100,100)	6.99	29.2	42.1	221.1	184.3	15.9	492.5	1.0875
4.	(34-0-0)	(80,80,80)	5.60	27.5	47.3	223.5	179.4	8.2	485.8	1.0885
5.	(34-0-0)	(120,60,60)	5.30	39.4	53.8	216.1	169.2	15.2	493.9	1.0895
6.	(34-0-0)	(80,80,0)	2.96	35.7	61.2	228.1	146.0	7.3	478.3	1.0900
7.	SR[2]	(80,80,0)	3.09	24.2	51.2	240.2	173.4	10.6	499.7	1.0890
8.	(34-0-0)	(40,40,40)	2.97	22.9	51.1	240.0	158.2	4.9	477.1	1.0895
9.	(34-0-0)	(40,40,40,40+40)[3]	7.34	35.6	41.5	221.4	200.0	13.3	511.8	1.0845
10.	(46-0-0)	(80,80,80)	7.40	21.5	39.9	218.4	188.9	7.3	486.6	1.0855
Significance			**	**	**	NS	**	*	**	**
BLSD (0.05)			2.73	13.2	10.1	--	38.9	11.6	41.4	0.0034
Contrasts										
Lin Starter N (2, 3, 4, 5)			*	**	**	NS	NS	NS	NS	**
Quad Starter N (2, 3, 4, 5)			NS	NS	++	NS	NS	NS	NS	NS
Lin Rate N (1, 8, 4)			**	++	NS	NS	**	NS	**	*
Quad Rate N (1, 8, 4)			NS	NS	NS	++	NS	NS	**	*
Treatment 4 vs 10			NS	NS	NS	NS	NS	*	NS	++
Treatment 7 vs 6			NS	++	NS	NS	NS	NS	NS	NS
Treatment 8 vs 9			**	*	*	NS	*	++	NS	**
Treatment 4 vs 7			NS	NS	*	NS	NS	NS	NS	NS
Treatment 4 vs 9			NS	NS	NS	NS	NS	NS	NS	*

[1] = Planting, emergence and hilling respectively. [2] = Slow release fertilizer. [3] = Two post-hillings based on sap analysis. NS = Nonsignificant, ++, *, ** = significant at 10%, 5%, and 1%, respectively.

Table 2. Effect of nitrogen treatments on the number of tubers per plant. Becker, MN.

Treatment			Date					
			June 24	July 2	July 16	July 30	Aug. 13	Sept. 10
	N source	N timing	Number of tubers per plant					
1.	Control	(0 N/A)	5.88	7.88	8.13	8.75	7.13	9.75
2.	(34-0-0)	(0,120,120)[1]	8.63	9.25	10.25	12.50	12.88	9.63
3.	(34-0-0)	(40,100,100)	10.88	15.88	10.00	10.88	9.50	8.88
4.	(34-0-0)	(80,80,80)	10.75	13.13	10.88	9.63	11.38	11.00
5.	(34-0-0)	(120,60,60)	9.75	12.50	11.13	9.13	12.75	9.38
6.	(34-0-0)	(80,80,0)	13.88	14.25	12.25	9.50	11.00	14.50
7.	SR[2]	(80,80,0)	4.25	13.25	10.50	10.38	9.75	13.25
8.	(34-0-0)	(40,40,40)	6.50	15.13	13.88	11.50	9.25	12.00
9.	(34-0-0)	(40,40,40,40+40)[3]	3.25	11.00	10.75	10.63	11.00	12.38
10.	(46-0-0)	(80,80,80)	10.13	10.38	10.00	8.50	7.50	12.25
Significance			NS	NS	NS	NS	*	NS
BLSD (0.05)			--	--	--	--	4.02	--
Contrasts								
Lin Starter N (2, 3, 4, 5)			NS	NS	NS	NS	NS	NS
Quad Starter N (2, 3, 4, 5)			NS	++	NS	NS	*	NS
Lin Rate N (1, 8, 4)			NS	++	NS	NS	**	NS
Quad Rate N (1, 8, 4)			NS	*	*	NS	NS	NS
Treatment 4 vs 10			NS	NS	NS	NS	*	NS
Treatment 7 vs 6			**	NS	NS	NS	NS	NS
Treatment 8 vs 9			NS	NS	NS	NS	NS	NS
Treatment 4 vs 7			++	NS	NS	NS	NS	NS
Treatment 4 vs 9			*	NS	NS	NS	NS	NS

[1] = Planting, emergence and hilling respectively. [2] = Slow release fertilizer. [3] = Two post-hillings based on sap analysis. NS = Nonsignificant, ++, *, ** = significant at 10%, 5%, and 1%, respectively.

Table 3. Effect of nitrogen treatments on N content and dry matter production. Becker, MN.

Treatment			Nitrogen content			N concentration		Dry matter		
	N source	N timing	Vines	Tubers	Total	Vine	Tubers	Vines	Tubers	Total
			lbs/A			% N		Tons/A		
1.	Control	(0 N/A)	13.7	56.0	69.7	0.70	0.80	0.97	3.50	4.47
2.	(34-0-0)	(0,120,120)[1]	58.6	106.5	165.1	1.03	1.07	2.85	5.01	7.86
3.	(34-0-0)	(40,100,100)	45.7	112.5	158.1	0.86	1.07	2.71	5.26	7.97
4.	(34-0-0)	(80,80,80)	31.9	113.1	144.9	0.67	1.05	2.37	5.39	7.76
5.	(34-0-0)	(120,60,60)	28.9	100.8	129.6	0.77	0.92	1.86	5.48	7.34
6.	(34-0-0)	(80,80,0)	23.9	85.4	109.3	0.85	1.02	1.86	5.24	7.10
7.	SR[2]	(80,80,0)	24.0	98.8	122.8	0.58	0.89	2.09	5.52	7.61
8.	(34-0-0)	(40,40,40)	28.8	94.5	123.3	0.73	0.90	1.99	5.25	7.25
9.	(34-0-0)	(40,40,40,40+40)[3]	45.2	124.9	170.2	1.07	1.15	2.10	5.45	7.56
10.	(46-0-0)	(80,80,80)	44.6	108.5	153.1	0.65	0.82	2.62	5.34	7.97
Significance			**	**	**	**	**	**	**	**
BLSD (0.05)			10.8	16.1	19.8	0.19	0.14	0.53	0.52	0.71
Contrasts										
Lin Starter N (2, 3, 4, 5)			**	NS	**	**	*	**	++	NS
Quad Starter N (2, 3, 4, 5)			NS	NS	NS	*	NS	NS	NS	NS
Lin Rate N (1, 8, 4)			**	**	**	NS	**	**	**	**
Quad Rate N (1, 8, 4)			NS	NS	++	NS	NS	NS	**	**
Treatment 4 vs 10			*	NS	NS	++	NS	NS	NS	NS
Treatment 7 vs 6			NS	NS	NS	NS	NS	NS	NS	NS
Treatment 8 vs 9			**	**	**	**	**	NS	NS	NS
Treatment 4 vs 7			NS	++	*	NS	*	NS	NS	NS
Treatment 4 vs 9			*	NS	*	**	NS	NS	NS	NS

[1] = Planting, emergence and hilling respectively. [2] = Slow release fertilizer. [3] = Two post-hillings based on sap analysis. NS = Nonsignificant, ++, *, ** = significant at 10%, 5%, and 1%, respectively.

Table 4. Effect of nitrogen treatments on nitrate-N concentration in potato petioles (dry weight basis) and nitrate concentration in petiole sap, as determined by various procedures. Becker, MN.

Treatment			Date							
			June 12				June 21			
	N source	N timing	dry weight Petiole-N	sap Horiba	sap Hach	sap Wescan	dry weight Petiole-N	sap Horiba	sap Hach	sap Wescan
			ppm							
1.	Control	(0 N/A)	8619	688	689	542	4094	688	626	601
2.	(34-0-0)	(0,120,120)[1]	18530	1650	1730	1525	25227	1725	1697	1617
3.	(34-0-0)	(40,100,100)	17007	1550	1594	1404	24157	1713	1738	1660
4.	(34-0-0)	(80,80,80)	17129	1513	1573	1368	24920	1663	1683	1629
5.	(34-0-0)	(120,60,60)	16216	1513	1566	1363	23988	1638	1675	1487
6.	(34-0-0)	(80,80,0)	16146	1563	1618	1404	17934	1463	1458	1382
7.	SR[2]	(80,80,0)	15490	1413	1435	1248	17768	1300	1305	1245
8.	(34-0-0)	(40,40,40)	14378	1313	1306	1200	19606	1525	1463	1464
9.	(34-0-0)	(40,40,40,40+40)[3]	14256	1350	1305	1157	21219	1525	1519	1480
10.	(46-0-0)	(80,80,80)	17100	1638	1662	1487	24709	1688	1732	1656
Significance			**	**	**	**	**	**	**	**
BLSD (0.05)			3323	170	171	105	3236	133	142	116
Contrasts										
Lin Starter N (2, 3, 4, 5)			NS	NS	++	**	NS	NS	NS	*
Quad Starter N (2, 3, 4, 5)			NS	NS	NS	NS	NS	NS	NS	*
Lin Rate N (1, 8, 4)			**	**	**	**	**	**	**	**
Quad Rate N (1, 8, 4)			NS	**	*	**	**	**	**	**
Treatment 4 vs 10			NS	NS	NS	*	NS	NS	NS	NS
Treatment 7 vs 6			NS	++	++	**	NS	*	++	*
Treatment 8 vs 9			NS	NS	NS	NS	NS	NS	NS	NS
Treatment 4 vs 7			NS	NS	NS	*	**	**	**	**
Treatment 4 vs 9			NS	++	**	**	*	++	*	*

[1] = Planting, emergence and hilling respectively. [2] = Slow release fertilizer. [3] = Two post-hillings based on sap analysis. NS = Nonsignificant, ++, *, ** = significant at 10%, 5%, and 1%, respectively.

Table 4 cont. Effect of nitrogen treatments on nitrate-N concentration in potato petioles (dry weight basis) and nitrate concentration in petiole sap, as determined by various procedures. Becker, MN.

Treatment			Date							
			July 1				July 15			
	N source	N timing	dry weight Petiole-N	sap Horiba	sap Hach	sap Wescan	dry weight Petiole-N	sap Horiba	sap Hach	sap Wescan
			ppm							
1.	Control	(0 N/A)	244	100	47	38	169	69	16	13
2.	(34-0-0)	(0,120,120)[1]	24833	1663	1622	1593	13084	1163	1121	1075
3.	(34-0-0)	(40,100,100)	21726	1525	1479	1497	11020	913	880	869
4.	(34-0-0)	(80,80,80)	19642	1488	1459	1392	6515	704	670	650
5.	(34-0-0)	(120,60,60)	15155	1175	1129	1111	4747	436	418	377
6.	(34-0-0)	(80,80,0)	6341	566	530	494	1348	201	148	149
7.	SR[2]	(80,80,0)	4362	520	469	464	1322	226	176	165
8.	(34-0-0)	(40,40,40)	10810	888	874	837	2434	309	274	266
9.	(34-0-0)	(40,40,40,40+40)[3]	18611	1450	1306	1403	8182	813	821	769
10.	(46-0-0)	(80,80,80)	19079	1438	1435	1372	9814	913	899	859
Significance			**	**	**	**	**	**	**	**
BLSD (0.05)			4061	191	222	168	4328	216	220	208
Contrasts										
Lin Starter N (2, 3, 4, 5)			**	**	**	**	**	**	**	**
Quad Starter N (2, 3, 4, 5)			NS	NS	NS	NS	NS	NS	NS	NS
Lin Rate N (1, 8, 4)			**	**	**	**	**	**	**	**
Quad Rate N (1, 8, 4)			NS	NS	NS	NS	NS	NS	NS	NS
Treatment 4 vs 10			NS	NS	NS	NS	NS	++	++	++
Treatment 7 vs 6			NS	NS	NS	NS	NS	NS	NS	NS
Treatment 8 vs 9			**	**	**	**	**	**	**	**
Treatment 4 vs 7			**	**	**	**	*	**	**	**
Treatment 4 vs 9			NS	NS	NS	NS	NS	NS	NS	NS

[1] = Planting, emergence and hilling respectively. [2] = Slow release fertilizer. [3] = Two post-hillings based on sap analysis. NS = Nonsignificant, ++, *, ** = significant at 10%, 5%, and 1%, respectively.

Table 4 cont. Effect of nitrogen treatments on nitrate-N concentration in potato petioles (dry weight basis) and nitrate concentration in petiole sap, as determined by various procedures. Becker, MN.

Treatment			Date							
			July 29				August 12			
	N source	N timing	dry weight Petiole-N	sap Horiba	sap Hach	sap Wescan	dry weight Petiole-N	sap Horiba	sap Hach	sap Wescan
			ppm							
1.	Control	(0 N/A)	633	125	73	38	127	43	26	5
2.	(34-0-0)	(0,120,120)[1]	6952	663	662	575	1446	265	272	274
3.	(34-0-0)	(40,100,100)	6092	663	640	570	1006	179	182	147
4.	(34-0-0)	(80,80,80)	3502	539	537	451	873	153	151	121
5.	(34-0-0)	(120,60,60)	2995	423	406	341	471	133	129	94
6.	(34-0-0)	(80,80,0)	905	236	200	158	153	51	38	11
7.	SR[2]	(80,80,0)	2564	248	191	159	164	58	36	16
8.	(34-0-0)	(40,40,40)	905	166	126	93	121	61	50	24
9.	(34-0-0)	(40,40,40,40+40)[3]	10918	950	974	886	2920	331	321	296
10.	(46-0-0)	(80,80,80)	7327	700	701	618	1122	220	257	195
Significance			**	**	**	**	**	**	**	**
BLSD (0.05)			2358	147	133	131	692	109	116	105
Contrasts										
Lin Starter N (2, 3, 4, 5)			**	**	**	**	**	*	**	**
Quad Starter N (2, 3, 4, 5)			NS	NS	NS	NS	NS	NS	NS	NS
Lin Rate N (1, 8, 4)			*	**	**	**	*	*	*	*
Quad Rate N (1, 8, 4)			NS	*	**	**	NS	NS	NS	NS
Treatment 4 vs 10			**	*	*	*	NS	NS	++	NS
Treatment 7 vs 6			NS	NS	NS	NS	NS	NS	NS	NS
Treatment 8 vs 9			**	**	**	**	**	**	**	**
Treatment 4 vs 7			NS	**	**	**	++	++	++	++
Treatment 4 vs 9			**	**	**	**	**	**	**	**

[1] = Planting, emergence and hilling respectively. [2] = Slow release fertilizer. [3] = Two post-hillings based on sap analysis. NS = Nonsignificant, ++, *, ** = significant at 10%, 5%, and 1%, respectively.

Table 5. Effect of nitrogen treatments on soil nitrate-N and ammonium-N concentrations in the top foot of soil at hilling (ppm ± one standard deviation). Becker, MN.

Treatment			In row	
	N source	N timing	Nitrate-N	Ammonium-N
			ppm	
1.	Control	(0 N/A)	2.17 ± 0.28	2.54 ± 1.02
2.	(34-0-0)	(0,120,120)[1]	5.24 ± 2.04	3.66 ± 0.92
3.	(34-0-0)	(40,100,100)	4.20 ± 2.40	3.51 ± 1.70
4.	(34-0-0)	(80,80,80)	3.56 ± 1.43	3.48 ± 0.53
5.	(34-0-0)	(120,60,60)	4.99 ± 1.38	2.56 ± 0.78
6.	(34-0-0)	(80,80,0)	2.81 ± 1.01	3.29 ± 0.93
7.	SR[2]	(80,80,0)	3.51 ± 0.79	3.88 ± 0.26
8.	(34-0-0)	(40,40,40)	3.26 ± 0.66	2.01 ± 0.47
9.	(34-0-0)	(40,40,40,40+40)[3]	3.21 ± 1.04	2.69 ± 1.07
10.	(46-0-0)	(80,80,80)	3.57 ± 1.38	2.95 ± 0.56

[1] = Planting, emergence and hilling respectively. [2] = Slow release fertilizer. [3] = Two post-hillings based on sap analysis.

Table 6. Effect of nitrogen treatments on soil nitrate-N in the top 3 ft. (pounds per acre ± one standard deviation) at the end of the growing season. Assumes half the field was in-row and the other half was between-row. Becker, MN.

Treatment			In-row	Between-row	Field total
	N source	N timing	Pounds per acre		
1.	Control	(0 N/A)	8.73 ± 3.31	10.79 ± 2.70	19.43 ± 10.85
2.	(34-0-0)	(0,120,120)[1]	8.67 ± 2.82	11.40 ± 4.62	20.07 ± 14.57
3.	(34-0-0)	(40,100,100)	8.71 ± 4.18	9.80 ± 4.35	18.51 ± 16.45
4.	(34-0-0)	(80,80,80)	9.40 ± 3.07	12.39 ± 2.52	21.79 ± 10.93
5.	(34-0-0)	(120,60,60)	9.83 ± 4.92	13.08 ± 3.90	22.91 ± 17.34
6.	(34-0-0)	(80,80,0)	10.80 ± 2.19	11.01 ± 2.34	21.81 ± 8.93
7.	SR[2]	(80,80,0)	11.18 ± 4.12	12.81 ± 6.40	23.99 ± 19.60
8.	(34-0-0)	(40,40,40)	8.74 ± 1.36	10.64 ± 2.28	19.38 ± 6.89
9.	(34-0-0)	(40,40,40,40+40)[3]	9.67 ± 2.67	12.63 ± 2.71	22.30 ± 10.54
10.	(46-0-0)	(80,80,80)	10.71 ± 4.18	14.84 ± 3.50	25.55 ± 15.07

[1] = Planting, emergence and hilling respectively. [2] = Slow release fertilizer. [3] = Two post-hillings based on sap analysis.

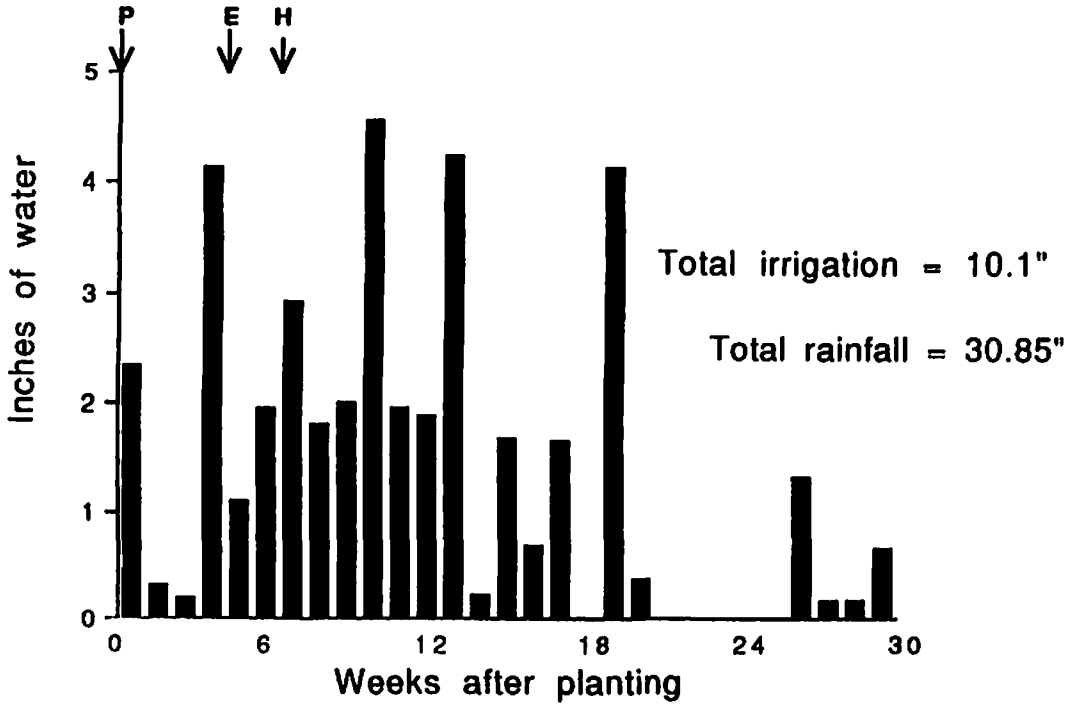

Figure 1. Rainfall and irrigation at Becker, MN during the 1991 growing season.

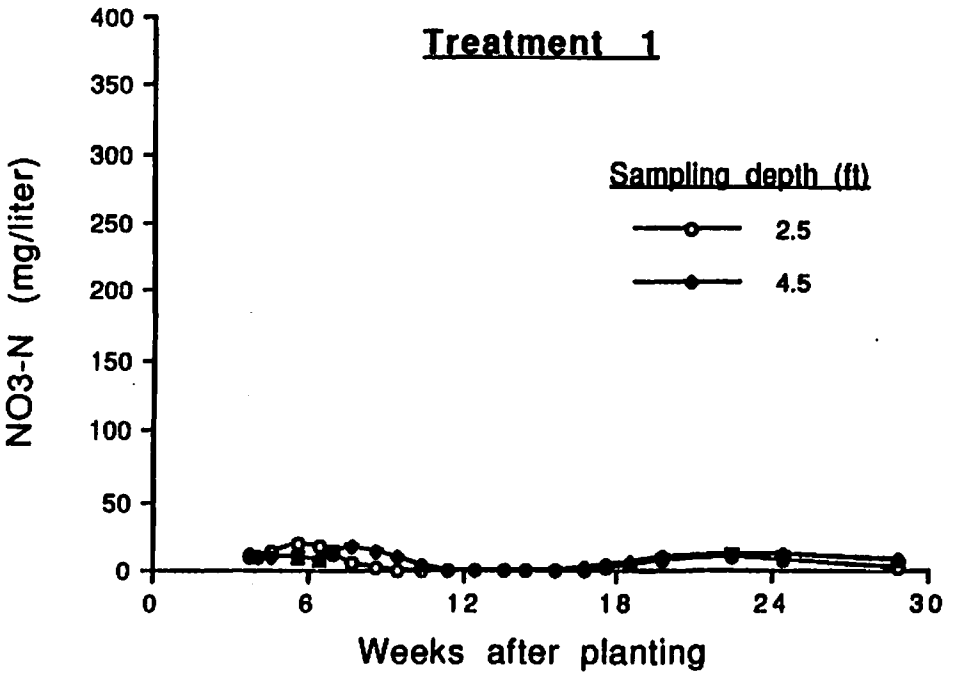

Figure 2. Nitrate - N concentration in soil water at two depths over the 1991 growing season. Nitrogen application rate: no nitrogen. Error bars represent SE of the mean.

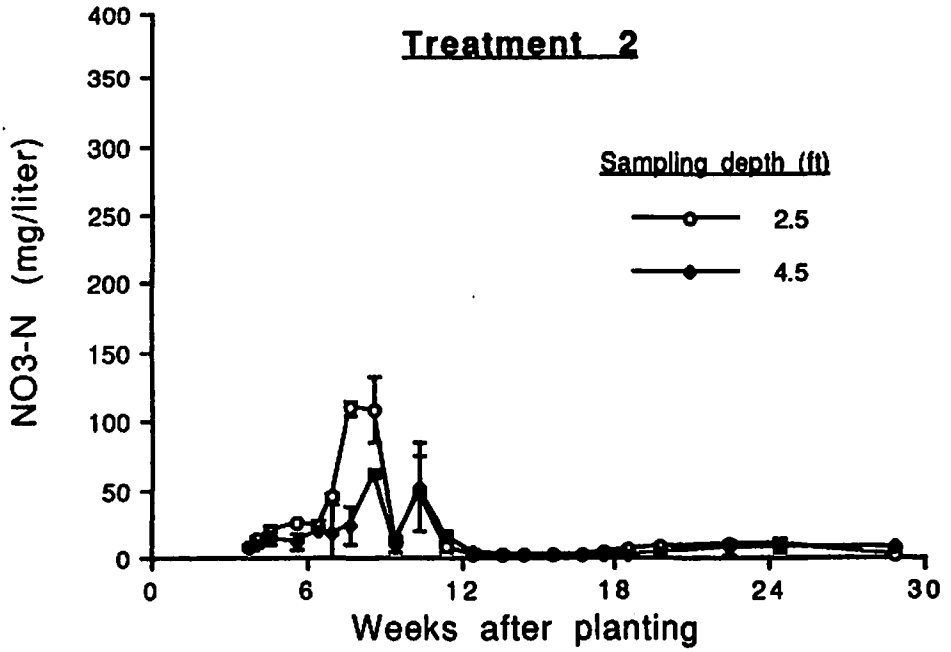

Figure 3. Nitrate - N concentration in soil water at two depths over the 1991 growing season. Nitrogen application rate: 120 lb N/A at emergence and hilling (34-0-0). Error bars represent SE of the mean.

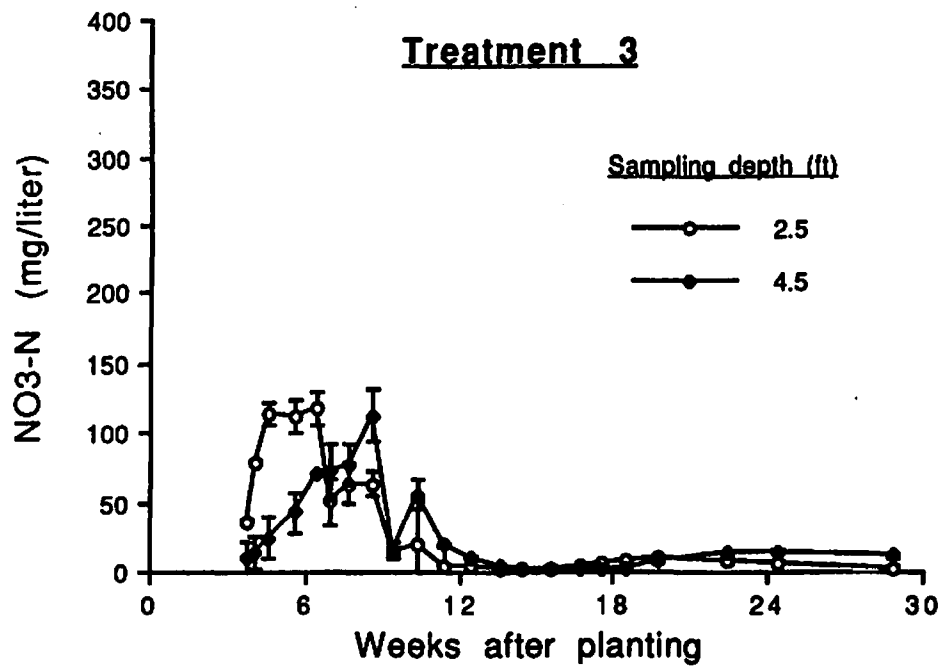

Figure 4. Nitrate - N concentration in soil water at two depths over the 1991 growing season. Nitrogen application rate: 40 lb N/A at planting, 100 lb at emergence and hilling (34-0-0). Error bars represent SE of the mean.

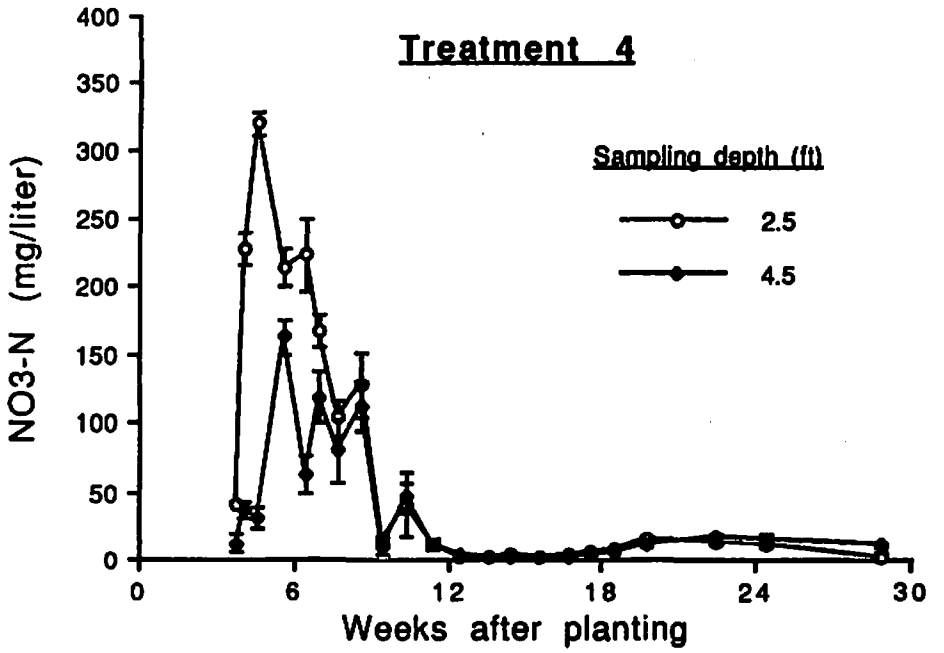

Figure 5. Nitrate - N concentration in soil water at two depths over the 1991 growing season. Nitrogen application rate: 80 lb N/A at planting, emergence and hilling - (34-0-0). Error bars represent SE of the mean.

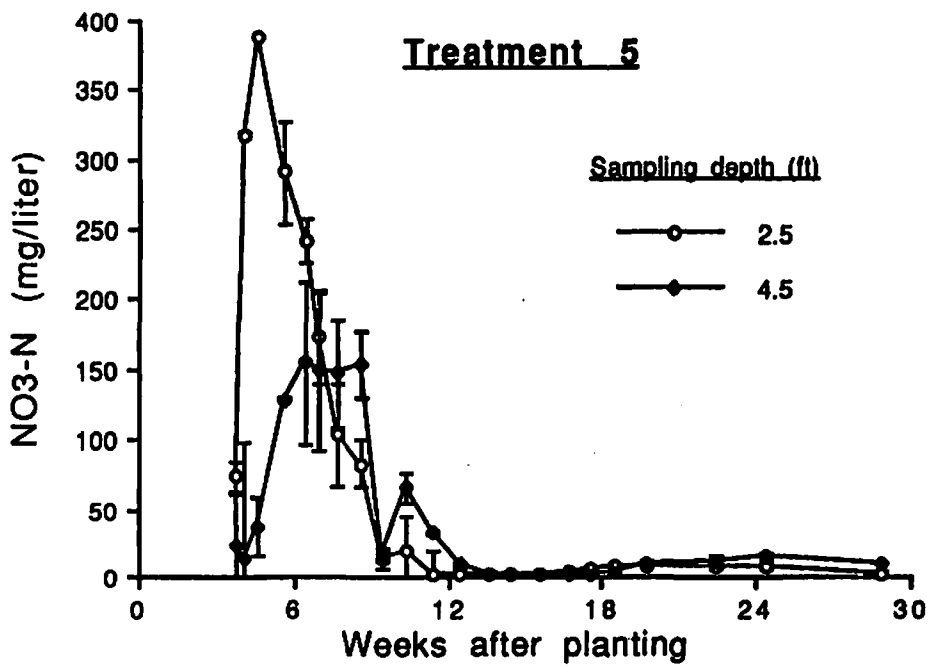

Figure 6. Nitrate - N concentration in soil water at two depths over the 1991 growing season. Nitrogen applicationg rate: 120 lb N/A at planting, 60 lb at emergence and hilling (34-0-0).

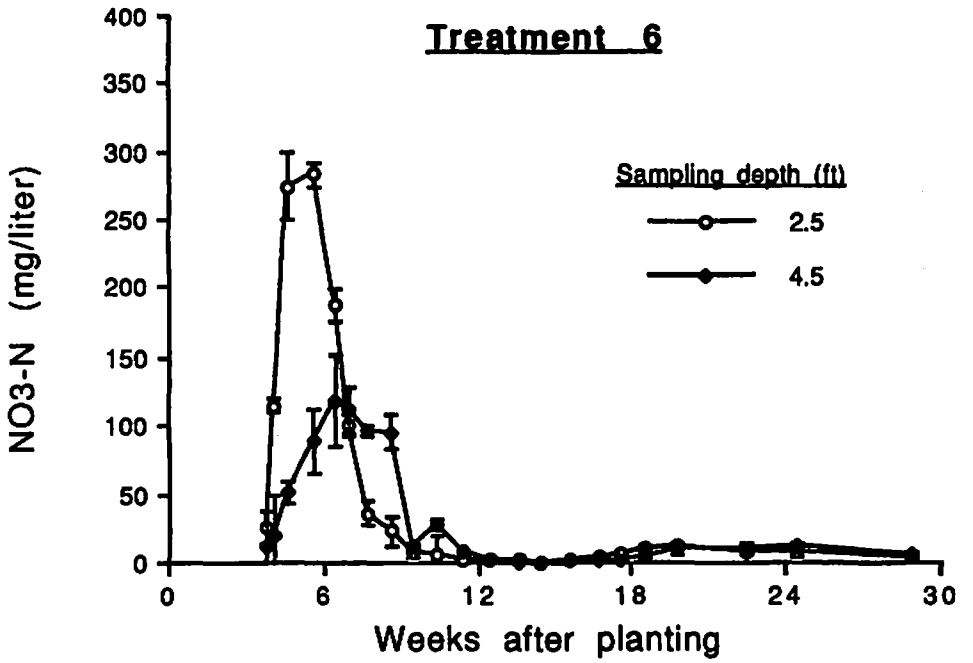

Figure 7. Nitrate - N concentration in soil water at two depths over the 1991 growing season. Nitrogen application rate: 80 lb N/A at planting and emergence - (34-0-0). Error bars represent SE of the mean.

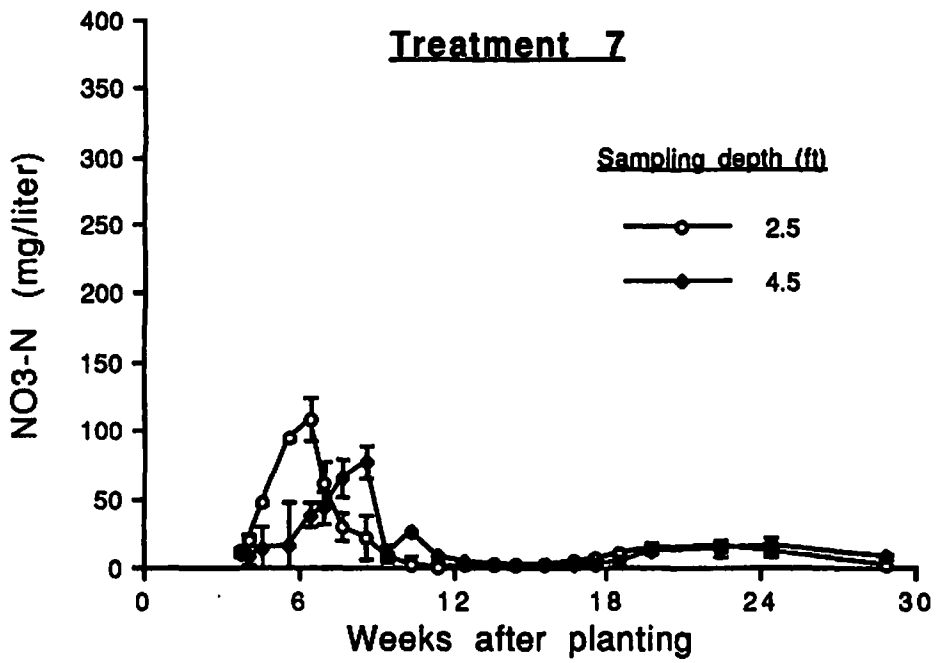

Figure 8. Nitrate - N concentration in soil water at two depths over the 1991 growing season. Nitrogen application rate: 80 lb N/A at planting and emergence - slow release. Error bars represent SE of the mean.

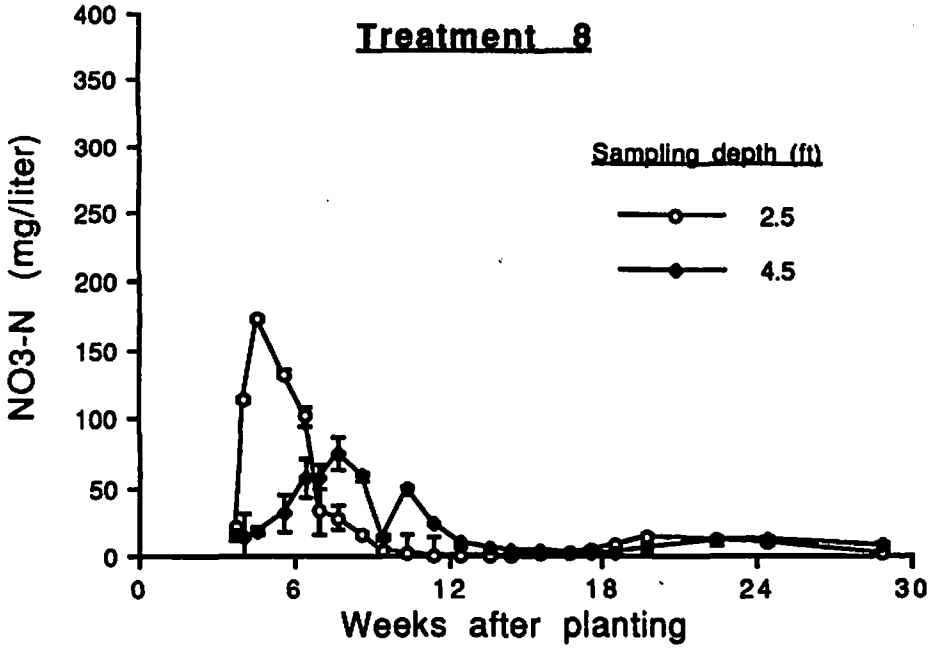

Figure 9. Nitrate - N concentration in soil water at two depths over the 1991 growing season. Nitrogen application rate: 40 lb N/A at planting, emergence and hilling - (34-0-0). Error bars represent SE of the mean.

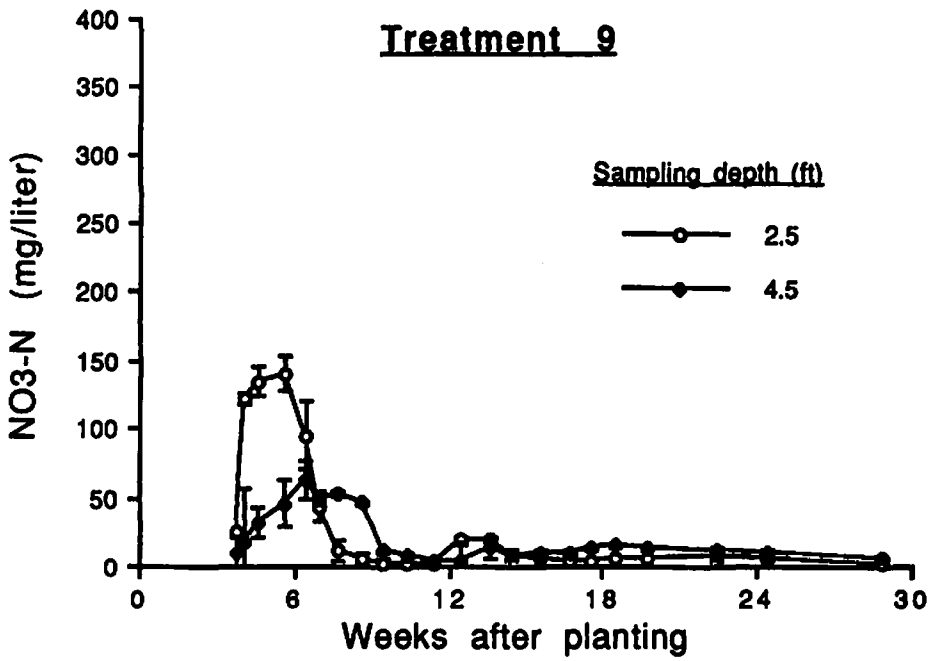

Figure 10. Nitrate - N Concentration in soil water at two depths over the 1991 growing season. Nitrogen application rate: 40 lb N/A at planting, emergence, hilling and two post-hillings - (34-0-0).

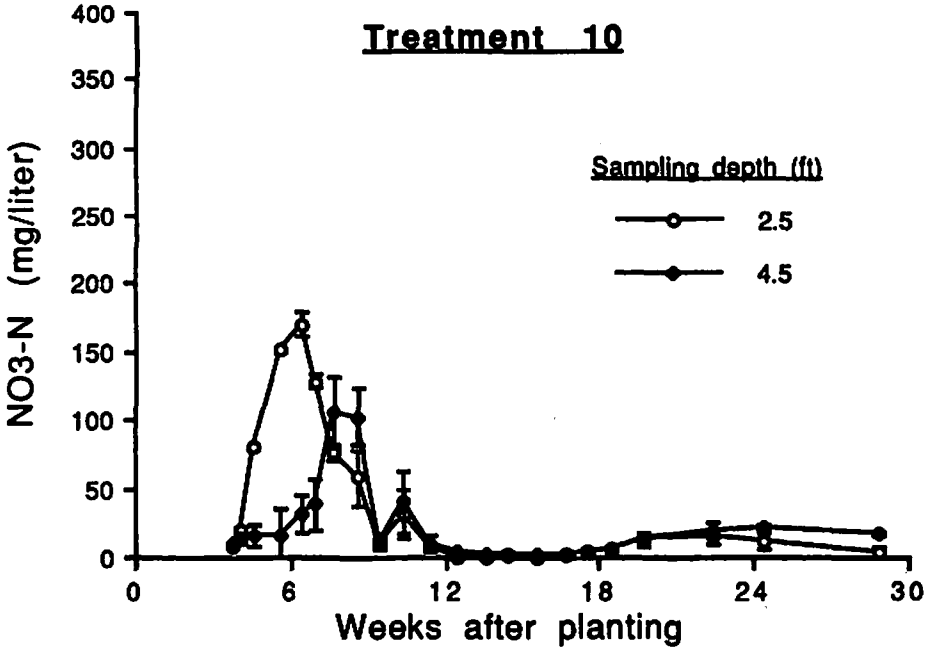

Figure 11. Nitrate -N concentration in soil water at two depths over the 1991 growing season. Nitrogen application rate: 80 lb N/A at planting, emergence and hilling - (46-0-0). Error bars represent SE of the mean.

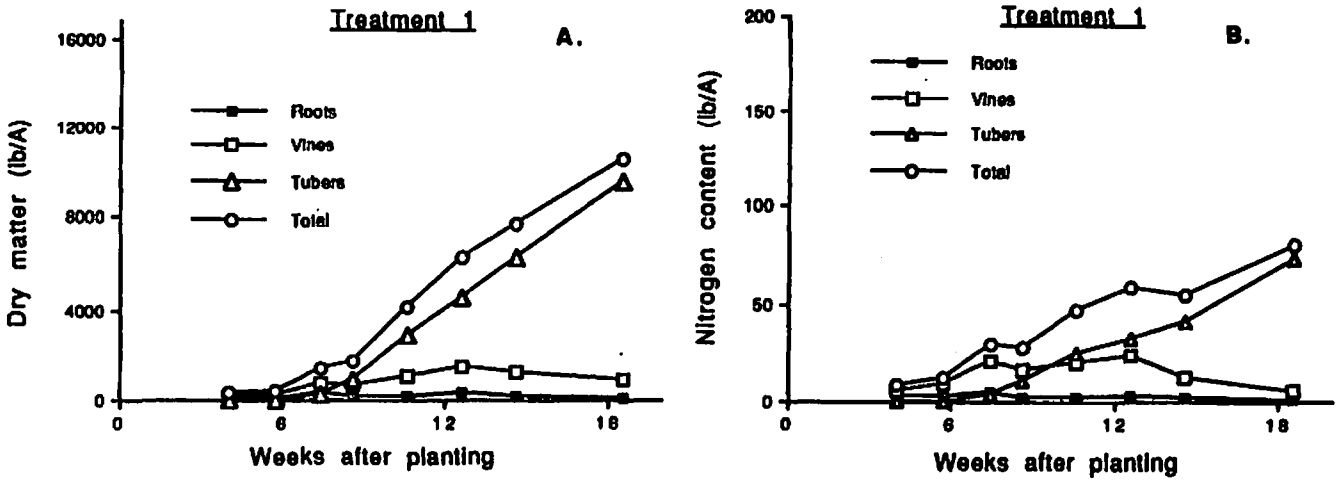

Figure 12. Dry matter (A) and nitrogen (B) accumulation in potato roots, vines and tubers during the 1991 growing season. Nitrogen application rate: no nitrogen.

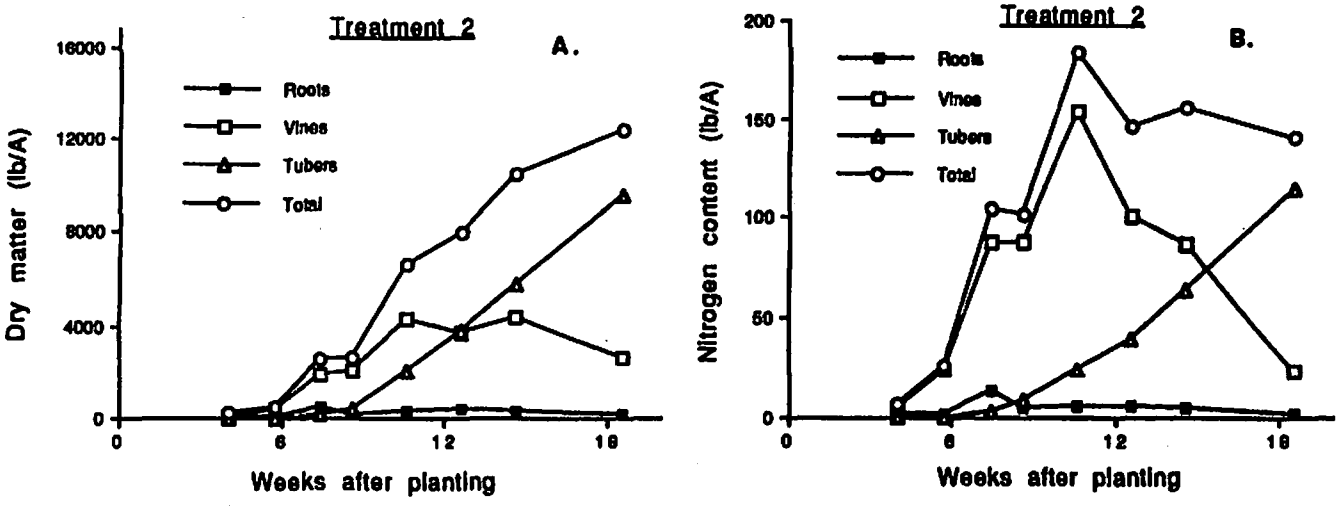

Figure 13. Dry matter (A) and nitrogen (B) accumulation in potato roots, vines and tubers during the 1991 growing season. Nitrogen application rate: 120 lb N/A at emergence and hilling - (34-0-0).

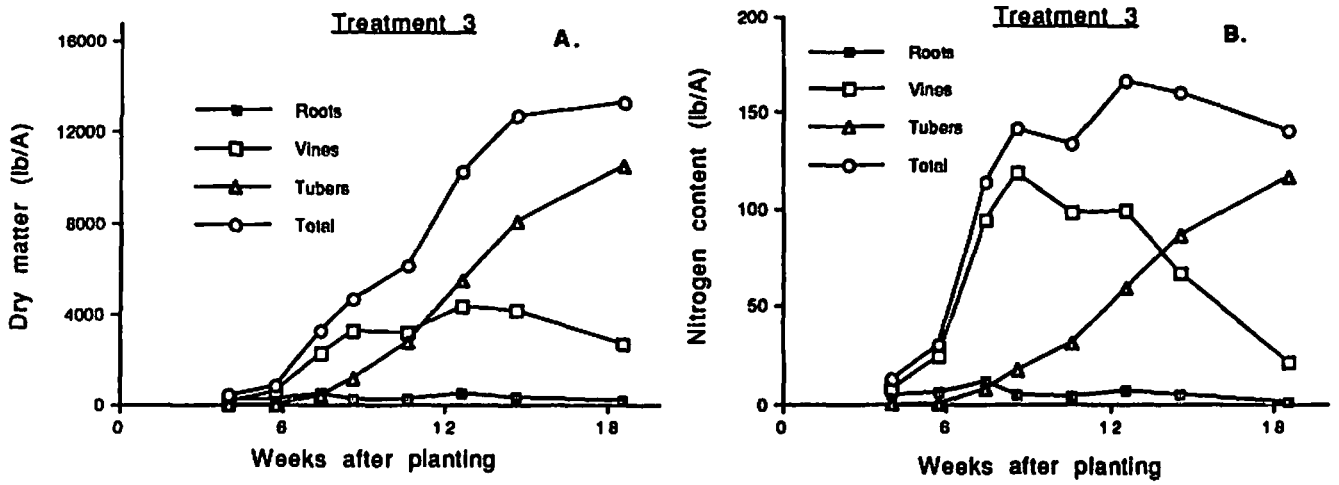

Figure 14. Dry matter (A) and nitrogen (B) accumulation in potato roots, vines and tubers during the 1991 growing season. Nitrogen application rate: 40 lb N/A at planting, 100 lb at emergence and hilling - (34-0-0).

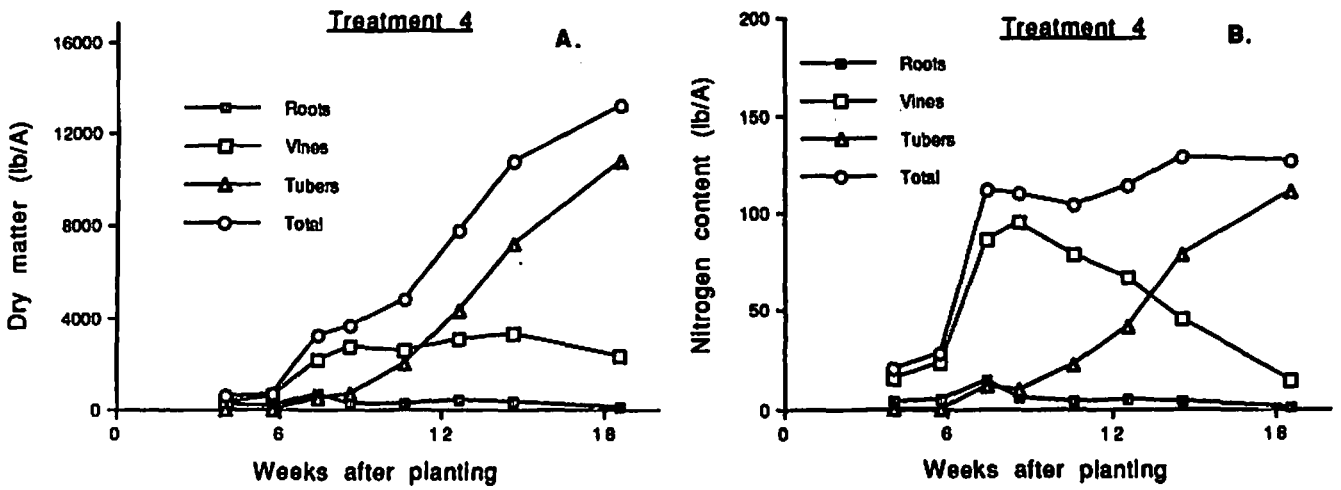

Figure 15. Dry matter (A) and nitrogen (B) accumulation in potato roots, vines and tubers during the 1991 growing season. Nitrogen application rate: 80 lb N/A at planting, emergence and hilling - (34-0-0).

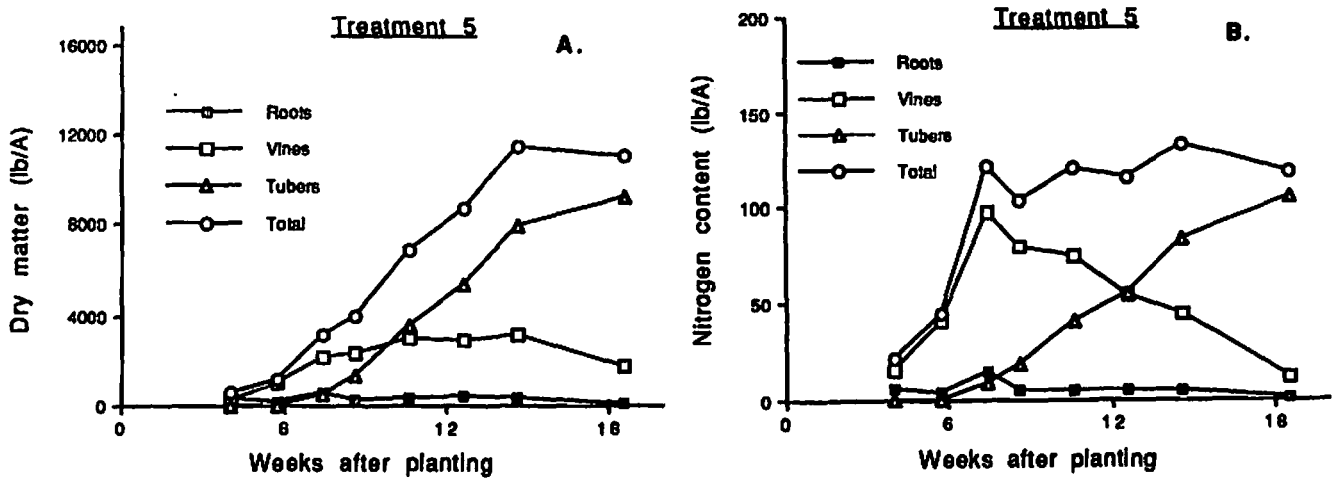

Figure 16. Dry matter (A) and nitrogen (B) accumulation in potato roots, vines and tubers during the 1991 growing season. Nitrogen application rate: 120 lb N/A at planting, 60 lb at emergence and hilling - (34-0-0).

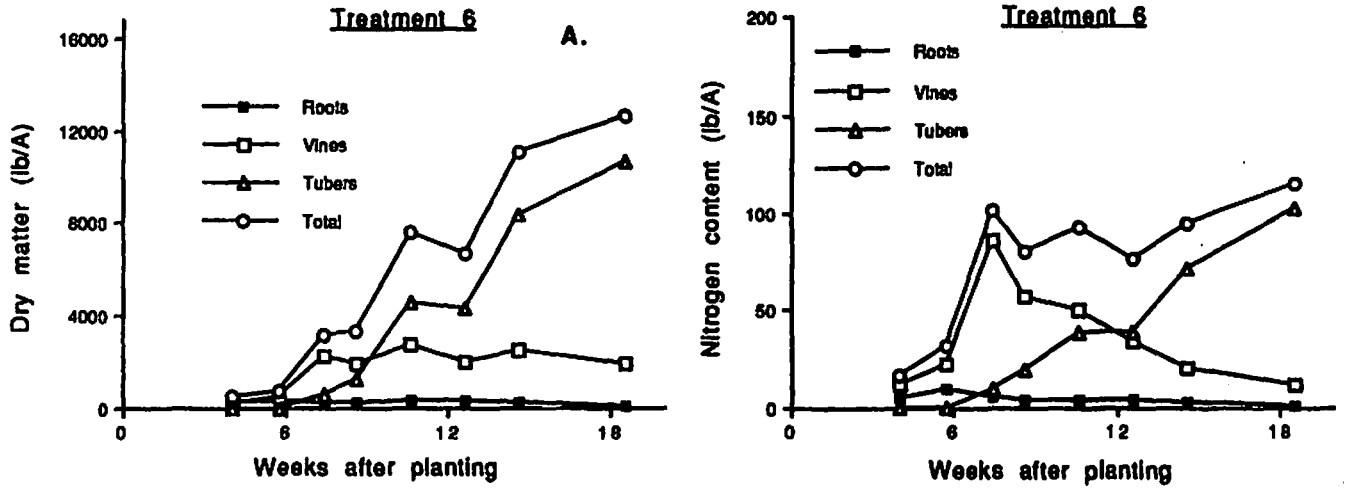

Figure 17. Dry matter (A) and nitrogen (B) accumulation in potato roots, vines and tubers during the 1991 growing season. Nitrogen application rate: 80 lb N/A at planting and emergence - (34-0-0).

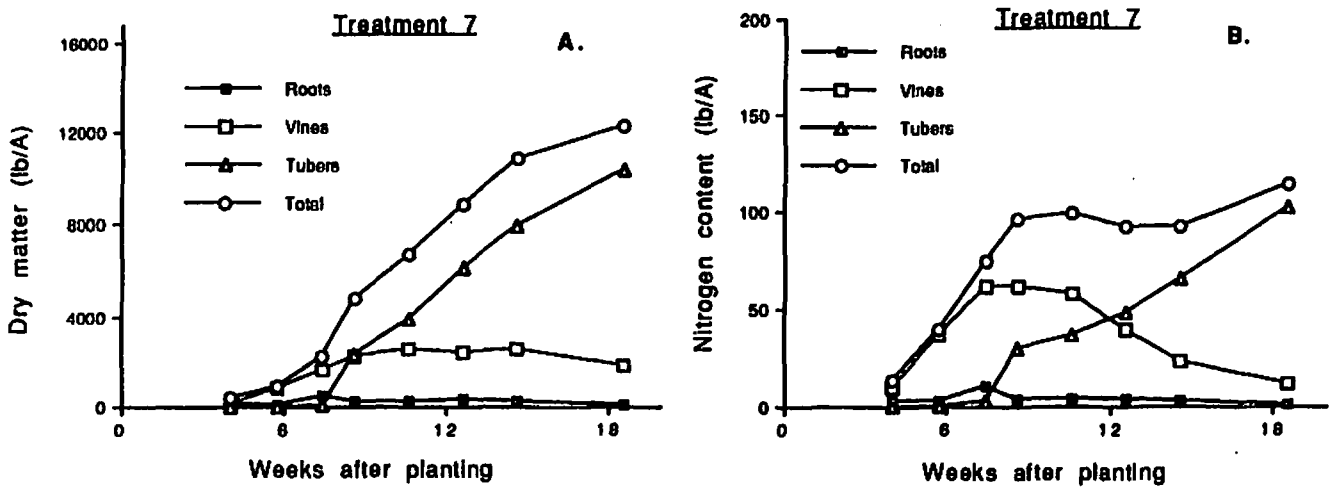

Figure 18. Dry matter (A) and nitrogen (B) accumulation in potato roots, vines and tubers during the 1991 growing season. Nitrogen application rate: 80 lb N/A at planting and emergence - slow release.

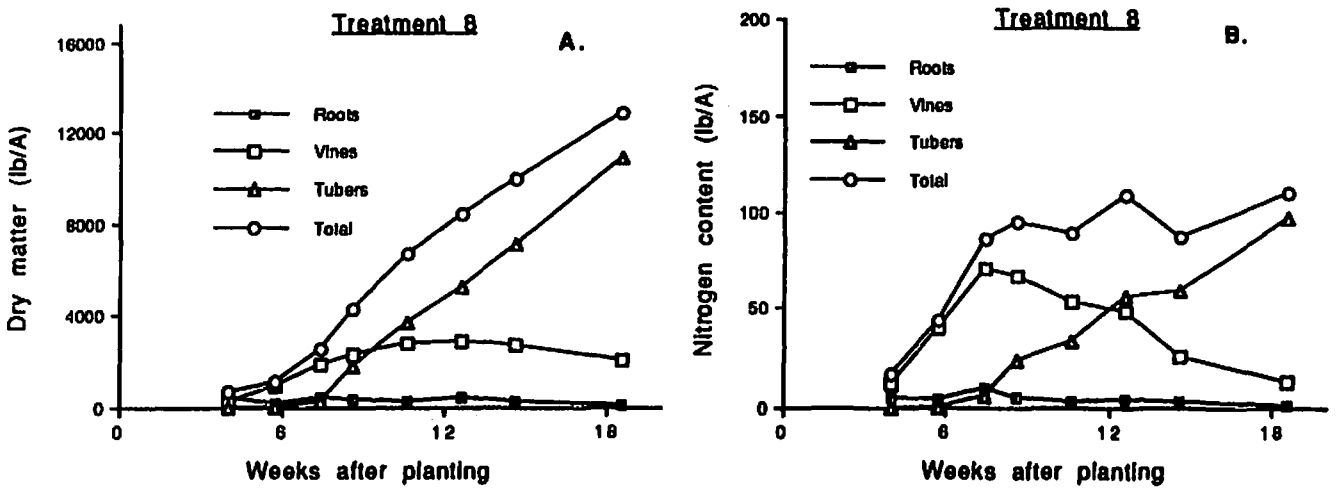

Figure 19. Dry matter (A) and nitrogen (B) accumulation in potato roots, vines and tubers during the 1991 growing season. Nitrogen application rate: 40 lb N/A at planting, emergence and hilling - (34-0-0).

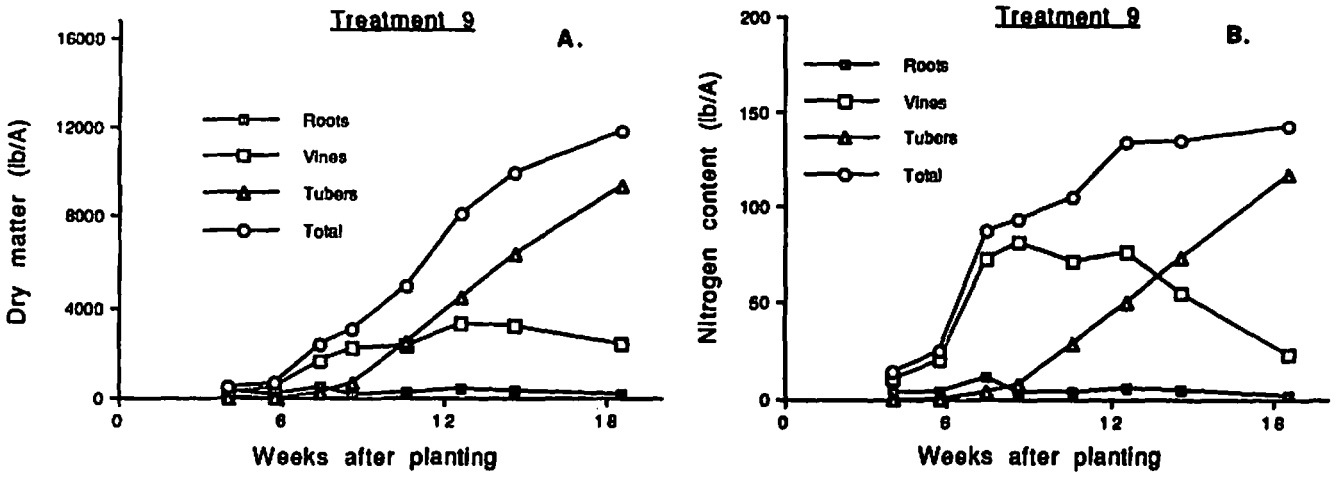

Figure 20. Dry matter (A) and nitrogen (B) accumulation in potato roots, vines and tubers during the 1991 growing season. Nitrogen application rate: 40 lb N/A at planting, emergence, hilling and two post-hillings (34-0-0).

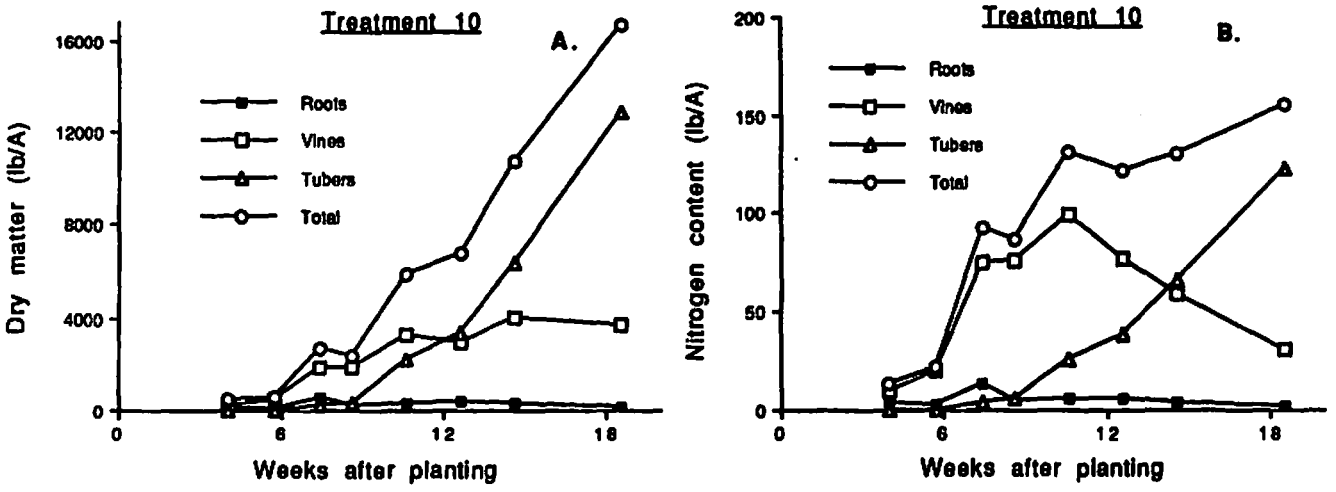

Figure 21. Dry matter (A) and nitrogen (B) accumulation in potato roots, vines and tubers during the 1991 growing season. Nitrogen application rate: 80 lb N/A at planting, emergence and hilling - (46-0-0).

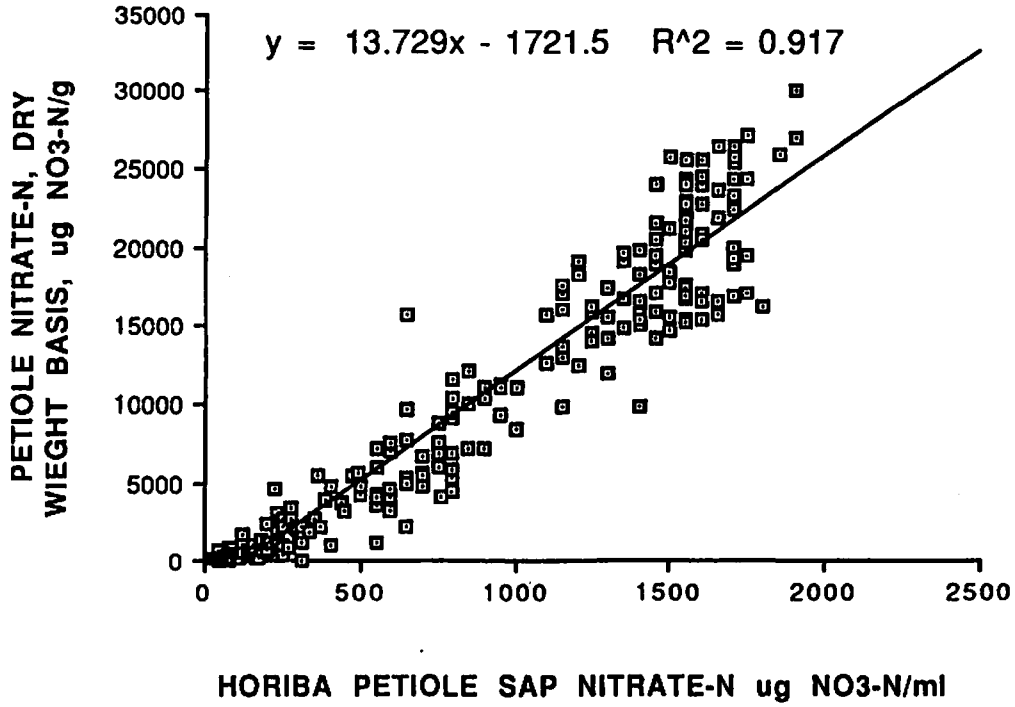

Figure 22. Correlation of petiole nitrate-N (dry wieght basis) with petiole sap nitrate-N measured by Horiba electrode.

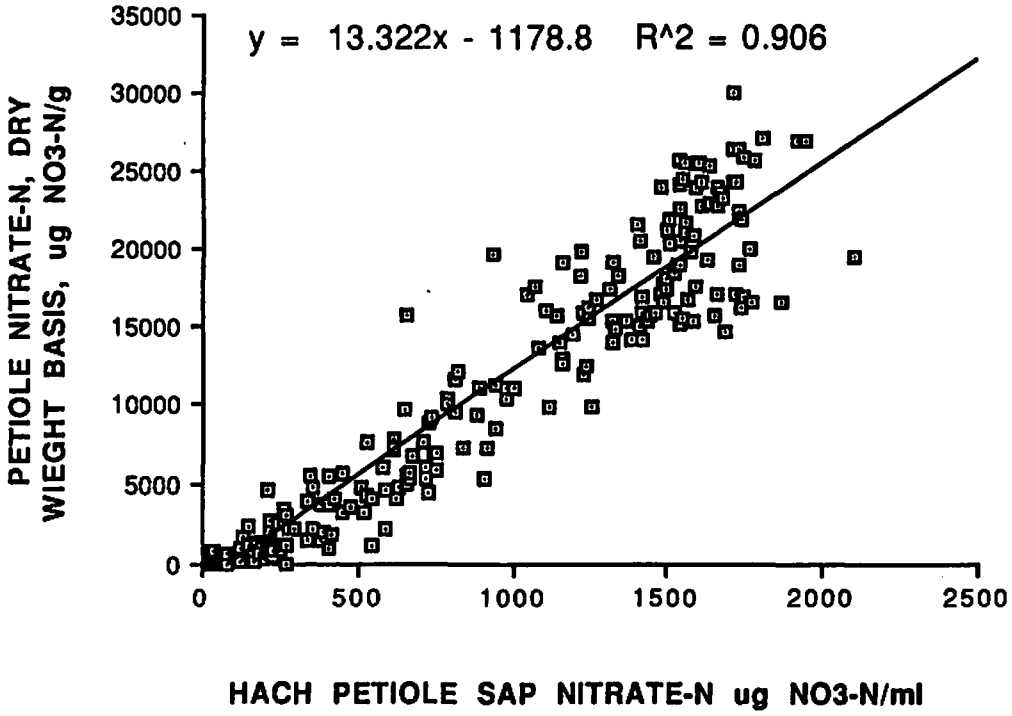

Figure 23. Correlation of petiole nitrate-N (dry wieght basis) with petiole sap nitrate-N measured by Hach electrode.

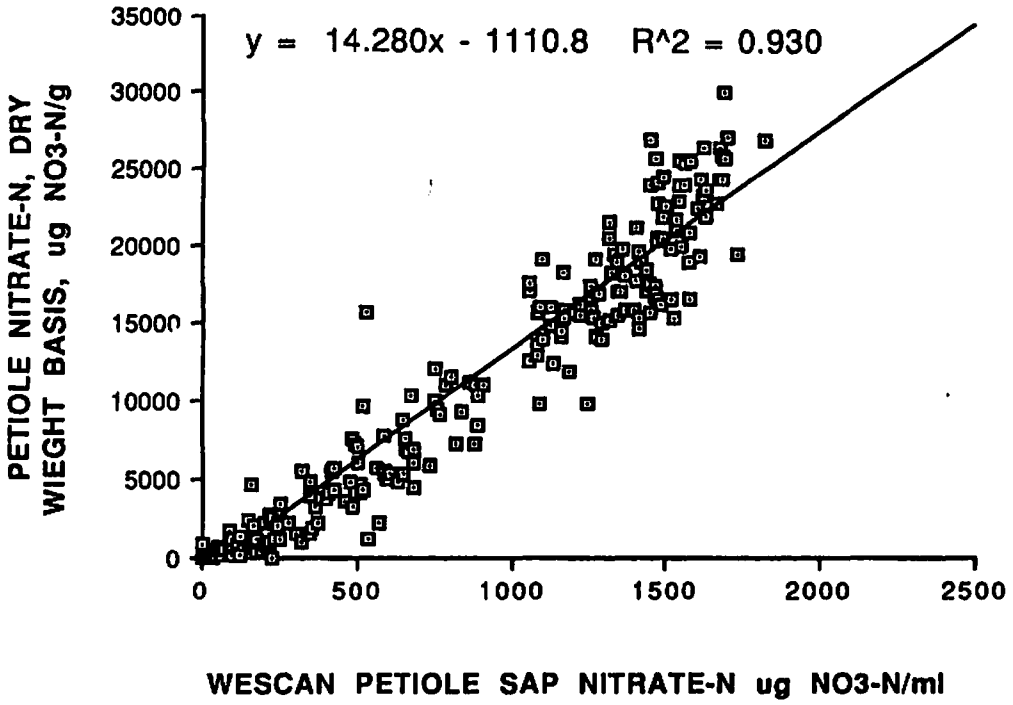

Figure 24. Correlation of petiole nitrate-N (dry wieght basis) with petiole sap nitrate-N measured by Wescan electrode.

PHOSPHORUS REQUIREMENTS FOR IRRIGATED POTATOES - 1991

Carl Rosen, Dave Birong, and Glenn Titrud

ABSTRACT: Response of irrigated potatoes to phosphate fertilizer on low and high P testing sites was evaluated. Soft rot was a problem at emergence in all plots and caused high variability in the data. There was a slight trend at both sites for increasing yield with P fertilizer application; however, further experiments will have to be conducted without soft rot problems to draw any conclusions on optimum P rates for potato production.

Little research has been conducted that defines the phosphorus requirements of potato on high P testing soils. Many soils used for irrigated potato production are natively high in P or have been built up to high levels of P through continuous use of phosphate fertilizers. Currently, high rates of phosphate fertilizer are recommended on soils testing above 25 ppm. The objective of this study therefore, was to evaluate the response of irrigated potatoes to phosphate fertilizer on both high and low P testing soils.

PROCEDURES: Two sites at the Sand Plain Research Farm in Becker, Minn. were selected for this study. The soil at both sites are Hubbard loamy sands and were selected based on their Bray P1 extractable P concentrations - one a 'low' P site and the other a 'high' P site. Characteristics of each site were as follows:

	High P site	Low P site
Previous crop	Rye	Alfalfa
Soil pH (1:1 - soil:water)	5.3	6.0
Bray P1	54 ppm	18 ppm
K - NH_4OAc	149 ppm	93 ppm

Prior to planting, 250 lb sul-po-mag and 100 lb K_2O (as 0-0-60) were broadcast applied and incorporated in both sites. At planting, all plots received 70 lb N/A and 200 lb K_2O as a band application. Phosphate fertilizer (triple superphosphate, 0-46-0) treatments were as follows: 0, 50, 100, 150, 200, 250 lb P_2O_5/A. Phosphate fertilizer was applied as a band 3 inches to each side and 2 inches below the row. Nitrogen was applied at the rate of 70 lb N/A at emergence (May 26), 70 lb N/A at hilling (June 12). Russet Burbank "A" size cut potatoes were planted on May 2, 1991 at a spacing of 36" between rows and 10" within the row. Each plot consisted of six, 20' rows. The experimental design was a randomized complete block with four replications. Due to soft rot problems at emergence, half the plots had to be eliminated. Therefore, the analysis is based on two reps from each site. Each site was irrigated according to the checkbook method for potatoes. Recently matured leaves (leaflets plus petioles) were sampled on July 11 and dried for subsequent nutrient analysis. Whole plant samples (five plants per plot) were also collected on July 11 and separated into roots, vines, and tubers. Tubers were counted and plant parts were dried at 60C for two weeks and then weighed. The two middle rows of each plot were harvested on Sept. 18 and tubers were graded according to weight classes: <4 oz, 4-7 oz, 7-14 oz, and >14 oz.

RESULTS: Dry weight of vines, roots, and tubers sampled in July are presented in Tables 1 and 2. For the high P testing site, phosphate fertilizer increased dry weight of vines, but not roots or tubers. Tuber number was not affected by phosphate fertilizer application. For the low P testing site, phosphate fertilizer had no significant effect on dry weight of the various plant parts; although there was a slight trend for increasing tuber number with phosphate fertilizer application.

Tuber yield and size distribution are presented in Tables 3 and 4. For the high P testing site, phosphate fertilizer tended to increase total tuber yield, primarily due to an increase in the 7-14 oz potatoes. At rates high than 150 lb P_2O_5/A, yields tended to decrease. Reasons for this decrease are not known. For the low P testing site, phosphate fertilizer had no significant effect on total yield; although yields in the control plots were numerically the lowest. There was a trend for increasing 4-7 oz size potatoes with phosphate fertilizer application. Soft rot problems caused extreme variability in the data at both sites and results should therefore be interpreted with caution. Phosphate fertilizer had no effect on specific gravity of the tubers.

Elemental composition of the most recently matured leaf sampled in July is presented in Tables 5 and 6. Concentrations of leaf P, Ca, and Mg generally increased and K decreased with increasing phosphate fertilizer application in the low testing site. For the high testing P site, concentrations of leaf nutrients were not affected by phosphate fertilizer application.

This study will be continued in next year to obtain data without the influence of soft rot.

[1]We thank the R. D. Offutt Co. for providing funds to support this project.
[2]Ext. Soil Scientist and Jr. Scientist, respectively, Dept. of Soil Sci.; Director, Sand Plain Research Farm.

Table 1. Effect of phosphate fertilizer on dry matter of vines, roots, tubers, and number of tubers sampled July 11, 1991. Previous crop - Rye; initial soil test P - 54 ppm.

Phosphate Treatment lb P_2O_5/A	Plant Part: vines	roots	tubers	Number of tubers per 5 plants
	tons dry wt/A			
0	1.89	0.24	0.56	39
50	2.10	0.22	0.56	45
100	1.87	0.22	0.77	38
150	3.36	0.29	0.79	53
200	2.64	0.25	0.56	36
250	2.39	0.27	1.26	71
Pr>F	0.06	0.86	0.31	0.36
Lin P_2O_5	++	NS	NS	NS
Quad P_2O_5	NS	NS	NS	NS
Cubic P_2O_5	++	NS	NS	NS

NS = nonsignificant; ++ = significant at 10%

Table 2. Effect of phosphate fertilizer on dry matter of vines, roots, tubers, and number of tubers sampled July 11, 1991. Previous crop - alfalfa; initial soil test P - 18 ppm.

Phosphate Treatment lb P_2O_5/A	Plant Part: vines	roots	tubers	Number of tubers per 5 plants
	tons dry wt/A			
0	2.30	0.25	0.48	55
50	1.86	0.24	0.55	48
100	2.36	0.27	0.66	60
150	2.80	0.24	0.51	41
200	2.42	0.25	0.60	49
250	3.28	0.32	0.99	67
Pr>F	0.50	0.70	0.66	0.18
Lin P_2O_5	NS	NS	NS	NS
Quad P_2O_5	NS	NS	NS	++
Cubic P_2O_5	NS	NS	NS	NS

NS = nonsignificant; ++ = significant at 10%

Table 3. Effect of phosphate fertilizer on yield and specific gravity of Russet Burbank potatoes. Previous crop - Rye; initial soil test P - 54 ppm.

Phosphate Treatment lb P_2O_5/A	Tuber Yield: Knobs	Tuber Size: <4 oz	4-7 oz	7-14 oz	>14 oz	Total	Specific Gravity
	cwt/A						
0	8.3	11.5	177.6	105.1	6.5	309.0	1.0830
50	7.2	12.0	135.9	191.7	19.9	366.7	1.0825
100	7.7	11.5	171.3	154.3	4.6	349.5	1.0810
150	9.0	14.0	185.9	161.6	6.0	376.6	1.0820
200	8.2	17.0	197.9	118.8	0.0	342.0	1.0810
250	8.5	16.1	183.9	124.6	13.4	346.5	1.0820
Pr>F	0.99	0.68	0.31	0.05	0.31	0.05	0.97
Lin P_2O_5	NS	NS	NS	NS	NS	NS	NS
Quad P_2O_5	NS	NS	NS	*	NS	*	NS
Cubic P_2O_5	NS	NS	++	*	++	NS	NS

NS = nonsignificant, ++ = significant at 10%, * = significant at 5%.

Table 4. Effect of phosphate fertilizer on yield and specific gravity of Russet Burbank potatoes. Previous crop - alfalfa; initial soil test P - 18 ppm.

Phosphate Treatment lb P_2O_5/A	Tuber Yield: Knobs	Tuber Size: <4 oz	4-7 oz	7-14 oz	>14 oz	Total	Specific Gravity
	cwt/A						
0	5.7	7.0	135.1	132.8	18.0	298.7	1.0820
50	5.7	9.2	193.9	151.4	14.8	375.1	1.0865
100	6.5	8.5	167.4	149.0	0.0	331.3	1.0815
150	14.9	10.1	169.1	119.9	9.0	323.1	1.0850
200	6.1	12.0	188.6	126.8	12.6	346.2	1.0830
250	3.7	8.7	185.1	183.6	13.6	394.7	1.0835
Pr>F	0.69	0.67	0.02	0.52	0.75	0.29	0.38
Lin P_2O_5	NS	NS	*	NS	NS	NS	NS
Quad P_2O_5	NS	NS	NS	NS	NS	NS	NS
Cubic P_2O_5	NS	NS	*	NS	NS	NS	NS

NS = nonsignificant, * = significant at 5%.

Table 5. Effect of phosphate fertilizer on elemental composition of recently expanded potato leaves (leaflets + petioles) sampled July 11, 1991. Previous crop - rye; initial soil test P - 54 ppm.

Phosphate Treatment lb P_2O_5/A	Element: N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	%					ppm				
0	4.99	0.32	5.51	0.61	0.40	116	280	20	7.6	25
50	5.00	0.29	5.26	0.56	0.36	103	226	17	3.8	22
100	4.82	0.31	5.60	0.54	0.37	107	232	18	3.8	24
150	4.90	0.34	5.65	0.60	0.41	105	265	21	4.0	26
200	4.91	0.31	5.01	0.57	0.38	99	189	21	3.0	21
250	5.12	0.33	5.33	0.61	0.40	103	217	18	3.7	24
Pr>F	0.43	0.52	0.07	0.67	0.68	0.93	0.68	0.67	0.38	0.26
Lin P_2O_5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Quad P_2O_5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cubic P_2O_5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = nonsignificant.

Table 6. Effect of phosphate fertilizer on elemental composition of recently expanded potato leaves (leaflets + petioles) sampled July 11, 1991. Previous crop - alfalfa; initial soil test P - 18 ppm.

Phosphate Treatment lb P_2O_5/A	Element: N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	%					ppm				
0	5.29	0.38	4.94	0.76	0.62	104	125	24	10.7	28
50	5.20	0.35	4.82	0.77	0.64	101	114	23	10.8	28
100	5.35	0.37	4.84	0.84	0.65	96	125	23	9.1	26
150	5.15	0.38	4.58	0.88	0.69	105	125	22	9.8	27
200	5.44	0.46	4.96	0.90	0.74	110	122	26	11.6	26
250	5.42	0.40	4.23	0.87	0.69	106	127	25	9.7	24
Pr>F	0.38	0.02	0.01	0.17	0.10	0.07	0.97	0.20	0.60	0.36
Lin P_2O_5	NS	*	**	*	*	NS	NS	NS	NS	++
Quad P_2O_5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cubic P_2O_5	NS	*	NS	NS	NS	*	NS	NS	NS	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

NITROGEN EFFECTS ON QUALITY OF SELECTED SUGAR BEET VARIETIES[1]

John A. Lamb[2]

During recent years, climate has caused, for some, difficulty in managing soil NO_3-N contents for sugar beet production. After studying the fall 1991 soil samples, this problem will continue into the 1992 production season. One possible management strategy would be to select a sugar beet variety which has low impurities. Most varietal development and testing is done under optimum soil N conditions. The objective of this study is to determine if there is a need to tailor variety selections to the nitrogen status of a producer's field.

This report is the combination of data from seven sites where this study was conducted from 1989 to 1991. Data from three locations was not used because of drought, root magot damage, and disease infestation. The other four locations were near Casselton, ND in 1990 and 1991 (CASS90 & CASS91), the Northwest Experiment Station, Crookston, MN in 1990 (NWES90), and near Bird Island, MN in 1990 (SOMN90). The treatments included three varieties with the following characteristics: 1) low amino-N (LAN), 2) low K, Na, and amino-N (LKNAN), and 3) high K, Na, and amino-N (HKNAN). These varieties were selected from the American Crystal Sugar Coded variety trial results for these characteristics. The varieties were grown on soil with two N levels (soil NO_3-N to 0-2 ft. + fertilizer) of 100 and 300 lb. N/A at the NWES90, CASS90, and CASS91 sites. The SOMN90 site's N levels were 84 and 211 lb. N/A. At each location the experimental design was a split plot with four replications. Nitrogen levels were the main plot with varieties the subplot. The subplot size was 14.7 ft. (8 rows) wide and 35 feet long. Sugar beet seed was overplanted in early May and thinned to a 125 plant per 100 foot of row. Roots were harvested late September and quality determined at American Crystal Sugar's Tare Lab in East Grand Forks, MN.

Results and Discussion

Root Yield: Root yields were increased by N an average of 2.7 T/A at three of the four locations, Table 1. On the average, the HKNAN variety had the greatest root yield, although at two locations, at the 300 lb. N/A level, this was not the case.

Sucrose Concentration: In the overall analysis, sucrose concentration was reduced by additional N (Tables 2 & 3). No trend occurred for varieties.

Recoverable Sucrose (lb/A): N level affected recoverable sucrose per acre in three of four locations (Table 4). Recoverable sucrose was increased 533 lb/A at NWES() and 662 lb/A at SOMN90. At CASS91, recoverable sucrose was reduced 585 lb/A by elevated N level. The HKNAN variety on the average had the greatest recoverable sugar per acre with LAN intermediate, and LKNAN the least. There are some departures from this trend at NWES90 and CASS90 at the 300 lb. N level and SOMN90 at the 100 lb. N level.

[1] Funding provided by North Dakota and Minnesota Sugarbeet Research and Education Board and Minnesota Agricultural Experiment Station.

[2] Associate Professor, Department of Soil Science, University of Minnesota, St. Paul, MN

Table 1. Means and statistical analyses for root yield as affected by N level and variety, 1990-1991.

Variety	N Level	NWES 90	CASS 90	SOMN 90	CASS 91	Mean
	lb/A	T/A				
LKNAN	100	11.3	19.8	8.5	19.9	14.9
LAN	100	11.9	18.8	12.2	20.7	15.9
HKNAN	100	12.2	20.4	12.5	22.5	16.9
LKNAN	300	16.3	22.4	12.1	20.4	17.0
LAN	300	13.9	20.8	14.7	20.9	17.6
HKNAN	300	13.3	21.7	16.8	22.1	19.2
Statistical Analyses						
N Level (N)		**	++	**	NS	
Variety (V)		*	**	*	**	
N X V		NS	NS	NS	NS	
C.V.		10.7	3.8	19.6	4.3	

**, *, and ++ are 0.01, 0.05, and 0.10 significance levels, respectively.

Table 2. Combined statistical analyses for root yield, sucrose concentration, recoverable sucrose per acre, recoverable sugar per ton of processed sugar beet, loss to molasses, and dollar return per acre for all four locations, 1990-1991.

Source of Variation	Root Yield	Sucrose Conc.	Recoverable Sucrose lb./A	Recoverable Sucrose lb/T	Loss to Molasses	$ Return Acre
Location (L)	**	**	**	**	**	**
N Level (N)	++	++	NS	*	*	NS
L X N	*	NS	**	NS	NS	**
Variety (V)	++	++	*	NS	*	**
L X V	**	NS	NS	NS	NS	NS
N X V	NS	NS	NS	NS	NS	NS
L X N X V	NS	NS	NS	NS	NS	NS
C.V.	9.2	4.2	10.4	5.6	8.5	13.3

**, *, and ++ are 0.01, 0.05, and 0.10 significance levels, respectively.

Table 3. Means and statistical analyses for sucrose concentration as affected by N level and variety, 1990-1991.

Variety	N Level	NWES 90	CASS 90	SOMN 90	CASS 91	Mean
	lb/A	%				
LKNAN	100	16.5	16.9	13.9	15.3	15.6
LAN	100	17.8	17.9	14.0	16.2	16.5
HKNAN	100	17.1	17.9	13.8	16.0	16.2
LKNAN	300	16.9	17.3	13.5	14.7	15.5
LAN	300	16.0	17.6	13.8	14.6	15.5
HKNAN	300	16.6	17.3	13.3	14.7	15.6
Statistical Analyses						
N Level (N)		NS	NS	NS	**	
Variety (V)		NS	**	NS	NS	
N X V		NS	NS	NS	NS	
C.V.		5.3	2.3	3.7	4.9	

** is the 0.01 significance level.

Table 4. Means and statistical analyses for recoverable sucrose per acre as affected by N level and variety, 1990-1991.

Variety	N Level	NWES 90	CASS 90	SOMN 90	CASS 91	Mean
	lb/A	lb/A				
LKNAN	100	3368	6029	2079	5234	4177
LAN	100	3808	6121	2958	5720	4652
HKNAN	100	3669	6625	2919	6170	4846
LKNAN	300	3877	6940	2776	4994	4647
LAN	300	3831	6584	3455	5054	4731
HKNAN	300	4735	6691	3712	5319	5114
Statistical Analyses						
N Level (N)		**	NS	++	++	
Variety (V)		*	NS	*	NS	
N X V		++	*	NS	NS	
C.V.		10.3	4.4	20.7	10.5	

**, *, and ++ are 0.01, 0.05, and 0.10 significance levels, respectively.

Recoverable Sucrose Per Ton: The overall analyses of all locations suggests that the increased N level decreased the amount of sucrose recovered from a ton of processed sugar beet (Table 2 and Table 5). Varieties did not affect the overall recoverable sucrose per ton (Table 2).

Loss to Molasses: Loss to molasses was increased 0.21% by the excess nitrogen situation (Table 2 and Table 6). As expected, the HKNAN variety had the greatest loss to molasses (1.95%). The loss to molasses for the LAN was 1.84% and 1.75% for the LKNAN. There was no significant N level by variety interaction which means the variety with the least loss to molasses was the same under both N levels (LKNAN) and the variety with the greatest loss to molasses was the same under both N levels (HKNAN).

Dollar Return Per Acre: The economic effect of these treatments is the bottom line for decision making for producers (Table 7). Increased nitrogen level increased returns at NWES90 by $43 but decreased returns by

$140 at CASS91. The other two locations were not affected by N level. The HKNAN variety return the greatest amount of money overall N levels and locations.

Table 5. Means and statistical analyses for recoverable sucrose per ton processed as affected by N level and variety, 1990-1991.

Variety	N Level	NWES 90	CASS 90	SOMN 90	CASS 91	Mean
	lb/A	lb/T				
LKNAN	100	298	305	243	261	271
LAN	100	321	326	242	277	292
HKNAN	100	302	325	236	273	284
LKNAN	300	292	311	231	244	269
LAN	300	274	316	238	242	268
HKNAN	300	291	309	233	239	265
Statistical Analyses						
N Level (N)		++	NS	NS	**	
Variety (V)		NS	**	NS	NS	
N X V		NS	*	NS	NS	
C.V.		6.6	2.4	5.9	7.0	

**, *, and ++ are 0.01, 0.05, and 0.10 significance levels, respectively.

Table 6. Means and statistical analyses for loss to molasses as affected by N level and variety, 1990-1991.

Variety	N Level	NWES 90	CASS 90	SOMN 90	CASS 91	Mean
	lb/A	%				
LKNAN	100	1.51	1.53	1.64	1.95	1.66
LAN	100	1.59	1.48	1.74	2.15	1.74
HKNAN	100	1.84	1.51	1.79	2.15	1.82
LKNAN	300	1.81	1.59	1.77	2.23	1.85
LAN	300	2.04	1.67	1.69	2.30	1.93
HKNAN	300	2.17	1.74	1.92	2.50	2.08
Statistical Analyses						
N Level (N)		**	*	NS	*	
Variety (V)		**	NS	NS	++	
N X V		NS	NS	NS	NS	
C.V.		8.0	6.2	10.2	8.5	

**, *, and ++ are 0.01, 0.05, and 0.10 significance levels, respectively.

Table 7. Means and statistical analyses for dollar return per acre as affected by N level and variety, 1990-1991.

Variety	N Level	NWES 90	CASS 90	SOMN 90	CASS 91	Mean
	lb/A	$/A				
LKNAN	100	446	810	227	620	526
LAN	100	530	864	323	710	607
HKNAN	100	488	931	304	760	621
LKNAN	300	505	944	282	548	570
LAN	300	474	910	363	549	574
HKNAN	300	613	908	358	572	613
Statistical Analyses						
N Level (N)		*	NS	NS	*	
Variety (V)		++	NS	++	NS	
N X V		*	*	NS	NS	
C.V.		12.1	5.4	24.9	17.6	

*, and ++ are 0.01, 0.05, and 0.10 significance levels, respectively.

Summary: The data presented above indicates that soil NO_3-N should not be a major consideration in variety selection by the sugar beet producer. The reasons for this lie in the fact that before a variety can be planted in the Minnesota and North Dakota sugar beet growing areas it must meet criteria in the coded variety trials. The differences in quality between approved varieties are smaller than the differences that can occur from soil types and climates.

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Allan Cattanach and the NDSU crew for their help at the Casselton location; Stan Prokosch for providing the Southern Minnesota location; The Northwest Experiment Station crew for planting, thinning and harvesting the study; American Crystal Sugar for the Quality Analyses; and the Sugar Beet Research and Education Board for the financial assistance to run this study.

THIRTY-TWO YEARS OF CONTINUOUS CORN WITH VARIABLE NITROGEN SOURCE, PLACEMENT, AND TIME OF APPLICATION AT THE SOUTHWEST EXPERIMENT STATION[1]

D.J. Fuchs, D.R Huggins and W.W Nelson[2]

ABSTRACT

Optimizing nitrogen management is an important objective of corn production. A field study was started in 1960 to determine if continuous corn yields are affected by nitrogen form, (urea or ammonium nitrate), amount (13 to 173 lbs N/ac), time of application (fall, spring or sidedressed). and placement (surface, moldboard plow incorporation or sidedress). Each year corn is established with conventional tillage (moldboard plow) and planted in 30-inch rows on a Normania loam. The 31-year average of the treatments indicate that corn yields respond the greatest to N rate with a slight advantage to spring application and with little difference between N form. In 1991, the corn yields, averaged across N form and time of application, were 77, 119, 141, and 160 (bu/ac) for the 13, 53 93 and 173 lbs N/ac treatments, respectively.

METHODS AND MATERIALS

The continuous corn study is a nitrogen fertilization experiment involving various rates and application times of ammonium nitrate and urea. The experiment has been conducted since 1960 on a tiled Normania loam. The fertilizer treatments have now been applied annually to the same plot area (1550 ft^2) for 32 years. The experimental design is a randomized incomplete block with four replications. After ear corn removal and stalk cutting, the plots with treatments of fall applied N receive either broadcast N followed by moldboard plowing or moldboard plowing followed by surface applied N. All other treatments are also fall moldboard plowed to a depth of 12 inches. Spring treatments of applied N are broadcast before seedbed preparations in late April or early May. The corn is planted in 30-inch rows, and starter fertilizer is banded at a rate of 13 lbs N/ac, 34 lbs P_2O_5/ac, and 12 lbs K_2O/ac in all treatments. Sidedress treatments of applied N are broadcast in June and incorporated during cultivation. Additional management information is provided in Table 1. A one-way analysis of variance is provided, also the average corn yields for the various treatments are given in Table 2 and 3, respectively. The 31-year yield averages are provided in Table 4 (In 1976, no yields were obtained due to drought, thus only 31 years of data exist).

RESULTS AND DISCUSSION

The one-way analysis of variance of corn yields in 1991 indicates a significant combined treatment effect (Table 2). In 1991, corn yield response to N rate ranged from 77 bu/ac for control plots (13 lbs N/ac) to 159 bu/ac for the 173 lbs N/ac treatments (Table 3). This year, as in the past, there was a trend of increased yield with delayed application time. Corn yields with 40 lbs N/ac, of either N form, applied as a side dress, were not significantly different from the 80 pounds N/ac treatments (Table 3).

The long-term average yields for the 40 and 80 lbs N/ac treatment indicate that urea nitrogen had about a 2 bu/ac yield advantage over ammonium nitrate (Table 4). This year, as in the past, there was little difference in yield between the nitrogen source.

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[1] Funding provided by Agricultural Experiment Station

[2] Assistant Scientist, Soil Scientist, and Superintendent - University of Minnesota, Southwest Experiment Station, respectively.

Table 1. 1991 Management Information.

Item	Type	Rate	Date
Secondary Tillage	Disc	1 pass	4/26
	Digger	1 pass	5/8
Seed	Pioneer	27,700 seeds/ac	5/9
Fertilizer	Starter	14-41-15 lbs/ac ($N-P_2O_5-K_2O$)	5/9
Herbicides	Lasso	3.0 lbs/ac (ai)	4/26
	Bladex	2.0 lbs/ac (ai)	
Insecticides	Counter	1.0 lbs/ac (ai)	5/9
	Pounce 3.2E	6.0 oz/ac (ai)	6/27
Cultivation		1 pass	6/18

Table 2. One-way analysis of variance for corn yield.

Source	DF	SS	MS	F	P
Block	3	853.23	284.4	1.13	0.3464
Treatment	17	31782	1869.5	7.42	0.0000
Error	51	12855	252.1		

Table 3. 1991 corn yields (bu/ac).

Application Time	Ammonium Nitrate (lbs/ac)			Urea (lbs/ac)		
	40	80	160	40	80	160
Fall Incorporated	102 b	137 cde	162 f	119 bc	136 cde	159 f
Fall Plowed Surface	115 bc	---	---	117 bc	---	---
Spring Pre-plant	117 bc	147 def	---	119 bc	142 def	---
Side Dress	130 cd	137 cde	157 ef	128 cd	148 def	---
Check: 77 a	Comparable AN Avg: 131			Comparable Urea Avg: 134		

$LSD_{0.05}$ = 22.5 (bu/ac)
Means with the same letter do not differ significantly using Fisher's $LSD_{0.05}$.

Table 4. 31 year long-term average yields (bu/ac).

Application Time	Ammonium Nitrate (lbs/ac)			Urea (lbs/ac)		
	40	80	160	40	80	160
Fall Incorporated	86	106	114	89	105	114
Fall Plowed Surface	84	---	---	89	---	---
Spring Pre-plant	97	109	---	95	110	---
Side Dress	99	106	118	99	114	---
Check: 67	Comparable AN Avg: 100			Comparable Urea Avg: 102		

THE EROSION-PRODUCTIVITY STUDY AT THE SOUTHWEST EXPERIMENT STATION[1]

D.J. Fuchs, M. Lindstrom, D.R. Huggins, and W.W. Nelson[2]

ABSTRACT

Field data is needed to evaluate crop growth simulation models. The objective of this study is to determine the effect of tillage and soil erosion class on corn yields. A field study was initiated in 1984 where continuous corn is grown with conventional tillage (fall moldboard plow) or ridge tillage on sites where soil types are slightly, moderately, or severely eroded. In 1991, erosion class had a significant effect on corn yields. Corn on severely eroded soil yielded 18 percent less and on moderately eroded 15 percent less than corn grown on soil that was only slightly eroded across tillage treatments. Over the course of the experiment, the effect of erosion class on corn yield has been consistent with the higher yields occurring on the less eroded treatments. In 1991, corn yields were not effected by tillage treatment. In the past, tillage effects on corn yields have been inconsistent.

MATERIALS AND METHODS

Field plots were established in 1984 with continuous corn and two tillage regimes in areas which had been slightly, moderately, and severely eroded. The soil type for the slight and moderately eroded areas is a Ves loam (fine-loamy, mixed, mesic Typic Haplustolls). The soil type on the severely eroded area is a Storden loam (fine-loamy, mixed (calcareous), mesic Typic Udorthents). The two tillage systems used on each erosion class were fall moldboard plow (MP) and ridge tillage (RT).

The entire study was moldboard plowed in the fall of 1989 because of the visual and measured potassium deficiency symptoms that occurred in the ridge tillage treatment. Ridges were re-established during the 1990 growing season. In 1991, the ridge tillage plots were row cultivated with a conventional cultivator, but because of wet field conditions, they were not ridged with the ridge cultivator. In the fall of 1991, the ridge tillage area was para-plowed. Additional management information is given in Table 1. Analysis of variance, using a spilt plot design (tillage = whole plots, erosion class = split plots) is given in Table 2. If treatments were significantly different (0.05 level), means were separated using the Fisher's $LSD_{(0.05)}$.

RESULTS AND DISCUSSION

The objectives of this study are to asses the effect of erosion on soil characteristics and potential productivity of selected soils with emphasis on evaluation of physically-based simulation models. In 1991, corn yields on severely eroded soil yielded 18 percent less and on moderately eroded 15 percent less than corn grown on soil that was only slightly eroded (Table 2 and 3). Over the past seven years, erosion levels affected corn yields with the greatest yields occurring on the least eroded soil. In 1991, tillage treatment did not significantly affect corn yields (Table 2 and 3). In the past, tillage effects on yields have been inconsistent, however, the seven year average corn yields indicate very little difference between the two tillage treatments (Table 4).

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[1] Funding provided by the USDA - CSRS and the Agricultural Experiment Station.

[2] Assistant Scientist - U of MN, Southwest Experiment Station; Soil Scientist - USDA-ARS, Morris, MN 56267; Soil Scientist, and Superintendent - U of MN, Southwest Experiment Station, respectively.

Table 1. 1991 Management Information.

Item	Type	Rate	Date
Primary Tillage (RT)	None	1	Fall 1990
	Para-plow	1	10/16/91
Primary Tillage (MP)	Moldboard Plow	1	Fall 1990
	Moldboard Plow	1	10/12/91
Secondary Tillage[1]	Disc	1 pass	5/9
	Digger	1 pass	5/10
Seed	Pioneer 3615	27,700 seeds/ac	5/10
Fertilizer	Urea	150 lbs N/ac	4/10
	Starter	13-34-12 lbs/ac ($N-P_2O_5-K_2O$)	5/10
Herbicides	Lasso	3.0 lbs/ac (ai)	5/11
	Bladex	2.0 lbs/ac (ai)	5/11
Insecticides	Counter	1.0 lbs/ac (ai)	5/10
Row Cultivation (MP)		once	6/3
row Cultivation (RT)		once	6/12

1/ Secondary tillage was only done on the moldboard plow area.

Table 2. Analysis of Variance.
Variable: Corn yields (bu/ac)
Randomized block with split plot restriction
Number of: Cases = 24 Blocks = 4
Tillage Levels = 2 Erosion Levels = 3

Source	DF	SS	MS	F	P
Block	3	32.01	10.67	0.07	0.97
Erosion class	2	3403.60	1701.80	11.51	** 0.01
Whole plot error	6	887.47	147.91		
Tillage	1	348.08	348.08	2.29	0.16
Tillage*Erosion	2	7.88	3.94	0.03	0.97
Sub-plot error	9	1370.20	152.25		

** significant at alpha = 0.01

Table 3. Mean corn yields (bu/ac) of tillage, erosion class and interactions.

Tillage	Erosion Class[1]			Overall average
	Slight	Moderate	Severe	
Moldboard plow	153.1	147.9	126.9	142.7
Ridge area	146.8	140.5	117.8	135.0
Overall average	150.0	144.2	122.3	138.8

1/ $LSD_{0.05}$ = 14.9 for comparing erosion classes (averaged over both tillage treatments)

Table 4. Average annual corn yields (bu/ac).

Tillage	1985	1986	1987	1988	1989	1990	1991	Average
Moldboard	162.5	164.2	136.6	44.0	124.4	123.5	142.7	128.3
Ridge area	153.4	149.5	129.0	52.1	123.9	135.2	135.0	125.4

TILLAGE MANAGEMENT FOR INCREASING CROP YIELDS AND DECREASING SOIL EROSION AT THE SOUTHWEST EXPERIMENT STATION[1]

D.J. Fuchs, M. Lindstrom, D.R. Huggins, and W.W. Nelson[2]

ABSTRACT

Field research is needed to evaluate soil movement under different crop production practices and the consequent effects on crop yield. This study was conducted to examine the effects of slope percentage (1%, 4%, and 8%), tillage (ridge tillage, moldboard plow, and chisel), tillage/planting direction (up and down the slope, or contour to the slope), and slope position (top, middle, and bottom) on soil movement and yield in a corn and soybean rotation. In 1991, the only significant treatment effect was tillage on the 8 percent slope. On the site with 8 percent slope, soybean yields with moldboard plowing were 26.8 percent and chisel plowing 21.7 percent greater than ridge tillage. The differences in yield were attributed to herbicide injury in the ridge tillage system. No other treatments significantly affected soybean yield.

MATERIALS AND METHODS

This study began in the spring of 1985 to examine the effects of slope percentage (1%, 4%, and 8%), tillage (ridge tillage, moldboard plow, and chisel), tillage/planting direction (up and down the slope, or contour to the slope), and slope position (top, middle, and bottom) on soil movement and yield in a corn and soybean rotation. The field experiments are located at three different sites with one site for each slope percentage. Treatments at the site with 8 percent slope are tillage, plant row direction, and position on the slope (top, middle, and bottom). Treatments at the site with 4 percent slope are tillage, and plant row direction, while the site with 1 percent slope has only a tillage treatment. Yields are measured every year. Base line data on soil movement was collected at the start of the experiment. Soil movement will be assessed at the conclusion of the study by grass catch strips and infrared transit survey. Additional management information is provided in Table 1. Analysis of variance was performed for each slope percentage. If treatments were significantly different (0.05 level), means were separated using Fisher's $LSD_{0.05}$.

RESULTS AND DISCUSSION

In 1991, the only significant treatment effect was tillage on the 8 percent slope (Tables 2, 5, and 7). On the site with 8 percent slope, soybean yields with moldboard plowing were 26.8 percent and chisel plowing 21.7 percent greater than ridge tillage (Table 3). The soybean plants with ridge tillage exhibited symptoms of severe herbicide injury from the pre-emergent application of Sencor and Lasso. Some of the soybeans did not recover from the herbicide injury and this reduced the stand and yield. The herbicide injury symptoms were not observed on the other two tillage treatments. Soybean yield data by row direction, tillage, and slope position are shown in Table 4, however, there were no significant yield differences on the 8 percent slope between row direction, or position (Table 2 and 4).

Soybean yields were not significantly affected by tillage treatment or row direction on the site with 4 percent slope (Table 5) or by tillage treatment on the site with 1 percent slope (Table 7). Yields by tillage and row direction (4 percent slope) are presented in Table 6 and by tillage (1 percent slope) in Table 8. The different slope percentages (8%, 4% & 1%) were not compared with an analysis of variance, however, the overall average soybean yield on the 8, 4, and 1 percent slopes were 36.8 (bu/ac), 40.5 (bu/ac), and 44.2 (bu/ac), respectively. The trend of decreasing yield with increasing slope percentage is consistent with past years.

The three year average soybean yields for each tillage system (averaged over all three slope areas) are similar but show a trend of increased yield in the moldboard plow tillage system (Table 9). The three year average corn yields for each tillage system (averaged over all three slope areas) are similar but indicate a slight yield advantage to the ridge tillage treatment (Table 10).

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[1] Funding provided by the USDA - CSRS and the Agricultural Experiment Station.

[2] Assistant Scientist - U of MN, Southwest Experiment Station; Soil Scientist - USDA-ARS, Morris, MN 56267; Soil Scientist, and Superintendent - U of MN, Southwest Experiment Station, respectively.

Table 1. 1991 Management Information.

Item	Type	Rate	Date
Secondary Tillage	Disc	1 pass	5/21
Soybean Variety	Hardin	150,000 seeds/ac	5/22
Herbicides	Lasso Sencor	3.0 lbs/ac (ai) 0.375 lbs/ac (ai)	5/22
Row Cultivation		Twice	6/17, 7/1

1/ No secondary tillage on ridge tillage plots.

Table 2. Analysis of Variance for the 8 Percent Slope.
Variable: Soybean grain yield (bu/ac)
Randomized block with split - split plot restriction
Number of: Cases = 54 Blocks = 3
Row Directions = 2 Tillage Levels = 3 Slope Positions = 3

Source	DF	SS	MS	F	P
Block	2	16.92	8.46	0.60	0.63
Row Direction	1	10.23	10.23	0.72	0.48
Whole Plot Error	2	28.29	14.15		
Tillage	2	1201.70	600.84	26.83	** 0.00
Row*Tillage	2	57.57	28.79	1.29	0.33
Sub-Plot Error	8	179.16	22.40		
Position	2	6.15	3.07	0.34	0.72
Row Position	2	2.09	1.05	0.12	0.89
Tillage*Position	4	55.40	13.85	1.53	0.23
Row*Tillage*Position	4	23.85	5.96	0.66	0.63
Sub-Sub Plot Error	24	217.85	9.08		

** significant at alpha < 0.01

Table 3. Soybean Yields on the 8 Percent Slope by Tillage.

Tillage	Average yield* (bu/ac)	Standard deviation
Moldboard	41.4 a	2.8
Chisel	38.7 a	3.7
Ridge	30.3 b	3.7

* $LSD_{0.05}$ = 3.6
Means in a column with the same letter do not differ significantly using Fischer's LSD (0.05 probability level).

Table 4. Soybean Yields on the 8 Percent Slope by Tillage-Row Direction-Slope Position Interaction.

Row direction	Tillage	Slope Position	Average yield (bu/ac)	Standard deviation
Up & Down	Moldboard	Top	41.1	4.3
		Middle	41.1	4.2
		Bottom	41.5	2.9
	Chisel	Top	39.9	3.4
		Middle	37.8	1.9
		Bottom	37.1	2.7
	Ridge	Top	31.7	1.3
		Middle	31.6	1.0
		Bottom	33.3	1.8
Contour	Moldboard	Top	42.2	2.7
		Middle	41.9	2.0
		Bottom	40.7	3.1
	Chisel	Top	40.9	5.1
		Middle	36.4	4.0
		Bottom	39.9	5.1
	Ridge	Top	25.8	3.1
		Middle	29.2	6.8
		Bottom	30.3	2.3

Table 5. Analysis of Variance for the 4 Percent Slope.
Variable: Soybean grain yield (bu/ac)
Randomized block with split plot restriction
Number of: Cases = 12 Blocks = 2
Tillage Levels = 3 Row Directions = 2

Source	DF	SS	MS	F	P
Block	1	112.24	112.24	0.91	0.51
Row direction	1	0.08	0.08	0.00	0.99
Whole plot error	1	123.52	123.52		
Tillage	2	70.45	35.22	0.82	0.50
Row*Tillage Interaction	2	263.16	131.58	3.06	0.16
Sub-plot error	4	171.86	42.97		

Table 6. Soybean Yields on the 4 Percent Slope by Tillage-Row Direction Interaction.

Tillage	Row direction	Average yield (bu/ac)	Standard deviation
Moldboard	Up & Down	42.2	5.7
	Contour	43.2	3.9
Chisel	Up & Down	36.1	2.6
	Contour	47.3	4.2
Ridge	Up & Down	43.0	18.3
	Contour	31.3	0.9

Table 7. Analysis of Variance for the 1 Percent Slope.
Variable: Soybean grain yield (bu/ac)
Randomized block
Number of: Cases = 6 Blocks = 2
Tillage Levels = 3

Source	DF	SS	MS	F	P
Block	1	10.40	10.40	0.58	0.53
Tillage	2	57.88	28.94	1.61	0.38
Whole plot error	2	36.05	18.03		

Table 8. Soybean Yields on the 1 Percent Slope by Tillage.

Tillage	Average yield (bu/ac)	Standard deviation
Moldboard	48.1	2.5
Chisel	44.0	2.1
Ridge	40.5	6.0

Table 9. Average Soybean Yields (bu/ac) for 1987, 1989 and 1991.

Tillage	1987	1989	1991	Average
Moldboard	44.0	45.1	43.2	44.1
Chisel	45.0	41.8	42.4	43.1
Ridge	45.4	41.9	36.0	41.1

Table 10. Average Corn Yields (bu/ac) for 1986, 1988 and 1990.

Tillage	1986	1988	1990	Average
Moldboard	176.0	23.8	133.1	111.0
Chisel	174.1	31.8	133.9	113.3
Ridge	175.1	41.7	132.3	116.4

MICRO-PLOT PESTICIDE LEACHING AND RUNOFF STUDY UNDER CONVENTIONAL AND SOIL SPECIFIC MANAGEMENT[1]

B.R. Khakural, P.C. Robert and D.J. Fuchs[2]

ABSTRACT: Leaching and runoff loss of alachlor was studied on a soil catena with varied slope and drainage characteristics under conventional and soil specific management. There was no significant difference in alachlor concentration of surface (0-6 in.) soil or runoff water between conventional and soil specific treatments. No alachlor was detected in the soil samples from below 1 foot depth. Detectable amount of alachlor (0.6, 1 ppb) was found in only 2 out of 60 soil water samples collected at 6 different dates in 1990. In 1991, an alachlor concentration of ≥ 1 ppb was detected in 17 to 33% of the earlier samples (collected within 8 days of application) and 17% of the later samples at a depth of 2 feet respectively. At 4 feet depth, a concentration of ≥ 1 ppb was detected in 33% of the earlier samples only. The highest alachlor concentration in runoff water was observed at the first runoff event (47 to 226 ppb) and the concentration decreased with time in later events during both years of study. Average alachlor concentration for the Ves (6-12%) soil was 1.5 and 2 times higher than the Ves (1-4%) and Webster (0-3%) soils respectively. Pesticide loss through surface runoff seems to be more of a problem in these soils than leaching.

Introduction:

Growing concerns about crop management sustainability and surface and ground water pollution by agricultural chemicals have initiated soil specific management system (SSMS). In order to measure the effect of SSMS on leaching and runoff of chemicals, landscape micro-plots were established for long term pesticide leaching and runoff study at the Southwestern Experiment Station, Lamberton, Minnesota in 1989.

Materials and Methods:

A landscape comprised of two soil series with varied drainage characteristics was selected for this study. Two soil series used in this study were a well drained Ves (fine-loamy, mixed, mesic Udic Haplustoll) and a poorly drained Webster (fine-loamy, mixed, mesic Typic Haplaquoll). They represent a catena with the Ves soils on the backslope (1-4%) and sideslope (6-12%) and the Webster soil on the toeslope (0-3%) positions. Selected properties of the three soil types studied are presented in Table 1.

Table 1. Selected physical and chemical properties of Ves and Webster soils.

Depth	CF† (> 2 mm)	Sand	Silt	Clay	OC	pH
in	%					
			Ves (1-4%)			
0-8	4	42	30	28	3.5	5.6
8-16	3	41	29	30	2.5	5.6
16-24	3	39	28	33	1.0	5.9
24-32	2	38	32	30	0.6	6.3
32-40	4	41	32	24	0.5	7.0
40-48	5	38	38	24	0.4	7.4
			Ves (6-12%)			
0-8	2	44	28	28	3.3	5.8
8-16	3	44	28	28	2.3	5.9
16-24	5	41	29	30	1.2	6.4
24-32	5	35	28	37	0.7	6.8
32-40	5	35	31	34	0.6	7.2
40-48	10	27	36	37	0.5	7.5
			Webster (0-3%)			
0-8	0	35	35	30	4.2	6.3
8-16	1	35	35	30	2.9	6.5
16-24	1	34	36	30	1.5	6.7
24-32	3	39	36	25	0.6	6.9
32-40	3	63	20	17	0.3	7.2
40-48	7	77	11	11	0.3	7.2

†Coarse Fragments

[1]Funding for this project was provided by a USDA-CSRS grant

[2]B.R. Khakural and P.C. Robert are Post Doctoral Research Associate and Assistant Professor respectively in the Soil Science Department at the University of Minnesota, St. Paul, MN 55108. D.J. Fuchs is Junior Scientist, Southwest Experiment Station, University of Minnesota.

Six micro-plots (7 feet X 7 feet: 2 on each soil type) were established. Each plot was isolated vertically with polyethylene sheets (0.0059 in.) to a depth of 5 feet. Suction cups were installed in duplicates at 2 and 4 feet depths. Half of the experimental area (including 3 micro-plots and buffer zone) receives a constant rate of nitrogen and alachlor (Lasso) herbicide (Conventional treatment) and remaining half receives soil specific rates (FBS). Stainless steel sampling gutters attached to a vertically installed glass container have been used to receive runoff water and sediments samples. Corn and soybean crops have been rotated each year. TDR wave guides and thermocouple wires were installed at 2, 6, 12, 24 and 48 in. depths in each micro-plot to monitor soil water and temperature in 1991.

Plot Management

1990	1991	
Crop-Soybean Variety: Corsoy 79	Crop- Corn Variety: Pioneer 3615	Planting Date: 5-11-1991
Herbicide used: alachlor	Herbicide used: alachlor	Date of application: 5-21-91
Date application: 5-3-90	Nitrogen source: Anhydrous ammonia	Date of Application: 5-22-91
Herbicide rate: Same as in 1991		

Soil	Fertilizer and herbicide rates (1991):			
	Nitrogen rate		Herbicide rate	
	Conventional	Soil Specific	Conventional	Soil Specific
	lb/A		lb/A	
Ves (1-4%)	100	85	3.0	3.5
Ves (6-12%)	100	60	3.0	2.5
Webster (0-3%)	100	135	3.0	4.0

Sampling and laboratory procedure:

TDR and neutron probe readings were recorded every week. Soil samples (0-4 feet) were collected using a sampler with a plastic liner. One sampling was done before alachlor application and 5 samplings were done afterwards during the growing season. Runoff samples were obtained by placing the stainless steel sampler at the end of a 30 feet crop row (30 feet X 30 in). Soil water suction samples were collected after each significant rainfall. Only surface runoff and soil water samples were collected during the 1990 cropping season. Soil, soil water and runoff water samples were analyzed for alachlor concentration in the laboratory using gas chromatographic procedure.

Results and Discussion:

There was no significant difference in alachlor concentration of surface (0-6 in.) soil or runoff water between conventional and soil specific treatments (Table 2). Soil alachlor concentration at different sampling dates is presented in Table 3. No alachlor was detected in soil samples obtained from deeper than 12 in. depth. Detectable amount of alachlor was observed at 6-12 in. only at the first sampling (16 days after alachlor application) and in treatments with higher herbicide rates (Ves 1-4%-FBS, Ves 6-12%-Conv and Webster-FBS). Average alachlor concentration in the surface (0-6 in) layer was higher in the Webster soil than in the Ves soils (Figure 1). This could be related to the differences in organic carbon content (Table 1). A high alachlor adsorption is expected in the Webster soil with the higher organic carbon content.

Two and five runoff events occurred during 1990 and 1991 cropping seasons respectively. The alachlor concentration in runoff water at different runoff events is presented in Table 4. Timing of runoff events (days after application) and slope gradient determined the alachlor concentration in runoff water. The highest alachlor concentration in runoff water was observed at the first runoff event and the concentration decreased with time in later events. The concentrations were 68 to 265 ppb in 1990 and 47 to 193 ppb in 1991 at the first runoff events which occurred 20 and 7 days after application respectively. The concentration decreased to 0.3 to 2 ppb at the fifth runoff event in 1991 (119 days after application). The Ves soil with 6-12% slope had higher alachlor concentration than the Ves (1-4%) and Webster soils at the first runoff event after alachlor application (Figure 2). At later events, the Ves soil in general had higher concentration than the Webster soil. The average concentration (of 7 events) was 1.5 and 2 times higher in the Ves (6-12%) soil compared to the Ves (1-4%) and Webster soils respectively.

No alachlor was detected in soil water samples collected at 5 different dates (5-21, 6-21, 6-29, 8-30, 9-24) in 1990. Alachlor concentration in soil water suction samples collected at 2 and 4 feet depths are presented in Table 5. The alachlor concentration in soil water samples varied from 0 (ND) to 15 ppb in 1991. An alachlor concentration of ≥ 1 ppb was detected in 17 to 33% of the earlier samples (collected within 8 days of application) and 17% of the later samples at a depth of 2 feet respectively. At 4 feet depth, a concentration of ≥ 1 ppb was detected in 33% of the earlier samples only. No particular trend with soil types or herbicide rates was observed.

Table 2. Analysis of Variance for alachlor concentration in soil and runoff water.

Source	Soil (0-6 in.)	Runoff water
Soil type (S)	*	*
Alachlor rate (Conv vs FBS) (AR)	NS	NS
S X AR	NS	NS
Date/Event (D)	****	****
S X D	*	**
AR X D	NS	NS
S X AR X D	NS	**

*,**,**** Significant at the p = 0.05, 0.01, and 0.0001 levels, respectively.
NS = Not significant at the p = 0.05 level.

Table 3. Alachlor concentration in soil samples.†

Soil	Date:	5-14-91		6-6-91				6-27-91		7-23-91		9-26-91	
	Depth:	0-6 in		0-6 in		6-12 in		0-6 in		0-6 in		0-6 in	
		Conv	FBS	Conv	FBS	Conv	FBS	Conv	FBS	Conv	FBS	Conv	FBS
		ppb											
Ves (1-4%)		9	16	64	79	ND	3	32	10	2	7	7	12
Ves (6-12%)		6	8	80	63	2	ND	6	7	1	3	1	2
Webster (0-3%)		24	13	221	128	ND	2	39	43	9	4	7	4

Table 4. Alachlor concentration in runoff water.†

Soil	Date:	5-23-90		6-18-90		5-28-91		6-11-91		6-21-91		6-28-91		9-17-91	
		Conv	FBS	Conv	FBS	Conv	FBS	Conv	FBS	Conv	FBS	Conv	FBS	Conv	FBS
		ppb													
Ves (1-4%)		103	68	11	13	82	111	37	52	11	4	14	8	2	0.3
Ves (6-12%)		224	226	36	36	110	193	56	29	12	16	20	6	4	0.3
Webster (0-3%)		166	-	28	11	133	47	32	-	8	8	4	4	1	2.0

Table 5. Alachlor concentration in soil water at 2 and 4 feet depths.†

Soil	Date:	7-23-90		5-20-91		5-29-91		6-5-91		6-21-91		7-3-91		7-23-91	
		Conv	FBS	Conv	FBS	Conv	FBS	Conv	FBS	Conv	FBS	Conv	FBS	Conv	FBS
		ppb													
		2 feet													
Ves (1-4%)		-	-	ND	2.0	1.3	0.3	ND	ND	1.0	ND	0.2	-	-	-
Ves (6-12%)		ND	ND	ND	ND	0.2	1.3	ND	ND	ND	ND	ND	0.2	-	-
Webster (0-3%)		0.6	ND	ND	ND	ND	0.5	ND	1.0	ND	ND	-	3.4	ND	0.5
		4 feet													
Ves (1-4%)		ND	ND	15.0	ND	0.1	2.2	ND	ND	ND	ND	ND	ND	0.4	ND
Ves (6-12%)		1.0	ND	0.1	0.1	0.1	1.0	ND	ND	ND	ND	ND	-	-	ND
Webster (0-3%)		-	ND	0.6	6.8	0.5	0.3	ND	ND	ND	ND	ND	ND	ND	-

†ND = Not detected - Unable to get samples

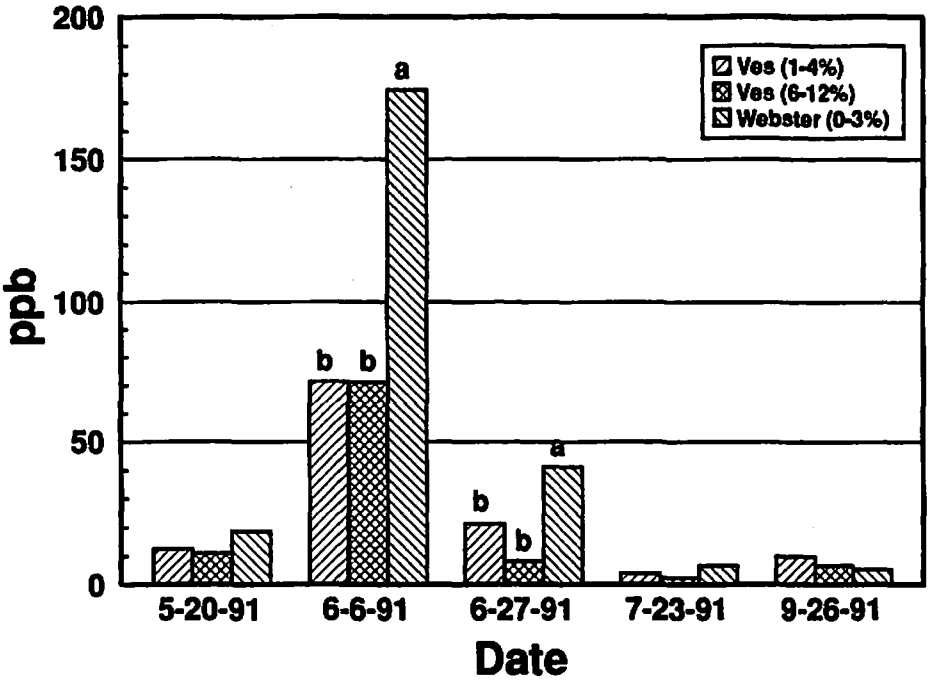

Figure 1. Soil alachlor concentration (0-6 in.)

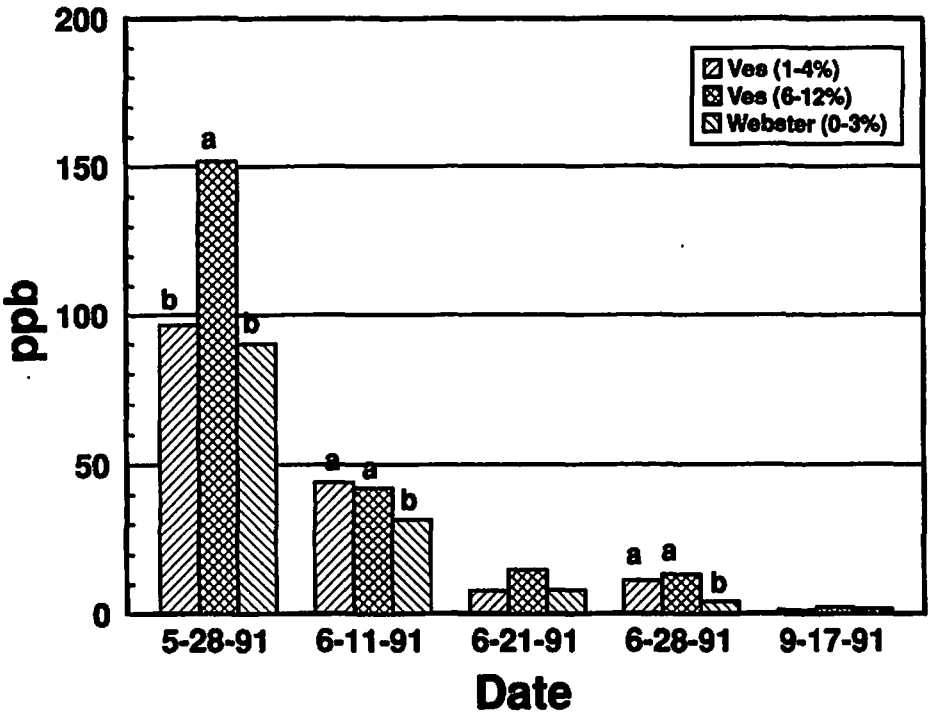

Figure 2. Alachlor concentration in runoff water

Means within a sampling date followed by the same letter are not significantly different at the p = 0.05 level. An absence of letters indicates no statistical difference

WEST CENTRAL EXPERIMENT STATION
WEATHER SUMMARY - 1991

		Precipitation			Temperature			Soil Temperature (10 cm depth)	
Month	Period	1991	100-yr. av.	Dev. from av.	1991	100-yr. av.	Dev. from av.	1991	10 yr. av.
January	1-31	0.36	0.68	-0.32	7.9	8.0	- 0.1	19.1	20.7
February	1-28	0.86	0.67	+0.19	21.9	12.8	+ 9.1	28.9	23.9
March	1-31	1.79	1.13	+0.66	29.9	26.7	+ 3.2	32.8	29.2
April	1-10	0.09	0.57	-0.48	53.3	38.0	+15.3	36.1	
	11-20	1.85	0.64	+1.21	39.4	44.4	- 5.0	40.7	
	21-30	1.78	1.05	+0.73	49.0	48.3	+ 0.7	51.6	
Total or av.		3.72	2.26	+1.46	46.6	43.6	+ 3.0	42.8	41.4
May	1-10	0.94	0.77	+0.17	43.3	52.0	- 8.7	47.0	
	11-20	0.56	0.95	-0.39	66.7	55.8	+10.9	68.7	
	21-31	1.99	1.25	+0.74	70.2	60.0	-10.2	73.4	
Total or av.		3.49	2.97	+0.52	60.4	56.1	+ 4.3	63.2	57.1
June	1-10	2.31	1.29	+1.02	68.4	63.0	+ 5.4	73.2	
	11-20	0.99	1.30	-0.31	71.5	66.3	+ 5.2	77.7	
	21-30	2.28	1.37	+0.91	69.3	68.1	+ 1.2	73.6	
Total or av.		5.58	3.96	+1.62	69.8	65.8	+ 4.0	74.8	69.3
July	1-10	1.70	1.44	+0.26	67.7	70.1	- 2.4	74.1	
	11-20	2.98	1.06	+1.92	74.9	71.4	+ 3.5	80.8	
	21-31	1.60	1.01	+0.59	67.3	71.4	- 4.1	74.2	
Total or av.		6.28	3.51	+2.77	69.9	70.9	- 1.0	76.3	76.7
August	1-10	1.62	1.04	+0.58	66.9	70.4	- 3.5	73.7	
	11-20	0.38	0.93	-0.55	68.6	69.0	- 0.4	79.0	
	21-31	0.76	1.04	-0.28	75.2	66.9	+ 8.3	80.9	
Total or av.		2.76	3.01	-0.25	70.4	68.7	+ 1.7	78.0	73.9
September	1-30	2.88	2.20	+0.68	57.7	59.0	- 1.3	66.2	61.5
October	1-31	0.74	1.74	-1.00	43.2	47.2	- 4.0	52.5	47.8
November	1-30	0.89	0.97	-0.08	22.6	29.7	- 7.1	32.5	33.6
December	1-31	0.35	0.61	-0.07	17.9	15.2	+ 2.7	29.4	23.4
April-Aug. Growing Season		21.83	15.71	+6.12	63.5	61.0	+ 2.5	67.6	63.8
January-December Annual		29.96	23.78	+6.18	43.3	42.0	+ 1.3	50.2	46.7

CONTINUOUS CORN SILAGE[1]

MORRIS, 1991

S.D. Evans[2]

ABSTRACT: This long-term study addresses the effects of removal of continuous corn silage and corn grain on soil properties and yield. In 1991 there were significant effects of silage removal vs. grain removal only and of fertilizer level. However, 26-year averages show no yield differences due to the removal of silage versus grain. A significant difference in yield exists between the long-term high and low fertilizer rates.

OBJECTIVE

This is the 26th year of a continuing study initiated in 1965 on a McIntosh silt loam soil. The study was initiated to determine the effects of removal of continuous corn silage and fertilizer rate on soil properties and yield. Half the plots receive a fertilizer rate of 74+48+48 ($N+P_2O_5+K_2O$) lbs./acre and the other half a rate of 148+96+96, fall applied. Silage and shelled corn yield samples were collected.

EXPERIMENTAL PROCEDURE

The experiment is set up as a latin square with 4 treatments: (1) silage, low fertility (2) silage, high fertility (3) grain, low fertility (4) grain, high fertility. The 1990 corn stalks were chopped and fall fertilizer was spread on October 9, 1990. The experimental area was disked on October 10 and moldboard plowed on October 23, 1990. The study was field cultivated on May 8, 1991 for seedbed preparation. The study was then seeded to Pioneer 3751 corn at 27,512 seeds per acre on May 9, 1991. Lorsban 15G was applied in the row at seeding at 10 lbs/acre (1.5 lbs./acre a.i.). Lasso @ 3 lbs./acre a.i. + Bladex @ 2.2 lbs./acre a.i. were applied pre-emergence broadcast on May 9. The study was cultivated on June 3 and June 13, and date of tasseling and silking was recorded. Silage yields were chopped from 3-10 foot rows on September 5 and grain yields were calculated from 2-45 foot rows harvested with a plot combine on September 26, 1991. Yields were also taken, as in past years, on an adjacent unfertilized (check) area where only the grain is removed. Prior to fall fertilization and tillage soil samples were collected to an 8-inch depth in each plot and analyzed by the Minnesota Soil Testing Laboratory.

RESULTS AND DISCUSSION

Silage Yields: There were significant differences in silage yields in 1991 (Table 1) at the 10% level. There appears to be no interaction between fertilizer and biomass harvested in 1991. The difference between low fertility and high fertility averaged close to 1.30 tons/acre on both the silage and grain treatments. The grain treatments averaged 1.27 ton/acre more than those on which silage has been removed continuously. The 26-year average shows no effect of silage versus grain but does show significant differences between high and low fertility treatments.

Grain Yields: The 1991 grain yields (Table 2) show a significant difference in grain yield between the high and low fertility treatments of 26.7 bu./acre. The long-term 26-year average also shows a significant grain yield advantage for high fertility over low fertility of 5.0 bu./acre.

Soil Analysis: The results of the soil analyses are given in Table 3. The P soil test differs significantly between low fertility and high fertility, but the small difference between grain and silage was not significant even though both low and high fertility treatments show about 3 ppm less available P where silage has been removed compared to only grain removal. The K soil tests show effects of both fertility treatment and biomass removal. The greatest effect on K soil test was the removal of the complete above ground biomass compared to removing only the grain. These results point out the need to apply extra fertilizer on those fields which are used routinely for corn silage production.

This study will be continued in 1992.

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[1] Funding provided by the West Cent. Expt. Sta., Univ. of Minnesota.

[2] Professor, West Cent. Expt. Sta., Univ. of Minnesota.

Table 1. Effect of removal of continuous silage or grain on silage yields.

Treatment	1991 Yield	1966-1991 Yield
	dry matter, tons/acre	
Silage, low fertility	6.42	5.55
Silage, high fertility	7.75	6.05
Grain, low fertility	7.72	5.62
Grain, high fertility	8.99	5.96
Signif. Levels (%)		
Treatment	93	>99
Year	--	>99
Treatment x Year	--	>99
LSD, treatment (.05)	NS	0.17
LSD, treatment (.10)	1.25	0.15

Table 2. Effect of fertilizer level on grain and silage yields.

Treatment	1991 Yield	1966-1991 Yield
	Bu/ac @ 15.5% M.	
Grain, low fertility	150.9	88.9
Grain, high fertility	177.6	93.9
Signif. Levels (%)		
Treatment	96	>99
Year	--	>99
Treatment x Year	--	>99
LSD, Treatment (.05)	25.3	2.9
Grain, check (Bu/Ac)	99.7	48.7
Silage, check (D.M. Tons/Ac)	4.32	3.54

Table 3. Effect of removal of continuous silage or grain on P and K Soil Tests after 26 years.

Treatment	pH	P	K
		ppm	
Silage, Low fertility	8.2	13.5	119
Silage, High fertility	8.2	33.3	139
Grain, Low fertility	8.1	16.5	158
Grain, High fertility	8.1	36.5	199
Signif. Level (%)	NS	>99	>99
BLSD (.05)	--	9.2	15
CV (%)	--	21.5	5.8

EFFECT OF TILLAGE AND SUBSOILING ON SOIL WATER RECHARGE AND CORN YIELDS[1]

Morris, 1991

S.D. Evans, M.J. Lindstrom, J.F. Moncrief, W.B. Voorhees, and G.A. Nelson[2]

Abstract: Many producers use subsoilers periodically to alleviate expected compaction due to traffic from tillage, planting, and harvesting equipment. In the fall of 1988 a study was initiated at the West Central Experiment Station to study the effects of a one-time subsoiling and its interaction with various primary tillage systems on subsequent soil compaction, soil water recharge, corn growth, and yield. This study was carried out on a site that had been farmed many years by normal 6-row equipment and on which serious compaction problems had not been observed. Results from the third year of a 3-year study, show subsoiling and subsoiling interactions with tillage had no significant effect on grain yield and other agronomic characteristics in 4 different primary tillage systems. Effects of subsoiling on soil bulk density 3 years after treatment were very small. It appeared that tillage and wheel traffic had repacked the soil to the extent that yield benefits did not occur from subsoiling even though small decreases in bulk density were observed in some soil depth increments. Subsoiling effects on the soil volumetric moisture content were not significant in 1991. Wheel traffic areas continued to have higher soil moisture content than non-wheel traffic areas.

OBJECTIVES

A 3-year study was initiated at the West Central Experiment Station to study the effects of (one time) subsoiling on subsequent crop growth, soil compaction, and soil moisture in 4 primary tillage systems (fall moldboard plow, fall chisel plow, spring disk, and no-till). The experiment was established on a Hamerly clay loam (Aeric Calciaquoll) and Aastad clay loam (Pachic Udic Haploboroll) complex and was cropped to continuous corn. This report will discuss the 3rd year (1991) results of the 3-year study.

EXPERIMENTAL PROCEDURES

Tillage, Planting, and Harvest: The experimental plot area was established the fall of 1988. The entire plot area was fertilized with 150 lbs. P_2O_5/acre and 10 lbs.zinc/acre broadcast on October 13, 1988. Four main plot treatments were then established in the experimental plot area with each treatment split into subsoiled and not subsoiled subtreatments. A split plot design with 4 replications was used with plots 30 feet wide by 100 feet long. The 1988 crop was corn grain harvested as silage and the 1989 and 1990 crops (1st and 2nd year of the study) were corn harvested with a combine. The plot area was planted with a 6-row planter. The treatments are moldboard, subsoiled (MSS), moldboard, no subsoiling (MNS), chisel, subsoiled (CSS), chisel, no subsoiling (CNS), no-till, subsoiled (NSS), no-till, no subsoiling (NNS), spring disk, subsoiled (DSS), and spring disk, no subsoiling (DNS). One-half of each main plot was subsoiled on October 14, 1988. A 5-tooth subsoiler with a 30-inch tooth spacing, operating 16 inches (41 cm) deep, was used on the MSS, CSS, and NSS treatments. A paraplow, operating 13 inches (33 cm) deep, was used on the DSS treatment. The MSS, CSS, NSS, and DSS plots were not tilled with any other implement in the fall of 1988. The non-subsoiled treatments were treated as follows: (1) The MNS treatment was plowed using an onland hitch with 6 18-inch bottoms and the CNS treatment was chiseled with a mounted 10-foot chisel plow, (2) The MSS and CSS treatments were not moldboard plowed or chisel plowed before or after the subsoiling operation in the fall of 1988, and (3) The DNS and NNS treatments were not tilled in the fall of 1988.

In the fall of 1989 and 1990 the plots were treated as follows: (1) The MSS and MNS treatments were plowed using an onland hitch with 6 18-inch bottoms, (2) The CSS and CNS treatments were chiseled with a 15-foot pull type chisel plow, and (3) The NSS, NNS, DSS, and DNS treatments were not tilled.

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[1] Funds provided by West Cent. Expt. Sta., Univ. of Minnesota. Measurements taken by USDA-ARS, Morris, MN.

[2] S.D. Evans and G.A. Nelson are Professor and Junior Scientist respectively with the West Cent. Expt. Sta., Univ. of Minnesota, M.J. Lindstrom and W.B. Voorhees are Soil Scientists with the Agricultural Research Service, USDA, Morris, MN, and J.F. Moncrief is Associate Professor, Soil Science Dept., Univ. of Minnesota.

Crop residue measurements were taken on May 14, 1991. On May 15 the DSS and DNS treatments were disked one time, and the MSS, MNS, CSS, and CNS treatments were field cultivated one time, for seedbed preparation. All wheel traffic from tractors during the tillage operations were confined to the position to be used by the tractor pulling the corn planter. All subsequent wheel traffic was also confined to corn planter tractor wheel tracks. The NSS and NNS treatments were not tilled. The plots were seeded to Pioneer 3788 corn at @ 27,512 seeds/ac on May 15, 1991 with a 6-row planter. Lorsban 15G @ 10 lbs./acre (1.5 lbs./acre a.i.) was applied at seeding. No starter fertilizer was used. Lasso + Bladex (3 + 2.2 lbs./acre a.i.) was broadcast pre-emergence on May 15. Accent (0.66 oz./acre + Booster) was sprayed on NNS and NSS plots on June 10 to control escaped grasses. Crop residue measurements after planting were taken on May 22. Anhydrous ammonia was applied at 120 lbs. N/acre on June 13. Plots were cultivated on June 17. Plant population counts were taken on June 26. Tasseling and silking notes were recorded July 18-20. Plots were harvested for grain with a plot combine on September 30, 1991 and harvest weight and grain moisture were recorded. A grain sample was retained and bulk corn was harvested from all plots.

Soil Sampling: There was no soil sampling in the spring of 1991 for moisture and bulk density due to extremely wet soil conditions. After grain harvest in the fall of 1991 two soil cores in 0-6, 6-12, 12-18, and 18-24 inch depth increments were taken in wheel track and non-wheel track areas of each plot for bulk density and soil moisture determination. At the same time one soil core of 24-36 and 36-48 inch increments was taken in the wheel track and non-wheel track areas of each plot for soil moisture determination. The soil samples were weighed, dried at 105°C, and weighed back for bulk density and soil moisture determination. Sampling took place on October 2-3 and penetrometer readings were taken on October 3.

RESULTS AND DISCUSSION

Planting and Growing Conditions: Planting was delayed by wet soil conditions and growth was retarded at some times by wet soils. Growing conditions were excellent in 1991 with 21.83 inches of precipitation from April through August, 6.12 inches above average, with the months April through July with above average precipitation.

Residue Cover and Plant Measurements: Subsoiling (fall 1988) had no effect (Table 1) on 1991 crop residue cover, tasseling date, silking date, grain moisture, or grain yield. Tillage systems did significantly affect residue cover and date of tasseling. There were no significant subsoiling by tillage interactions.

Soil Bulk Density: An overall statistical analysis of soil bulk densities is given in Table 2. The main effects, subsoiling and tillage, had no significant effect on soil bulk density. The 1991 bulk density interaction of subsoiling by wheel traffic by depth (Table 3) showed greater bulk densities in the 0-6 and 6-12 inch soil increments of wheel-tracked areas than in non-wheel track areas. There were no significant differences in bulk density in the 12-18 and 18-24 inch depth increments. There also appeared to be a slight reduction in bulk density remaining due to subsoiling in the 6-12 inch depth increment, non-tracked area. This trend was been observed in fall soil measurements the past 2 years and was within the subsoiling depth of 16 inches for moldboard, chisel and no-till and 13 inches for disk. The same effect appeared only in 1991 in the 18-24 inch depth increment, non-tracked area, but this was below the subsoiling depth.

Soil Volumetric Moisture: A 3-way interaction of subsoiling by wheel traffic by depth (Tables 2 and 4) also occurred in soil volumetric moisture content, showing a larger content in wheel tracked than in non-tracked areas in the 0-6 inch depth increment, a very small difference in the 6-12 inch depth increment, and no differences at deeper depths. The volumetric water content difference between wheel tracked and non-wheel tracked areas was very small in the subsoiled plots, but was considerably larger in non-subsoiled plots (Tables 4 and 5). A tillage by depth interaction (Table 6) showed some variation in volumetric water content by depth, but the effects were small and no clear trends were apparent.

Soil Penetrometer Measurements: Penetrometer readings taken in the fall of 1991 after harvest are shown in Figure 1. Major differences observed were due to wheel traffic with tracked area having much higher penetrometer resistance than non-wheel track areas. In general, resistance increased with soil depth with no large differences between moldboard, chisel, and no-till. It appeared that resistance was highest in 35-50 cm depth increment in wheel tracked areas that had been subsoiled, except in the disk treatment. In the disk treatment this effect was not apparent and may have been due to a shallower subsoiling with the paraplow (33 cm). This effect did not appear in the fall of 1990. The penetrometer data has not been statistically analyzed.

SUMMARY

A one-time subsoiling of a soil that had been farmed with normal 6-row equipment had no effect on plant growth or yield over 3 cropping seasons following the subsoiling operation. Subsoiling had significant effects on soil bulk density and soil volumetric water content, but these effects decreased with time. The effects of normal wheel traffic following the subsoiling operation showed that the soil quickly returned to the same density and moisture condition as that of non-subsoiled areas. There were no large differences between 4 primary tillage systems that followed the subsoiling operation. Therefore, subsoiling areas that do not have serious compaction problems did not result in better yields or a better soil moisture availability.

Table 1. Summary of plant measurements due to tillage and subsoiling, 1991.

Treatment	5/14	5/22	Tassel Date from 7/1	Silk Date from 7/1	Grain Harvest Moisture	Grain Yield 15.5% M.
	- -% cover-				-- % --	-bu/ac-
Moldboard	14.5	14.8	18.0	19.1	19.7	150.3
Chisel	58.5	53.5	18.6	19.6	20.4	143.1
Spr. Disk	80.8	59.0	18.6	19.6	20.4	149.1
No-Till	81.0	80.3	19.0	20.0	19.9	140.9
Main plots:						
Signif. Level (%)	>99	>99	98	94	11	62
LSD (.05)	4.1	7.7	0.6	NS	NS	NS
C.V. (%)	3.2	6.5	1.3	1.6	4.4	5.4
Subsoiled	58.8	52.0	18.6	19.6	20.1	143.9
Not Subsoilded	58.6	51.8	18.6	19.6	20.1	147.8
Sub plots:						
Signif. Level (%)	15	16	--	43	--	81
Interaction:						
Signif. Level (%)	49	38	69	66	61	71

Table 2. Statistical analysis of bulk density and soil volumetric moisture content in subsoiler study, fall 1991.

Variable	Bulk Density	Soil Volumetric Moisture
Tillage (T)	.3362	.3146
using Rep * T as an error term		
Subsoiling (SS)	.4014	.6341
T * SS	.1646	.6819
using Rep * T * SS as an error term		
Wheel Traffic (Wt)	.0001	.0001
T * Wt	.7015	.3626
SS * Wt	.1842	.0090
T * SS * Wt	.4843	.8837
using Rep * T * SS * Wt as an error term		
Depth (D)	.0001	.0001
T * D	.4647	.0376
SS * D	.7817	.7857
Wt * D	.0001	.0001
T * SS * D	.2380	.3998
T * Wt * D	.5772	.2939
SS * Wt * D	.0219	.0441
T * SS * Wt * D	.5733	.5679
C.V. (%)	7.6	9.8

Table 3. Effect of subsoiling and wheel traffic on soil bulk density at several soil depths, fall 1991.

Trt.	0-6 inch increment			Trt.	12-18 inch increment		
	SS	NSS	Mean		SS	NSS	Mean
	- - - g/cm³ - - - -				- - - g/cm³ - - - -		
WT	1.34	1.34	1.34	WT	1.49	1.49	1.49
NWT	.96	.95	.96	NWT	1.49	1.49	1.49
Mean	1.15	1.15		Mean	1.49	1.49	
	6-12 inch increment				18-24 inch increment		
	SS	NSS	Mean		SS	NSS	Mean
	- - - g/cm³ - - - -				- - - g/cm³ - - - -		
WT	1.44	1.47	1.46	WT	1.55	1.56	1.56
NWT	1.37	1.41	1.39	NWT	1.51	1.55	1.53
Mean	1.41	1.44		Mean	1.53	1.56	

NWT = Non-wheel traffic zone
WT = Wheel traffic zone
SS = Subsoiled
NSS = Not subsoiled

Table 4. Effect of subsoiling and wheel traffic on volumetric soil moisture at several soil depths, fall 1991.

Trt.	0-6 inch increment			Trt.	12-18 inch increment		
	SS	NSS	Mean		SS	NSS	Mean
	- - - - % v/v - - - -				- - - - % v/v - - - -		
WT	42.0	41.4	41.7	WT	38.8	38.4	38.6
NWT	29.3	28.7	29.0	NWT	38.8	38.6	38.7
Mean	35.7	35.0		Mean	38.8	38.5	
	6-12 inch increment				18-24 inch increment		
	SS	NSS	Mean		SS	NSS	Mean
WT	45.1	44.6	44.9	WT	37.5	37.4	37.4
NWt	42.6	42.6	42.6	NWT	40.1	37.8	38.9
Mean	43.8	43.6		Mean	38.8	37.7	

Table 5. Effect of subsoiling and wheel traffic on volumetric water content, fall 1991.

	Subsoiling		
Trt.	SS	NSS	Mean
	- - - - - - - - - - % v/v - - - - - - - - - - - -		
NWT	38.7	37.4	38.1
WT	39.7	40.5	40.1
Mean	39.2	39.0	

Table 6. Effect of tillage on volumetric soil moisture at several soil depths, fall 1991.

Depth Increment	Moldboard	Chisel	Spr. Disk	No-Till	Mean
- in. - -	- - - - - - - - - - - - % v/v - - - - - - - - - - - - - - - -				
0-6	32.2	35.6	36.1	37.5	35.3
6-12	42.5	43.6	45.2	43.7	43.7
12-18	37.8	38.6	40.2	37.9	38.6
18-24	36.4	37.1	39.1	40.2	38.2
24-36	36.4	41.5	42.5	39.3	39.9
36-48	37.8	38.9	40.9	37.2	38.7
Mean	37.2	39.2	40.7	39.3	

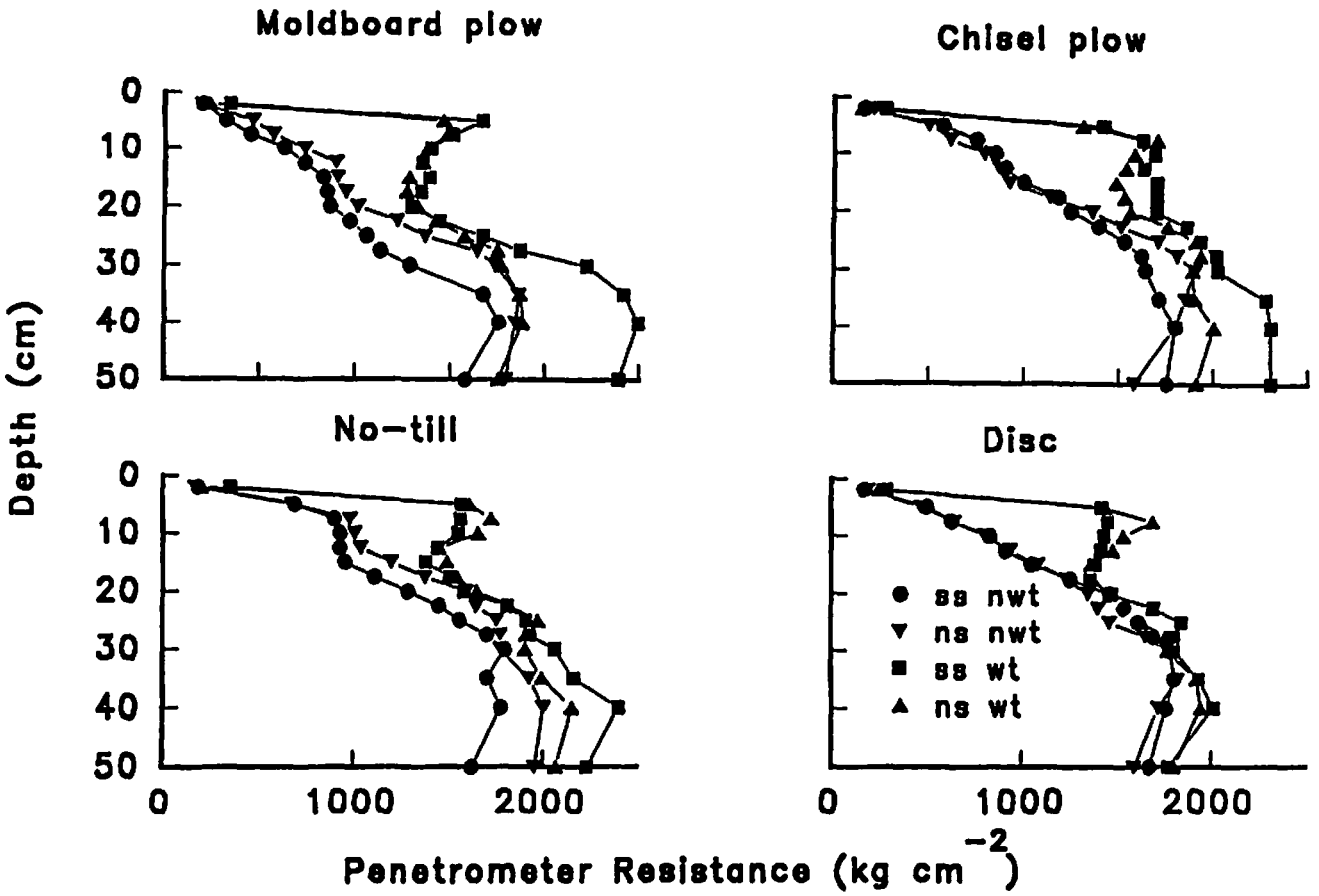

Figure 1. Penetrometer resistance readings for the four tillage systems in the spring and fall for subsoiled (SS), non-subsoiled (NS), wheel track (WT), and non-wheel tracked (NWT) interrows during the 1991 cropping season.

RESIDUAL EFFECT OF HEAVY APPLICATIONS OF ANIMAL MANURES ON CORN GROWTH, YIELD, AND SOIL PROPERTIES[1]

Morris, 1991

S.D. Evans, P.R. Goodrich, G.L. Malzer, R.C. Munter[2]

ABSTRACT: This study completed its 21st year in 1991. Nitrate movement and yield responses from two initial annual applications of manure have been measured. Results over 21 years show 1986 as the first year the fertilized check yielded significantly more than the manure treatments. This occurred again in 1989, 1990, and 1991. In 1987 the fertilized check yielded more than the manure treatments, but the difference was not significant. In 1988, a drouth year, all yields averaged about 50 bushels/acre. Soil samples, measuring NO_3-N, were taken to a depth of 4 feet in the fall of 1991. The fertilizer treatment had significantly more NO_3-N in the root zone than the manure treatments. Mineralization of organic N from manure applications has evidently slowed to a point were less N is being mineralized than is being supplied by the fertilized treatment.

This is the 21st year of a study initiated to measure the residual effects of 1970 and 1971 applications of two types of manure on corn yields and soil nitrogen levels. The total manure applications were as follows: Solid Beef Manure-200 tons/acre (wet weight), Liquid Beef Manure-136,000 gal./acre, and Liquid Hog Manure-136,000 gal./acre. The fertilized plots received the same amount of fertilizer annually (120+50+50 of $N+P_2O_5+K_2O$ in lbs./acre, respectively).

EXPERIMENTAL PROCEDURE

The fertilized plots received 120+50+50 ($N+P_2O_5+K_2O$) lbs./acre on October 9, 1990, and the entire experimental area was moldboard plowed October 15, 1990. The experimental area was worked with a field cultivator 2 times on May 8, 1991 for seedbed preparation. The study was planted to Pioneer 3788 corn on May 9, 1991, at 27,512 seeds/acre. Lorsban 15G was applied at 10 lbs./acre (1.5 lbs./acre a.i.) in the row at seeding. Lasso and Bladex (3.0 lbs./acre a.i. + 2.2 lbs./acre a.i. respectively) were tank mixed and applied broadcast pre-emergence on May 9. Plots were cultivated on June 7. Corn heights were measured and whole plant samples were taken on June 17. Tasseling and silking dates were recorded and ear leaf samples were taken at mid-silk on July 17. Two 10-foot rows were harvested for silage yields on September 5, 1991. Two 110-foot rows were harvested with a plot combine on September 19, 1991 for grain yields. Grain yield and grain moisture were recorded at harvest. On September 22 plots were soil sampled to a depth of 4 feet in 1-foot increments with three subsamples taken per plot. These cores were combined, subsampled, and submitted for nitrogen analysis. On September 24 plots were sampled to a depth of 16 inches in 0-8, 8-12, and 12-16 inch increments for phosphorus analysis. Ten subsamples of each depth increment were composited per plot.

RESULTS AND DISCUSSION

Early Plant Height and Dry Weight: The fertilizer treatment and all manure treatments had significantly taller and heavier plants than the check treatment (Table 1), with the exception of liquid hog manure which was statistically equal to the check treatment in early plant dry weight.

Grain Yield and Moisture: The grain yield (Table 1) on the fertilizer treatment was significantly higher than on all other treatments. Solid beef and liquid beef yielded more than the liquid hog and check treatments. The fertilizer treatment has now yielded more than the manure treatments the last 6 years with the effects being significant in 1986, 1989, 1990, and 1991. The effect of the 1970-71 manure applications on grain yield has decreased to the extent that the fertilizer treatment now has higher yields than the manure treatments and the liquid hog manure treatment grain yield is the same as the check treatment.

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[1] Funding provided by the West Cent. Expt. Sta. Soil analysis provided by the Center for the Impacts of Agricultural Practices on Water Quality.

[2] Professor, West Cent. Expt. Sata., Prof., Dept. of Agr. Eng., Assoc. Prof., Dept. of Soil Science, and Asst. Prof., Dept. of Soil Science, Univ. of Minnesota

Silage Yields: Solid beef and liquid beef silage yields (Table 1) are intermediate between the fertilized and liquid hog/check treatments yields, but are substantially lower than the fertilizer treatment yields. There was no significant difference in silage yield between the check and liquid hog treatments.

Soil Nitrate-N and Ammonium-N Analysis: The results of nitrate and ammonium analyses are given in Table 2. Nitrate-N levels generally increased with depth while NH_4-N levels decreased with depth. Nitrate-N levels found in the fertilizer treatment were significantly greater than NO_3-N levels found in the manure treatments. Ammonium-N levels in all treatments were essentially the same. Low NO_3-N levels in the manure treatments, similar to those found in the check treatment, indicate mineralization of nitrogen from added organic material (manure) has decreased substantially, but not completely, as indicated by taller and heavier plants in the manure treatments than in the check treatment.

Table 1. Summary of plant measurements - 1991.

Treatment	Early Plant Height	Early Plant (10) Dry Weight	Grain: Moisture at Harvest	Grain: Yield at 15.5% Moisture	Grain: Dry Matter at Harvest	Silage: Silage Yield (D.M)	Silage: Ear Wt. as a % of Silage
	- cm -	- grams -	--%--	-bu/ac-	- % -	-lb/ac-	- - % - -
Check	23.9	49.3	33.4	77.0	50.4	8,037	52.0
Fertilized	32.6	138.7	29.8	162.6	50.8	14,448	59.1
Solid Beef Manure	31.6	116.0	30.4	107.2	49.8	10,741	53.1
Liquid Beef Manure	32.4	154.3	30.0	114.9	49.2	11,566	55.3
Liquid Hog Manure	28.5	87.0	31.7	86.8	49.8	9,216	53.1
Signif. Level (%)	>99	>99	>99	>99	26	99>	99
LSD (.05)	2.3	43.2	1.4	14.5	NS	1,773	3.9
CV (%)	4.2	21.0	2.5	7.5	3.0	9.0	3.6

Table 2. Nitrate and ammonium nitrogen concentration of a Tara soil 21 years (Fall, 1991) after application of high rates of manure.

Depth Incr.	CK	Fert	Solid Beef Manure	Liquid Beef Manure	Liquid Hog Manure	Mean	CK	Fert	Solid Beef Manure	Liquid Beef Manure	Liquid Hog Manure	Mean
ft.	- - - - - - - ppm NO_3 - N - - - - - - - - -						- - - - - - - ppm NH_4 - N - - - - - - - - -					
0-1	4.1	4.9	4.9	4.7	3.7	4.4b	4.5	6.6	3.1	7.5	6.9	5.5a
1-2	0.8	1.2	0.8	0.9	0.6	0.9c	2.2	2.6	1.5	3.8	2.6	2.5b
2-3	1.9	20.5	1.5	1.5	1.1	4.5b	1.6	1.4	1.4	1.8	1.6	1.6c
3-4	4.3	33.0	3.2	5.8	2.9	8.4a	1.7	1.4	1.3	1.4	1.6	1.4c
Mean	2.8b	14.9a	2.6b	3.2b	2.1b		2.5	3.0	1.8	3.6	3.2	

Signif Level (%):

Replication	- 72	Replication	- 55
Treatment	- 98, LSD (.05) = 8.1	Treatment	- 88
Depth	- >99, LSD (.05) = 3.3	Depth	- >99, LSD (.05) = 0.4
Trt x Depth	- >99	Trt x Depth	- >99

EFFECT OF NITROGEN APPLICATION RATE ON GRAIN YIELD IN CORN AND SOIL WATER NITROGEN IN MORRIS, MN[1]

A. Bhattacharjee, S.D. Evans, J.F. Moncrief, S.C. Gupta, B.J. Johnson, and G.N. Nelson[2]

Abstract

Experiment is being conducted at Morris, MN to study the effect of rate of application of nitrogenous fertilizer on the concentration of nitrate nitrogen in soil water in reduced tillage system. Results of 1991 shows that there was increase in the grain nitrogen uptake with the increase rate of nitrogen application. The grain yield and the total dry matter also increased with the increase in the nitrogen rate. However all the treatments except the control treatment (no nitrogen) were on par with each other with respect to grain yield and total dry matter. The treatment with 100 lbs/A nitrogen showed the maximum concentration of soil water nitrate over the other treatments. There was an increase in the mean soil water nitrate nitrogen from initial stage to the harvest stage of the crop. The increase in the mean nitrate nitrogen concentration in the soil water was 12 ppm with the first increament of the nitrogen fertilizer and an additional 17 ppm with second fertilizer increament.

Introduction

With the advent of the high yielding varieties of the crops in 1960 's, there was an increased application of chemical fertilizers. A major component of many fertilizers is nitrogen,a very mobile nutrient, which can find its way to the groundwater and streams by leaching and with the surface runoff water,respectively. With the increased concern for wind and water erosion, interest has also increased in reduced tillage system and their effect on nitrogen fertilizer movement in the soil. A Minnesota survey has found nitrate in 43% of the 500 wells tested in 51 counties. Therefore it has become increasingly necessary to know the effect of rate of application of nitrogenous fertilizer on the concentration of nitrate in the soil water in reduced tillage systems. With these in mind the present study is being conducted at the West Central Experiment Station, University of Minnesota, Morris,MN.

Methods and Materials

The experimental design is a randomized complete block design with rates of nitrogen application as treatments (0, 50, 100, 150 lbs/A)and corn as the test crop. The study is being conducted on a LaPrairie loam. This soil series is formed in alluvium underlain by stratified sand and gravel. The surface layer in a typical profile is black loam about 24 inches thick. The subsoil is very dark grayish-brown to dark grayish-brown,friable loam in the upper part and dark-brown to olive-brown loam the lower part. Water moves through these soils at a moderate rate. Prior to establishing the study, test holes were made in the potential plot area. The experiment was established where the depth to fine sand varied from 40 - 60 inches. These soil samples were saved and will be analyzed for NO_3-N. The plot size are 65 feet in length and 30 feet in width (12-30 inches row). The area was in corn in 1990 and was moldboard plowed that fall. In the spring of 1991 the area was field cultivated and urea fertilizer was broadcast, the area was field cultivated again, and planted to Pioneer 3788 @ 27,800 seeds per acre on 05/10/91. On 06/12/91 two suction samplers were placed in each plot. The samplers were installed in the corn row and the bottom of the sampler was placed at the loam-fine sand interface. Therefore, the sampling depth varied from 40 to 60 inches, depending on the depth to the fine sand layer. Samples were taken on a 7- day interval throughout the growing season. The soil water collected was analyzed for total, nitrate, and ammoniacal nitrogen. The corn was cultivated twice during the season; on 06/03/91 and 06/13/91. On 09/19/91 four rows were harvested with a 2-row Almaco plot combine. Yields and soil moisture were determined electronically and recorded. A grain sample was saved for nitrogen analysis. Shortly afterwards on 09/25/91, one row was harvested with a forage chopper to assess total dry matter and total nitrogen uptake. The remainder of the corn was harvested and corn stalks were chopped. The area will be maintained in the future in a ridge-till system.

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[2] A. Bhattachrajee, J.F. Moncrief, S.C. Gupta, B.J. Johnson are graduate Student, Associate Professor, Professor and Assistant Scientist respectively in the Soil Science Department at the University of Minnesota, St. Paul, MN, 55108. S. D. Evans and G.A. Nelson are Professor and Assistant Scientist,West Central Experiment Station, University of Minnesota, Morris, MN.

Results and Discussion

Grain and total nitrogen content. The grain and the total N content are given in the table 2. As evident from the table there were significant differences between the treatments. The highest grain nitrogen was observed in the treatment with 150 lbs/ac nitrogen (1.43%) which was followed by the treatment with 100 lbs/ac of nitrogen(1.30 %). Though the grain nitrogen percent was higher in the treatment with 50 lbs/A nitrogen, it was on par with the control treatment (No nitrogen i.e. 0 lbs/A).

Grain and total nitrogen uptake. The grain and the total N uptake are shown in the table 3 and Fig. 1. The maximum nitrogen uptake in grain was observed in the treatment with 150 lbs/A nitrogen (119.9 lbs/A). The treatments with 50 and 100 lbs/A of nitrogen was on par with each other. The minimum grain nitrogen percent was observed in the control treatment as expected. It is interesting to note that the treatment with 50 lbs/A nitrogen was on par with the control treatment (0 lbs/A).
There were no significant difference between 50, 100, and 150 lbs/A nitrogen treatments for total nitrogen uptake. However the maximum total nitrogen uptake was obtained in the treatment with 150 lbs/A nitrogen (163.46 lbs/A).

Grain Yield and total dry matter. The yield of both grain and total dry matter is shown in the table 4 and Fig. 2. There were no significant differences in grain yield and total dry matter of corn between the nitrogen application rates. However with the increase in the application rate of nitrogen there was a corresponding increase in grain yield as well as in total dry matter yield. Grain yield increased by 8 bu/A (5 % by wt) in 150 lbs/A of nitrogen when compared to 50 lbs/A of nitrogen.

Soil water nitrogen . The mean values of soil water nitrogen over the sampling dates are given in the table 5 and Fig. 3. Nitrate was the primary form of nitrogen observed in the soil water. There was an increase in the mean soil water nitrate concentration from initial stage of the crop (46.2 ppm) to harvest stage (64.4 ppm). Though there was variation in the soil water nitrate within the growing season, it could not be attributed directly to the effect of precipitation that occurred within the growing season (Fig. 4).

The mean values of total, nitrate and ammoniacal nitrogen in soil water over the different treatments and the sampling dates are shown in the table 6 and Fig. 5. It is evident from the figure that the treatment with

100 lbs/A of nitrogen showed higher concentration of nitrate nitrogen concentration in the soil water over the other treatments. The increase in mean nitrate nitrogen was about 12 ppm with the first increament of nitrogen fertilizer and an additional 17 ppm with the second fertilizer increament. However it is interesting to note that the treatment with 150 lbs/A of nitrogen showed lower concentration of nitrate nitrogen than the check treatment (No nitrogen) over the entire period of the growing season. This could be attributed to some extent to the increased uptake of nitrogen shown in the grain nitrogen and total nitrogen uptake (Fig. 6). It could be also attributed to variation in residual nitrate existing in the soil from the 1990 crop.

Table 1.Cultural practices at Morris, MN in 1991.

Tillage
Fall Moldboard and
Field cultivated twice before planting

Cropping Pattern
Corn - Soybean rotation from 1991

1991 crop
Corn - Pioneer 3788

Planting and harvest dates

Corn - was planted with a two row Hiniker Series 1 EconoTill planter with 30 inches row spacing.

	Planting			
Crop	Date	Planter	Rate	Harvest date
Corn	May 10, 1991	Row	27,800 seeds/ac	September 25, 1991

Weed control

3.0 qt/A (3.0 lb/A) Lasso + 2.2 qts (4.0 l/A) Bladex 90 DF was broadcasted on May 10, 1991.
Furadan (9.8 lbs/A) with planter.

Table 2 Effect of nitrogen application rate on grain nitrogen percent and total nitrogen percent of corn at Morris ,MN, 1991

Nitrogen rate (lbs/A)	Grain N (%)	Total N (%)
0	1.20 a	0.87 a
50	1.22 a	1.01 b
100	1.30 b	0.82 b
150	1.43 c	0.89 ab

The p value for nitrogen rate on grain nitrogen percent and total nitrogen percent are 0.0001 and 0.101 respectively. The means within the same column with the same letters are not significantly different(α= 0.10).

Table 3 Effect of nitrogen application rate on grain nitrogen uptake and total nitrogen uptake of corn at Morris, MN, 1991

Nitrogen rate (lbs/A)	Grain N uptake (lbs/A)	Total N uptake (lbs/A)
0	89.1 a	125.3 a
50	97.9 ab	152.4 b
100	108.4 b	150.7 b
150	119.9 c	163.4 cb

The p value for nitrogen rate on grain nitrogen uptake and total nitrogen uptake are 0.0004 and 0.010 respectively. The means within the same column with the same letters are not significantly different(α= 0.10).

Table 4 Effect of nitrogen application rate on grain and total dry matter of corn at Morris ,MN, 1991

Nitrogen rate (lbs/A)	Grain Yield (bu/A)	Total dry matter (tons/A)
0	156.6 a	5.8 a
50	170.2 b	6.7 b
100	176.5 b	6.7 b
150	178.4 b	6.6 b

The p value for nitrogen rate on grain yield and total dry matter are 0.047 and 0.029 respectively. The means within the same column with the same letters are not significantly different(α= 0.10).

FIG.1 GRAIN , STOVER AND TOTAL NITROGEN UPTAKE AT DIFFERENT NITROGEN RATES ON CORN AT MORRIS,MN,1991

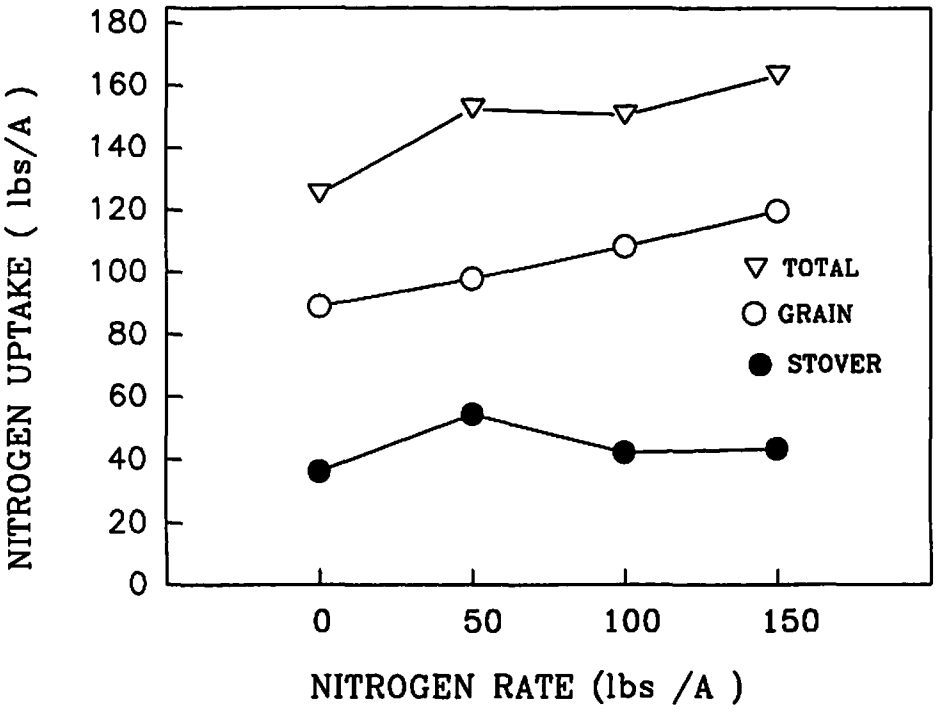


FIG. 2 GRAIN YIELD AND TOTAL DRY MATTER OF CORN AT DIFFERENT NITROGEN APPLICATION RATE AT MORRIS MN.

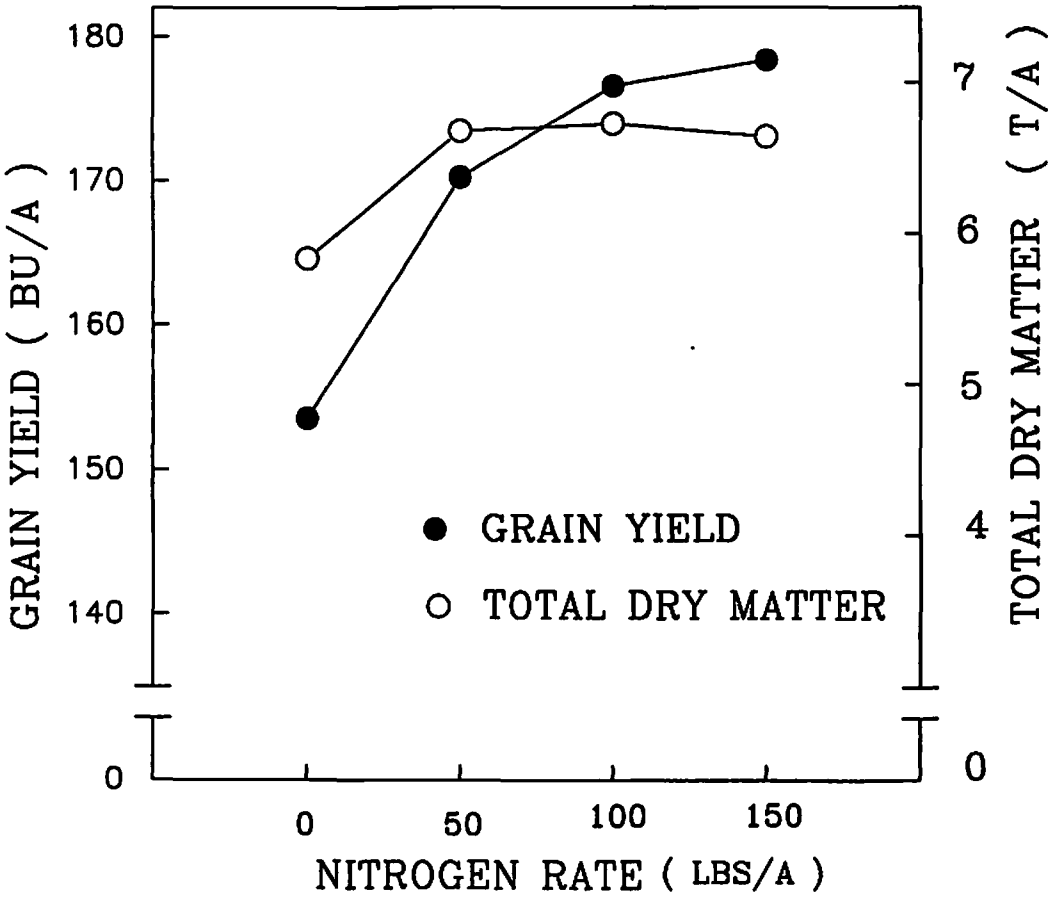


Table 5. Distribution of total, nitrate and ammoniacal nitrogen concentration[1] in soil water on different dates of sampling in Morris, MN, 1991.

Date	Total N (ppm)	Nitrate N (ppm)	Ammoniacal N (ppm)
06/18/91	46.5	46.2	0.27
07/03/91	52.2	52.1	0.16
07/09/91	62.8	62.5	0.03
07/16/91	57.8	57.7	0.11
07/23/91	59.9	59.8	0.02
07/30/91	70.3	70.2	0.01
08/06/91	69.9	68.8	0.05
08/13/91	59.9	59.8	0.05
08/20/91	69.8	69.7	0.03
08/26/91	72.8	72.7	0.05
09/04/91	66.4	66.3	0.04
09/20/91	64.5	64.4	0.13

1. Mean values over different treatments.

Table 6. Effect of nitrogen application rate on total, nitrate and ammoniacal N[1] in soil water over different sampling dates in Morris, MN, 1991.

Dates sampled	Total N(ppm) lbs/ac				Nitrate N (ppm) lbs/ac				Amm.-N (ppm) lbs/ac			
	0	50	100	150	0	50	100	150	0	50	100	150
06/18	43.3	50.9	57.3	35.4	43.1	50.8	56.9	35.2	0.18	0.2	0.49	0.22
07/03	51.3	52.9	72.2	35.5	51.2	52.6	71.9	35.4	0.09	0.34	0.15	0.09
07/09	61.1	72.5	74.1	44.6	61.0	72.4	74.0	43.6	0.02	0.03	0.04	0.05
07/16	58.5	57.6	63.8	48.5	58.4	57.3	63.7	48.4	0.04	0.31	0.05	0.03
07/23	54.4	76.1	64.7	48.8	54.3	76.0	64.6	48.7	0.01	0.04	0.01	0.04
07/30	64.9	91.4	77.4	50.2	64.8	91.4	77.4	50.1	0.01	0.00	0.00	0.02
08/06	70.5	68.4	87.1	29.5	70.4	68.3	87.0	29.4	0.05	0.06	0.02	0.09
08/13	60.6	64.7	68.1	46.3	60.5	64.6	68.0	46.2	0.04	0.05	0.04	0.05
08/20	68.4	83.0	90.4	46.9	68.3	82.9	90.3	46.8	0.03	0.02	0.03	0.03
08/26	61.4	83.2	89.5	54.6	61.4	83.1	89.4	54.6	0.00	0.002	0.01	0.00
09/04	59.8	66.6	90.1	46.6	59.7	66.5	90.0	46.5	0.04	0.02	0.02	0.09
09/20	47.7	84.7	87.2	42.9	47.6	84.5	87.0	42.8	0.12	0.14	0.14	0.13

1. Mean values over different replications.

FIG. 3 SOIL WATER-N DISTRIBUTION OVER TIME IN CORN AT MORRIS ,MN.

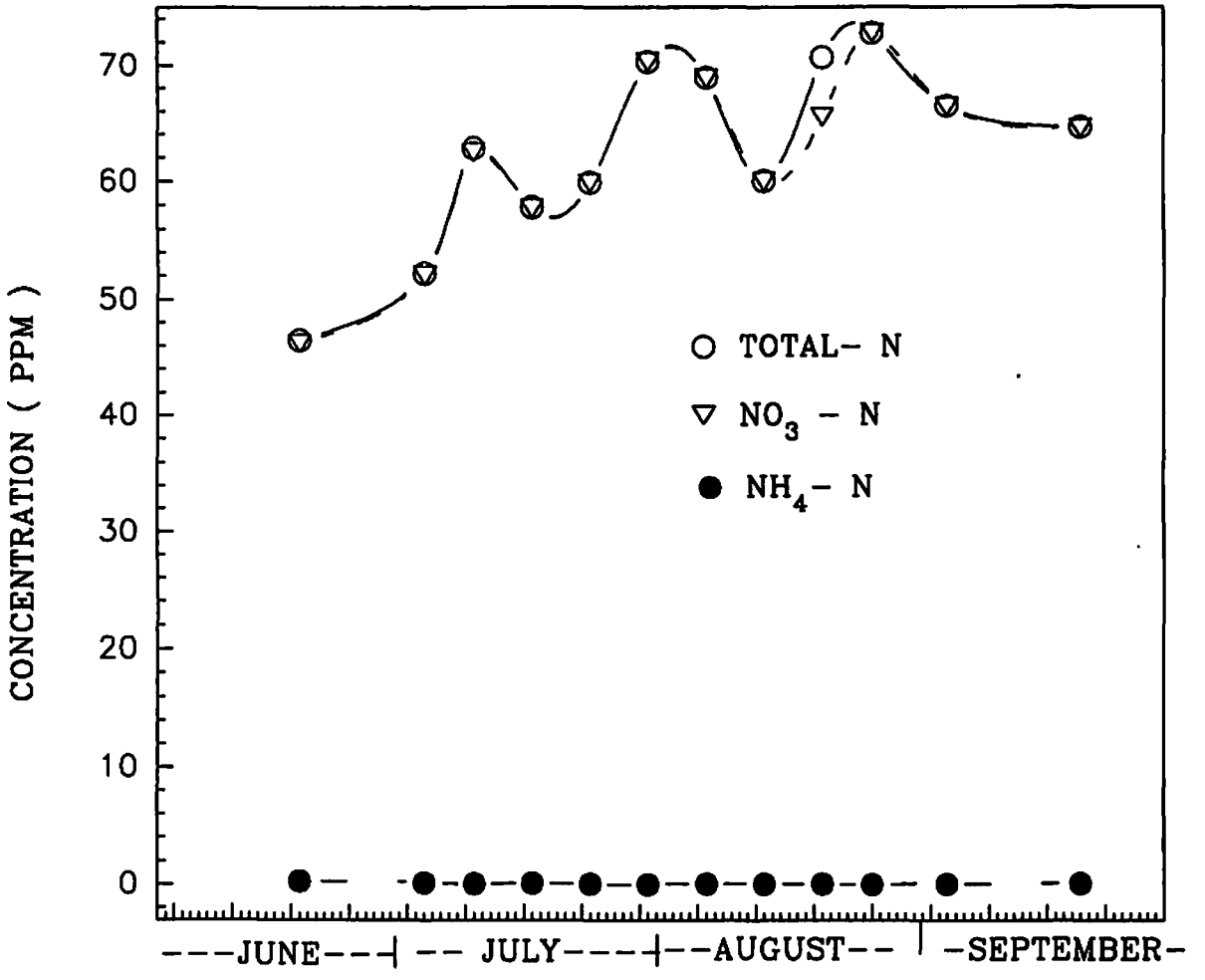


FIG. 4 DISTRIBUTION OF PRECIPITATION AND SOIL WATER-N CONCENTRATION IN CORN AT MORRIS, MN.
1991

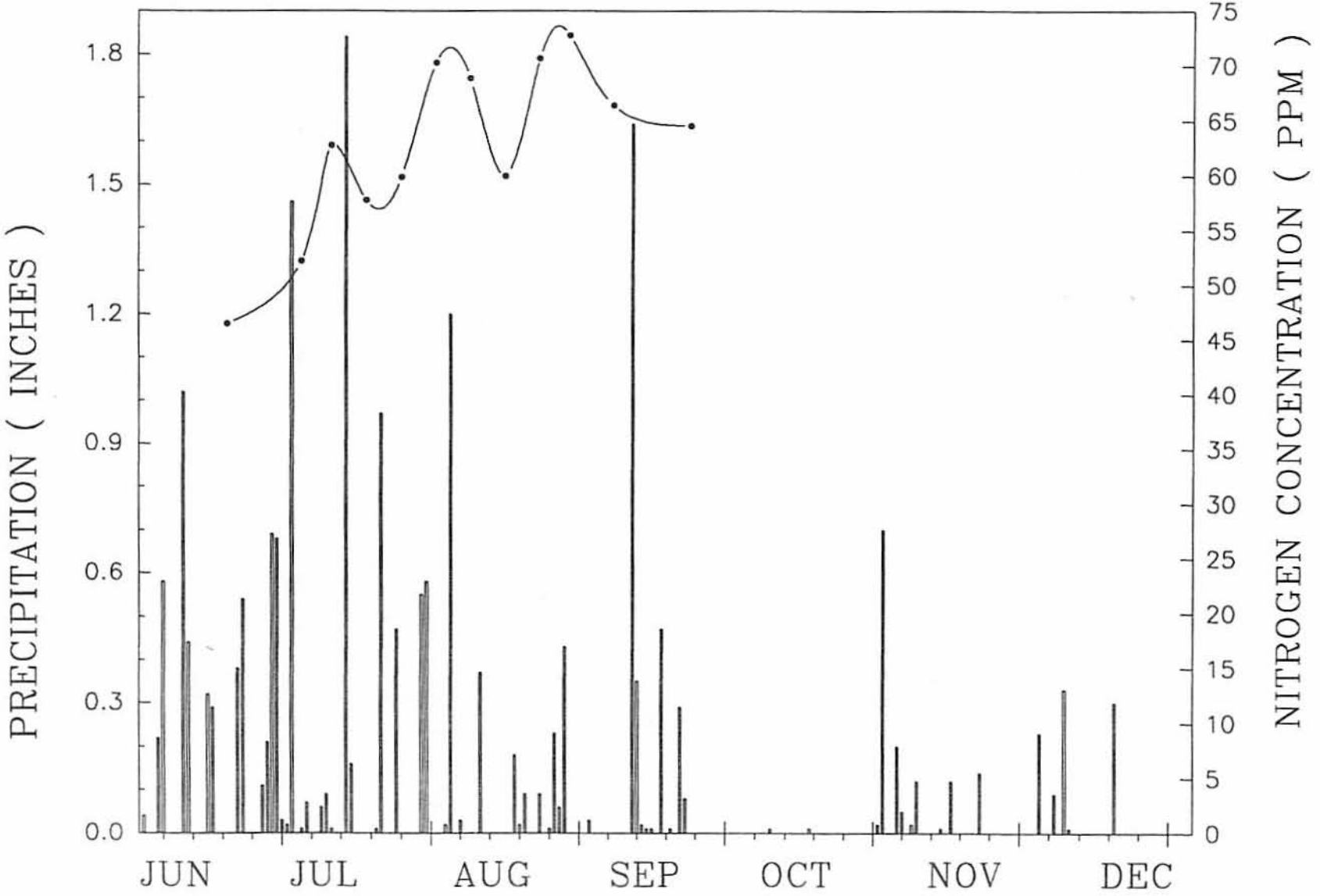


FIG. 5 SOIL WATER-N CONCENTRATION OVER TIME IN CORN AT MORRIS.MN

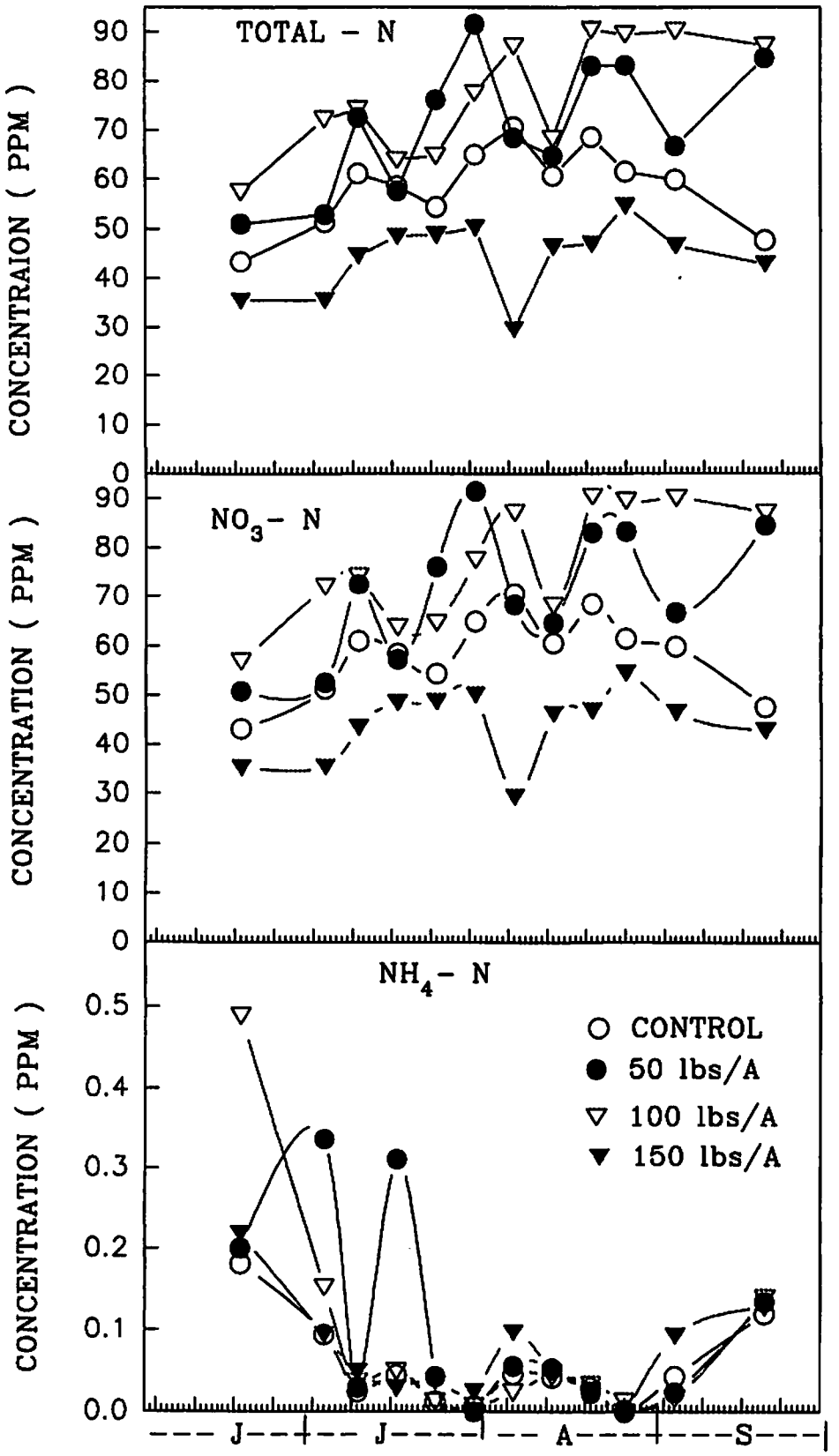
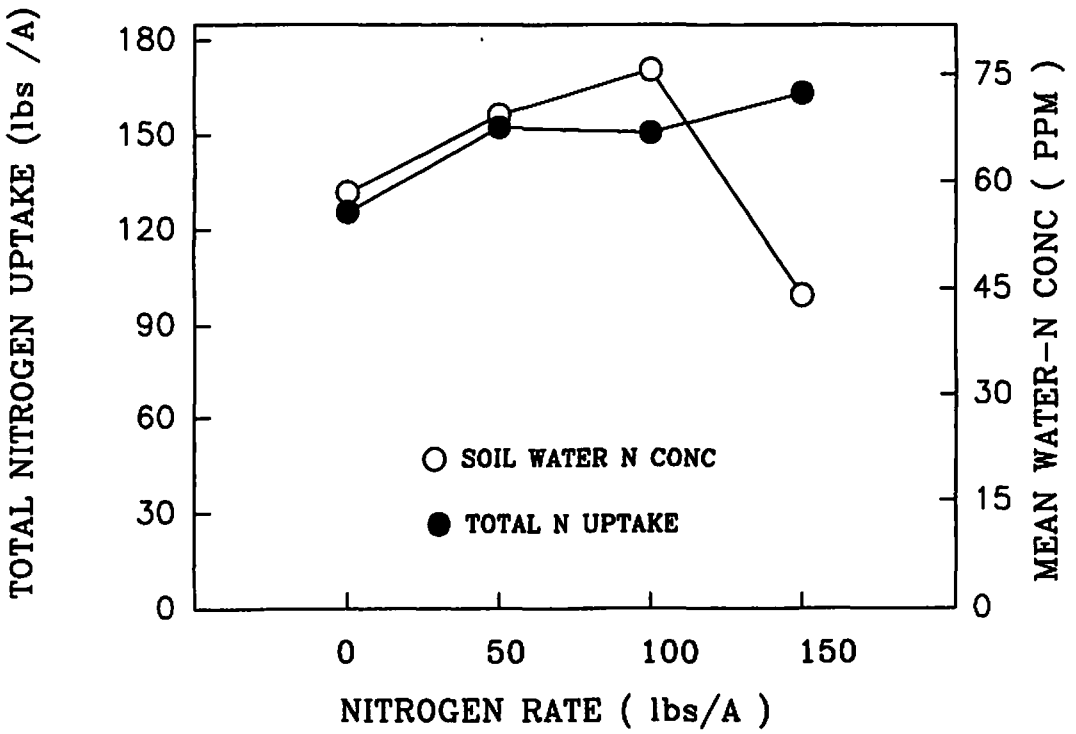


FIG. 6 TOTAL NITROGEN UPTAKE AND MEAN SOIL WATER NITROGEN CONCENTRATION OVER THE SAMPLING SEASON AT DIFFERENT NITROGEN RATE ON CORN AT MORRIS,MN, 1991



MATCHING PRECISION PLACEMENT OF POTASH FERTILIZER TO ROOT GROWTH DYNAMICS IN A RIDGE-TILL PLANTING SYSTEM[1]

Deborah Allan, George Rehm, and Sam Evans[2]

Potassium deficiency symptoms often appear in ridge-tilled corn even when soil test values for potassium are high. In this trial, we compared early growth, yield, K uptake and root activity for three tillage systems (chisel plow, ridge-till, and no-till), two hybrids (Pioneer 3732 and 3737), and two fertilizer treatments (control and 40 lb/A banded K_2O). Tillage system had no effect on grain yields, but there was greater early growth and K uptake with the chisel plow system. Banded K increased plant growth, K uptake and grain yield. Pioneer hybrid 3732 had higher early shoot growth, but significantly lower uptake of K, and tended to show less root activity at 6" and 12" depths than 3737.

Recent interest in ridge-till and no-till planting systems for corn has raised the question of appropriate fertilizer placement. Early season K deficiency symptoms have been repeatedly observed in ridge-tilled corn in diverse soil environments, even where K soil test values are high. Banding of fertilizer K has been shown to alleviate the K deficiency problem in ridge-tilled corn, but the reasons for occurrence of the deficiency are still unknown. The objectives of this study were to: 1) determine more precisely the effect of potash placement on root activity, K uptake, plant growth, and subsequent corn yield in a ridge-till planting system compared to fall chisel and no-till planting systems; and 2) quantify differences in K uptake and root activity in the three tillage systems for two corn hybrids.

Methods and Materials

This study was initiated at the West Central Experiment Station in Morris, Minnesota in the fall of 1990. Soil test values for K prior to fertilization are listed in Table 1. Fertilizer treatments were supplied as shown below:

control (no K_2O) + 124 lb/A 10-34-0 starter
200 lb/A 7-21-7 starter
40 lb/A K_2O in row-band (fall) + 124 lb/A 10-34-0 starter
80 lb/A K_2O broadcast (fall) + 124 lb/A 10-34-0 starter
40 lb/A K_2O in row-band (fall) + 200 lb/A 7-21-7 starter

Fall banded (40 lb/A) and broadcast (80 lb/A) applications were made on October 29, prior to any fall tillage. Adequate N was applied to all treatments as 82-0-0.

Corn was planted on May 13, 1991 at a population of 30,000 plants per acre. Two hybrids (Pioneer 3732 and 3737) were combined with the applied rates of K_2O and four tillage systems in a complete factorial arranged in a randomized complete block design with four replications. Weed control was achieved by Lasso EC (3.0 lbs/A a.i.) and Bladex 90 DF (2.2 lbs/A a.i.). Only the ridge-till plots were cultivated on June 13 and ridged on June 19. The plots were harvested September 26 and grain yields were corrected to 15.5% moisture.

A portion of the above experiment was chosen for more intensive study of root activity and K uptake. For three tillage systems (chisel plow, ridge-till and no-till), two K rates (0 and 40 lb K/A banded) and both hybrids, injections were made of three non-essential ions [rubidium (Rb), strontium (Sr) and lithium (Li)] to serve as tracers for root activity. Injections were made on June 2 with a syringe apparatus opposite each plant along 14 feet of the two center rows in each plot. Each plant in one row was labeled with Sr (at 3" depth) and Li (at 12" depth) at a distance of four inches from the plant, perpendicular to the row on the outer side. In the other row, each plant was labeled with Rb (at 6" depth) in a similar fashion. This labelling scheme allowed sampled plants from the first row to serve as controls for background levels of Rb, and in the second row for Sr and Li.

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[1]Funding for this project was provided by the Minnesota Agricultural Experiment Station and the NSF Young Scholars Program. Pang Thao and Eric Olund provided assistance in sample analysis.

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Table 1. Soil test values for potassium at the experimental site.

Depth	Distance From Row (inches) 0	3	6	9	12	15
inches	ppm K					
Fall chisel:						
0 - 3	202	165	169	157	177	167
3 - 6	142	140	130	140	127	101
6 - 9	113	124	121	123	127	139
Fall Plow:						
0 - 3	134	139	145	143	141	122
3 - 6	128	124	132	135	132	117
6 - 9	145	137	145	118	126	116
No Till:						
0 - 3	195	200	204	212	216	176
3 - 6	139	132	122	133	118	132
6 - 9	123	120	117	123	123	131
Ridge Till:						
0 - 3	212	196	181	163	184	165
3 - 6	135	136	132	136	134	99
6 - 9	105	120	115	127	127	119

Plant samples were collected from these plots at four times during the growing season (6/12, 6/21, 7/15 and 9/18) approximately 30, 40, 60 and 120 days after planting. At each sampling time, 4 plants from each of the two labeled rows were harvested, dried, weighed, ground and analyzed for K, Rb, Sr, and Li. A border zone of 20" was left between each group of sampled plants.

In order to interpret the results and to convert all tracer uptake values to a common measure of root activity, an additional tracer study was established in the field border. In this case, the three tracer ions were injected to the same depth (6"), at the same distance from the plant (4"), in three subplots separated by border zones, and replicated four times. Five plant samples were taken from the middle of each subplot on June 21. By analysis and calculation of ion uptake, it was established that relative uptake of Rb:Sr was 9.7 and Rb:Li was 14.4. These numbers allowed us to convert all Sr and Li uptake values to equivalent Rb uptake rates. In this study, net uptake of Rb per plant is used as an index of root activity.

Bulk density and moisture content in the top 12 inches were measured on July 31, 1992. Twelve cores were taken from two plots in each tillage treatment in blocks 1 and 2, and twelve from blocks 3 and 4. All plots selected were controls planted to 3732. Gravimetric soil moisture content was sampled in two plots for each tillage and fertility treatment on 6/26, 7/18, 8/1, and 8/29. Soil levels of K, Rb, Sr, and Li in a sampling of injection points were determined to confirm that the injected tracers reached the intended location.

Results and Discussion.

Tillage effects on soil properties. Bulk density was similar for ridge-till and chisel plow, and greater for no-till when averaged over the top 12" (Table 2). However, moisture content was higher for both ridge-till and no-till planting systems. Below 6", the bulk density values were very similar for all three tillage treatments, but moisture contents remained lower for chisel from 6-12" (data not shown).

Table 2. Bulk density and soil moisture averaged over a soil depth of 12". Sampled 7/31/91. Significance calculated at the 5% level.

	Bulk Density (g/cm^3)	Moisture Content %
Tillage		
Chisel Plow	1.29 b	22.8 b
Ridge Till	1.30 b	24.5 a
No Till	1.37 a	24.7 a

When soil moisture was measured at 4 different times during the season in 4 plots for each tillage treatment, there were no significant differences in moisture content among any of the tillage systems at any date (Table 3).

Table 3. Soil moisture at 4 sampling times under 3 tillage systems.

	Sampling Date											
	6/26			7/18			8/01			8/29		
Depth in.	Chisel Plow	Ridge Till	No Till	Chisel Plow	Ridge Till	No Till	Chisel Plow	Ridge Till	No Till	Chisel Plow	Ridge Till	No Till
0-6	24.9	23.8	24.8	24.1	23.4	24.0	26.4	26.3	26.0	22.8	22.2	22.4
6-12	24.8	24.0	26.3	24.7	24.4	24.9	25.0	25.0	25.8	21.8	21.6	22.7
12-18	23.2	23.2	24.6	22.2	24.2	22.7	23.0	24.8	24.8	17.6	19.2	18.8
18-24	21.1	21.1	22.0	19.1	19.9	20.0	18.7	22.1	21.0	15.8	17.0	16.6

At a distance of 4" from the row, soil test values for K sampled in 2 plots for each tillage treatment (ridge and chisel, 9 samples per plot) were the same in the top two inches, but significantly lower for ridge tillage at the 10% confidence level for all other depths up to 15" (Table 4). Ridge-till K values were anywhere from 15-30% lower, but the values were in the medium range for both tillage systems.

Table 4. Soil test values for potassium in two tillage systems, using ammonium acetate extraction, n=18.

Depth in.	Chisel Plow	Ridge Till	Significance
	ppm K		
0-2	191	204	NS
2-4	218	168	*
4-6	199	134	*
6-8	156	119	*
8-10.5	149	111	*
10.5-13	139	119	*
13-15	169	122	*

NS = not significant; * = significant at 10%

Grain yields and plant growth during the season. As has been seen previously, there was a significant effect of banded K_2O on grain yield (Table 5). Application of K_2O and hybrid both significantly affected early growth (prior to physiological maturity at 120 DAP) and grain yield (Table 6). Pioneer 3732 had greater early season growth than 3737, but yields were significantly lower. At 60 DAP, there was a significant interaction between K application and hybrid for plant weight. Fertilizer application increased 3732 shoot growth by 18% compared to only 7% for 3737. Tillage treatment had no effect on grain yields, but early growth (from 30-60 DAP) was significantly higher for chisel plow than ridge-till or no-till. There were no significant interactions between tillage and the other variables.

Table 5. Effect of different K fertilizer treatments on grain yields. Significance calculated at the 5% level.

Treatment	Grain Yield bu/A
0	169.4 c
Starter K	169.7 bc
40 lb/A band	175.0 a
80 lb/A broadcast	171.0 abc
40 lb/A band and starter K	173.7 ab

K concentration and uptake. Tillage had a significant effect on K uptake at the first three sampling times, with chisel plow showing consistently higher K uptake than ridge-till or no-till (Table 7). Potassium concentration differed only at the 40 DAP sampling date, with ridge-till significantly lower. Concentration and uptake of K was significantly less for Pioneer 3732 at all sampling times. The banded K treatment resulted in significantly higher K uptake at all sampling times and higher K concentrations at 30 and 40 DAP. Significant interactions occurred for fertilizer treatment by hybrid at 60 DAP, where fertilizer application narrowed the differences between the two hybrids, and for tillage by hybrid at 40 DAP, where much greater differences occurred between the two hybrids in chisel plow and no till than for ridge-till.

Root activity. Almost no significant differences were measured in root activity due to tillage, fertilizer treatment, or hybrid, due to the large variability in both the tracer uptake and the tracer concentration in the soil (Table 8). Coefficients of variation for the tracer uptake averaged 80, 50, 35 and 45% for the 30, 40, 60 and 120 DAP sampling times. For tracer placement, cv's averaged 98, 150, and 66% for Sr, Rb and Li, respectively. Variability was lower later in the season, which indicates that this technique may not be appropriate for measuring early season root activity. The trends in the data suggest that at 3 and 6" depths, root activity tended to be higher with chisel plow than ridge-till or no-till, although at 12", ridge-till tended to be highest. Hybrid 3732 had more root activity at the 3" depth and less at 6" and 12", especially at later sampling times (60 and 120 DAP). Generally, K application tended to increase rooting with depth and decrease root activity at the surface.

Summary. Although tillage system had no effect on grain yields, there was greater early growth, K uptake, and a trend to greater root activity at 3 and 6" depths in the chisel plow system. Banded K_2O increased plant growth, K uptake and grain yield. Pioneer 3732, although it had higher early shoot growth and, possibly, root activity at the 3" depth, had significantly lower K concentration and accumulation and tended to have less root activity at 6" and 12".

Both soil properties as affected by tillage and hybrid differences appear to be involved in the observed early season K deficiency. Soil moisture for both ridge-till and no-till were greater than chisel plow, possibly affecting soil temperature and root growth. Less soil K may be available in ridge-till compared to chisel plow planting systems (15-30% less in this study). Some effect of the tillage system on root and/or soil properties seems likely, since ridge tillage causes significantly lower K uptake for both hybrids.

Clearly, hybrid 3732 is more prone to K deficiency, more sensitive to the ridge- and no-till systems, and more responsive to banded K_2O application. Possible causes for this may be greater early shoot growth at the expense of roots, or greater proliferation of surface roots at the expense of deeper rooting. In future growing seasons, we plan to investigate this question further by using a more intensive root sampling technique and attempting to reduce the variability in the tracer injection procedure.

Table 6. Growth at 4 sampling times and grain yield.

Tillage	K rate	Hybrid	Days After Planting 30	40	60	120	Grain Yield
	lb K/A		g per plant				bu./A
Chisel Plow	0	3732	5.1	18.9	102.9	130.8	163.0
	0	3737	4.1	20.0	94.6	129.2	169.9
	40	3732	6.2	21.2	112.0	152.6	164.1
	40	3737	5.2	23.0	96.2	144.0	182.4
Ridge Till	0	3732	4.3	13.7	80.1	134.7	159.2
	0	3737	3.3	13.6	85.4	130.7	175.5
	40	3732	5.5	17.2	105.9	144.9	178.5
	40	3737	4.3	15.1	92.8	141.7	178.0
No Till	0	3732	4.2	12.0	89.9	139.6	161.7
	0	3737	2.9	13.7	81.9	136.6	178.9
	40	3732	4.6	15.2	103.4	148.0	172.8
	40	3737	3.8	14.9	89.4	131.7	174.4
Analysis of Variance							
Tillage (T)							
Chisel Plow			5.2a	20.8a	101.4a	139.2	170.2
Ridge Till			4.4b	14.9b	91.0b	138.0	171.0
No Till			3.9b	13.9b	91.1b	138.9	172.5
Significance			**	**	**	NS	NS
K rate (K)							
0			4.0	15.3	89.1	133.6	169.4
40			4.9	17.8	99.9	143.8	175.0
Significance			**	**	**	NS	*
Hybrid (H)							
3732			5.0	16.4	99.0	141.8	166.7
3737			3.9	16.7	90.0	135.6	176.9
Significance			**	NS	**	NS	**
Interactions							
T X K			NS	NS	NS	NS	NS
T X H			NS	NS	NS	NS	NS
K X H			NS	NS	**	NS	NS
T X K X H			NS	NS	NS	NS	NS

NS = not significant; * = significant at 5%; ** = significant at 1%

Table 7. Potassium concentration in corn tissue and uptake by plants

			Days After Planting							
			30		40		60		120	
Tillage	K rate lb K/A	Hybrid	K Conc. %	K Uptake mg per plant	K Conc. %	K Uptake mg per plant	K Conc. %	K Uptake mg per plant	K Conc. %	K Uptake mg per plant
Chisel Plow	0	3732	1.96	98.9	1.93	372.0	0.90	924	0.52	682
	0	3737	3.48	141.9	3.53	700.5	1.57	1479	0.95	1237
	40	3732	3.26	203.0	2.77	603.3	1.19	1338	0.85	1303
	40	3737	4.20	222.5	4.03	942.5	1.58	1530	0.93	1294
Ridge Till	0	3732	1.77	77.0	1.66	226.9	0.79	639	0.64	876
	0	3737	3.16	105.4	2.16	301.3	1.44	1208	0.84	1078
	40	3732	3.08	166.7	2.55	440.4	1.00	1070	0.70	1025
	40	3737	3.88	168.7	3.03	457.7	1.29	1200	0.89	1259
No Till	0	3732	2.07	88.0	1.83	224.7	0.88	793	0.63	903
	0	3737	3.10	89.3	3.14	442.4	1.61	1316	0.97	1325
	40	3732	2.84	131.0	2.48	380.1	1.06	1040	0.75	1107
	40	3737	3.84	145.7	3.77	559.5	1.62	1439	0.99	1308
Analysis of Variance										
Tillage (T)										
Chisel Plow			3.22	166.6a	3.07a	654.6a	1.31	1318a	0.81	1129
Ridge Till			2.97	129.4b	2.35b	356.6b	1.13	1029b	0.77	1060
No Till			2.96	113.5b	2.81a	401.7b	1.29	1147b	0.83	1161
Significance			NS	*	**	**	NS	*	NS	NS
K Rate (K)										
0			2.59	100.1	2.37	378.0	1.20	1060	0.76	1017
40			3.52	172.9	3.11	563.9	1.29	1269	0.85	1216
Significance			**	**	**	**	NS	**	NS	*
Hybrid (H)										
3732			2.49	127.4	2.20	374.6	0.97	967	0.68	983
3737			3.61	145.6	3.28	567.3	1.52	1362	0.93	1250
Significance			**	**	**	**	**	**	**	**
Interactions										
T X K			NS	NS	NS	NS	NS	NS	NS	NS
T X H			NS	NS	**	*	NS	NS	NS	NS
K X H			*	NS	NS	NS	**	**	NS	NS
T X K X H			NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant; * = significant at 5%; ** = significant at 1%

Table 8. Root activity at three depths as estimated by net rubidium uptake during the growing season.

Tillage	K rate lb K/A	Hybrid	3" Depth Days after planting 30	40	60	120	6" Depth Days after planting 30	40	60	120	12" Depth Days after planting 30	40	60	120
			mg net Rb uptake/plant				mg net Rb uptake/plant				mg net Rb uptake/plant			
Chisel Plow	0	3732	1.31	8.83	8.78	7.75	0.55	2.09	4.33	2.92	0.012	0.22	1.24	2.92
	0	3737	1.60	7.21	5.53	9.58	0.15	2.85	5.10	4.29	0.011	0.42	1.75	4.08
	40	3732	2.54	7.06	5.36	4.87	0.20	1.01	3.91	3.22	0.009	0.35	1.20	3.21
	40	3737	3.28	8.39	5.61	7.17	0.18	1.44	4.68	3.14	0.047	0.37	1.27	4.02
Ridge Till	0	3732	3.49	3.32	4.75	7.45	0.07	1.81	4.06	3.12	0.012	0.20	1.02	3.56
	0	3737	1.87	4.74	6.62	6.29	0.15	0.71	5.13	3.40	0.042	0.17	1.82	3.95
	40	3732	0.67	3.55	5.18	7.15	0.38	2.60	3.99	3.79	0.020	0.42	1.34	3.37
	40	3737	2.23	2.82	5.68	4.66	0.24	1.79	4.27	5.74	0.021	0.40	2.09	4.69
No Till	0	3732	1.48	2.92	4.76	6.56	0.15	1.12	3.57	2.98	0.011	0.26	1.09	1.89
	0	3737	1.46	5.58	3.38	4.16	0.13	0.69	3.11	4.52	0.003	0.24	1.02	3.23
	40	3732	2.93	3.67	8.63	6.47	0.17	1.20	3.24	3.28	0.006	0.27	1.27	2.22
	40	3737	1.74	3.83	3.35	3.34	0.14	0.98	4.70	4.75	0.010	0.14	1.52	2.74
Analysis of Variance														
Tillage (T)														
Chisel Plow			2.19	7.87a	6.32	7.34	0.27	1.85	4.51	3.39	0.020	0.34	1.36	3.56a
Ridge Till			2.07	3.61b	5.56	6.39	0.21	1.73	4.37	4.01	0.024	0.30	1.57	3.89a
No Till			1.90	4.00b	5.03	5.14	0.15	1.00	3.66	3.88	0.007	0.23	1.23	2.52b
Significance			NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
K rate (K)														
0			1.87	5.43	5.64	6.97	0.20	1.54	4.22	3.54	0.016	0.25	1.32	3.27
40			2.23	4.89	5.64	5.61	0.22	1.50	4.13	3.99	0.019	0.33	1.45	3.38
Significance			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Hybrid (H)														
3732			2.07	4.89	6.25	6.71	0.25	1.64	3.85	3.22	0.012	0.29	1.19	2.86
3737			2.03	5.43	5.03	5.87	0.16	1.41	4.50	4.31	0.022	0.29	1.58	3.79
Significance			NS	NS	NS	NS	NS	NS	NS	*	NS	NS	**	*
Interactions														
T X K			**	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
T X H			NS	NS	NS	NS	NS	*	NS	NS	NS	NS	*	NS
K X H			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
T X K X H			NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS

NS = not significant; * = significant at 5%; ** significant at 1%

Tillage effects on N available to irrigated corn from alfalfa-five year summary[1]

J.F. Moncrief, M.J. Wiens, J.J. Kuznia, N. Krause, and B.J. Johnson[2]

This study is designed to evaluate the effect of tillage on corn response following alfalfa. Tillage affected stand establishment and development rate.

The objective of this study is to evaluate the effect of full width tillage on corn growth following alfalfa in two separate studies at the Staples Area Technical School Irrigation Center. Alfalfa was killed with herbicide in the spring of 1987 and 1990 and planted to corn. This is the fifth and second year of these two studies. Tillage systems established in the spring were: moldboard with plow packer, discing twice, and no tillage. Nitrogen was applied as urea (from 12 to 224 lbs/acre) in three applications: 12 lbs/acre with the planter, and the remainder in two equal applications at the 4-6 and 8-12 leaf growth stage of corn. Urea was irrigated in to prevent volatilization losses. Irrigation amounts and timing as well as N responses are presented in a companion papers. The planter used was equipped with two inch fluted coulters in 1987 to 1989. In 1990 and 1991 clearing discs were used.

Planting and harvest dates are shown in table 1. Harvest was done after physiological maturity or frost occurrence. The cumulative growing degree days (base 10-30) from planting to harvest are also shown in table 1. Three years were very similar ('87, '89, and '91). The season was very warm in '88 and cold in '90.

The soil cover by corn residue after planting are shown in table 2. The planter equipped clearing discs were only partially successful in removing crop residue from the row area. In 1987 and 1990 soil cover is with alfalfa residues for studies 1 and 2 respectively. Soil cover ranged from 55 to 92% cover. The fluted coulter used to do tillage in the row area did not reduce the residue very much. Clearing discs were much more effective (1990 and 1991). It is recommended that "in row" cover by corn residue be less than 20% to minimize the potential of detrimental effects on corn emergence and early growth.

Emergence was delayed up to 10 days with a no till systems (data not shown). Cover by corn residue affected grain moisture in all years. Cover by alfalfa residue did not. As corn residue levels accumulated with time plant stands reduced with "in row" soil cover. The cool year of 1990 had the largest effect on stand mortality with soil cover in the row.

The effect of tillage on corn yield following alfalfa is shown in figure 1. There are two sets of curves, one for control plots (no applied nitrogen) and one for plots where N was not limiting yields (applied as urea, see companion papers).

After three years check plot yields stabilized at 65 and 40 bu/acre for the moldboard and disc, and no till treatments respectively. The yields with N applied are steadily decreasing over the length of the study. The yields of the conservation tillage systems in 1990 are primarily the result of the cool growing conditions and the subsequent stand loss and delayed growth.

Study two contrasts with study one in that the N benefits of first year corn are less even though the stand densities are greater (3 versus 8 plants per square foot). It also appears that yield levels without applied N have reached the base line after the first year.

These graphs show several trends. Firstly, the N benefits from the alfalfa are gone after the first or second year on coarse textured irrigated soils. Secondly the tillage effects on control plot yields due not change with time. Applied N the first year following alfalfa does result in similar grain yields irrespective of tillage. After the first year following alfalfa, N does not eliminate tillage affects on grain yields. Lastly, if one looks just at the moldboard lines to eliminate the confounding effects of tillage, the yields are still slowing declining even after five years of corn. The rotation effect is very prominent on these soils.

The average of the three tillage treatments are presented in figure 2. The residual N from alfalfa and declining yields following alfalfa without N limiting are apparent.

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[1] *Support for this project was provided by the Minnesota Department of Agriculture, the Agricultural Utilization and Research Institute, the Staples Irrigation Center, and the Soil Conservation Service. Their support is greatly appreciated.*

[2] *J.F. Moncrief, J.J. Kuznia, and B.J. Johnson are Associate Professor and Assistant Scientists in the Soil Science Department at the University of Minnesota, St. Paul, MN, 55108. M.J. Wiens and N. Krause are Senior Plot Coordinator and Center Director respectively at the Staples Irrigation Center, Staples Area Technical College, Staples, MN.*

Tillage study 1 data, five years of corn on corn after alfalfa, at Staples Irrigation Center. Staples, MN. Tillage study 2 data, 2 years of corn on corn after alfalfa at Staples.

Table 1. Growing Degree Days.

YEAR	1987		1988		1989		1990		1991	
Planted/Harvested	5/11	10/1	4/27	9/29	5/10	10/10	5/7	10/8	5/8	9/8
GDD	1248		1453		1237		1146		1237	

Table 2. Soil cover (%) as effected by tillage.

Tillage	1987		1988		1989		1990		1991		Mean	
	Residue Cover, %											
Study 1	In[1]	Bet.	In	Bet.	In	Bet.	In	Bet.	In	Bet.	In	Bet.
No Till	92a	97a	84a	90a	92a	98a	69a	80a	55a	84a	**78**	**90**
Disk	48b	41b	64b	57b	43b	46b	53b	49b	28b	40b	**47**	**46**
Moldboard	13c	11c	9c	6c	10c	10c	17c	18c	5c	3c	**11**	**10**
Mean	**51**	**49**	**52**	**51**	**48**	**51**	**46**	**49**	**29**	**42**	**45**	**49**
Study 2							In	Bet.	In	Bet.	In	Bet.
No Till							26a	72a	70a	85a	**48**	**79**
Disk							16b	14b	31b	37b	**23**	**25**
Moldboard							3c	7b	6c	7c	**4**	**7**
Mean							**15**	**31**	**36**	**43**	**25**	**37**

1. In = in-row cover, Bet.= between-row cover.

Table 3. Grain moisture of corn as effected by tillage.

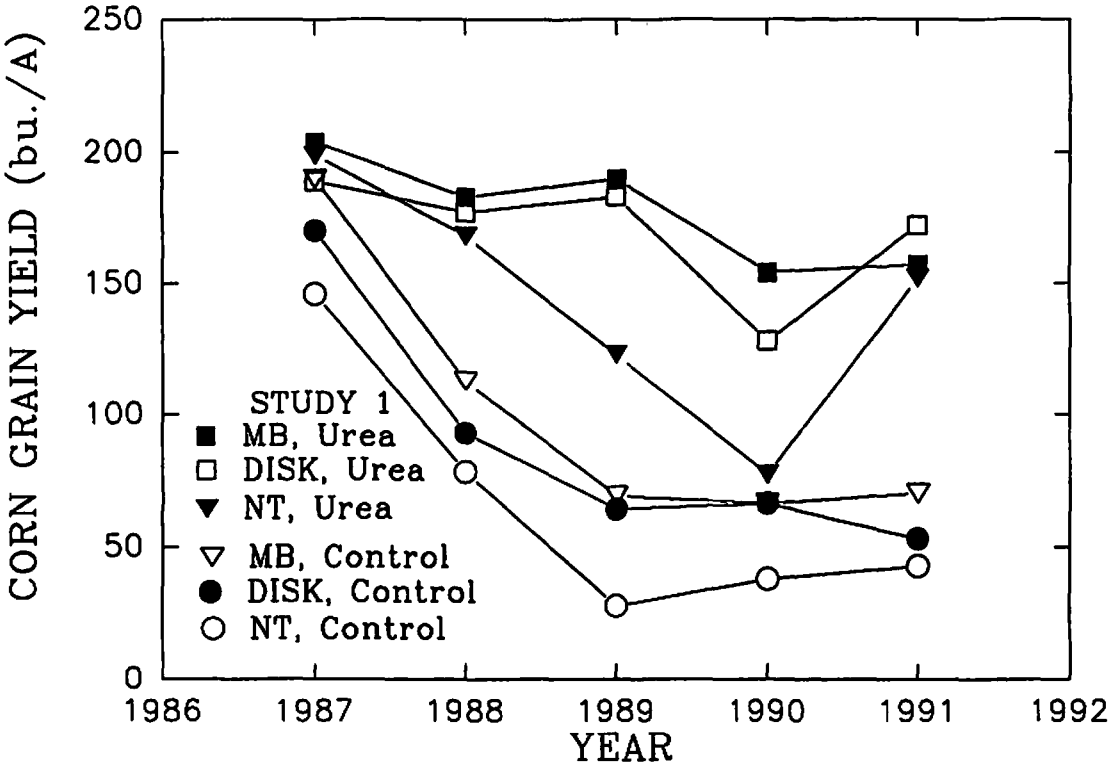
Tillage	1987	1988	1989	1990	1991	Mean
	Grain Moisture, %					
Study 1						
No Till	32.8a	28.4a	26.4a	34.6a	29.4a	**30.3**
Disk	32.3a	23.6b	21.6b	29.6b	26.8b	**26.8**
Moldboard	31.8a	22.7c	21.7b	26.5c	26.5c	**25.8**
Mean	**32.3**	**24.9**	**23.2**	**30.2**	**27.6**	**27.6**
Study 2						
No Till				27.2ab	32.8a	**30.0**
Disk				27.5a	29.7b	**28.6**
Moldboard				26.4b	27.5c	**27.0**
Mean				**27.0**	**30.0**	**28.5**

Table 4. Plant population stand as effected by tillage.

Tillage	1987	1988	1989	1990	1991	Mean
	Plant Population ($Ax10^{-3}$)					
Study 1						
No Till	29.0a	29.6a	23.3a	23.7a	38.4a	**28.8**
Disk	28.2a	31.7a	31.1b	27.1b	42.4b	**32.1**
Moldboard	28.4a	32.4a	33.0b	29.8c	42.1b	**33.1**
Mean	**28.5**	**31.2**	**29.1**	**26.9**	**41.0**	31.3
Study 2						
No Till				29.8a	35.1a	**32.4**
Disk				30.0a	37.7b	**33.8**
Moldboard				30.0a	38.5b	**34.2**
Mean				**29.9**	**37.1**	**33.5**

1. Values with the same letter, within the same column, are not significantly different.

FIG 1. THE EFFECT OF TIME AND TILLAGE ON NITROGEN AVAILABLE TO CORN FROM ALFALFA RESIDUES, SOIL ORGANIC MATTER, AND UREA AT STAPLES, MN



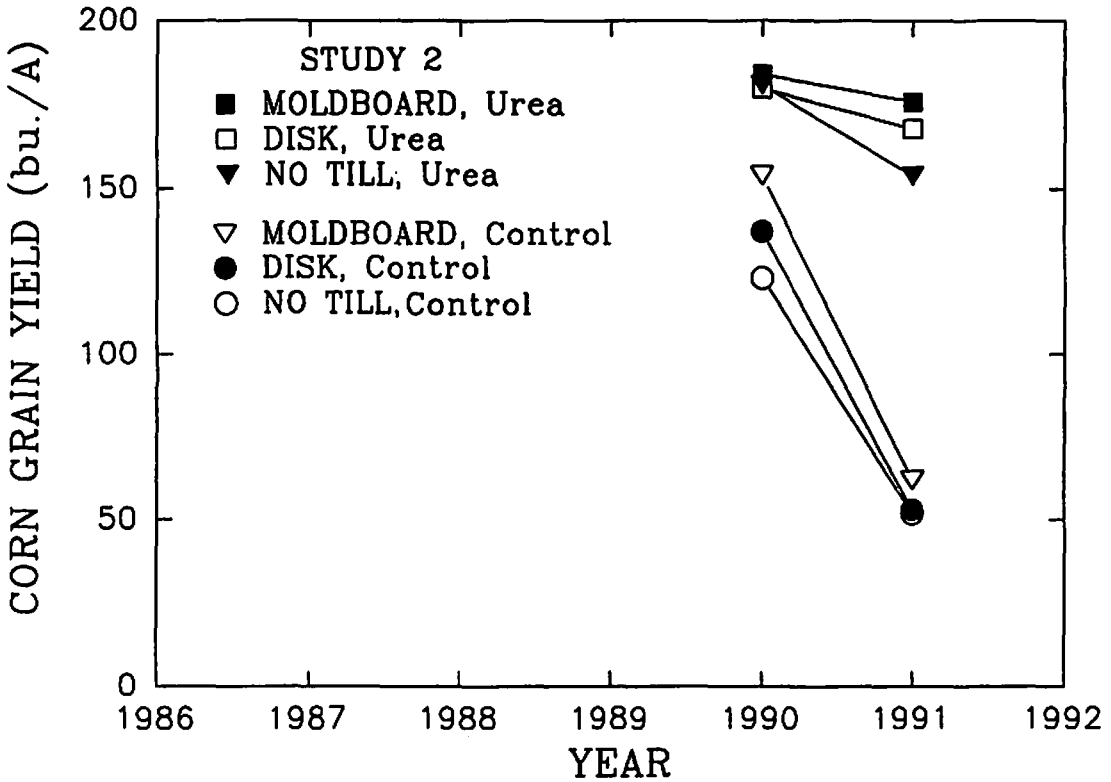
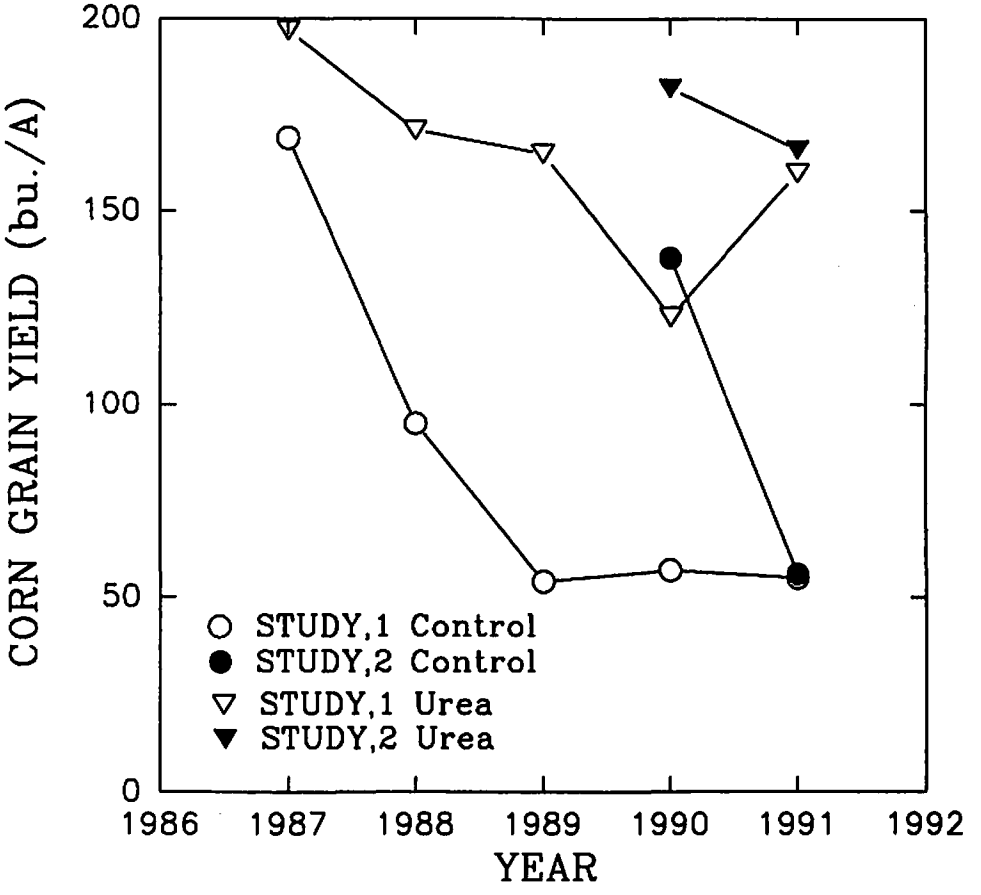


Fig 2. THE EFFECT OF TIME ON NITROGEN AVAILABLE TO CORN FROM ALFALFA RESIDUES, SOIL ORGANIC MATTER, AND UREA AT STAPLES, MN



Tillage effects on N available to irrigated corn from alfalfa and urea N sources[1]

J.F. Moncrief, M.J. Wiens, N. Krause, and B.J. Johnson[2]

This study is designed to evaluate full width tillage and row cultivation on the N available to second year corn following alfalfa. Tillage affected stand establishment and emergence rate. Corn grown under conservation tillage systems did not differ in their nitrogen repsonse. The cultivation response by corn interacted with tillage system. Cutivation increased N uptake most under no till conditions but also with moldboard plowing. Corn that was planted into spring discing plots did not result in increased uptake when cultivated.

The objective of this study is to evaluate the effect of full width tillage and row cultivation in June on the amount of nitrogen available to corn from alfalfa. Alfalfa was killed with herbicide in the spring of 1990 and planted to corn. This is the second year of a three year study. Tillage main plots are split with nitrogen subplots. Tillage systems established in the spring were: moldboard with plow packer, discing twice, and no tillage. Nitrogen was applied as urea (from 12 to 224 lbs/acre) in three applications: 12 lbs/acre with the planter, and the remainder in two equal applications at the 4-6 and 8-12 leaf growth stage of corn (table 1). Urea was irrigated in to prevent volatilization losses. Irrigation amounts and timing are presented in a companion paper.

The soil cover by corn residue after planting and corn emergence are shown in table 2. The planter equipped clearing discs were only partially successful in removing crop residue from the row area. It is recommended that "in row" cover by corn residue be less than 20% to minimize the potential of detrimental effects on corn emergence and early growth. The emergence rate is shown in figure 1. Emergence was delayed six and three days with no till and spring discing systems respectively. This is in contrast to 1990 with similar cover levels but by alfalfa residues when emergence was only delayed by 2 days with the no till treatment and not at all with the spring disc treatment. Final stands were reduced significantly under no till conditions. This is also in contrast to 1990 following alfalfa when final stands were not affected by tillage.

Treatment means and statistical significance are shown in table 3. Soil cover in the row of 70% increased grain moisture 5% over moldboard plowing grown corn with 6% soil cover in the row. This is graphically presented in figure 2. The fifth year corn results are reported elsewhere. These results are in contrast to 1990 results for first year corn following alfalfa. In 1990 tillage affected grain moisture, but only slightly. The tillage delay in development also is reflected in the stover moisture levels. Grain yields were reduced under no till conditions by 16 bushels per acre. Although final stands were affected by tillage, they are above the level expected to affect yields.

Although there were no consistent effects of tillage on tissue nitrogen content, total uptake was lower with conservation tillage systems. Corn grain yields responded to 170 lbs/acre N. About 20 lbs/acre N was applied with irrigation water (figure 3). This study received water from the Irrigation Center Pit. Stover yields did not respond beyond the second rate of N.

Although cultivation did not affect grain yields, it did increase N uptake by stover and grain. There was an interaction between tillage and cultivation for stover and total N uptake. The cultivation response was greatest with the no till system intermediate with moldboard plowing and absent with spring discing.

There were no interactions between tillage and N rate for measured variables. This is also in contrast to 1990 when tillage affected grain response to applied N for first year corn. Three way interactions between tillage, cultivation, and N rate also do not show any consistent trends (tables 4a and 4b).

Figures 4 and 5 show the soil water nitrate at 3 and 5 feet under moldboard and no till conditions. Figure 4 shows the individual sampler duplicates within the plots. The variability within plots makes it difficult to identify any treatment trends. The moldboard system appeared to have higher levels of nitrate through out the season (figure 5). This was consistent with 1990 data.

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[1] *Support for this project was provided by the Agricultural Utilization and Research Institute, the Staples Irrigation Center, and the Soil Conservation Service. Their support is greatly appreciated.*

[2] *J.F. Moncrief and B.J. Johnson are Associate Professor and Assistant Scientist in the Soil Science Department at the University of Minnesota, St. Paul, MN, 55108. M.J. Wiens and N. Krause are Senior Plot Coordinator and Center Director respectively at the Staples Irrigation Center, Staples Area Technical College, Staples, MN.*

Table 1. Cultural practices at Staples Irrigation Center, Wadena County, MN. 1991.

Tillage

No Till
Spring Disced and moldboard plowed May 7, 1991
Cultivated with a Hiniker 5000 conservation cultivator on June 13, 1991

Previous Crop

Alfalfa 1987-89
Corn 1990

1991 Crop

Corn-Pioneer 3790

Planting and Harvest Date

The planter is a 4 row Deutz-Allis Model 385 with 30 inch row spacing, equipped with 2 inch fluted coulters and disc row cleaners.

	Planting		Harvested	
Crop	Date	Rate	Grain	Stover
Corn	May 8, 1991	44,000 seeds/A	September 18, 1991	September 20, 1991

Soil

The soil is a Verndale sandy loam (coarse-loamy mixed, Udic Argiborolls) with a slope of 0 to 2 percent. The soil is well drained.

Fertilizer 1990

Material Analysis	Rate[3]	Actual N	P_2O_5	K_2O	S	Date Applied
	--------- lb/A -------					
20-5-30-10[1]	87	17	4	26	9	May 7, 1990
46-0-0[2]	0	0	0	0	0	June 29, 1990
46-0-0[2]	26	12	0	0	0	June 29, 1990
46-0-0[2]	85	39	0	0	0	June 29, 1990
46-0-0[2]	143	66	0	0	0	June 29, 1990

1. Planter applied 2" below and 2" beside row.
2. Broadcast as urea and irrigated in.
3. The resulting N rates are: 17, 29, 56, and 83 lb/A.

Weed Control

3.0 pt/A (3.0 lb/A) Bladex + 1.5 pt/A (1.5 lb/A) Dual on 5/10/91.
1.0 qt/A (1.0 lb/A) Roundup spot sprayed on 5/22/91.
2.0 qt/A (2.0 lb/A) Ranger + 1.25 qt/A (1.25 lb/A) 2,4-D Amine on 9/6/91.

Fertilizer 1991

Material Analysis	Rate[3]	Actual N	P_2O_5	K_2O	S	Zn	Date Applied
	------ lb/A ------						
8-12-28-4-1[1]	150	12	18	11	6	2	5/8/91
46-0-0[2]	0	0	0	0	0	0	5/29/91
46-0-0[2]	65	30	0	0	0	0	5/29/91
46-0-0[2]	152	70	0	0	0	0	5/29/91
46-0-0[2]	239	110	0	0	0	0	5/29/91
46-0-0[2]	0	0	0	0	0	0	6/13/91
46-0-0[2]	65	30	0	0	0	0	6/13/91
46-0-0[2]	152	70	0	0	0	0	6/13/91
46-0-0[2]	239	110	0	0	0	0	6/13/91

1. Planter applied 2" below and 2" beside row.
2. Broadcast as urea and irrigated in.
3. The resulting N rates are: 12, 72, 152, and 232 lbs/A.

Table 2. Effect of tillage on soil cover by corn residue, and emergence from 5-15-91 to 5-29-91 at Wadena Co[1].

Tillage	Date 5/08/91 Residue[2] In Row	Bet Row	Date 5-15	5-17	5-20	5-21	5-23	5-29
			---------- plants/acre x 10^{-3} ----------					
No Till	70.2a	85.1a	1.8b	9.1a	24.1a	27.9a	33.3a	35.6a
Disk	30.7b	36.9b	3.6b	31.9b	41.7b	42.2b	42.5a	43.2a
Moldboard	5.7c	7.4c	12.1a	40.1c	42.6b	42.8b	43.1a	43.8a
Mean	35.5a	43.2b						
Signif. (Pr > F)			.006	.002	.001	.001	.004	.001

1. Means within the same column when followed by the same letter are not significantly different (α=.10).
2. The p value for residue location, tillage, and tillage by location interaction are .023 (n=48), .001 (n=32), .838 (n=16).

Fig 1. Effect of Tillage on corn emergence at Staples, Wadena Co., MN. 1991

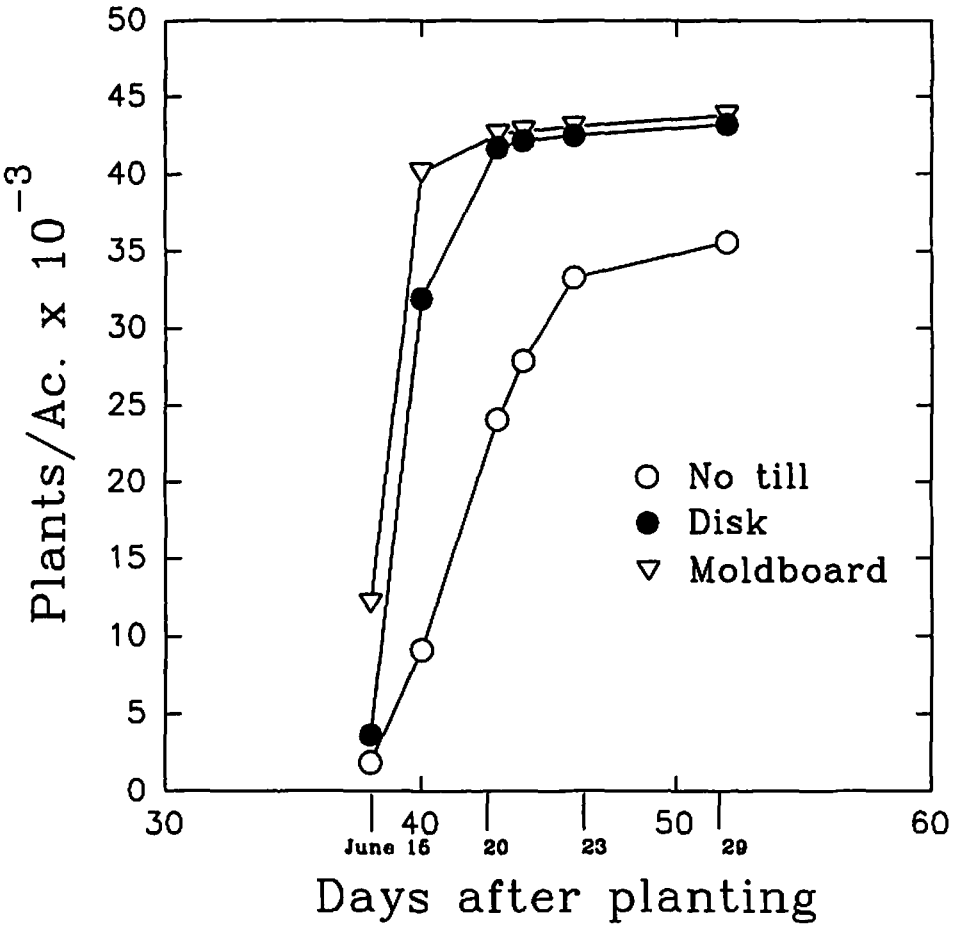


Fig 2. RESIDUE COVER VS. GRAIN MOISTURE
STAPLES, MN., 1991

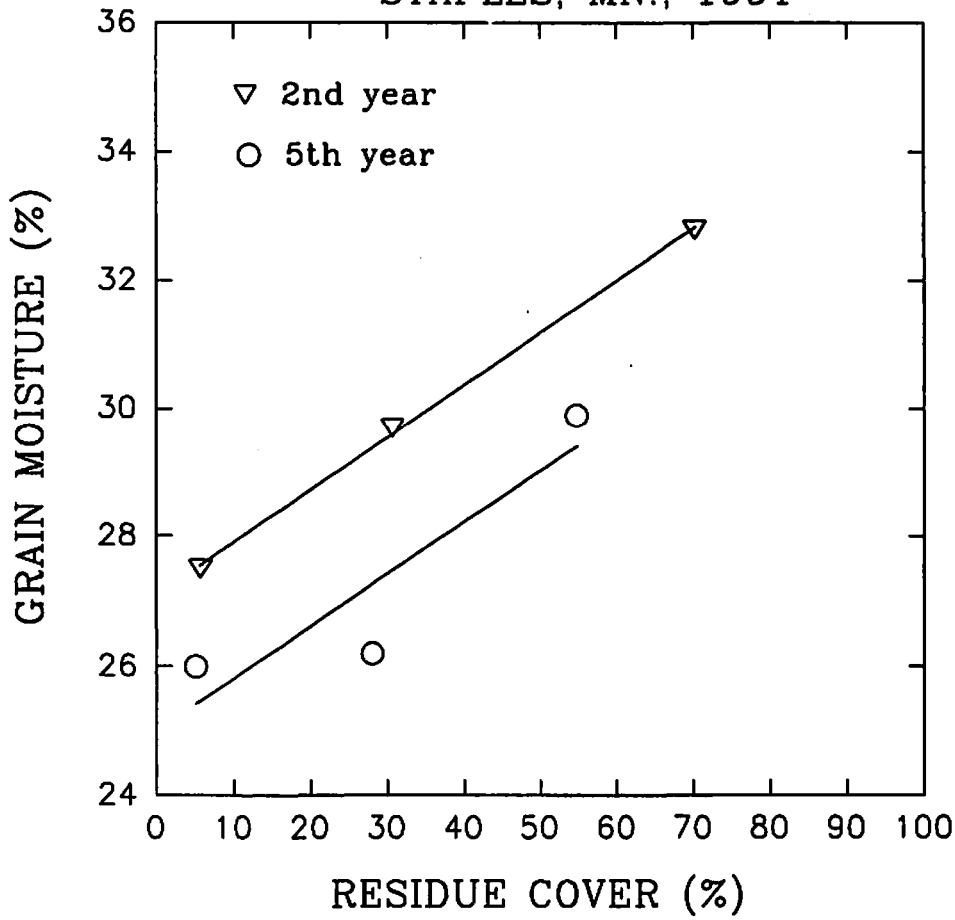


Figure 3.

STAPLES 1991 WATER NO3-N ANALYSIS
TILLAGE PLOTS

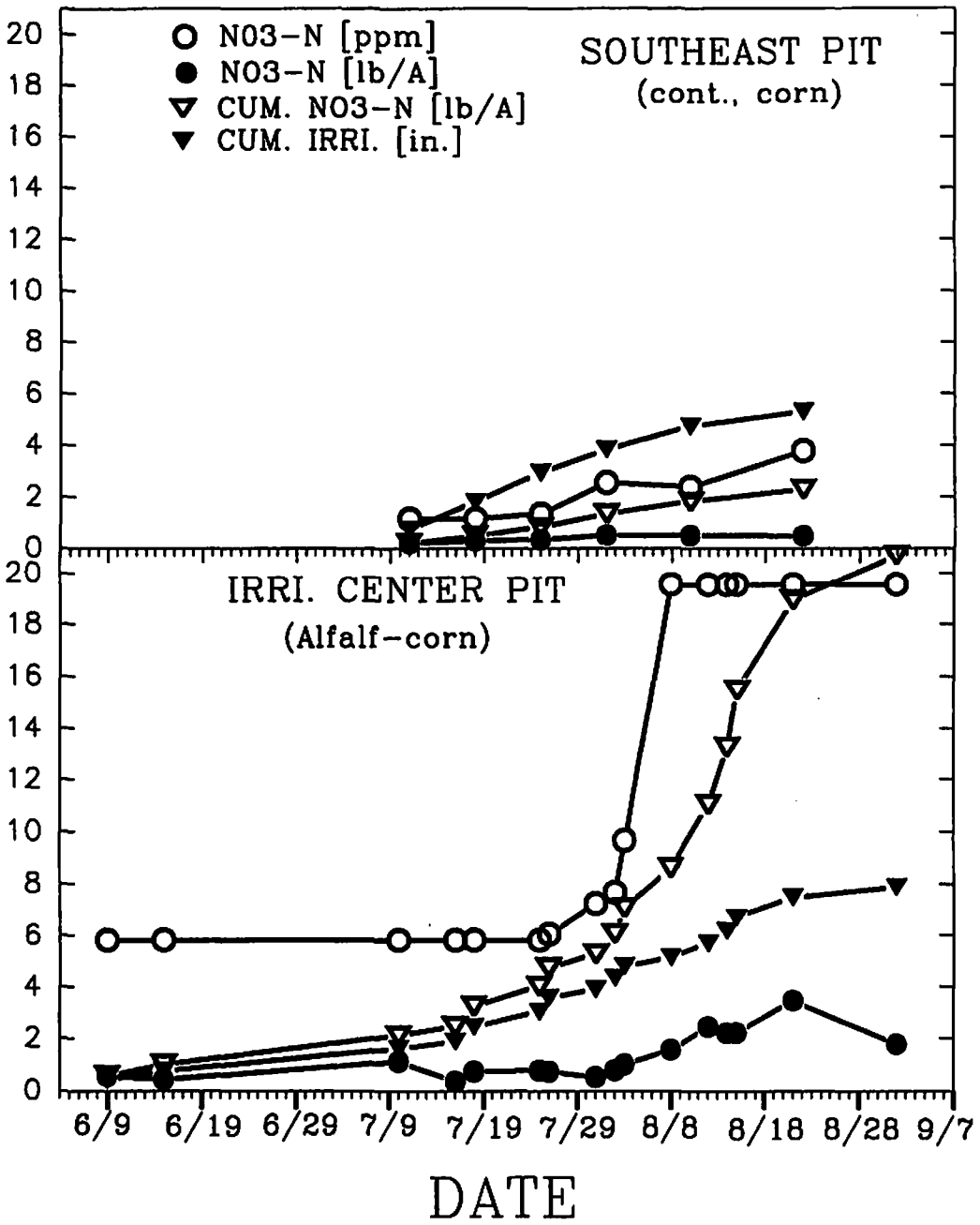


Table 3. Effect of tillage, nitrogen rate, and cultivation on corn response., 1991[1].

Treatment	Stover Moisture	Stover Yield	Grain Moisture	Grain Yield	Total D.M.	Harvest Index	Final Stand	Grain Protein	Grain N	Stover N	N uptake Grain	N uptake Stover	N uptake Total
	--%--	-T/A-	--%--	-bu/A-	-T/A-		Plants Ax10^{-3}	-------%---------			---------lb/A---------		
Tillage (n=32)													
No Till	56.5a	2.5a	32.8a	119.9a	5.4a	0.52a	35.1a	7.1a	1.14a	1.08a	67.6a	54.9a	122.5a
Disk	53.5b	2.4a	29.7b	127.1ab	5.4a	0.54a	37.7b	7.0a	1.13a	1.15b	71.0b	55.7a	126.7ab
Moldboard	49.0c	2.6a	27.5c	136.5b	5.8a	0.54a	38.5b	7.4a	1.18a	1.09a	79.8b	55.8a	135.6b
Sig. (Pr > F)	.003	.373	.000	.153	.241	.252	.006	.279	.276	.025	.022	.924	.084
N Rate lb N/A (n=24)													
12	57.8a	1.6a	33.3a	55.8a	3.0a	0.44a	37.0a	6.1a	.981a	1.07a	26.0a	35.0a	61.0a
72	56.9a	2.6b	29.7b	124.1b	5.6b	0.53b	37.7a	6.0a	.960a	.878b	56.7b	46.1b	102.8b
152	49.3b	2.9b	28.5b	168.6c	6.9c	0.58c	37.4a	8.1b	1.29b	1.18a	103.4c	68.2c	171.6c
232	48.0b	2.8b	28.5b	162.8c	6.7c	0.58c	36.2a	8.5c	1.36c	1.29c	105.2c	72.6c	177.8c
Sig. (Pr > F)	.000	.000	.000	.000	.000	.000	.754	.000	.000	.000	.000	.000	.000
Cultivation (n=48)													
Cultivation	52.5a	2.5a	29.8a	129.2a	5.6a	0.53a	36.6a	7.3a	1.17a	1.11a	74.8a	56.2a	131.0a
No Cultivation	53.5a	2.5a	30.3a	126.5a	5.5a	0.53a	37.5b	7.1b	1.13b	1.09a	70.9a	54.7b	125.0b
Sig. (Pr > F)	.402	.538	.195	.383	.362	.818	.099	.071	.070	.547	.115	.279	.036
Interactions													
Tillage X Cultivation (n=16)													
No Till W/	55.9	2.6	32.9	120.3	5.4	0.513	34.1	7.4	1.19	1.10	71.5	57.2	128.7
No Till W/O	57.2	2.5	32.7	119.4	5.3	0.519	36.0	6.8	1.08	1.06	63.7	52.6	116.4
Disk W/	53.8	2.4	29.5	129.0	5.4	0.544	37.3	7.1	1.13	1.13	72.5	53.7	126.2
Disk W/O	53.1	2.4	29.9	125.1	5.4	0.528	38.0	7.0	1.12	1.16	69.5	57.7	127.3
Mldbd W/	47.7	2.6	26.9	138.1	5.8	0.535	38.4	7.4	1.18	1.11	80.3	57.7	138.0
Mldbd W/O	50.3	2.5	28.2	134.9	5.7	0.541	38.5	7.4	1.18	1.06	79.3	53.8	133.2
Sig. (Pr > F)	.562	.421	.263	.916	.920	.230	.381	.050	.050	.566	.504	.020	.099
Tillage X N Rate lb N/A (n=16)													
Notill 12	59.1	1.6	35.5	52.5	2.8	0.44	35.1	6.0	.960	1.06	23.9	33.4	57.3
Notill 72	58.9	2.7	32.2	119.1	5.5	0.51	36.6	5.9	.946	.890	53.5	48.2	101.7
Notill 152	54.6	2.9	31.8	156.8	6.6	0.56	35.7	8.2	1.32	1.16	98.7	67.1	165.8
Notill 232	53.5	2.9	31.6	151.0	6.5	0.55	32.6	8.2	1.32	1.22	94.4	70.9	165.3
MEAN	56.5	2.5	32.8	119.9	5.4	0.52	35.1	7.1	1.14	1.08	67.6	54.9	122.5
Disk 12	56.6	1.6	33.0	52.6	2.8	0.44	36.1	6.1	.978	1.13	24.3	34.9	59.2
Disk 72	58.4	2.5	30.3	120.3	5.4	0.53	38.9	5.9	.941	.831	53.7	41.8	95.5
Disk 152	50.6	2.8	28.0	164.6	6.7	0.58	36.3	7.6	1.22	1.20	95.0	65.8	160.7
Disk 232	48.4	2.8	27.6	170.8	6.9	0.59	39.4	8.6	1.37	1.42	111.1	80.4	191.5
MEAN	53.5	2.4	29.7	127.1	5.4	0.54	37.7	7.1	1.13	1.15	71.0	55.7	126.7
Mldbd 12	57.7	1.8	31.4	62.3	3.3	0.44	39.9	6.3	1.01	1.03	29.7	36.6	66.4
Mldbd 72	53.4	2.6	26.7	132.8	5.8	0.54	37.5	6.2	.991	.911	62.9	48.3	111.3
Mldbd 152	42.8	3.1	25.9	184.2	7.4	0.59	40.2	8.3	1.33	1.17	116.4	71.7	188.1
Mldbd 232	42.0	2.7	26.1	166.7	6.6	0.59	36.2	8.8	1.40	1.24	110.1	66.5	176.6
MEAN	49.0	2.6	27.5	136.5	5.8	0.54	38.5	7.4	1.18	1.09	79.8	55.8	135.6
Sig. (Pr > F)	.262	.598	.824	.582	.624	.809	.340	.642	.642	.720	.420	.360	.315

1. Means within a column followed by the same letter are not significantly different at α=0.10 according to Duncan's Multiple Range Test. Means within the same column with the same mean are not significantly different.

Table 4a. Interaction of tillage, nitrogen rate, and cultivation on corn response., 1991.

Treatment		Stover Moisture		Stover Yield		Grain Moisture		Grain Yield		Total D.M.		Harvest Index		Final Stand	
		---%---		-T/A-		---%---		-bu/A-		-T/A-				Plants Ax10^{-3}	
Till x N Rate(lb/A)x Cult, n=4															
		C[1]	NC[2]	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC
NT	12	59.2	59.1	1.7	1.5	35.9	35.1	55.0	50.0	3.0	2.7	0.44	0.44	34.6	35.6
NT	72	59.4	58.4	2.6	2.8	32.3	32.1	120.5	117.8	5.5	5.6	0.52	0.50	33.3	39.8
NT	152	53.8	55.5	3.0	2.8	32.1	31.5	158.3	155.4	6.7	6.5	0.56	0.57	35.3	36.0
NT	232	51.4	55.6	3.0	2.9	31.3	32.0	147.4	154.5	6.5	6.5	0.54	0.56	33.1	32.7
MEAN		55.9	57.2	2.6	2.5	32.9	32.7	120.3	119.4	5.4	5.3	0.51	0.52	34.1	36.0
DISC	12	57.1	56.0	1.5	1.7	32.3	33.8	53.8	51.4	2.8	2.9	0.46	0.42	34.6	37.6
DISC	72	57.8	59.1	2.6	2.5	30.7	29.8	121.0	119.6	5.4	5.3	0.53	0.53	39.3	38.5
DISC	152	52.3	48.8	2.7	2.9	27.9	28.0	166.8	162.4	6.6	6.7	0.60	0.57	36.4	36.1
DISC	232	48.1	48.6	2.8	2.8	27.2	28.0	174.6	166.9	7.0	6.8	0.59	0.58	38.9	39.8
MEAN		53.8	53.1	2.4	2.4	29.5	29.9	129.0	125.1	5.5	5.4	0.54	0.53	37.3	38.0
MB	12	57.5	58.0	1.7	1.8	31.2	31.6	56.3	68.2	3.1	3.5	0.42	0.45	38.9	40.9
MB	72	52.2	54.6	2.7	2.6	25.7	27.7	141.6	124.0	6.1	5.5	0.54	0.53	37.5	37.6
MB	152	40.4	45.3	2.9	3.2	24.6	27.1	184.3	184.2	7.3	7.6	0.60	0.58	40.5	39.8
MB	232	40.6	43.5	2.9	2.5	26.0	26.3	170.4	163.1	6.9	6.3	0.60	0.61	36.7	35.7
MEAN		47.7	50.3	2.6	2.5	26.9	28.2	138.1	134.9	5.8	5.7	0.54	0.54	38.4	38.5
SIG. (Pr> F)		.960		.171		.603		.677		.409		.329		.242	

1. C = cultivated.
2. NC= not cultivated.

Table 4b. Interaction of tillage, nitrogen rate, and cultivation on various corn response at Wadena Co., 1991.

Treatment		Grain Protein		Grain Nitrogen		Stover Nitrogen		N uptake Grain		N uptake Stover		N uptake Total	
		----------%----------						----------lb/A----------					
Till x N Rate(lb/A)x Cult, (n=4)													
		C	NC	C	NC	C	NC	C	NC	C	NC	C	NC
NT	12	6.0	6.0	.955	.965	1.03	1.10	25.0	22.8	34.4	32.5	59.3	55.3
NT	72	6.1	5.7	.982	.910	.932	.848	56.1	50.8	49.4	47.1	105.5	97.9
NT	152	9.0	7.4	1.44	1.19	1.15	1.16	95.2	87.7	68.6	65.6	163.8	153.3
NT	232	8.5	8.0	1.36	1.27	1.28	1.15	109.7	93.6	76.4	65.4	186.1	159.0
MEAN		7.4	6.8	1.19	1.08	1.10	1.06	71.5	63.7	57.2	52.6	128.7	116.4
DISC	12	6.1	6.1	.975	.980	1.19	1.08	24.7	23.9	33.8	36.1	58.5	59.9
DISC	72	5.9	5.9	.942	.940	.870	.792	54.0	53.4	44.5	39.0	98.5	92.4
DISC	152	7.7	7.6	1.23	1.21	1.23	1.17	97.1	92.9	64.9	66.6	162.0	159.5
DISC	232	8.6	8.6	1.38	1.37	1.24	1.60	114.2	108.0	71.5	89.2	185.8	197.2
MEAN		7.1	7.0	1.13	1.12	1.13	1.16	72.5	69.5	53.7	57.7	126.2	127.3
MB	12	6.3	6.3	1.01	1.00	1.02	1.03	26.9	32.6	35.2	38.1	62.0	70.7
MB	72	6.2	6.1	1.00	.982	.938	.885	67.8	58.1	51.0	45.7	118.8	103.8
MB	152	8.2	8.4	1.31	1.35	1.24	1.10	114.2	118.7	72.6	70.8	186.8	189.4
MB	232	8.8	8.8	1.40	1.40	1.25	1.23	112.3	107.9	72.1	60.9	184.4	168.8
MEAN		7.4	7.4	1.18	1.18	1.11	1.06	80.3	79.3	57.7	53.8	138.0	133.2
SIG. (Pr> F)		.373		.376		.064		.546		.012		.222	

1. C = cultivated.
2. NC= not cultivated.

FIGURE 4.

SOIL WATER NITRATE BY DEPTH IN 2nd YEAR CORN FOLLOWING ALFALFA

STAPLES 1991

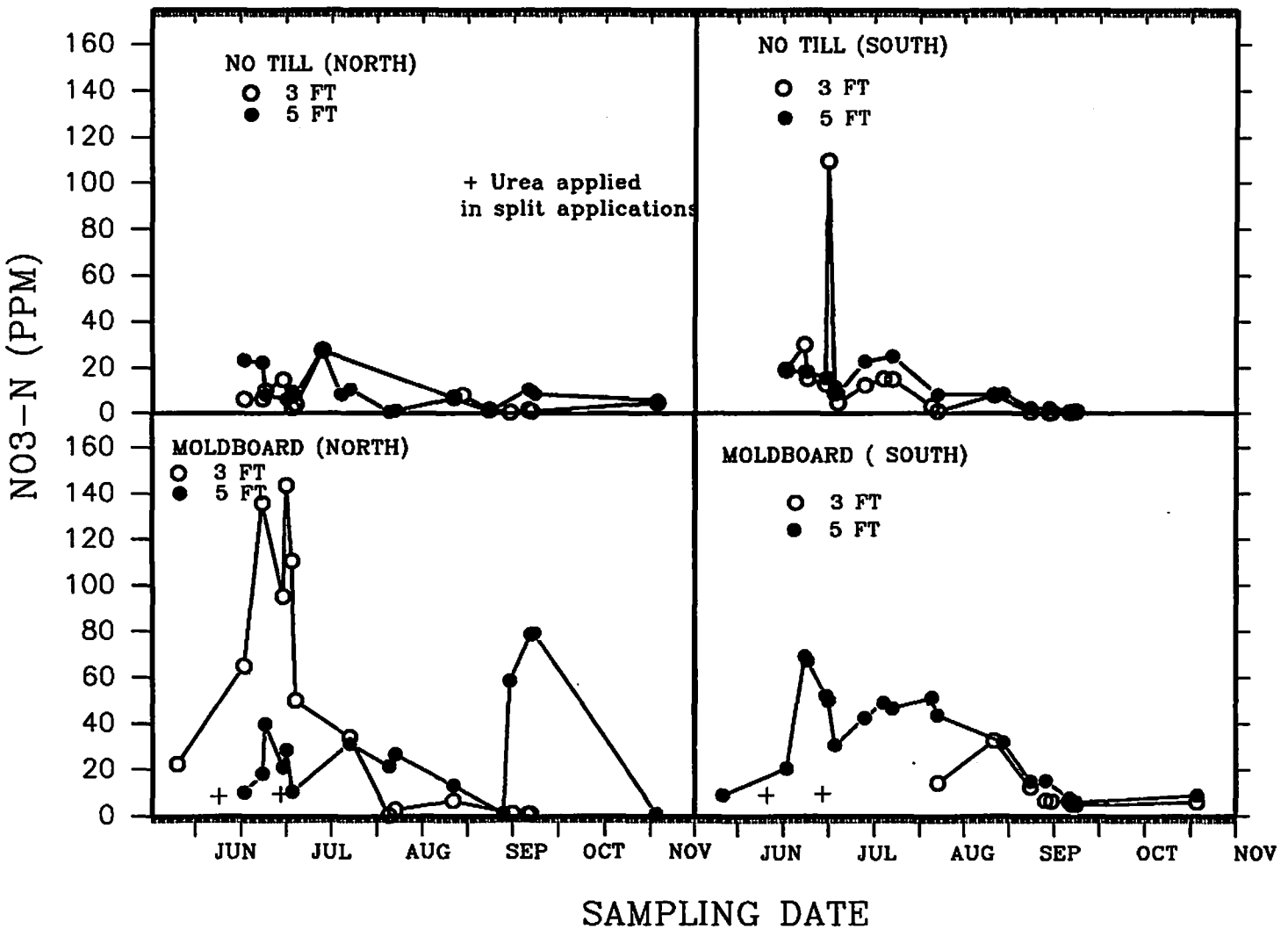
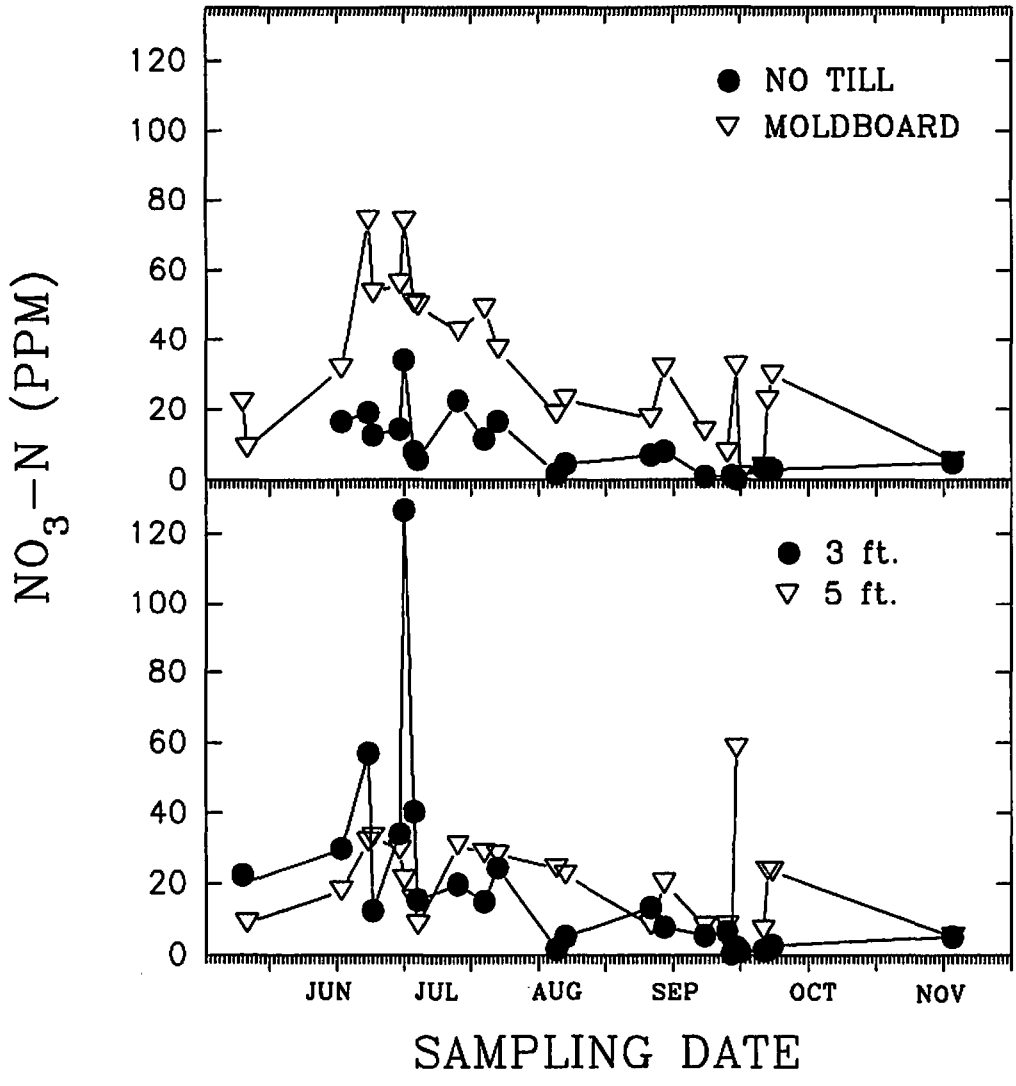


FIGURE 5.

SOIL WATER NITRATE IN 2nd YEAR CORN FOLLOWING ALFALFA AT STAPLES 1991



Tillage effects on N available to irrigated corn from turkey manure and urea N sources[1]

J.F. Moncrief, M.J. Wiens, N. Krause, and B.J. Johnson[2]

This is the fifth year of a tillage and urea study on irrigated corn on a sandy soil that has had a turkey manure treatment introduced in 1990. In 1991 residual benefits of manure applied in 1990 was evaluated. This study is divided into two substudies: tillage by manure rate by cultivation and tillage by urea rate. The presence of corn residue in the row area over 59% delayed corn phenology by two weeks. It did not reduce plant stands if residue was shallowly incorporated with discing. Stands were reduced less if row cleaners were used to clear the row area. Turkey manure performed better in supplying N to corn as tillage was increased to incorporate it. Cultivation also increased the N available to corn from turkey manure, although only subtly. Corn did not respond beyond the 137 pound per acre rate of applied urea. Tillage limited the N response with the conservation treatments. Disc row cleaners increased stands and phenology although effects on soil cover were small.

This is the second year of a two year study to investigate the effect of tillage on the availability of N to corn from urea and turkey manure. Previous to the introduction of the manure variable (since 1987) urea fertilizer was the sole N source and this field was in alfalfa in 1986. Tillage treatments are shown in table 1 (moldboard plowing, spring discing, and no tillage). A small amount of urea was applied with the planter (24 lbs/acre) and the remainder split between 4-6 and 8-12 leaf growth stage of corn. Turkey manure was applied in the spring of 1990 before tillage. There was no additional nitrogen applied to turkey manured plots in 1991. Manure analysis is shown in tables 2 and 3. It is estimated that 12 and 20 lbs N/acre will be crop available in 1991 for the two rates of turkey manure applied in 1990.

Irrigation amounts for this and the companion study evaluating second year corn following alfalfa (summarized separately) are shown in figure 1. The water source for this study is the southeast pit. About 2 lbs N/acre was applied with irrigation water (see companion study paper).

This is the fifth year of corn. The previous three years averaged about a 190 bushel per acre grain yield. This left corn residue levels quite high under no till conditions. Row cleaners reduced soil cover by corn residue from 84 to 55% (table 4). Spring discing plots had soil cover reduced from 40 to 28% with the planter mounted clearing discs. The cover by corn residue in the row affects corn emergence and growth.

Corn Response to Residual Turkey Manure

Final stands were reduced 4 thousand plants per acre under no till conditions and only slightly affected by discing (table 5). Conservation tillage systems reduced yield and N uptake from residual turkey manure. Even though the differences in estimated crop available N were small, there was a measurable difference in yield and N uptake between the two rates of turkey manure applied in 1990.

Cultivation also increased yields and N uptake. There was a significant interaction between tillage and cultivation on grain yields. The cultivation response was greatest under no till conditions, followed by moldboard plowing, with the smallest response under spring discing. This is consistent with the response from residual alfalfa N in a companion study.

Corn Response to Urea

Tillage and N rate effects on corn are shown in table 6. No tillage increased grain moisture by about 4%. Yields and grain moisture were similar for the moldboard and discing systems. Tillage did not affect the N uptake from applied urea. Corn responded to about 160 lbs N/acre. There were no significant interactions between tillage and N rate.

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[1] *Support for this project was provided by the Agricultural Utilization and Research Institute, the Staples Irrigation Center, and the Soil Conservation Service. Their support is greatly appreciated.*

[2] *J.F. Moncrief and B.J. Johnson are Associate Professor and Assistant Scientist in the Soil Science Department at the University of Minnesota, St. Paul, MN, 55108. M.J. Wiens and N. Krause are Senior Plot Coordinator and Center Director at the Staples Irrigation Center, Staples Area Technical College, Staples, MN.*

Soil Water Nitrate

Soil water access tubes (PVC with ceramic cup) were installed in duplicate at 3 and 5 feet deep in one replication of the high urea and turkey manure treatments. Water samples were taken by applying 1/2 bar of suction on the sample tubes. Samples were taken from June until December. Since only one replication was monitored the values are graphically presented over time but no statistical test are possible.

Figure 2 shows the effect of tillage, N source, and depth on the concentration of nitrate over the 1990 (year of application of turkey manure) growing season. Concentrations declined with the season for both sources. Individual plot data are shown in figure 3. There are large differences between plots which make it difficult to establish treatment trends.

Soil water nitrate concentration data for 1991 are similarly shown in figures 4 and 5. Concentrations are generally lower than in 1990. Urea resulted in higher soil water concentrations as would be expected since no further N was applied to turkey manure plots.

Table 1. Cultural practices at Staples Irrigation Center, MN. 1991.

Tillage
No Till
Spring Disc and Moldboard Plow: 5/7/91
Cultivation on: 6/13/91

Previous Crop
1984-86 Alfalfa, 1987-90 Corn

1991 Crop
Corn-Pioneer 3790

Soil
The soil at this site is a Verndale sandy loam (Udic Argiborolls, coarse-loamy, mixed) with a slope of 0 to 2 percent. The soil is well drained.

Planting and Harvest Date

The planter is a 4 row Deutz-Allis Model 385 with 30 inch row spacing, equipped with 2 inch fluted coulters and disc row cleaners.

	Planting	
Crop	Date	Rate
Corn	May 8, 1991	44,000 seeds/A

Harvested	
Grain	Stover
September 8, 1991	September 20,1991

Fertilizer 1987

Material	Rate[3]	Actual N	P_2O_5	K_2O	S	
Analysis	--------	lb/A	--------			Date Applied
17-7-23-6[1]	93	16	6	21	6	5/11/87
46-0-0[2]	0	0	0	0	0	6/16/87
46-0-0[2]	75	35	0	0	0	6/16/87
46-0-0[2]	146	67	0	0	0	6/16/87
46-0-0[2]	221	102	0	0	0	6/16/87

1. Planter applied 2" below and 2" beside row.
2. Broadcast as urea and irrigated in.
3. The resulting N rates are: 16, 51, 83, and 118 lbs/A.

Fertilizer 1988

Material	Rate[3]	Actual N	P_2O_5	K_2O	S	
Analysis	--------	lb/A	--------			Date Applied
24-8-15-8[1]	85	20	7	13	7	4/27/88
46-0-0[2]	0	0	0	0	0	6/1/88
46-0-0[2]	137	63	0	0	0	6/1/88
46-0-0[2]	254	117	0	0	0	6/1/88
46-0-0[2]	400	184	0	0	0	6/1/88

1. Planter applied 2" below and 2" beside row.
2. Broadcast as urea and irrigated in.
3. The resulting N rates are: 20, 83, 137, and 204 lbs/A.

Fertilizer 1989

Material	Rate[3]	Actual N	P_2O_5	K_2O	S	
Analysis	-------	lb/A	------			Date Applied
20-7-20-7[1]	95	19	7	19	7	5/10/89
46-0-0[2]	0	0	0	0	0	5/6/89
46-0-0[2]	72	33	0	0	0	5/6/89
46-0-0[2]	139	64	0	0	0	5/6/89
46-0-0[2]	207	95	0	0	0	5/6/89
46-0-0[2]	0	0	0	0	0	5/30/89
46-0-0[2]	70	32	0	0	0	5/30/89
46-0-0[2]	139	64	0	0	0	5/30/89
46-0-0[2]	200	92	0	0	0	5/30/89

1. Planter applied 2" below and 2" beside row.
2. Broadcast as urea and irrigated in.
3. The resulting N rates are: 19, 84, 147, and 206 lb/A.

1990 Fertilizer

Material Analysis	Rate[3]	Actual N	Actual P_2O_5	Actual K_2O	Actual S	Date Applied
	-------- lb/A -------					
20-5-30-10[1]	87	17	4	26	9	5/7/90
46-0-0[2]	0	0	0	0	0	6/29/90
46-0-0[2]	113	52	0	0	0	6/29/90
46-0-0[2]	261	120	0	0	0	6/29/90
46-0-0[2]	457	210	0	0	0	6/29/90

1. Planter applied 2" below and 2" beside row on all plots.
2. Broadcast as urea and irrigated in.
3. The resulting N rates are: 17, 69, 137, and 227 lb/A.

Fertilizer 1991

Material Analysis	Rate[3]	Actual N	Actual P_2O_5	Actual K_2O	Actual S	Date Applied
	------ lb/A ------					
16-5-25-8[1]	150	24	6	38	12	5/8/91
46-0-0[2]	0	0	0	0	0	5/29/91
46-0-0[2]	65	30	0	0	0	5/29/91
46-0-0[2]	152	70	0	0	0	5/29/91
46-0-0[2]	239	110	0	0	0	5/29/91
46-0-0[2]	0	0	0	0	0	6/13/91
46-0-0[2]	65	30	0	0	0	6/13/91
46-0-0[2]	152	70	0	0	0	6/13/91
46-0-0[2]	239	110	0	0	0	6/13/91

1. Planter applied 2" below and 2" beside row.
2. Broadcast as urea and irrigated in.
3. The resulting N rates are: 24, 84, 164, and 244 lbs/A.

Weed Control

3.0 pt/A (3.0 lb/A) Bladex + 1.5 pt/A (1.5 lb/A) Dual on 5/10/91.
1.0 qt/A (1.0 lb/A) Roundup spot sprayed on 5/22/91.
2.0 qt/A (2.0 lb/A) Ranger + 1.25 qt/A (1.25 lb/A) 2,4-D Amine on 9/6/91.

Table 2. Analysis and rate of application of manure (4/24/90).

Manure Source	Date Applied	Rate	Solids	NH_4	NO_3	Total Mineral N	Organic N	Total N	Total P	Total K
		t/A	- % --	----------	----------	%	----------	----------	----------	----------
Turkey[1]	4/24/90	4.0	55.1	.87	.05	.91	1.01	1.92	.35	.42
		6.7	55.1	.87	.05	.91	1.01	1.92	.35	.42

1. Collected in the fall of 1989 and stored untill application at Staples Irrigation Center.

Table 3. Rate applied, and value[1] of nitrogen[2], phosphorus, and potassium(4/24/90).

Manure Source	Mineral	Organic	Total Nitrogen	Value	Available N Manure '90	Available N Manure '91	Available N + Starter '90	Available N + Starter '91	P_2O_5	Value	K_2O	Value
	-- Applied N lb/acre ---			$	---- lb/A -------				lb/A	$	lb/A	$
Turkey	73	81	154	20.02	97	12	114	36	64	13.22	40	4.59
	122	136	258	33.54	163	20	180	44	107	22.10	68	7.81

1. It is assumed that fertilizer cost .13, .21, and .12 per pound of N, P_2O_5, and K_2O, respectively.
2. It is assumed that all of the mineral N and 30% of the organic N will be available during the year of application and 15% of organic N in the year after application.

Table 4. Effect of tillage on soil cover by corn and litter residue at Wadena County[1].

Location	Tillage No Till	Tillage Disk	Tillage Moldboard	Avg
	----------	% cover	----------	- % -
In Row	54.8a	28.0b	5.1c	29.3b
Between Row	83.9a	39.9b	3.0c	42.3a
Average	69.3a	33.9b	4.0c	35.8

1. The p value for residue location, tillage, and tillage by location interaction are .001 (n=48),.001 (n=32), .019 (n=16). Means within the same row with the same letter are not signficantly different (α=.10).

Table 5. Effect of tillage and nitrogen rate as manure on corn response, 1991[1].

Treatment	Grain Moisture	Grain Yield	Final Stand	Stover Moisture	Stover Yield	Total D.M.	Harvest Index	Grain Prot.	Grain N	Stover N	N uptake Grain	N uptake Stover	N uptake Total
	--%--	bu/A	Plant Ax10^{-3}	--%--	-T/A-	-T/A-		-------%--------			-------lb/A--------		
Tillage													
No Till	29.4a	41.0a	38.4a	59.2a	1.4a	2.4a	.385a	5.8a	.929a	.883a	17.8a	25.1a	42.2a
Disk	26.8b	46.1a	42.4b	55.0a	1.6b	2.7b	.398a	5.8a	.932a	.792b	20.5b	24.9a	45.9a
Mldbd	26.5c	63.7b	42.1b	56.2a	2.0c	3.4c	.423a	5.9a	.948a	.819ab	25.8b	32.1b	60.2b
Sig. (Pr > F)	.026	.008	.070	.169	.000	.002	.613	.509	.509	.126	.003	.016	.003
N Rate (n=48)[2]													
36 lb N/A	27.2a	46.9a	41.2a	56.8a	1.6a	2.7a	.380a	5.9a	.942a	.820a	20.8a	26.8a	47.0a
44 lb N/A	27.9a	54.3b	40.7a	56.8a	1.7a	3.0b	.425b	5.8a	.931a	.873a	23.8b	27.9a	51.8b
Sig. (Pr > F)	.212	.022	.614	.962	.486	.032	.040	.343	.343	.297	.030	.183	.047
Cultivation													
W/ Cult	27.4a	58.4a	41.5a	57.4a	1.6a	3.0a	.443a	5.8a	.929a	.810a	25.6a	26.7a	51.7a
W/O Cult	27.7a	42.7b	40.0a	56.1b	1.6a	2.7b	.361b	5.9b	.944b	.853a	19.0b	28.1a	47.2b
Sig. (Pr > F)	.653	.000	.283	.145	.890	.002	.000	.085	.085	.155	.000	.269	.036

1. Means within the same column with the same letter are not significantly different.
2. N rate was determined from Table 3.

Interactions

Tillage x N Rate (lb/A, n=16)														
Notill	36	29.0	36.8	39.0	58.9	1.4	2.2	.361	5.9	.944	.820	16.3	23.1	38.1
Notill	44	29.7	45.3	37.8	59.4	1.4	2.5	.409	5.7	.914	.946	19.4	27.1	46.3
Disk	36	26.1	41.8	43.1	54.7	1.6	2.6	.351	5.7	.918	.819	17.8	26.2	43.4
Disk	44	27.5	52.1	41.6	55.2	1.5	2.8	.445	5.9	.946	.766	23.2	23.7	48.4
Mldbd	36	26.4	62.0	41.6	56.8	1.9	3.4	.426	6.0	.963	.821	28.2	31.3	59.6
Mldbd	44	26.6	65.4	42.6	55.7	2.0	3.5	.420	5.8	.933	.816	28.8	32.9	60.8
Sig. (Pr > F)		.675	.570	.588	.633	.250	.811	.148	.074	.074	.017	.304	.015	.424
Tillage x Cultivation (n=16)														
No Till W/		29.2	52.1	39.1	59.4	1.4	2.6	.456	5.7	.912	.816	22.4	23.2	44.8
No Till W/O		29.5	29.9	37.7	58.8	1.4	2.1	.314	5.9	.945	.950	13.4	27.0	39.7
Disk W/		27.1	51.0	42.4	55.2	1.6	2.7	.412	5.8	.931	.822	22.2	25.7	47.1
Disk W/O		26.5	43.0	42.3	54.7	1.6	2.7	.383	5.8	.932	.762	18.8	24.1	44.7
Mldbd W/		26.0	72.3	42.8	57.6	2.0	3.7	.462	5.9	.942	.791	32.2	31.0	63.2
Mldbd W/O		27.0	55.1	41.3	54.8	2.0	3.2	.385	6.0	.954	.846	24.8	33.1	57.1
Sig. (Pr > F)		.483	.034	.791	.480	.954	.101	.061	.321	.321	.042	.047	.216	.739
Nrate (Lb N/A) x Cultivation (n=24)														
36 W/Cult		27.1	56.1	41.5	57.4	1.6	2.9	.434	5.8	.932	.800	24.7	26.2	50.5
36 W/O Cult		27.2	37.6	40.9	56.2	1.6	2.5	.325	5.9	.950	.840	16.8	27.5	43.6
44 W/Cult		27.7	60.8	41.4	57.4	1.7	3.1	.453	5.8	.925	.820	26.4	27.2	52.9
44 W/O Cult		28.1	47.8	40.0	56.1	1.7	2.8	.396	5.9	.937	.866	21.2	28.6	50.8
Sig. (Pr > F)		.848	.216	.664	.998	.897	.313	.156	.735	.735	.921	.160	.978	.245
Till X N Rate X Cultivation (n=8)														
NT	36 W/	28.7	47.3	39.2	57.9	1.3	2.3	.430	5.9	.939	.735	21.0	19.5	38.4
NT	36 W/O	29.4	26.2	38.8	59.9	1.5	2.1	.293	5.9	.949	.905	11.6	26.7	37.8
NT	44 W/	29.7	56.9	39.1	61.0	1.5	2.9	.482	5.5	.886	.898	23.8	26.9	51.1
NT	44 W/O	29.7	33.6	36.6	57.8	1.4	2.1	.336	5.9	.941	.995	14.9	27.2	41.5
Disk	36 W/	26.4	50.1	42.2	56.3	1.6	2.8	.403	5.6	.904	.880	21.1	28.6	49.3
Disk	36 W/O	25.8	33.6	43.9	53.0	1.6	2.3	.299	5.8	.931	.758	14.4	23.8	37.5
Disk	44 W/	27.8	50.1	42.6	54.1	1.5	2.6	.422	6.0	.959	.765	23.2	22.9	44.8
Disk	44 W/O	27.2	51.8	40.7	56.4	1.6	3.0	.467	5.8	.934	.768	23.2	24.5	51.9
Mb	36 W/	26.2	71.0	43.1	58.1	1.9	3.7	.470	6.0	.955	.785	32.1	30.5	63.7
Mb	36 W/O	26.6	53.0	40.1	55.5	1.9	3.1	.383	6.1	.971	.858	24.3	32.1	55.4
Mb	44 W/	25.7	73.6	42.6	57.1	2.0	3.7	.454	5.8	.930	.797	32.3	31.6	62.7
Mb	44 W/O	27.4	57.2	42.6	54.2	2.0	3.3	.386	5.8	.936	.835	25.4	34.1	58.8
Sig. (Pr > F)		.774	.174	.346	.054	.121	.022	.186	.074	.074	.355	.329	.108	.034

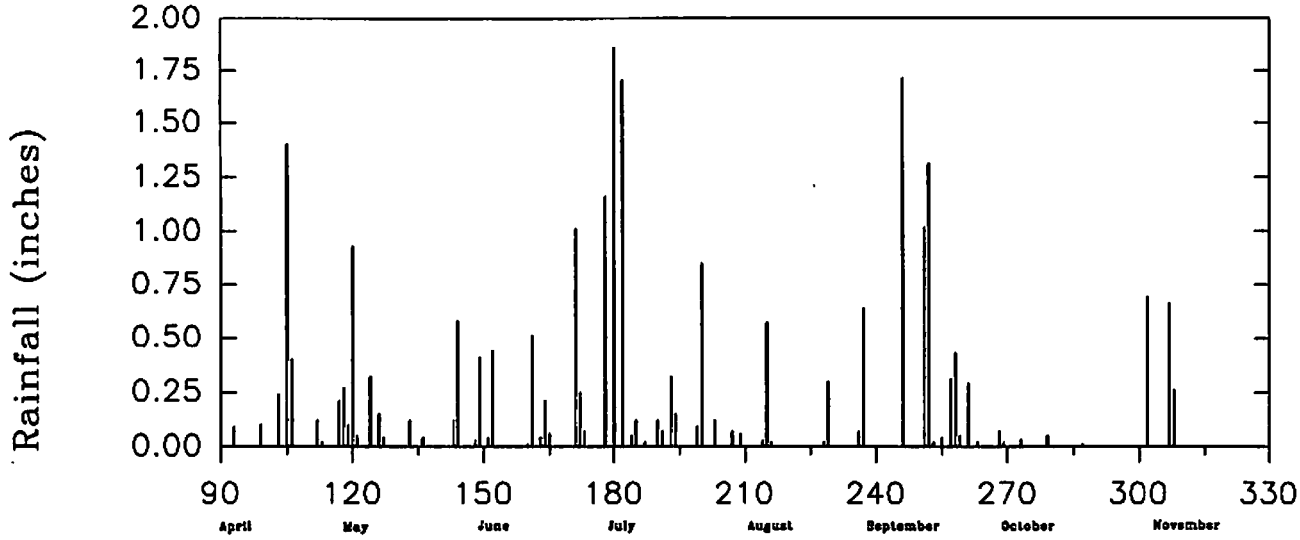
Table 6. Effect of tillage and urea nitrogen rate on corn response.,1991[1].

Treatment	Grain Moisture	Grain Yield	Final Stand	Stover Moisture	Stover Yield	Total D.M.	Harvest Index	Grain Protien N	Grain N	Stover N	N uptake Grain	N uptake Stover	N uptake Total
	--%--	bu/A	Plant Ax10^{-3}	--%--	-T/A-	-T/A-		-------%---------			---------lb /A---------		
Tillage (n=16)													
No Till	29.9a	113.8a	37.5a	57.9a	2.1a	4.8a	.532a	6.3a	1.01a	1.05a	56.2a	45.6a	101.8a
Disk	26.2b	128.8b	41.6b	55.2a	2.2a	5.3ab	.555a	6.3a	1.06a	1.04a	67.6ab	46.5a	114.1a
Moldboard	26.0b	131.8b	38.6b	52.9a	2.4a	5.5b	.531a	6.7a	1.07a	1.08a	70.3b	53.2a	123.5a
Sig. (Pr > F)	.005	.039	.127	.277	.199	.077	.262	.532	.532	.801	.138	.395	.214
N Rate (n=12)													
24 lb N/A	26.6a	55.4a	41.5a	55.8ab	1.8a	3.1a	.400a	5.7a	.915a	.880a	24.4a	31.9a	56.3a
84 lb N/A	26.9a	123.5b	41.1a	55.9ab	2.4b	5.3b	.546b	5.8a	.929a	.872a	54.8b	42.0b	96.8b
164 lb N/A	26.7a	164.6c	39.2ab	53.0a	2.5b	6.4c	.612c	7.0b	1.12b	1.10b	88.1c	54.4c	142.5c
244 lb N/A	29.3b	155.9c	35.1b	56.6b	2.3b	6.0ab	.601ab	7.6c	1.22c	1.38c	91.6c	65.3d	156.9c
Sig. (Pr > F)	.011	.000	.055	.218	.000	.000	.000	.000	.000	.000	.000	.000	.000

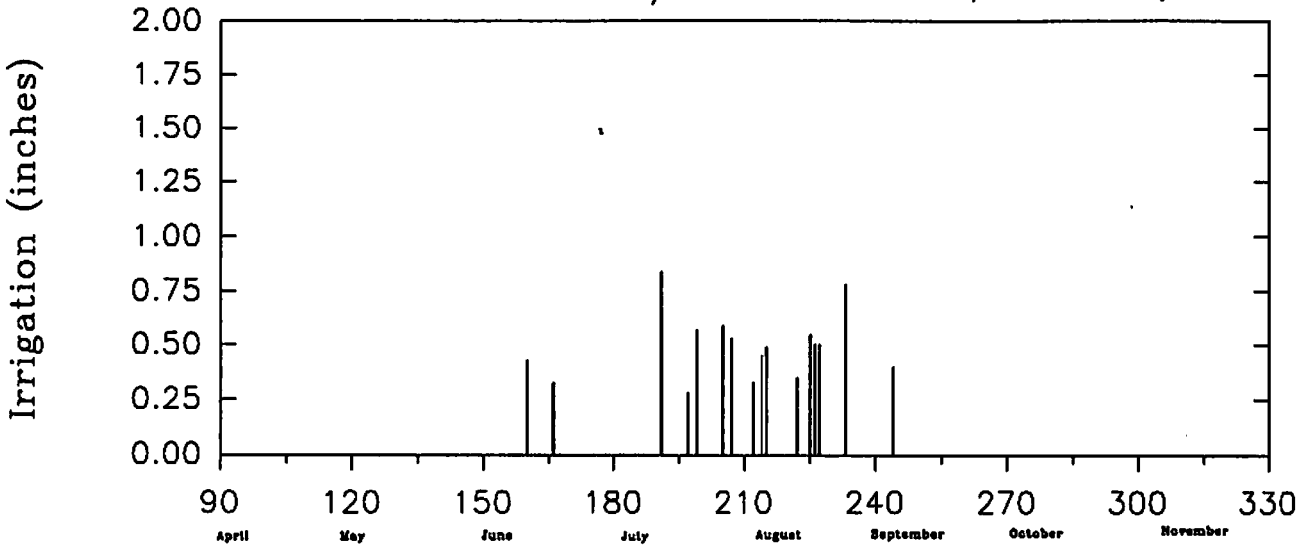
1. Means within the same column with the same letter are not significantly different.

Interactions													
Tillage X N Rate Lb N/A (n=8)													
No Till	24	28.3	43.4	39.5	56.3	1.6	2.6	.398	5.6	.898	.915	18.4	28.4	46.9
No Till	84	29.3	107.4	39.3	57.8	2.3	4.9	.524	5.5	.880	.892	44.7	41.0	85.7
No Till	164	29.9	158.5	38.8	57.5	2.5	6.3	.599	6.7	1.07	1.20	80.4	60.9	141.3
No Till	244	32.2	145.9	32.4	60.1	2.2	5.7	.609	7.4	1.18	1.19	81.2	52.1	133.3
Disk	24	24.8	52.6	45.5	54.9	1.9	3.2	.387	5.7	.908	.778	22.6	30.7	53.3
Disk	84	26.1	119.5	43.6	55.4	2.3	5.1	.551	5.9	.940	.850	53.2	39.2	92.4
Disk	164	25.8	177.5	41.8	52.4	2.4	6.6	.638	7.3	1.17	1.09	98.0	52.1	150.1
Disk	244	28.4	165.5	35.4	57.9	2.2	6.1	.644	7.7	1.23	1.44	96.7	63.8	160.5
Mldbd	24	26.9	70.0	39.6	56.0	1.9	3.6	.413	5.9	.940	.948	32.1	36.7	68.8
Mldbd	84	25.4	143.5	40.5	54.5	2.6	6.0	.562	6.0	.968	.875	66.4	45.8	112.2
Mldbd	164	24.4	157.7	36.9	49.2	2.5	6.2	.599	7.1	1.14	1.01	85.8	50.2	135.9
Mldbd	244	27.4	156.2	37.5	51.9	2.6	6.3	.549	7.8	1.25	1.50	96.9	80.1	176.9
Sig. (Pr > F)		.510	.868	.860	.478	.608	.903	.777	.967	.967	.051	.928	.114	.763

Fig 1. PRECIPITATION, STAPLES, MN., 1991



IRRIGATION ON CORN/ALFALFA STUDY, STAPLES,1991



IRRIGATION ON CORN/CORN STUDY, STAPLES, 1991

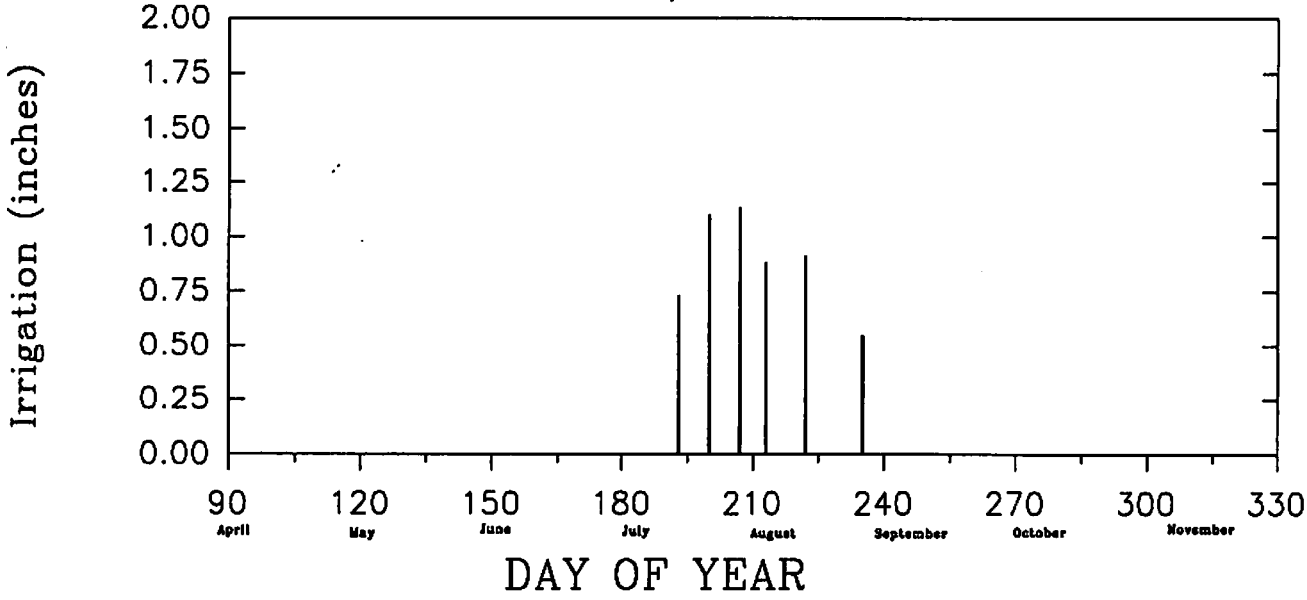


FIGURE 2.
SOIL WATER NITRATE IN CORN
FOLLOWING CORN AT STAPLES 1990

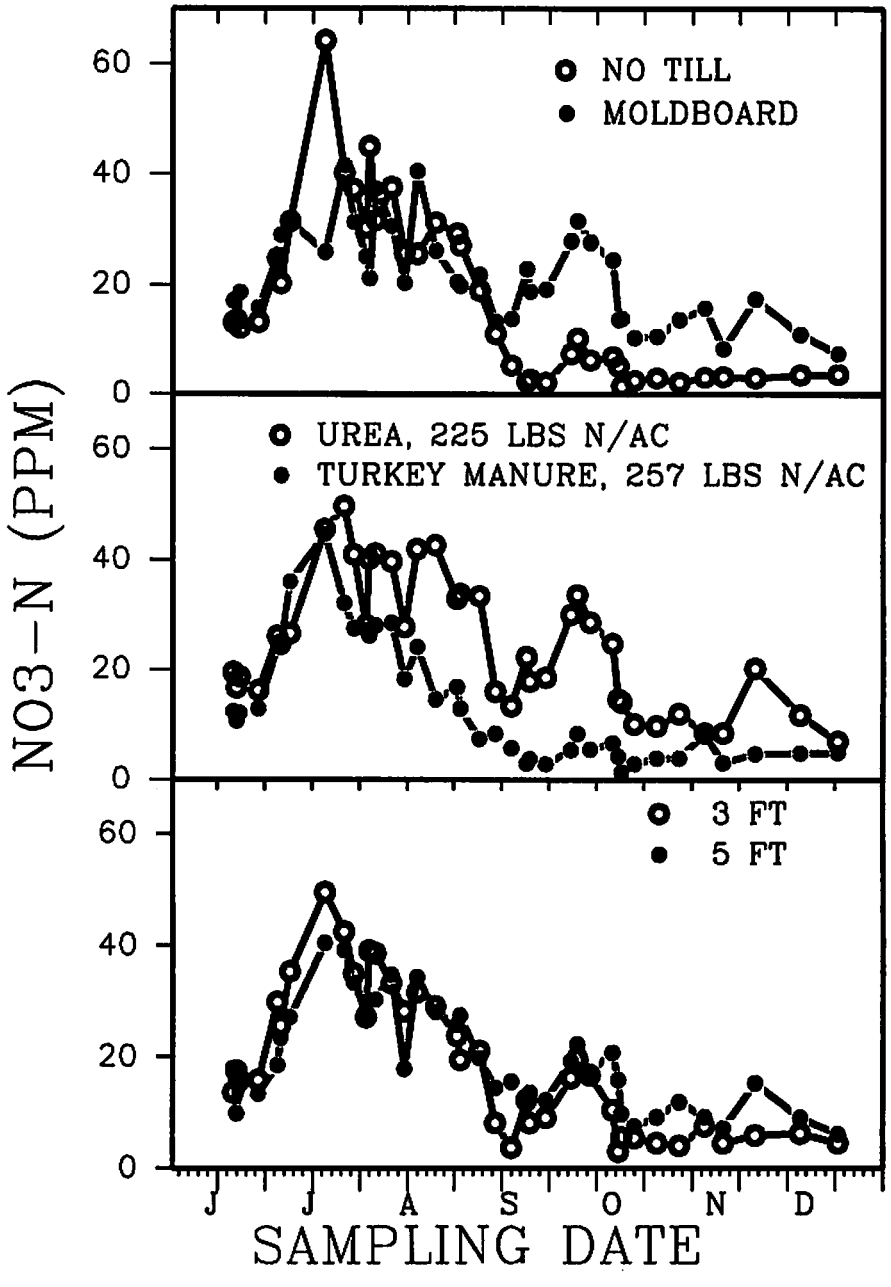


FIGURE 3.

SOIL WATER NITRATE BY DEPTH IN CORN FOLLOWING CORN

STAPLES 1990

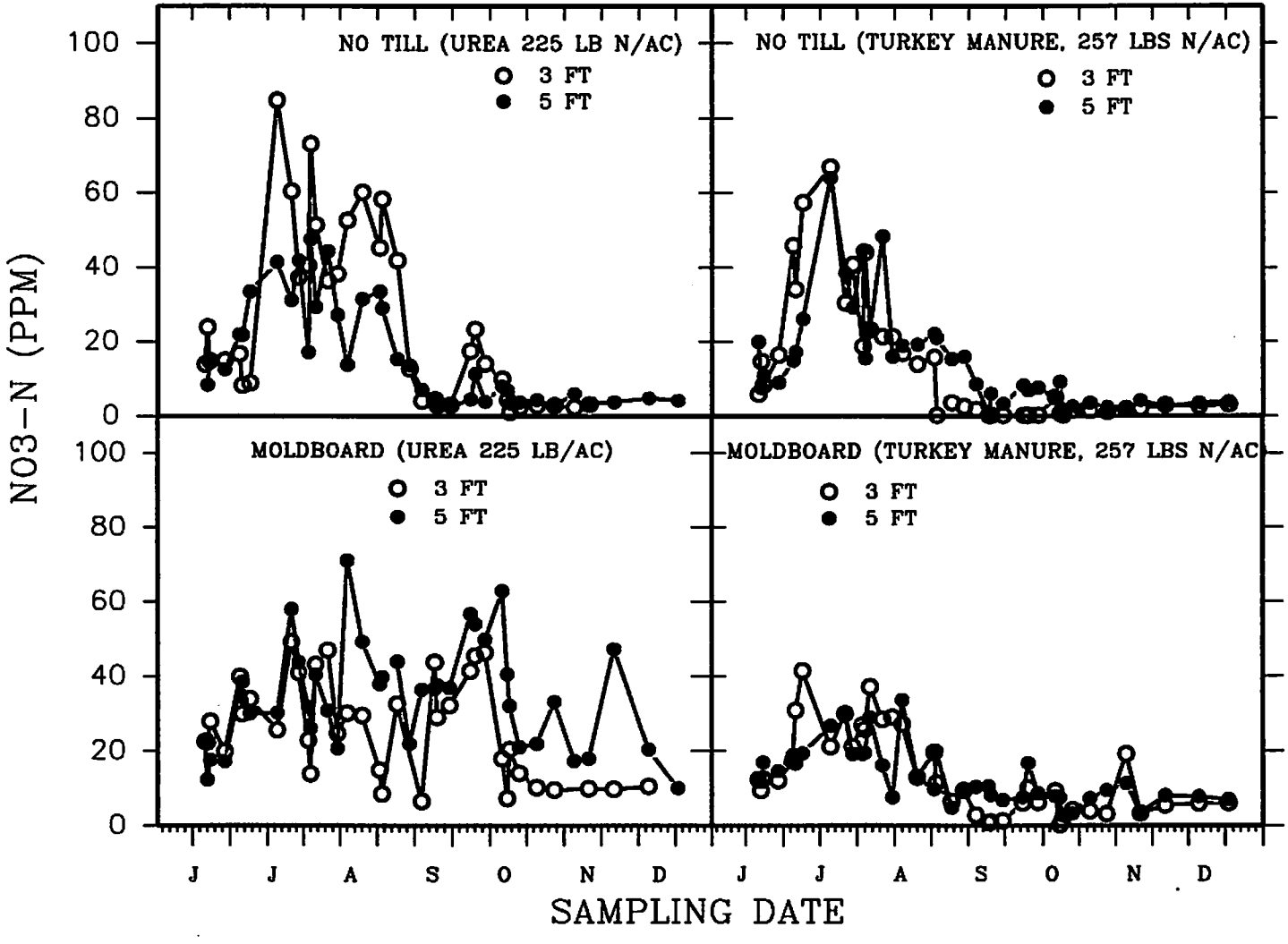


FIGURE 4.

SOIL WATER NITRATE IN 5th YEAR CORN FOLLOWING ALFALFA AT STAPLES 1991

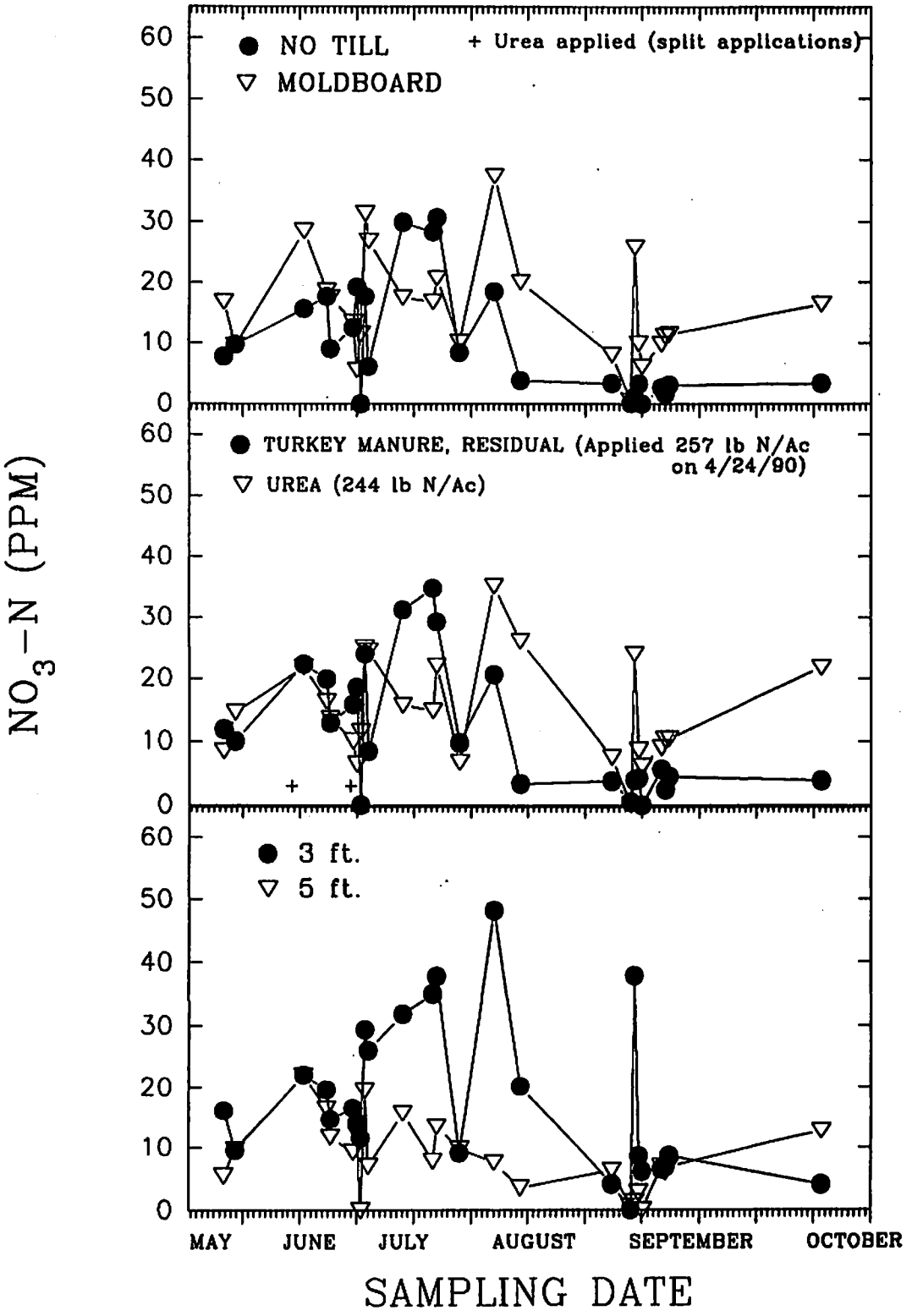
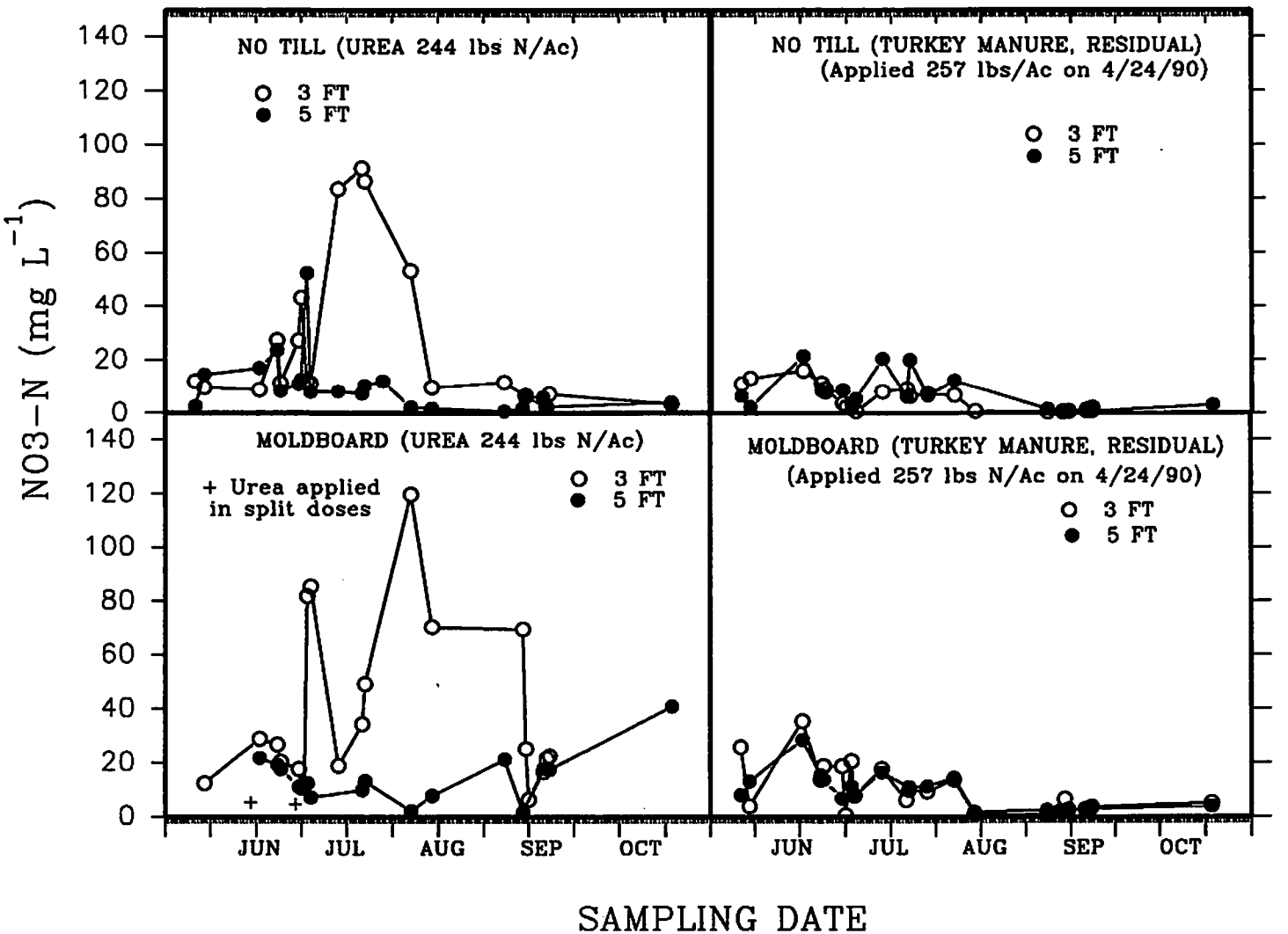


FIGURE 5.

SOIL WATER NITRATE IN FIFTH YEAR CORN FOLLOWING ALFALFA

STAPLES 1991



NITROGEN AND IRRIGATION MANAGEMENT EFFECTS ON CORN/POTATO YIELDS AND NITRATE LEACHING [1]

B.T. Sexton, J.F. Moncrief, C.J. Rosen, S.C. Gupta,
H.H. Cheng, J.A. Wright and M.J. Wiens.[2]

Test plots were located on a Verndale sandy loam (coarse loamy, mixed, frigid Udic argiboroll). Nitrogen sources included urea ($CO(NH_2)_2$) for corn, ammonium nitrate (NH_4NO_3) for potatoes, and turkey manure for both corn and potatoes. Four rates of commercial N fertilizer and two rates of turkey manure were used. The previous crop for potatoes was corn. Lupine, a legume, was the previous crop on the corn plots. All plots were moldboard plowed prior to planting. Corn responded up to 165 lb N/acre. Potatoes were still responding at the highest N rate, 425 lb estimated available N/acre from turkey manure. In all but two instances, NO_3-N leaching losses increased with N inputs. Due to early and late season rains, irrigation treatments differed little in water applied, crop yield or NO_3-N leached. Potatoes had more water percolation, but lower NO_3-N leaching compared to corn.

Introduction:

1991 was the first year of a three year effort to quantify water and NO_3-N movement under crops in the Central Sands of Minnesota. The test plots are located on the Staples Irrigation Center, Staples, Minnesota. Data from this experiment will be used to field validate computer models which will then be used to assess nitrogen and water Best Management Practices (BMPs) for the Central Sands.

Methods and Materials:

The test plots are located on a Verndale sandy loam. The area has a maximum slope of 2% with little or no runoff. The upper argillic horizon is compacted into a plow pan and has bulk densities up to 1.9 Mg/m^3. A typical soil profile from the plot area has the following description:

TABLE 1. TYPICAL VERNDALE SANDY LOAM PEDON DESCRIPTION

DEPTH		DESCRIPTION
0-10"	Ap	10YR 2/1; loamy sand; coarse, weak, subangular blocky structure; friable; abrupt boundary.
10-16"	Bt	10YR 4/4; sandy loam; med., mod, subangular blocky structure; friable to firm; clear boundary; <10% gravel.
16-21"	BC	10YR 4/6; loamy sand; coarse, weak, subangular blocky structure; friable; gradual boundary; <10% gravel.
21-32"	C1	2.5Y 6/6; sand; single grain; loose; gradual boundary; <10% gravel.
>32"	C2	2.5Y 6/4; sand; single grain; loose; some lamellae present at depths >48".

Soil tests were conducted in the spring, prior to manure spreading (see Table 2). Turkey manure was broadcast in the spring prior to tillage. Previous studies at Staples (Moncrief et. al., 1991) demonstrated the need to incorporate turkey manure for full nitrogen benefit. All plots were spring moldboard plowed. The rates of manure application were 10 and 16.6 tons/acre for corn, and 13.1 and 19.9 tons/acre for potatoes. Estimated available N from manure was determined by chemical analysis of KCl extraction and total N digestion (see Table 3). Thirty percent of total organic N was considered available for 1991. Estimated available N rates for turkey manure were then 228 and 367 lb N/acre for corn, and 282 and 425 lb N/acre for potatoes. These rates include 11 lb N/acre added as starter fertilizer for corn and 7 lb N/acre for both crops added as NO_3-N in irrigation water. Corn was planted on 8 May at a rate of 32,000 seeds/acre. Corn variety was Pioneer 3291. Russet Burbank potatoes were planted on 10 May at a 9 inch spacing.

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[1] *Support for this project was provided by the Legislative Commission on Minnesota Resources, Agricultural Utilization and Research Institute, and the Minnesota Dept. of Agric.. Their support is greatly appreciated.*

[2] *B.T. Sexton, Graduate Research Assistant, J.F. Moncrief and C.J. Rosen, Extension Specialists, S.C. Gupta and H.H. Cheng Professors of Soil Sci., Dept. Soil Sci., Univ. Minn, St. Paul, MN. J.A. Wright, Extension Irrigation Specialist, Dept. Ag. Eng. Univ. Minn., Morris, MN., M.J. Wiens is the Univ. Minn. Senior Plot Coordinator, Staples Irrigation Center, Staples, MN.*

TABLE 2. SOIL TEST RESULTS

CROP	P_2O_5	K_2O	S	Zn	Mg
CORN	143 lb/A	189 lb/A	12 lb/A	1.3 lb/A	259 lb/A
POTATOES	153 lb/A	240 lb/A			

TABLE 3. MANURE NITROGEN ANALYSIS ON DRY AND WET WEIGHT BASIS: Average water content was 78%, assuming 30% of organic N available and 80% of inorganic N available for the 1991 growing season. All numbers represent lb N/ton manure.

	total N	total mineral N	NH_4^+	NO_3^-	Est. avail. mineral N	total organic N	Est. avail. organic N	Total est. avail. N
dry wgt	83.8	24.7	20.9	3.8	19.8	59.1	17.7	37.5
wet wgt	47.1	13.9	11.7	2.1	11.1	33.2	9.9	21.0

TABLE 4. NUTRIENT ADDITIONS

CROP or treatment	ADDITION	RATE(S)	DATE	N lb/A	P_2O_5 lb/A	K_2O lb/A	S lb/A	Zn lb/A
CORN								
manure** plots only	turkey manure	10 ton/A 16.6 ton/A	2 May	210 349	171 284	178 295		
all plots	starter fert. 8-12-28-4-1	140 lb/A	8 May	11	17	39	5.6	1.4
commercial fert. plots only	urea $CO(NH_2)_2$ (46-0-0)	76,163,250 lb/A 76,163,250	29 May 13 Jun	36,74,118 36,74,118				
POTATOES								
manure plots only	turkey manure	13.1 ton/A 19.9 ton/A	2 May	275 418	224 340	233 353		
all plots	K, Mg, SO_4 (sulpomag)	340 lb/A	2 May			75	61	Mg 37
comm. fert. plots only	NH_4NO_3 35-0-0	77,154,231 lb/A	9 May	27,53,80				
all plots	0-46-0	108 lb/A	9 May		50			
all plots	0-0-61	258 lb/A	9 May			156		
comm. fert. plots only	NH_4NO_3 NH_4NO_3	77,154,231 lb/A 77,154,231	30 May 14 Jun	27,53,80 27,53,80				

** all manure application rates are on a wet weight basis

Commercial nitrogen fertilizer rates for corn were 18, 90, 165 and 254 lb N/acre from urea. Corn received 11 lb N/acre, from starter, and the remainder as two equal applications of urea. The first application was applied at the 4 to 6 leaf stage, on 29 May, and the second application at the 8 to 12 leaf stage, on 13 June (see Figure 1). NH_4NO_3 rates for potatoes were 7, 87, 167, and 247 lb N/acre. Potatoes received three equal applications of NH_4NO_3 at planting, on 9 May, emergence, on 30 May, and tuberization, on 14 June (see Figure 2). All fertilizer applications were incorporated by tillage or irrigation (see Table 4 for complete listing of fertilizer additions). All reported N rates include 7 lb N/acre applied as NO_3-N applied in irrigation water.

Two irrigation schedules were used for each crop (see Tables 5 and 6). The checkbook method (Wright

and Bergsrud, 1986) was used to calculate soil water deficits and schedule irrigations. A 20 inch rooting depth was used for both corn and potatoes, giving 2.33 inches of available water. The term "TRIGGER DEFICIT", used in Tables 5 and 6, refers to a water deficit, as determined from the checkbook method, which initiates irrigation.

Corn final stand was 31,065 plants/acre. Corn grain was harvested on 18 September. Potato vines were killed on 12 September and tubers harvested on 19 September.

Soil water content was determined prior to precipitation and irrigation events using tensiometers and soil water desorption curves. Water movement (PERCOLATION) was calculated by subtracting storable soil water (STORAGE), and estimated evapotranspiration (ET) from precipitation (PRECIP) and/or irrigation (IRRIG) amounts.

PERCOLATION = PRECIP + IRRIG - STORAGE - ET

Soil water nitrate concentrations were determined using two replicates of suction cup samplers placed in the row at a depth of 24 inches. One half bar suction was applied to the suction cup samplers on mornings when the soil water deficit was less than 0.2 inches, according to

TABLE 5. CORN IRRIGATION SCHEDULE

SCHEDULE	GROWTH STAGE	TRIGGER DEFICIT % , INCHES	INCHES OF IRRIG.
#1	all stages	0.75"	0.75"
#2	emergence-tasseling	60% , 1.40"	0.75"
#2	tasseling-1st dent	40% , 0.92"	0.92"
#2	1st dent-maturity	66% , 1.55"	0.75"

TABLE 6. POTATO IRRIGATION SCHEDULE

SCHEDULE	GROWTH STAGE	TRIGGER DEFICIT % , INCHES	INCHES OF IRRIG.
#1	all stages	0.7"	0.8"
#2	planting-tuberization	50% , 1.16"	1.16"
#2	tuberization-maturity	30% , 0.71"	0.75"

the checkbook method (Wright and Bergsrud, 1986). Soil water samples were collected the following morning. NO_3-N flux was calculated by multiplying water flux by soil water NO_3- concentration. The 254 lb N/acre, irrigation schedule two treatment corn NO_3-N fluxes are not included due to sampler tube malfunction.

Results and Discussion:

Total rainfall for the season 1 May to 20 September was 18.58 inches. Due to rainfall events early and late in the season, the two irrigation schedules differed little in total water inputs (see Table 7). Crop yields were not significantly affected by irrigation schedule (see Table 8). Timing of irrigations, however, were different (see Figures 1 and 2).

TABLE 7. TOTAL IRRIGATION INPUTS, PERCOLATION

CROP	IRRIG. SCHEDULE	INCHES OF IRRIGATION APPLIED	INCHES OF PERCOLATION
CORN	# 1	7.17 inches	7.2 inches
CORN	# 2	7.14 inches	7.0 inches
POTATO	# 1	7.95 inches	9.7 inches
POTATO	# 2	8.58 inches	9.8 inches

Figures 1 and 2 show individual rainfall, irrigation and calculated percolation events for the 1991 growing season for each crop irrigation schedule. Water percolation due to irrigation alone was

small, but instead, was related to rainfall events. During the irrigation season, more frequent irrigations to field capacity increases the probability of NO_3-N losses due to rainfall events following irrigations.

Corn responded up to 167 lb N/acre. Crop yields showed little difference between irrigation treatments (see Tables 8 and 9), but are presented separately due to differences in NO_3-N leaching (see Figures 3 and 4). For the growing season, manure leached less NO_3-N than comparable amounts of commercial fertilizers for both corn and potatoes.

TABLE 8. Effects of irrigation schedule, and N-rate on various crop yield parameters
Values are Pr > F; NS = nonsignificant; alpha = 0.1; culls = < 3 oz. potatoes

POTATOES	total yld	cull yld*	misshapen yld
irrig. schedule	NS	NS	NS
n-rate	.0043	.0668	.0035
n-rate*irrig	NS	NS	NS

CORN	grain yld	final stand
irrig. schedule	NS	NS
n-rate	.000	NS
n-rate*irrig	NS	NS

TABLE 9. POTATO HARVEST values are cwt/A **CORN HARVEST values are bu/A**

irrig sched.	n rate lb/A	total yld mean	total yld s.d.	cull yld mean	cull yld s.d.	mishp yld mean	mishp yld s.d.		irrig sched.	n rate lb/A	grain yld mean	grain yld s.d.
1	7	193.1	6.6	37.9	13.6	4.7	2.0		1	18	146.7	42.7
1	87	324.6	6.7	21.8	6.3	18.0	10.2		1	85	186.4	18.7
1	167	358.1	18.1	31.5	5.9	21.5	5.8		1	165	191.2	33.4
1	247	391.4	26.6	31.9	6.8	27.9	4.4		1	245	192.1	16.8
1	282*	388.3	23.1	30.6	6.0	30.0	12.1		1	228*	198.4	26.0
1	425*	416.1	64.3	32.3	7.4	39.2	32.8		1	367*	199.4	18.2
2	7	192.2	2.7	42.4	15.7	11.1	1.9		2	18	153.3	25.3
2	87	328.2	15.8	31.7	1.8	20.8	7.8		2	85	173.4	20.0
2	167	394.2	21.6	35.6	12.8	24.7	6.4		2	165	195.4	27.0
2	247	393.5	6.3	27.1	10.4	31.7	13.0		2	245	177.4	33.4
2	282*	429.6	15.6	36.0	4.8	43.4	12.6		2	228*	192.8	22.6
2	425*	445.3	38.9	32.8	6.3	42.9	23.0		2	367*	198.2	20.5

* estimated available N from turkey manure

Potatoes continued to respond through the highest N treatment, 425 lb estimated available N/acre from turkey manure. Irrigation treatments did not significantly affect crop yield but did affect NO_3-N leaching, especially in potatoes, with Schedule #2 showing slightly lower N loss due to leaching, (see Figures 3 and 4).

Over one half of NO_3-N leaching occurred following the rainfall events on the 29th of June and 1st of July. Nearly all of the precipitation from these two events percolated, since a 1.2 inch rainfall on the 27th of June brought the soil up to field capacity. Nitrate concentrations were also relatively high at this time, compared to water percolation events during the rest of the growing season. While some NO_3-N concentrations were higher, up to 240 ppm, these samples were taken during times of little or no water movement.

Figure 1 RAINFALL, IRRIGATION AND PERCOLATION FOR CORN

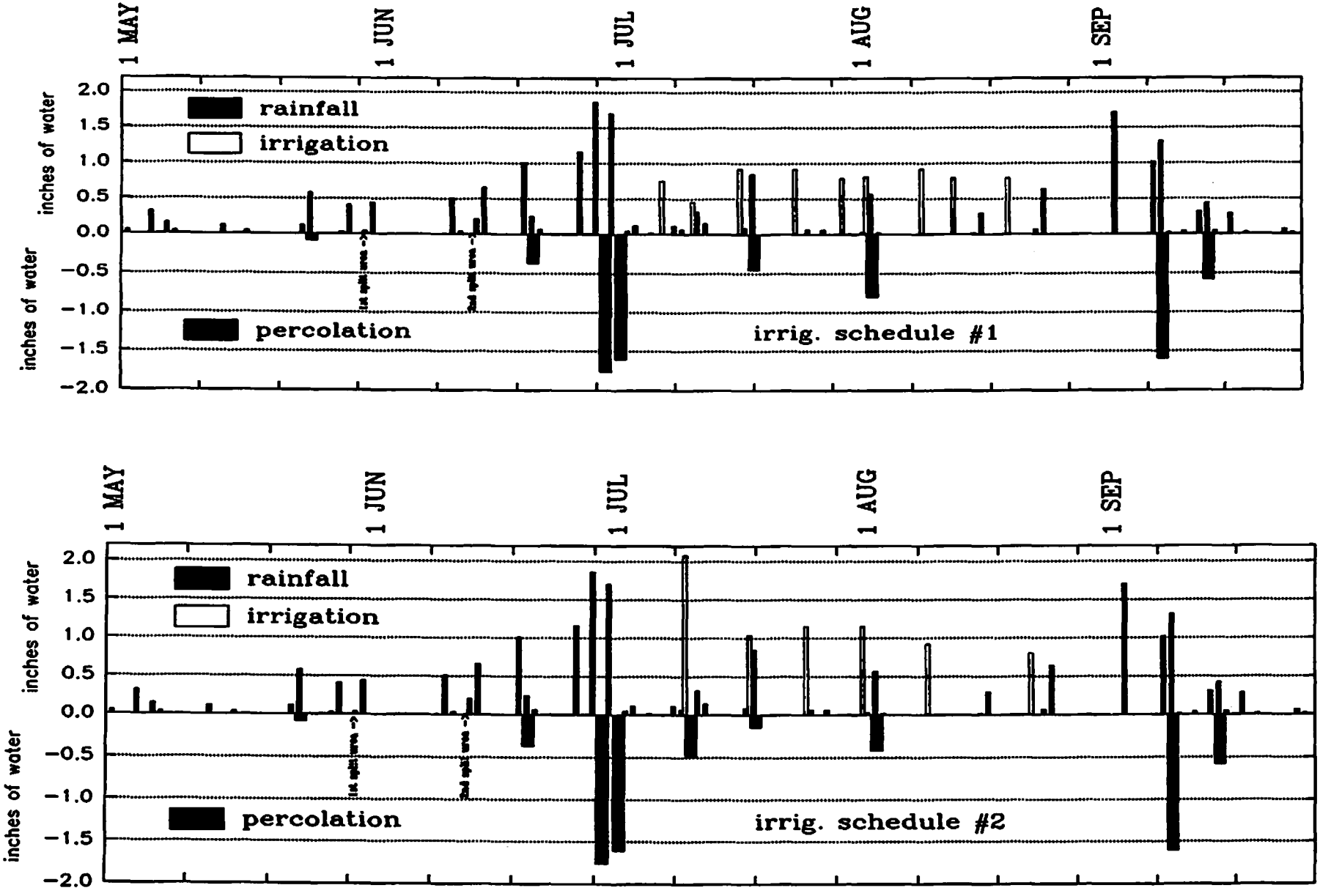


Figure 2 RAINFALL, IRRIGATION AND PERCOLATION FOR POTATOES

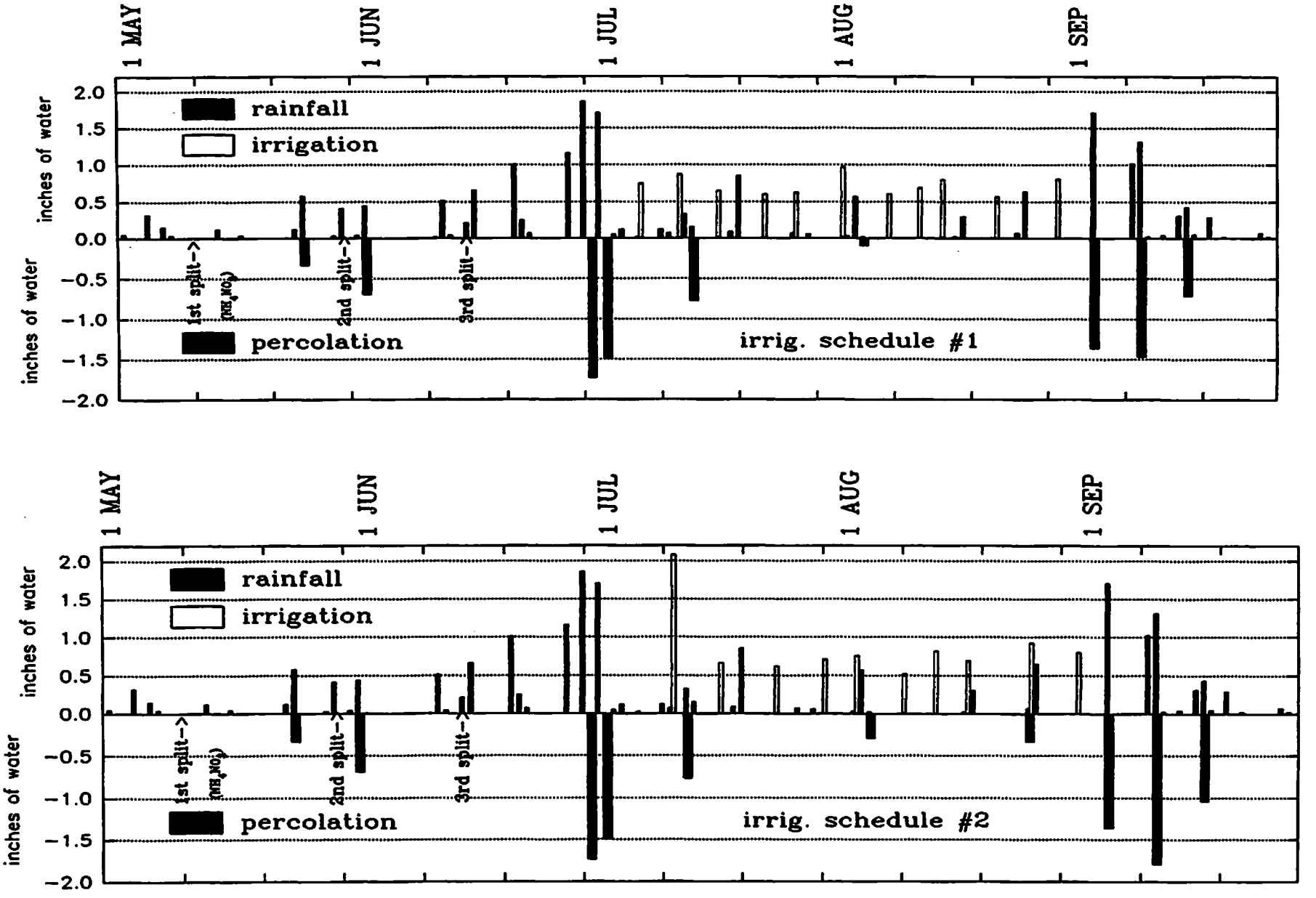
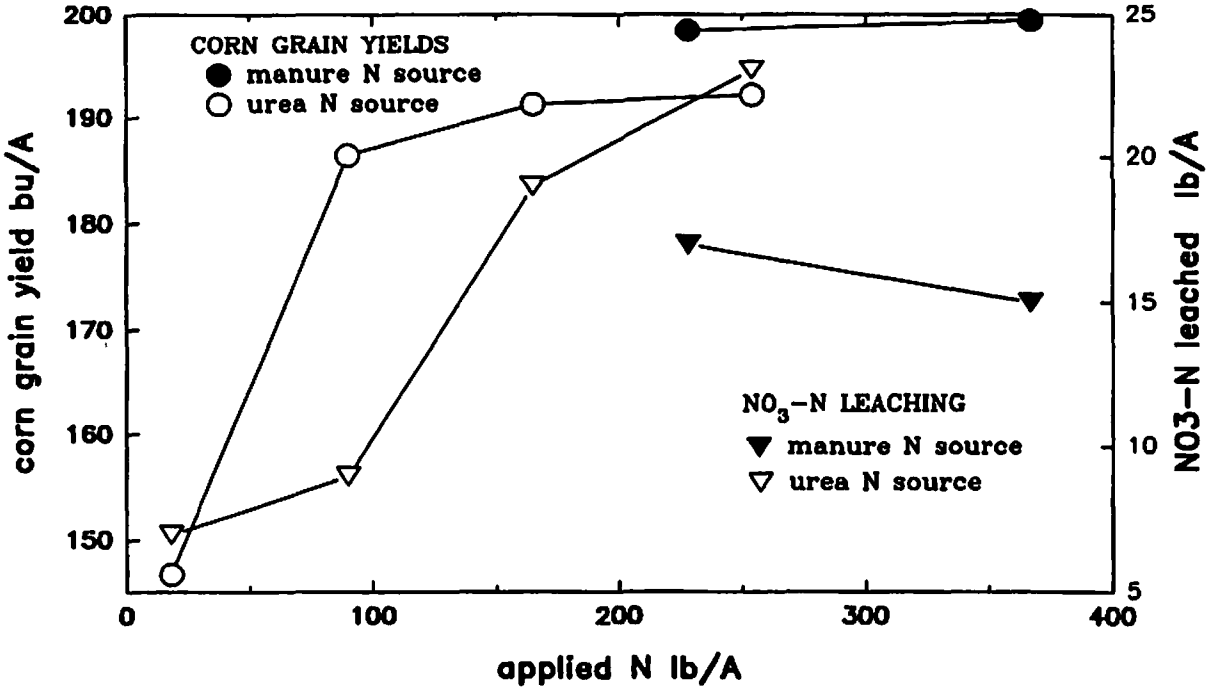


Figure 3 Corn grain yields and NO_3-N leaching

irrigation schedule #1



irrigation schedule #2

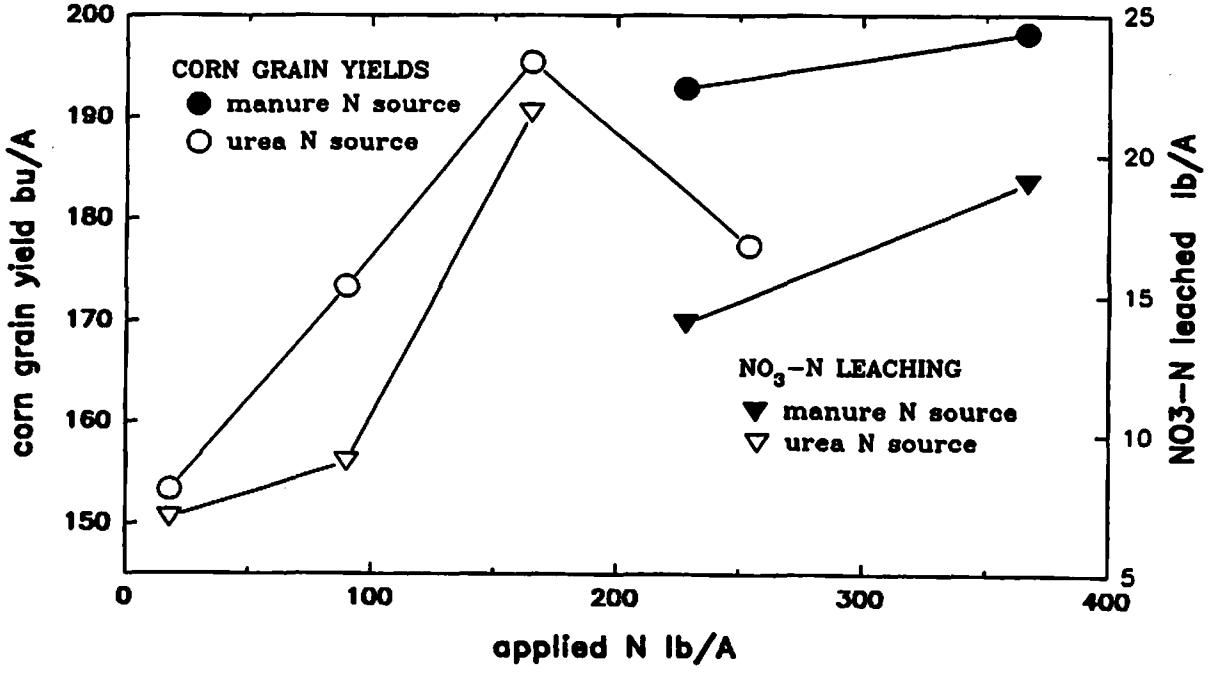
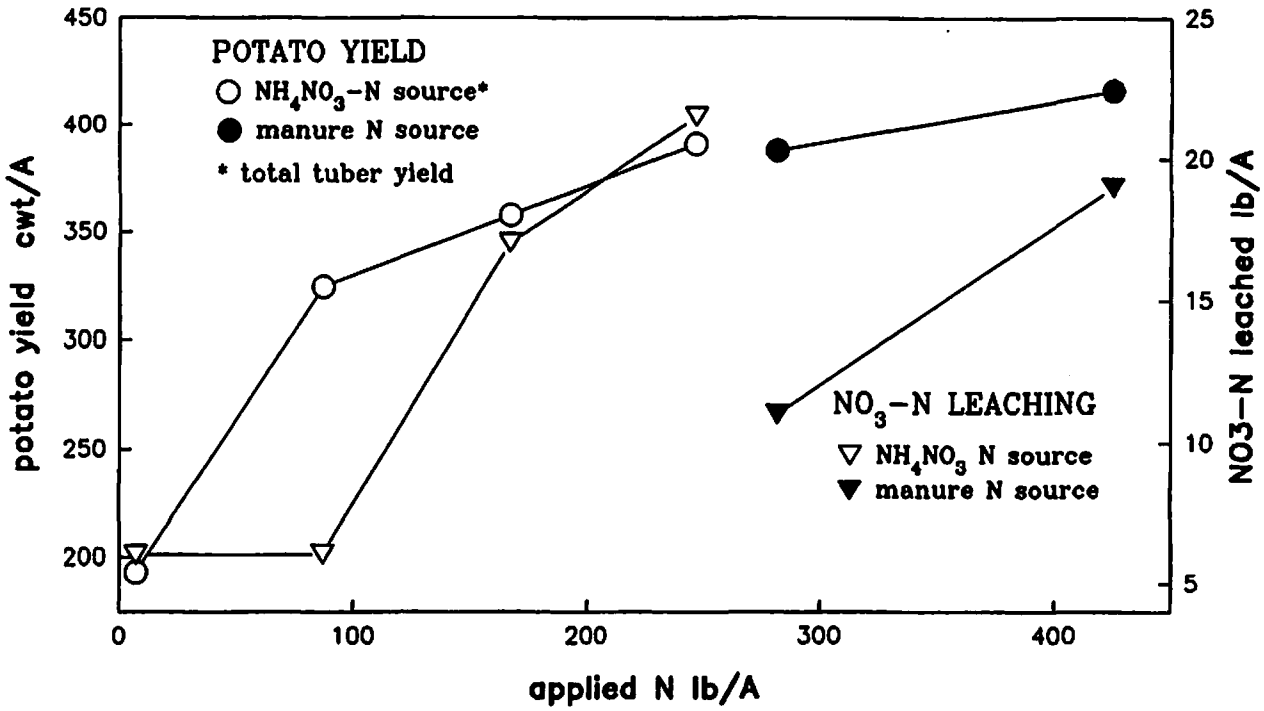
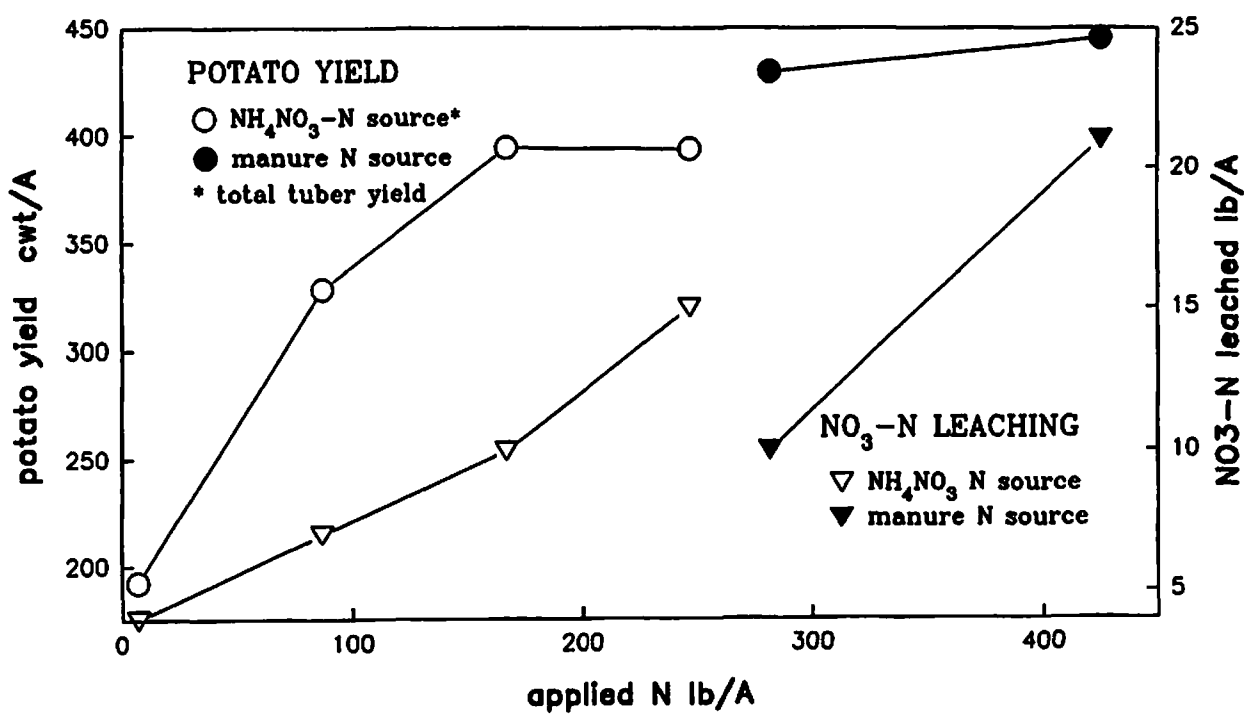


Figure 4 Potato tuber yields and NO_3-N leaching

irrigation schedule #1



irrigation schedule #2



CONCLUSIONS:

Corn grain yields were higher than expected for the 165 lb N/acre rate. University of Minnesota Extension N recommendation for 200 bushel/acre corn following corn is 220 lb N/acre (Rehm and Schmitt, 1989). The previous crop of lupine probably provided nitrogen to the corn crop. Potato yields were still increasing at the highest N rate, 425 lb estimated available N/acre from turkey manure. This affect may also have been due to the phosphorus and potassium additions from the manure.

Water percolation was lower under corn, but NO_3-N losses were higher compared to potatoes. The greater rooting depth of corn probably allowed more efficient use of water. The irrigation season for corn also ended 11 days prior to potatoes. The final irrigation on potatoes was shortly before a 1.7 inch rainfall in early September. Neither corn irrigation treatment showed water leaching from this event, while both potato irrigation treatments experienced over 1.3 inches of water percolating from this one event.

Lower N losses in potatoes was most likely due to potatoes still responding at the the highest N rate and the manner that water moves under the two crop. Warner and Young (1991) showed preferential flow to occur through the soil 4 inches on either side of a mature corn row. Cultivation with sweeps was used to incorporate the first application of urea applied to the corn. Such cultivation tends to push surface soil (and surface applied urea) towards the row, increasing the potential for NO_3-N leaching. The practice of hilling potatoes was shown by Saffigna et. al. (1976) to decrease water percolation through the sides of the hills, where commercial fertilizers were incorporated.

Irrigation scheduling is most critical following N application. Both irrigation schedules #2 (corn and potatoes) would decrease the probability of a leaching rain occurring during early growth stages. By not irrigating as often or to field capacity, the soil serves as a water storage buffer. Early growth stages are also the times when nitrogen applications are made. Manure tended to produce higher yields than comparable amounts of commercial fertilizer. The high organic content of manure serves as a slow release N source.

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CORN NITROGEN RATE STUDY

H. Meredith, Mel Wiens, and Andy Scobbie[1/]

ABSTRACT: A nitrogen rate study was initiated in 1990 on an irrigated sandy loam soil on the research area at the Staples Irrigation Center. The study is a multi-year ongoing research project to determine the optimum yield of irrigated corn in response to applied N, and intensive management.

Introduction: Production of high yields of corn on coarse textured soils with optimum use of supplemental moisture from irrigation is a common practice. These soils are subject to leaching of soluble constituents, especially nitrates. This study evaluates the response of corn to various rates of applied nitrogen.

Experimental: A Pioneer hybrid 3787 was seeded with a Duetz-Allis Model 385 four-row planter in 30-inch rows on April 23, 1991. The rate of planting was 32,000 seeds per acre. Nitrogen was applied in three equal applications beginning one month following planting, one month later, and the last increment was applied just prior to tassel. Nitrogen was applied at the 60, 90, 120, 150, 180, 210, and 240 pounds of N per acre.

Discussion: Maximum yield was achieved at the 180 pound N treatment. The most efficient response to N was at the 60-pound treatment (1.08 bu grain/lb N). AT the 180 pound N treatment, the increased yield was 0.2 bu grain/lb N. Corn at $2.50/bu and N at $.22 provides a small profit for applied N at the 180-pound/A rate.

Table 1. N rates, corn yield, grain moisture, and ear leaf N values at silking.

N Treatment	Grain Yield[1/]	Grain Harvest Moisture	Ear Leaf N at Silking	Stover
lbs/A	bu/A (15.5% H_2O)	%	%	D.M./A
0	56.1	27.2	1.03	1.54
60	121.1	27.7	1.74	2.45
90	133.8	26.1	1.96	2.42
120	137.4	27.7	2.17	2.24
150	147.8	26.4	2.41	2.67
180	153.6	27.5	2.43	2.46
210	151.9	27.0	2.61	2.25
240	153.7	25.6	2.67	2.49

[1/] Average of four replications

[1/] Regional Manager, TVA; Research Plot Supervisor, Staples Irrigation Center; Assistant Scientist, University of Minnesota, respectively.

LUPIN BEAN FERTILITY STUDY

H. Meredith, Mel Wiens, Andy Scobbie, and Dan Schmitz[1/]

ABSTRACT: A fertility study initiated in 1984 to determine nutrient requirements of the lupin bean (Lupinus albus) continued in 1991. Disease was quite prevalent and yields were reduced. As has been noted since the inception of these studies, no nutrient response to applied nutrients was noted. Yields appear in three tables.

Table 1 represents "good yields" (over 60 bu/A), and Table 2 lists the poor yields (less than 60 bu/A). The 1991 yields appear in Table 3. Yields are based on 13.5% moisture and 60 pounds bushel weight.

It is interesting to note that all yields over 60 bu/A average 62.8 bu/A while all yields under 60 bu/A average only 41.3 bu/A. Yields averaged over 60 bu/A on five occasions while yields under 60 bu/A occurred eight times, but a substantial difference of 21.5 bu/A.

Table 1. Summary of "good" Lupin yields, 1984-1991, Staples Irrigation Center.

Fertilizer Treatment	Yield, bu/A 1985	1987	1988	1990	
None	71.4[2/]	61.8[4/]	61.9[4/]	61.9[3/]	68.7[4/]
S	71.2	62.8	67.2	61.2	64.0
S+K	63.8	61.9	61.1	57.1	59.8
S+K+P	68.8	61.8	57.2	61.2	67.0
S+K+P+Zn	64.1	56.3	58.0	60.3	67.2
S+K+P+Zn+B	64.9	60.8	55.3	56.2	67.2
Average	67.4	60.9	60.0	60.0	65.6

Table 2. Summary of "poor" Lupin yields, 1984-1991, Staples Irrigation Center.

Fertilizer Treatment	Yield, bu/A 1984	1986		1987	1988	1989	
None	39.1[1/]	40.6[3/]	32.0[4/]	57.2[3/]	47.6[3/]	37.3[3/]	31.9[4/]
S	43.2	44.0	31.7	54.2	58.7	40.1	33.0
S+K	40.5	40.6	43.3	49.9	50.9	31.9	27.3
S+K+P	39.4	39.2	40.2	56.6	42.3	40.6	33.9
S+K+P+Zn	39.4	41.8	37.4	47.2	42.8	35.6	27.7
S+K+P+Zn+B	41.5	33.8	32.8	54.8	52.0	35.9	29.5
Average	40.5	40.0	36.2	53.3	49.0	36.9	30.6

[1/] 30-inch row spacing
[2/] 6-inch drill rows 1985 forward
[3/] Old fertility site
[4/] New fertility site

Table 3. Lupin yields in response to fertility treatments, Staples Irrigation Center, 1991.

No.	Treatment/A	Yield, bu/A[1/] 1991
1	No Fertility	45.0
2	50 lbs S	48.1
	100 lbs S	48.6
3	300 lbs K_2O	44.7
4	100 lbs P_2O_5	43.9
5	10 lbs Zn	33.5
6	2 lbs B	44.9
Average		44.1

[1/] 6-inch drill rows 1985 forward

[1/] Regional Manager, TVA; Research Plot Supervisor, Staples, Irrigation Center; Technical Field Crew, Soils Department, University of Minnesota, respectively.

Summary and Conclusions:

The 1991 growing season provided near ideal early growing conditions with temperatures well above average. Lush foliage developed coupled with irrigation provided an ideal situation for a high incidence of disease. Yields were drastically reduced.

The experience of wide-spread disease has thrown a ray of caution on the lupin growing project. It is apparent that seed stocks introduced from various regions have infected the area. Prudence must prevail such that only disease-free seed stocks are planted and that lupins follow a cereal crop to provide a near disease-free media for lupin production.

The lupin plant mobilizes sparingly soluble nutrients from the soil. A nutrient response has not been achieved which distinctively points to a nutrient deficiency. In some years, a tendency to slightly increased lupin yields is achieved following the addition of sulfur. This has not been a consistent observation, however.

Lupins are sensitive to soluble salts and lupin yields have been observed to be lower where high rates of fertilizer salts are applied or where fertilizer salts are placed in close proximity of the seed. High yields are attainable without application of fertilizer as evidence from the yields from previous years, especially 1985.

Lupins benefit from characteristics that provide "good husbandry." That is, high quality seed, freedom from disease, excellent vigor, high germination, establishment of "perfect" population density, weed-free, adequate heat and moisture, etc.

Lupin production is commonly compared to soybean production. Where soybeans are produced successfully in the 40-50 bushel range, lupins must exceed this production considerably to be competitive. This can be achieved consistently only after high yielding disease tolerant strains are introduced. Progress is being made along these lines. The present day lupin varieties have the capability to produce over 70 bushels per acre.

The highest yields were attained in 1985. This was a near ideal growing season for lupins. The year was one of the cooler summers in some time. The temperature was near ideal throughout the flowering period for lupins. Irrigation provided ample moisture. Pod set was heavy and essentially no aborting of fertilized ovaries was observed. The filling period was slow and was extended well into late summer. The cool temperatures prolonged maturity. A late frost permitted harvesting in mid October. Harvest normally occurs in August or early September. Poor seed viability resulted in disappointing yields in 1986.

Weed competition, inadequate population density and more recently disease have been the primary factors contributing to poor yields.

Crop rotation is deemed essential for lupin production. Ideally, lupins should follow a cereal crop and lupins should not be grown for more than one year on a site. Selection of disease-free sites must be accepted as one of the key management concepts.

TRITICALE PRODUCTION

H. Meredith, Mel Wiens, Andy Scobbie, and Dan Schmitz[1/]

ABSTRACT: Winter and spring triticale varieties have been evaluated under irrigation at the Staples Irrigation Center for several years. Winter triticale varieties as winter wheat do not have the winter hardiness needed to survive harsh winter, especially when a consistent snow cover is absent. Spring triticale varieties have greater promise although yields on the irrigated sands have been disappointing, Table 1.

Table 1. Winter triticale trials at the Staples Irrigation Center, 1991.

Variety	Grain Yield bu/A	Straw Yield Tons/A
Winterfest	30.7	3.80
Gold Rush	29.4	3.86
Snowfield	32.6	3.85
Centennial	31.5	3.42
Exp. 93	29.4	4.27
Exp. 97	27.0	3.20
Exp. 113	34.9	4.14
Exp. 192	24.2	3.40
Mitzi	28.9	4.18
Rymin	37.3	3.91
Dacold (ND)	25.7	3.35
Ave.	30.1	

Yields have been disappointing generally. Rye is included with the triticale plots to give an indication of hardiness. A summary of yields and chemical analysis follow:

Table 2. Winter triticale yields, Staples Irrigation Center. 1988.

Variety	Crop	Yield bu/A	Test Wt. lbs/A	Straw Yield tons/A
Ind 6-6-2	Triticale	34.9	51.9	1.79
Ind 5-3-3	"	31.6	50.2	2.00
Mitzi	Rye	55.3	60.2	2.04
Iowa 2-19-4	Triticale	35.9	56.1	1.68
Rymin	Rye	61.1	61.0	2.09
Ind 3-2-2	Triticale	40.1	54.7	2.06
Ind 2-2-4	"	45.9	55.0	2.00

Table 3. Spring triticale yields, Staples Irrigation Center. 1990.

Varieties	Yield bu/A	Test Wt. lbs/A	Straw Yield tons/A
Wapati	43.4	56.0	2.67
Florico	40.8	57.0	2.53
Companion	39.6	53.9	2.63
Plains	46.5	54.3	2.63
Norico	45.0	58.7	2.66
Norita	39.2	54.1	2.31

[1/] Regional Manager, TVA; Research Plot Supervisor, Staples, Irrigation Center; Technical Field Crew, Soils Department, University of Minnesota, respectively.

Table 4. Winter triticale yields, Staples Irrigation Center, 1990.

Varieties	Yield bu/A	Test Wt. lbs/A	Straw Yield tons/A
Winteri	9.2	44.8	1.37
81 DED 1015	11.1	50.3	1.30
81 DED 1012	7.5	49.4	1.45
Ind 5-3-3	11.2	47.9	1.48
Ind 3-2-2	11.0	45.6	1.28

Table 5. Nutrient Content of Rye and Triticale Seed, Staples 1987

Variety	N	S	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	%						ppm				
Ia 2-19-4	2.8	.17	.48	.63	.06	.18	40	53	58	1.4	1.2
Ind 2-2-4	2.4	.16	.45	.57	.07	.18	42	54	55	1.7	1.3
Mitzie	2.0	.14	.40	.58	.05	.15	51	40	39	2.3	1.4
Ind 6-6-2	2.5	.17	.51	.67	.07	.18	41	60	57	1.9	1.2
Mitzie	2.0	.14	.41	.58	.05	.15	52	34	40	2.3	1.4
Rymin	1.9	.14	.40	.58	.05	.15	51	36	37	2.2	1.2

Table 6. Nutrient Uptake in Grain of Triticale and Rye, Staples 1987

Variety	N	S	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	lbs/A										
Ia 2-19-4	55	3.5	10	13	1.2	3.7	.08	1.2	.12	.003	.002
Ind 2-2-4	64	4.4	12	16	2.0	4.8	.11	1.4	.15	.005	.003
Mitzie	76	5.6	16	22	2.0	5.9	.20	1.5	.15	.009	.005
Ind 6-6-2	51	3.4	10	14	1.3	3.6	.08	1.2	.11	.004	.002
Mitzie	67	4.8	14	20	1.7	5.2	.18	1.2	.14	.008	.005
Rymin	71	5.3	15	22	1.8	5.5	.19	1.3	.14	.008	.005

Table 7. Nutrient Composition of Straw of Triticale and Rye, Staples 1987

Variety	N	S	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	%						ppm				
Ia 2-19-4	.42	.05	.06	1.3	.28	.07	.02	.34	.14	1.0	2.4
Ind 2-2-4	.56	.06	.11	1.5	.41	.10	.01	.50	.16	1.3	5.0
Mitzie	.41	.06	.09	1.2	.30	.07	.02	.42	.10	1.0	2.2
Ind 6-6-2	.43	.06	.08	1.4	.36	.08	.03	.50	.13	1.2	4.0
Mitzie	.46	.06	.12	1.3	.31	.08	.02	.33	.10	1.0	2.3
Rymin	.48	.05	.11	1.4	.30	.08	.02	.38	.10	1.1	2.3

Triticale is a cross between durum wheat and rye. The Latin names of wheat, Triticum Aestinum and rye, Secale cereale are combined in the term Triticale. A naturally occurring triticale was identified as early as 1875. A successful cross between wheat and rye was successfully made in 1890. Triticales are not hybrids. Triticale in essence is an "artificial " genus combining the desirable characteristics of wheat and rye into one new specie.

When a cross between rye and wheat is made, the progeny or F_1 plant is sterile because the difference in the chromosome number of wheat and rye. Wheat has 42 chromosomes and rye has 14. The trick is to treat the developing embryo with colchicine. All of the chromosomes are doubled and the resulting F_1 triticale plant

is fertile and has 56 chromosomes. Triticales are largely self fertilized and usually breed true from one generation to the next.

Winter hardiness continues to plague newer triticale varieties. Snow cover provides vital protection against the severe cold. Warming periods in early spring followed by a severe drop in temperature have resulted in severe injury to an otherwise promising crop.

WATER QUALITY STUDIES

H. Meredith and Mel Wiens[1/]

ABSTRACT: For the past several years, a limited quantity of irrigation water samples have been collected and analyzed. Samples were taken from pumping wells, streams, and dug pits. The purpose of this study is to monitor the contents of dissolved nutrients from the irrigation water and to use this information as a guide to measure the long-term effects of irrigation.

The primary nutrients of significance are calcium and magnesium. Sodium, of great concern in arid regions where irrigation is common, is uncommonly low in Minnesota water used for irrigation.

Table 1. Analysis of Irrigation Water in Proximity of Staples, MN - 1991

PPM or Mg/L

Sample #	Date	N	P	K	Ca	Mg	Na	S
1 Well B	7/24	3.2	.10	1.2	79.0	20.4	2.1	2.0
2 Well B	7/24	5.7	.07	1.2	70.4	18.8	2.0	2.4
3 2 Tower	7/24	17.0	T	1.3	78.1	23.6	2.6	8.8
4 Farm Shop	7/24	<0.1	T	1.1	41.0	16.3	12.3	1.3
5 Energy Well	7/24	5.6	.04	2.5	72.4	22.4	7.2	9.2
6 NW Pit	7/24	12.8	T	1.2	72.5	24.2	2.6	6.4
7 SW Pit	7/24	<0.1	.27	2.9	47.5	13.0	1.7	4.8
8 Well B	8/1	3.2	.08	1.3	80.0	20.3	2.1	1.9
9 Well C	8/1	5.2	.08	1.2	67.9	20.0	2.1	2.0
10 Well D	8/1	6.3	.09	1.3	61.9	20.0	2.1	2.0
11 2 Tower	8/1	18.1	.05	1.3	92.0	24.6	2.8	9.2
12 Energy Well	8/1	6.5	.05	2.7	76.5	23.5	7.2	9.8
13 NE Pit	8/1	15.2	.04	1.2	83.1	24.4	2.7	6.9
14 Well B	8/8	3.6	.09	1.0	71.3	20.2	2.0	2.0
15 Well C	8/8	2.3	.09	1.2	71.1	20.4	2.0	1.2
16 Well D	8/8	5.8	.08	1.1	68.5	19.1	2.0	2.5
17 2 Tower	8/8	11.2	.04	1.2	78.1	22.6	2.5	6.9
18 Energy Well	8/8	6.7	.06	2.5	77.6	23.2	7.0	10.0
19 NW Pit	8/8	14.9	.05	1.4	76.8	24.2	2.8	6.6
20 SW Pit	8/8	<0.1	.24	3.2	49.5	14.8	2.1	8.5
21 Well B	8/19	3.9	.10	1.2	63.6	19.9	2.1	2.1
22 Well D	8/19	4.8	.10	1.4	69.4	19.1	2.0	2.4
23 2 Tower	8/19	11.9	.05	1.3	79.0	23.4	2.6	6.8
24 TS, Sec 5,N Germ		<0.1	.09	3.2	51.8	24.4	46.1	<.01
24 TS, Sec 6,N Germ		<0.1	.15	3.4	51.7	24.5	46.9	<.01
26 Forest Dingman Pit	8/21	3.4	.08	1.2	60.4	16.9	5.8	5.1
27 A.Carow #1, Sec 24, 60'	9/1	15.4	.06	2.7	85.9	27.3	3.0	11.8
28 A.Carow #1, Sec 13, 160'	9/1	<0.1	.24	2.4	62.4	31.1	7.6	.16
29 N.Schmitz 1, 55	1976	8.7	.05	1.9	78.5	23.2	7.3	11.3
30 N.Schmitz 2, 52'	1977	7.7	.05	1.7	77.1	21.1	3.7	5.0
31 N.Schmitz 3, Pit	1977	14.0	.05	2.2	91.1	27.6	2.9	19.0
32 House Well, Hard		16.5	.04	2.1	40.8	24.2	5.1	3.6
33 D.Sommars, House Soft		16.5	.04	1.9	58.1	27.6	4.5	4.0
34 D Sommars, Irr. Well		19.4	.04	2.7	101.6	26.7	3.4	4.6

[1/] Regional Director, TVA; Research Plot Supervisor, Staples Irrigation Center, respectively.

Table 2. Analysis of Irrigation Water in Proximity of Staples, MN - 1991.

Sample #	Specific Conductivity, Mmhos/cm	Lbs Nutrients/Ac Inch of Water						$CaCO_3$ Eq.
		N	K	S	Ca	Mg	Na	
1	470	.72	.27	.45	17.8	4.6	.5	61
2	430	1.3	.27	.55	15.8	4.2	.5	55
3	570	3.8	.27	2.0	17.6	5.3	.6	63
4	340	T	.26	.29	11.5	3.7	2.8	48
5	490	1.3	.55	2.1	16.3	5.1	1.6	62
6	500	2.9	.27	1.4	16.4	5.5	.6	61
7	340	T	.65	1.1	10.7	2.9	.4	38
8	450	.72	.29	.43	18.1	4.6	.5	62
9	420	1.2	.26	.43	15.3	4.5	.5	55
10	410	1.4	.29	.44	14.0	4.5	.5	55
11	540	4.1	.30	2.1	20.8	5.6	.6	72
12	520	1.5	.60	2.2	17.3	5.3	1.6	66
13	530	3.4	.27	1.6	18.8	5.5	.6	68
14	440	.81	.23	.44	16.1	4.6	.5	57
15	410	.52	.27	.28	16.1	4.6	.5	57
16	410	1.3	.23	.57	15.5	4.3	.5	55
17	500	2.5	.26	1.6	17.6	5.1	.6	62
18	520	1.5	.57	2.3	17.5	5.2	1.6	65
19	530	3.4	.31	1.5	17.4	5.5	.5	64
20	350	T	.71	1.9	11.2	3.3	.5	40
21	420	.88	.28	.47	14.4	4.5	.5	52
22	390	1.1	.31	.55	15.7	4.5	.5	55
23	520	2.7	.30	1.54	17.8	5.3	.6	60
24	540	T	.72	T	11.7	5.5	10.4	70
25	540	T	.77	T	11.7	5.5	10.6	71
26	400	.77	.27	1.1	13.6	3.8	1.3	56
27	580	3.5	.62	2.7	19.4	6.2	.7	71
28	500	T	.55	.04	14.1	7.0	1.7	63
29	530	2.0	.42	2.6	17.7	5.2	1.7	66
30	480	2.7	.49	1.1	17.4	4.7	.8	62
31	560	3.2	.47	4.3	20.6	6.2	.7	75
32	400	3.7	.84	.81	9.2	5.5	1.2	43
33	510	3.7	.84	.90	13.1	6.2	1.0	99
34	460	4.4	.99	1.0	22.8	6.0	.8	80

Summary and Conclusions Typically, irrigation farmers apply up to 10 acre inches of water in a dry year. It will be noted that the highest nutrient content was from samples No. 34. Ten inches of irrigation water would supply 44 pounds of N and 800 pounds of lime equivalent per acre.

SOUTHERN EXPERIMENT STATION

WASECA, MINNESOTA

WEATHER DATA - 1991

Month	Period	Precipitation 1991	Precipitation Normal[1]	Avg. Air Temp. 1991	Avg. Air Temp. Normal[1]	Growing Degree Days 1991	Growing Degree Days Normal[1]
		------ inches -----		------- ° F ------			
January	1-31	0.57	0.84	8.8	10.0		
February	1-28	0.65	0.99	23.5	16.4		
March	1-31	3.33	1.99	33.0	27.6		
April	1-30	4.30	2.64	48.6	44.7		
May	1-10	2.89		46.2		19.5	
	11-20	1.95		63.8		147.5	
	21-31	2.92		71.9		239.5	
	Total	7.76	3.76	61.0	57.7	406.5	334
June	1-10	.84		70.9		208.5	
	11-20	2.65		72.9		227.5	
	21-30	.24		76.3		242.5	
	Total	3.73	4.48	73.4	67.1	678.5	518
July	1-10	.86		72.0		213.5	
	11-20	3.82		76.3		244.0	
	21-31	3.99		67.8		198.5	
	Total	8.67	4.02	71.9	71.2	656.0	641
August	1-10	5.60		67.1		168.5	
	11-20	.64		68.9		189.5	
	21-31	.05		75.3		268.0	
	Total	6.29	3.99	70.5	68.8	626.0	579
September	1-30	4.61	3.36	59.2	59.8	308.0	311
October	1-31	1.40	2.08	45.7	48.9		38
November	1-30	7.42	1.43	23.0	32.5		
December	1-31	1.73	1.02	20.9	18.0		
Year	Jan-Dec	50.46	30.60	45.1	43.6	2675.0[2]	2421
Growing Season	May-Sep	31.06	19.61	67.2	64.9	2675.0	2383

[1] 30-year normal from 1951 – 1980.
[2] 50 to 86 ° F base, May 1 until first fall frost.

Notes:
1) Highest annual and growing season precipitation on record.
2) November precipitation was a record high while average temperature was a record low.
3) Highest temperature on June 27 & 28 – 97°F.
4) Only 16 days of ≥90 ° F.
5) Highest 24-hour precipitation on August 8 - - - 5.30".
6) Last spring frost - - - April 24.
7) First fall frost - - - September 20.

1991 Soil Moisture
0-5' Profile, Webster Clay Loam
Continuous Corn
Southern Experiment Station, Waseca, MN 56093

Depth	4/17	5/2	5/14	5/31	6/17	7/3	7/15	8/1	8/15	8/30	9/17	10/1	10/15	10/31
	inches available water in zone													
0-6[1]	1.08	.87	.92	1.07	1.25	.78	.74	.75	.89	.25	.72	.91	.62	1.14
6-12	.97	.61	.75	1.02	.99	.47	.58	.46	.70	.07	.42	.68	.39	.83
12-18	.89	.92	.83	.98	.90	.76	.63	.66	.79	.36	.77	.88	.55	.92
18-24	.89	.84	.71	.77	.84	.77	.63	.59	.69	.47	.67	.72	.47	.78
24-36	2.11	2.43	1.92	1.86	2.06	1.75	1.80	1.40	1.93	1.45	1.38	1.75	2.01	1.85
36-48	2.92	3.28	2.79	2.68	2.41	2.39	2.42	2.23	2.73	2.27	2.14	2.26	2.47	2.76
48-60	2.56	2.60	2.46	1.90	2.10	1.91	2.06	1.57	2.16	1.78	1.62	1.81	1.99	2.18
Total available water in 0-5' profile (inches)	11.43	11.56	10.38	10.29	10.55	8.85	8.87	7.66	9.90	6.66	7.71	9.01	8.49	10.47
% of Capacity[2]	100	100	94	93	95	80	80	69	90	60	70	82	77	95

[1] All values obtained by gravimetric sampling using Waseca D_b and WP constants.

[2] Assuming 11.05" field moist capacity.

Available soil moisture in the five-foot profile was plentiful throughout 1991. Above average rainfall resulted in a full soil moisture profile in June and no lower than 60% of a full profile at the height of evapotranspiration demand (July and August). Soil moisture conditions going in to 1992 are saturated with the profile being 95% full at the end of October.

NITROGEN LOSS TO TILE LINES AS AFFECTED BY TILLAGE[1]

Waseca, 1991

G. W. Randall and B. W. Anderson[2]

ABSTRACT: No tillage (NT) is thought to increase infiltration and, therefore, should increase the amount of water percolating through the soil compared to conventional tillage. This long-term study is being conducted to determine if greater amounts of NO_3-N and pesticides are being lost to tile drainage water with NT compared to moldboard plow (MP) tillage. Rainfall during 1991 was 19.9" above normal and tile flow was plentiful. The slightly higher tile drainage with NT was offset by higher NO_3-N concentrations with the MP system. Nitrate-N losses to the tile lines were 20% higher for the MP system. Corn yields, N uptake, and N removal in the grain were all significantly higher for MP compared to NT. Grain yield was 26% less with NT. Slightly higher amounts of NO_3 remained in the 8-foot soil profile in October with the MP system compared to NT.

Nitrogen losses to tile lines have been documented in a number of research studies including some conducted at Lamberton and Waseca, Minnesota. These studies primarily showed that N losses were a function of the N application rate and amount of precipitation. To some degree the time of application and crop grown have been shown to influence NO_3-N loss to tile lines. The purpose of this long-term study is to determine if tillage has an effect on N utilization, accumulation of NO_3-N in the soil profile, and the subsequent loss of NO_3-N to tile lines.

EXPERIMENTAL PROCEDURES

A study was initiated in 1975 on a Webster clay loam at Waseca to monitor the movement of N into a tile line installed in each of 12 plots measuring 45' x 50'. Each plot is enclosed with plastic sheeting to a 6' depth. Annual N rates of 0, 100, 200, and 300 lb N/A were applied from 1975-1979. No N was applied for the 1980 and 1981 crops. Residual N from N applied over the 5-year period (75-79) was utilized by the 1980 and 1981 corn crops. Soil samples to 10' and tile water samples taken in late 1981 showed little remaining evidence of the previous treatments.

In the fall of 1981, eight plots with the most uniform tile flow rates over the 1975-81 period were selected. Two tillage treatments (fall moldboard plow and no tillage) were replicated four times and randomized over the previous plot histories. Beginning in 1990, three replications and 6 plots were used. Corn was grown on these plots in 1982 through 1990. The stalks were chopped in October, 1990 and moldboard plots plowed.

On May 2, 180 lb N/A as ammonium nitrate was broadcast applied to the surface of all plots. The moldboard treatment was then field cultivated. Corn (Dekalb 547) was planted on May 15 at a population of 27700 plants/A with a John Deere Max-Emerge planter equipped with ripple coulters. Starter fertilizer was not used because of the high soil tests. Force was applied at 1 lb (ai)/A to control rootworms. Weeds were controlled with a preemergence application of Lasso (3-1/2 lb/A) and Bladex (3 lb/A) applied May 21. Weed and insect control were excellent. Percent surface residue was measured on May 3 and averaged 9 and 86% for the MP and NT systems, respectively.

The leaf opposite and below the ear was taken from 10 randomly selected plants per plot at silking (MP = July 22 and NT = July 24) and was analyzed for N. Silage yields were taken at physiological maturity by hand harvesting 40' of row from each plot.

Grain yields were taken by combine from 2 - 45' rows. Tile lines flowed from March 21 to August 21, Sept. 14 to 26 and November 16 to December 21. When tile lines were flowing, flow rates were measured daily and samples taken on a daily basis for the first week and then on a M-W-F basis thereafter for NO_3 analysis. All analyses were done by the Research Analytical Lab.

Soil NO_3-N in the 0-8' profile was determined from two cores/plot taken in 1-foot increments on October 18, 1991.

RESULTS

Yields, N uptake by the whole plant (silage), and N removal in the grain were all significantly higher for the moldboard plow (MP) system compared to no tillage (NT) (Table 1). This was the sixth year of ten where MP yields were significantly higher. Neither leaf N nor grain N concentration was affected by tillage (P = 90% level). Final population was slightly higher with NT.

Precipitation during the growing season was 11.4" above normal. Consequently, tile flow was substantially higher than in previous years and averaged about 19% higher with NT compared to MP tillage (Table 2). Flow-weighted NO_3-N concentration for the season averaged 53% higher with MP tillage. Thus, NO_3-N losses via the drainage water were 23% higher for MP tillage. On an annual basis these NO_3-N losses were the equivalent of 56% to 69% of the fertilizer N added. This figure is erroneous, however, because some of the NO_3 lost, especially early in the season, would have come from the residual NO_3 remaining in the soil after the 1990 crop. Much of that residual NO_3 was probably due to carryover of unused fertilizer N in the drier years and soil mineralization especially with MP tillage.

[1] Funding provided by the North Central Regional Research Committee (NC-201) and the Southern Experiment Station.

[2] Professor and Asst. Scientist, Southern Experiment Station, Univ. of Minnesota.

Table 1. Influence of tillage system on corn production and N utilization at Waseca in 1991.

Tillage system	Final population	Leaf N	Silage Yield	Silage N uptake	Grain Yield	Grain N	Grain N removal
	x10^{-3}	%	T DM/A	lb N/A	bu/A	%	lb N/A
Moldboard Plow	25.4	2.79	6.51	136.5	162.9	1.34	103.5
No Tillage	26.6	2.61	5.24	97.7	120.6	1.18	67.1
Signif. Level (%):[1]	96	79	92	92	99	87	97
CV (%) :	1.0	4.6	8.0	12.	3.1	6.6	9.8

[1] Probability level of significance.

Table 2. Influence of tillage system on tile flow, flow-weighted NO_3-N concentration and NO_3-N loss in 1991.

Month	Tile Flow		NO_3-N Concentration	NO_3-N Loss
	acre-in		ppm	lb/A
			Moldboard plow	
March	0.36		25.3	2.22
April	3.01		25.4	16.28
May	8.70		25.2	48.21
June	2.45		27.1	14.02
July	3.06		22.8	15.49
August	2.20		19.8	9.74
September	0.52		18.3	2.15
November	2.89		18.1	11.62
December	1.00		19.6	4.14
Total	24.19	Avg. =	23.5	123. 87
			No tillage	
March	0.51		18.4	2.09
April	3.51		16.1	12.59
May	9.04		16.6	31.87
June	3.48		19.7	14.98
July	4.03		18.6	16.65
August	2.84		15.5	9.63
September	0.70		12.3	1.94
November	3.20		11.4	8.13
December	1.38		10.2	3.08
Total	28.69	Avg. =	15.4	100.96

Residual NO_3-N in the soil profile at the end of the 1991 growing season showed about 30 lb/A more N remaining with the MP system (Table 3). The largest differences between the two tillage systems occurred in the 3 to 7' zone where more NO_3 accumulated with MP. These results are similar to previous years except that the greatest difference between the two systems usually occurred in the top 1 to 2 feet.

Table 3. Influence of tillage systems on residual NO_3-N in the soil profile in Oct., 1991.

Profile depth	Tillage System: Mb. Plow	Tillage System: No Tillage
feet	NO_3-N (lb/A)	
0-1	18.8	16.7
1-2	10.0	9.7
2-3	12.1	13.5
3-4	24.3	18.9
4-5	31.2	24.8
5-6	34.8	26.0
6-7	33.1	22.1
7-8	22.4	24.4
Total (lb NO_3-N/A 0-8')	186.7	156.1

TEN-YEAR SUMMARY

The cumulative totals for the 10-year period (1982-1991) are shown in Table 4. Corn yields over this period averaged 17.2 bu/A better with moldboard plow tillage. Approximately 20% more N has been removed in the grain with moldboard plow tillage. This has been due to both higher yields and slightly higher grain N concentrations with the moldboard tillage system some years. As a result an equivalent of 52 and 43% of the applied N has been removed in the grain by the MP and NT systems, respectively. Even though total water flow through the tile lines was 11% higher with NT compared to MP tillage, 3% more NO_3-N was lost via the tile lines with MP. This was due to higher NO_3-N concentrations, expecially in the last two years. This small difference is considered to be insignificant when considering tile flow variability among the plots. The equivalent of 20 to 21% of the fertilizer N applied to these plots has been lost to tile drainage over this 10-year period.

Table 4. Cumulative effects of the two tillage systems over the 10-year period.

	Tillage System	
Parameter	Mb. plow	No tillage
Fert. N applied (lb/A)	1800	1800
Corn grain removed (bu/A)	1395	1223
N removed in grain (lb/A)	929	775
N removed in grain as a percent of applied N (%)	52	43
Tile flow (acre inches)	104.6	116.3
Nitrate-N lost in tile (lb/A)	372.7	361.0
N lost via tile lines as a percent of applied N (%)	21	20

NITRATE LOSSES TO TILE DRAINAGE AS AFFECTED BY NITROGEN FERTILIZATION OF CORN IN A CORN-SOYBEAN ROTATION[1]

Waseca, 1991

Gyles W. Randall, Gary L. Malzer and Brian W. Anderson[2]

ABSTRACT: A study to determine the influence of time of N application and N-Serve on the uptake of N by corn and the loss of NO_3 to tile drainage was continued in 1991. Results from this fifth year showed significant yield improvement over the control with all N treatments, and significant differences among the four primary application time/method treatments. Corn yields and N efficiency were lowest with the fall N without N-Serve treatment, highest with the spring N treatments, and intermediate with the fall N plus N-Serve treatment. Tile lines flowed from late March through mid December. Tile flow averaged 17.10" for corn and 14.77" for soybean. Highest NO_3-N losses in the corn plots occurred with the fall application of N regardless of N-Serve while the highest losses under soybean occurred with fall application of N without N-Serve and split application to the previous corn crop. Nitrate-N concentrations and losses from continuous fallow plots that did not receive fertilizer N or a planted crop for five years were 60% higher than from the fertilized corn. This was due to high levels of NO_3 throughout the 8-foot profile as a result of soil mineralization and no crop uptake.

Nitrogen (N) losses to tile drainage water have been directly linked to N additions, crop grown, and soil organic matter level. Research has been conducted on NO_3 losses to tile water in Minnesota since 1972. This research has focused primarily on the effects of rates and timing of fertilizer N application and tillage in a continuous corn system. The purpose of this study is to determine the influence of time of N application and the use of a nitrification inhibitor on NO_3 movement and accumulation in the soil, NO_3 losses via tile drainage, and yield and N uptake by corn grown in a rotation with soybean.

EXPERIMENTAL PROCEDURES

Thirty-six individual tile line plots were installed on a poorly drained Webster clay loam at the Southern Experiment Station in 1976. Each 20 x 30' plot is completely surrounded by plastic sheeting to a depth of 6' to prevent lateral flow and contains a tile line (4' deep) 5 feet from one end. All tiles drain to collection pits where flow rates can be measured and water samples collected for analyses. After completing a research project in 1983 using this tile facility, the plots were cropped to corn with a blanket N rate in 1984 and 1985 to establish uniformity.

Beginning in 1986 corn was planted on one-half of the experimental site while soybean was planted on the other half. Thirty two plots (16 with corn and 16 with soybean) with the most uniform drainage were selected from the 36 for the primary study. The experimental design consists of a 4 x 4 Latin square where the rows and columns were based on the previous (1977-83) tile flow rates from each plot. The four basic N treatments (see Table 1) are applied to the corn phase each year with the residual effects measured in the soybean phase. Three additional N treatments were replicated four times around the edge of the core 16-tile-plot area and were planted to corn. These three treatments were analyzed along with the other four as a completely randomized design.

Anhydrous ammonia was applied at a rate of 135 lb/A for all N treatments while N-Serve was applied at 0.5 lb/A. Fall treatments were applied on October 26. Average soil temperature at the 4" depth on that date was 47°F with an average of 48°F over the following 10-day period. Spring preplant treatments were applied on May 21. The sidedress portion (60%) of the split treatments was applied at the V-9 stage on July 8.

The soybean area that was planted to corn in 1991 was field cultivated once before planting. The corn area (1990), however, was fall chiseled and field cultivated once prior to planting soybean. Surface residue accumulation estimated by the line-transect method on May 3 showed an average of 52 and 48% for the areas that were planted to corn and soybean, respectively, in 1990. Because of high soil P and K tests, no broadcast nor starter fertilizer was used.

Corn (Pioneer 3751) was planted at 30,200 plants/acre on May 29 with a JD Max-Emerge planter equipped with waffle coulters. A corn rootworm insecticide was not used. Weeds were chemically controlled with a preemergence application of Lasso (3.5 lb/A) plus Bladex (3 lb/A).

Soybeans (Hardin) were planted in 30" rows at 9 beans per foot of row on May 29. Weeds were chemically controlled with a post emergence application of Pursuit (4 oz/A) at the 1st trifoliate stage.

Two plots within each of the corn and soybean areas were not planted and were fallowed all summer. These four fallow plot areas were located on those tile plots that showed greatest water flow variability (1977-83). The purposes of these plots were to simply check the NO_3-N concentrations in the tile water in a fallow system and to utilize all 36 of the tiled plots, even though these four historically showed the highest flow variability.

Stand counts were taken at the V-5 stage and plots were thinned to a uniform population. Eight randomly selected plants were removed from the center rows at silk initiation (July 30) and were chopped, dried, weighed and ground for total dry matter accumulation and analyzed for total N concentration. Stover and grain samples were taken at physiological maturity by hand harvesting 30' of row for stover yields and 60'

[1] Partial funding provided by Dow Chemical U.S.A., Minnesota Agric. Exp. Stn., and Center for Agric. Impacts on Water Quality.

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of row for grain yields and moisture. Chemical analyses of whole plant, stover and grain samples were performed by the Research Analytical Laboratory, University of Minnesota. Tile line flow rates were determined daily and were recorded when flow exceeded 10 ml/minute (0.01"/day). Samples were collected for NO_3-N analysis on an every-other-day basis. Periodic samples were collected for alachlor (Lasso), cyanazine (Bladex), and imazethapyr (Pursuit) analyses.

Soil samples for NO_3-N analysis were taken in 1-foot increments to a depth of 8 feet from the fallow plots and selected corn and soybean plots on April 15. The same technique was used to sample all fallow and corn plots and selected soybean plots on October 21.

RESULTS AND DISCUSSION

Plant

Whole plant N concentration at the silking stage was highly affected by the N treatments (Table 1). This is in contrast to 1990 probably because of the high amount of rainfall during the 1991 growing season (11.4" above normal). Very low plant N concentrations were found with the fall applications with a slight but non-significant improvement when N-Serve was applied. Plant N concentrations at silking were increased significantly by all spring and split applications over the fall applications. Dry matter accumulation at silking was not improved over the control by fall application without N-Serve. Spring applications resulted in highest DM accumulation at silking. Stover N concentration was increased significantly over the control by all spring applications but not by either of the fall applied treatments. Dry matter yield of the stover at physiological maturity (PM) was increased by all of the N treatments over the control. However, spring applications were clearly superior to fall N without N-Serve while fall N plus N-Serve showed an intermediate stover DM yield. Final population was not significantly different among the N treatments.

Table 1. Influence of time of N application and N-Serve on whole plant N, stover yield, and final population of corn following soybeans.

N application		Whole Plant Silk Stage		Stover		Final
Time	N-Serve	N	DM	N	Yield	Population
		%	g/plt	%	TDM/A	ppA x 10^3
Primary trts						
Fall (Oct.)	No	1.01	86	.32	1.90	28.0
Fall (Oct.)	Yes	1.11	99	.37	2.17	27.9
Spr. (April)	No	1.59	107	.43	2.30	28.2
Split[1]	No	1.30	103	.43	2.30	28.4
Additional trts						
Check	-	1.02	76	.34	1.49	28.4
Spr. (April)	Yes	1.53	114	.46	2.34	28.2
Split[1]	Yes	1.63	97	.46	2.21	27.4
		Statistical Analysis				
Latin square (Primary Trts)						
Signif. Level (%) :		99	97	90	99	42
BLSD (.05) :		0.16	13	-	0.22	-
CV (%) :		7.8	7.3	15.	5.8	1.6
Completely randomized (7 trts)						
Signif. Level (%) :		99	99	99	99	95
BLSD (.05) :		.14	11	.08	.27	0.7
CV (%) :		7.9	8.2	13.	9.1	1.4

[1] 40% preplant + 60% sidedress.

Grain and silage yields were increased significantly over the check (0 lb N/A) by all of the N treatments (Table 2). However, grain and silage yields with fall applied N without N-Serve were clearly inferior to the spring N applications and fall N with N-Serve. Although not statistically significant (P = 95% level), spring applications of N gave consistently higher grain and silage yields. Grain moisture at harvest was significantly higher (P = 99% level) for the check compared to the N treatments with no significant difference (P = 95% level) among the four primary time/method treatments. Grain N concentration and N removal in the grain were increased over the 0-lb N check by all of the N treatments and was significantly higher with the spring applications compared to fall application regardless whether N-Serve was used. Total N uptake was increased over the control by 23.6 lb/A (43%) for the fall N without N-Serve, 40.5 lb/A (74%) for the fall N with N-Serve, and over 65 lb/A (121%) with the four spring N treatments. In summary, all plant yield and N efficiency parameters were significantly improved by the spring N treatments, regardless of method or N-Serve, compared to fall applications.

Total N removal in the grain ranged from 65.8 to 108.2 lb/A for the six N treatments (Table 2). Based on these removal amounts, N efficiency (N removed by a treatment - N removed in the check ÷ 135 lb N/A) ranged from 16 to 48% for the six N treatments. Efficiency of the spring treatments ranged from 42 to 48% and was substantially higher than the 16 and 26% with the fall treatments without and with N-Serve, respectively. Nitrogen efficiency based on total plant uptake ranged from 17 to 56% for the six N treatments. Again, N efficiency with the spring N treatments (49 to 56%) was clearly higher than from the fall treatments (17 to 30%) regardless if N-Serve was used.

Table 2. Corn grain and silage production as influenced by time of N application and N-Serve.

N application		Grain					Total N
Time	N-Serve	Yield	H_2O	N	N removal	Silage	uptake
		bu/A	%	%	lb/A	TDM/A	lb/A
Primary trts							
Fall (Oct.)	No	122.5	22.8	1.14	65.8	5.21	78.0
Fall (Oct.)	Yes	143.4	21.8	1.16	79.0	6.00	94.9
Spr. (April)	No	151.2	19.3	1.40	100.8	6.41	120.5
Split[1]	No	152.8	20.3	1.42	103.0	6.47	122.7
Additional trts							
Check	-	93.2	25.4	1.00	44.0	4.02	54.4
Spr. (April)	Yes	154.5	21.0	1.48	108.2	6.57	129.9
Split[1]	Yes	151.3	20.7	1.40	100.2	6.35	120.2
			Statistical Analysis				
Latin square (Primary trts)							
Signif. Level (%) :		99	92	99	99	99	99
BLSD (.05) :		16.0	-	0.08	13.9	0.43	12.9
CV (%) :		6.3	7.6	3.7	9.3	4.2	7.3
Completely randomized (7 trts)							
Signif. Level (%) :		99	99	99	99	99	99
BLSD (.05) :		12.6	1.8	.08	10.4	.45	12.5
CV (%) :		6.8	6.1	5.0	9.1	5.7	9.0

[1] 40% preplant + 60% sidedress

Table 3. Influence of time of N application and N-Serve on time of N uptake.

N application		Fodder N Yield at[1]		Grain N Yield at PM			
Time	N-Serve	Silk	PM	Total	OLD[2]	NEW[3]	NEW[3]
		lb N/A					%
Primary trts							
Fall (Oct)	No	53.7	12.2	65.8	14.5	24.5	36
Fall (Oct)	Yes	68.0	16.0	79.0	52.0	26.9	34
Spr (April)	No	105.7	19.8	100.8	86.0	14.8	13
Split[4]	No	83.5	19.7	103.0	63.8	39.2	38
Additional trts							
Check	-	48.1	10.4	44.0	37.7	6.3	14
Spr (April)	Yes	108.1	21.7	108.2	86.4	21.8	20
Split[4]	Yes	95.8	20.0	100.2	75.8	24.4	24
			Statistical Analysis				
Latin square (Primary trts)							
Signif. Level (%):		99	99	99	99	88	92
BLSD (.05) :		13.6	4.2	13.9	13.1	-	-
CV (%) :		10.	14.	9.3	13.	44.	40.
Completely randomized (7 trts)							
Signif. Level (%):		99	99	99	99	95	94
BLSD (.05) :		9.8	3.8	10.4	11.2	21.9	-
CV (%) :		9.1	16.	9.1	13.	56.	53.

[1] Silk = Silk stage, PM = physiological maturity.

[2] OLD N = N in stover at silk – N in stover at PM; the difference is assumed to be translocated to the grain.

[3] NEW N = Total N in grain – Old N; the difference is assumed to be absorbed from the soil and/or translocated from the roots after silking.

[4] 40% preplant + 60% sidedress.

Total N uptake by the plants receiving fertilizer N prior to silking (Fodder N yield at silking) divided by total N uptake at PM shows that from 62 to 87% of the N was accumulated by the plants prior to silking (Table 3). NEW N in the grain (assumed to be taken up by the plant after silking and translocated to the grain) ranged from 14% in the check treatment to between 13 and 38% for all treatments receiving fertilizer N. Under the 1991 conditions there was no clear effect of time/method of N application on post-silk (NEW N) N uptake into the grain.

The General Linear Model program in SAS was used to "contrast" the four primary treatments and determine if significant differences existed. The significance levels shown in Table 4 show consistent yield and N efficiency differences among the N-Serve treatments with fall-applied N. Spring application of N showed significant advantages over fall-applied N for all plant parameters except plant population. With the exception of whole plant N concentration at silking, there was no difference between the spring preplant and split application of N.

Table 4. Significance levels for differences among the four primary treatments as determined by contrast statistics.

Parameter	Contrast: Fall w/o N-Serve vs Fall w/N-Serve	Fall vs Spring	Spring preplant vs Split
	Significance Level (%)		
DM Yield at Silking	99	99	57
Plant N Conc. at Silking	87	99	99
Stover N Conc. at PM	79	99	0
Grain N Conc. at PM	43	99	32
Grain Moisture	65	99	68
Grain Yield	99	99	17
Stover Yield	92	98	1
Silage Yield	99	99	19
Final Population	40	85	40
Grain N Removal	97	99	30
Silage N Uptake	98	99	25

Water

Weather conditions during the 1991 growing season were slightly warmer than normal but were 11.4" wetter than normal. Rainfall during May through August totaled 10.20" above normal. This resulted in tile flow from March 25 through December 6. Tile drainage volumes shown in Table 5 indicate highest flows in May and July. Drainage from the 16 corn plots averaged 17.10" with a 1.78" range among the four time/method treatments. Soybeans showed slightly less tile drainage compared to corn with an average of 14.77" from the 16 plots and a range of 2.91" among the four time/methods. Ideally, drainage should be uniform among the time/method treatments; however, normal soil and drainage variability exists in these plots and results in these unfortunate differences.

Monthly flow-weighted NO_3-N concentrations in the corn plots averaged less than 15 mg/L in April but increased up to 34 mg/L in June with the fall N treatment without N-Serve (Table 6). Nitrate-N concentrations in the tile water with the fall N plus N-Serve and the spring N treatments peaked in June but at lower concentrations of 27 and 16 mg/L, respectively. Nitrate-N concentrations continued to decline after June until reaching levels as low as 6.6 mg/L in December. The fall N treatments tended to give slightly lower NO_3-N concentrations in the tile water in September thru December than the spring treatments. Flow-weighted NO_3-N concentration for the season averaged about 19.0 mg/L for the fall treatments, 15.1 mg/L for the spring treatment and 14.1 mg/L for the split treatment. An opposite trend occurred under soybean where N had been applied in either October, 1989 or spring 1990 for the 1990 corn crop. In this case, flow-weighted monthly NO_3-N concentration started above 20 mg/L in March and slowly declined through the season. The NO_3-N concentration associated with the fall N plus N-Serve treatment was generally lower than the spring treatments and was consistently lower than the fall N without N-Serve treatment. Highest and lowest flow-weighted annual NO_3-N concentrations were associated with the split-applied treatment and fall N plus N-Serve treatment, respectively, when applied to corn the previous year. Nitrate-N concentrations under a 5-yr continuous fallow system (no fertilizer N applied) were approximately 3 to 4X as high as from corn or soybean early in the season but dropped to 2 to 3X as high later in the season.

Under corn, substantially higher NO_3-N losses occurred with the fall treatments compared to the spring treatments (Table 7). This was due to higher NO_3-N concentrations. Little difference was observed between the NO_3-N losses from the spring and split treatments. Nitrate-N losses under soybean were highest for the fall N without N-Serve and the split application treatments that were applied for the 1990 corn crop. This was due primarily to higher NO_3-N concentrations with these two treatments and higher flow rates with the fall treatment. Very high NO_3-N losses occurred under the fallow system where the mineralization of the soil organic matter was the nitrate source. This emphasizes the importance of growing a crop to absorb N released from these high organic matter soils.

Table 5. Tile water discharge from the corn, soybean, and fallow plots in 1991.

N application		Month									Year
Time	N-Serve	March	April	May	June	July	Aug.	Sept.	Nov.	Dec.	Total
		acre-inches									
		CORN									
Fall (Oct.)	No	0.00	2.03	6.22	0.83	4.94	1.43	0.40	1.49	0.19	17.53
Fall (Oct.)	Yes	0.00	2.02	6.05	0.88	4.78	1.25	0.15	1.36	0.21	16.70
Spr. (April)	No	0.00	1.88	5.24	1.13	4.79	1.62	0.22	1.22	0.10	16.20
Split	No	0.00	2.09	5.96	0.99	5.65	1.75	0.11	1.23	0.20	17.98
		SOYBEANS									
Fall (Oct.)[1]	No	0.22	1.95	6.74	0.72	4.23	1.61	0.00	0.92	0.09	16.26
Fall (Oct.)[1]	Yes	0.16	2.34	5.96	0.69	3.98	1.24	0.00	1.31	0.06	15.74
Spr. (April)[1]	No	0.18	1.82	5.32	0.65	3.75	1.22	0.00	0.68	0.10	13.72
Split[1]	No	0.32	1.93	5.23	0.50	3.49	1.06	0.00	0.78	0.04	13.35
		FALLOW									
NONE		-	1.40	4.72	0.74	2.67	0.98	0.28	1.16	0.13	12.08

[1] N applied for the 1990 corn crop.

Table 6. Flow-weighted NO_3-N concentrations for each month from the corn, soybean, and fallow plots in 1991.

N application		Month									Year
Time	N-Serve	March	April	May	June	July	Aug.	Sept.	Nov.	Dec.	Avg.
		mg NO_3-N/L									
		CORN									
Fall (Oct.)	No	-	15.8	22.9	33.6	24.4	13.8	7.1	14.3	6.6	18.9
Fall (Oct.)	Yes	-	15.7	20.4	27.4	22.5	14.4	7.3	11.5	9.2	19.0
Spr. (April)	No	-	13.9	16.5	16.8	14.0	9.4	13.0	10.9	13.6	15.1
Split	No	-	14.1	16.5	16.3	14.0	10.7	13.0	13.2	8.4	14.1
		SOYBEANS									
Fall (Oct.)[1]	No	21.5	23.4	18.9	18.2	14.8	13.4	-	14.3	13.6	17.7
Fall (Oct.)[1]	Yes	21.4	17.1	15.7	16.0	14.4	11.8	-	11.5	11.7	14.9
Spr. (April)[1]	No	22.8	19.4	17.5	17.2	13.7	11.4	-	10.9	9.5	16.2
Split[1]	No	19.5	21.0	20.7	19.7	17.7	14.3	-	13.2	15.6	19.0
		FALLOW									
NONE		-	60.6	46.8	41.9	33.0	34.3	12.2	35.2	29.8	37.9

[1] N applied for the 1990 corn crop.

Table 7. Nitrate-N loss for each month from the corn, soybean and fallow plots in 1991.

N application		Month									Year
Time	N-Serve	March	April	May	June	July	Aug.	Sept.	Nov.	Dec.	Total
		lb NO_3-N/A									
		CORN									
Fall (Oct.)	No	-	6.69	30.94	5.58	24.65	3.93	0.66	2.16	0.28	74.89
Fall (Oct.)	Yes	-	7.18	28.32	5.19	24.13	3.84	0.22	2.53	0.40	71.81
Spr. (April)	No	-	6.84	21.59	4.54	15.60	3.47	0.35	2.77	0.31	55.47
Split	No	-	6.71	22.27	3.69	17.37	4.00	0.19	2.64	0.46	57.33
		SOYBEANS									
Fall (Oct.)[1]	No	1.05	10.71	28.83	2.97	13.68	4.79	0.01	2.95	0.29	65.28
Fall (Oct.)[1]	Yes	.79	8.87	21.03	2.46	12.99	3.33	0.00	3.38	0.15	53.00
Spr. (April)[1]	No	.92	8.36	21.60	2.59	11.71	3.10	0.00	1.69	0.23	50.20
Split[1]	No	1.50	9.06	24.42	2.26	13.92	3.51	0.01	2.45	0.15	57.28
		FALLOW									
NONE			15.78	44.88	7.51	18.44	6.60	1.19	8.32	0.90	103.62

[1] N applied for the 1990 corn crop.

Nitrate-N losses to the tile drainage water were normalized to tile water flow to minimize the influence of water flow volume among the N treatments on the interpretation of the data (Table 8). Normalized values for corn were highest for the two fall treatments with no difference between them. In the year following corn and its associated treatments, normalized losses ranked in the order split > fall w/o N-Serve > spring preplant > fall w/N-Serve. Apparently, sufficient N was not utilized by the corn and remained in the soil profile following the split application; thus, higher NO_3 losses in the succeeding year. Normalized NO_3-N losses for the corn-soybean system were highest for the fall application without N-Serve and lowest for the spring application. Additional years with adequate drainage losses are necessary to determine if these findings are consistent over time.

Table 8. "Flow-normalized" NO_3-N losses to tile drainage in a corn-soybean sequence in 1991.

Crop[1] System	Time/Method of N Application: Fall No N-Serve	Fall N-Serve	Spring No N-Serve	Split
	NO_3-N Lost (lb/A/inch of drainage)			
Corn	4.27	4.30	3.42	3.19
Soybean	4.01	3.39	3.71	4.39
C-Sb System	4.12	3.88	3.57	3.70

[1] Continuous fallow (5 years without fertilizer N) = 8.58

Soil

Nitrate-N remaining in the 0-8' soil profile in mid-April was high in the fallow plots (226 lb/A) compared to those where either soybean or corn were grown in 1990 (Table 9). This value is considerably less than the 377 lb/A that was measured in late October 1990. The reason for the 150 lb/A change over the winter months is not known but may have been largely due to immobilization coupled with some sampling error. Soybean that had not received fall-applied N averaged 99 lb/A with 67 lb/A remaining in the top 5'. Very low amounts of residual NO_3-N remained in the 0-8' profile when corn receiving no N fertilizer was the previous crop (55 lb/A). Residual NO_3-N remaining from the 1990 crop was increased by 30 to 60 lb/A with the previous fall, spring preplant, and split applications. Distribution of NO_3 within the profile was markedly different among the crop/fallow systems. In the fallow plots NO_3-N concentration increased with depth to 4 feet and then remained consistently high. With soybean and corn that received 0 lb N/A, NO_3-N concentrations were highest in the surface foot, decreased in the 1-2' layer, and then remained consistent throughout the rest of the profile. Corn that received the 135-lb N rate in 1990 showed a relatively uniform distribution of NO_3 throughout the profile.

Table 9. Nitrate-N in the soil profile in April, 1991 as influenced by previous crop and N treatment for corn in 1990.

Profile depth	1990 Crop: Fallow	Soybean	Corn[1]: 0 lb N	Fall	Preplant	Split
feet	lb/A[2]					
0-1	14.3	17.8	11.1	11.1	14.3	15.6
1-2	21.2	11.8	6.2	7.0	11.5	11.3
2-3	24.1	13.3	7.3	10.1	14.8	14.6
3-4	35.5	11.0	4.8	9.7	16.0	12.5
4-5	38.9	13.3	5.4	12.7	15.9	12.0
5-6	32.2	11.9	6.0	13.4	15.2	13.1
6-7	32.2	9.7	8.0	10.5	13.3	11.5
7-8	27.8	10.4	6.1	8.4	9.6	10.0
Total in						
0-5' profile	134.0	67.2	34.8	50.6	72.5	66.0
0-8' profile	226.2	99.2	54.9	82.9	110.6	100.6

[1] These fall, spring preplant and split treatments all received N-Serve.
[2] Average of 4 replications.

A comparison of the residual NO_3 amounts found in April, 1991 (Table 9) with those amounts found in the same plots in October, 1990, shows the spring NO_3 levels to be approximately 40% less for the fallow plots, 19% less with the corn that did not receive fertilizer N, and about 26% less with the corn that received 135 lb N/A in 1990.

Residual NO_3-N remaining in the 0 to 5' profile after the 1991 season shows low amounts of NO_3 and markedly less than after the 1990 season (Table 10). This was not surprising considering the high amount of rainfall and subsequent leaching in 1991. Residual NO_3 in the fallow plots was reduced 39% in the 0-5' profile and 25% in the 0-8' profile in this one-year period. The low amounts of NO_3 found in all of the corn plots showed no large differences among time/method of application or between the N-Serve treatments. The spring preplant application of N with N-Serve, however, did show slightly higher amounts of residual NO_3 in the top four feet. Residual NO_3-N levels for the fallow plots were higher in October than in April (Table 9). This is puzzling and cannot be explained considering that over 100 lb NO_3-N/A was lost in the drainage water and that NO_3-N concentration in the water decreased throughout the season.

Table 10. Residual NO_3-N remaining in the 0-8' soil profile after harvest as influenced by time of N application and N-Serve.

Profile depth	Fallow	Check	Application Time					
			N-Serve			No N-Serve		
			Fall	Preplant	Split	Fall	Preplant	Split
feet	lb NO_3-N/A[1]							
0-1	43.9	11.7	16.3	21.1	22.3	14.7	17.7	21.5
1-2	22.8	3.5	5.1	11.3	7.2	5.5	5.9	6.0
2-3	23.3	3.3	3.8	8.5	5.4	4.3	4.3	5.5
3-4	29.5	4.2	6.4	12.7	9.5	7.8	7.9	9.2
4-5	42.5	6.1	12.3	12.6	12.2	12.1	12.3	11.8
5-6	48.3	7.4	12.6	12.5	11.3	14.1	12.5	12.1
6-7	42.7	6.9	13.3	11.3	11.2	14.0	11.6	12.6
7-8	31.2	9.2	12.8	10.2	10.2	16.0	10.8	12.4
Total in								
0-5' profile	162	29	44	66	57	44	48	54
0-8' profile	284	52	83	100	89	89	83	91

[1] Avg. of 4 replications

CONCLUSIONS

The warm and wet conditions resulted in good corn production and excellent tile drainage. Corn production was greatly improved by the various N treatments over the control. Fall-applied N, especially without N-Serve, gave lower corn yields and showed poorer N efficiency compared to the spring applications. Crop production differences were not apparent between the spring preplant and split applications. Tile flow data indicated only small differences among the four N treatments with respect to amount of drainage but did show markedly elevated NO_3-N concentrations and losses with the fall applications (regardless of N-Serve use) compared to the spring applications. Nitrate-N concentrations and losses in the drainage water in the "residual" year with soybeans were significant and were highest with the previous fall N without N-Serve treatment and the split application treatment. Residual soil NO_3 at the end of the season was low except in the fallow plots. These data again indicate the importance of growing a crop to utilize the N mineralized from these high organic matter soils.

IMPACT OF RESIDUAL SOIL NITRATE ON CORN PRODUCTION[1/]

Waseca, 1991

Gyles W. Randall, Brian W. Anderson, and Michael Schmitt[2/]

ABSTRACT: A study was conducted to determine the impact of residual nitrate (NO_3) on corn production in 1991. High amounts of residual NO_3 carried over from 1990 to late April 1991. Between late-April and early June, approximately 38% of the residual NO_3 was lost from the 0-3' profile, probably due to the excessive 9.71" of rain during this period. Low amounts of NO_3 remained in the 0-5' soil profile after harvest regardless of the 1990 or 1991 N rate applied. Corn production was not affected by any of the 1990 N treatments but was increased significantly by the 1991 N rate (75 lb N/A) applied to all 1990 plots. No interaction between 1990 and 1991 N rate was found. Under these wet conditions, residual NO_3 was not found to be a reliable source of N. This illustrates the difficulty in developing a good soil NO_3 test under humid conditions.

Carryover of residual nitrate (NO_3) from one season into the next can reduce fertilizer N rate recommendations in the second year if accurately determined with a soil NO_3 test. This is especially true in the more arid areas of the Corn Belt and Great Plains where the soil NO_3 test has been used for years. The purpose of this study was to determine the carryover of nitrate from N applied to corn in June 1990 and to measure the effect of that residual NO_3 on corn production in 1991.

EXPERIMENTAL PROCEDURES

Corn was planted in 1990 following alfalfa (1987-89) on a Nicollet clay loam at the Southern Experiment Station, Waseca. Anhydrous ammonia was sidedress-applied at rates of 0, 60, 90, 120 and 180 lb N/A in June 1990 as part of a study to evaluate soil N tests. Yield responses to the applied fertilizer N were not found but significant differences in residual soil NO_3-N were found (Table 1). The amount of NO_3-N in the 0-5' soil profile ranged from 125 lb/A in the control (0 lb N/A) to 293 lb/A with the 180 lb N/A rate.

Table 1. Residual soil NO_3-N in October, 1990 as influenced by N rates applied to corn in June 1990.

	N rate (lb/A)				
Depth	0	60	90	120	180
feet	ppm NO_3-N				
0-1	15.7	19.0	19.8	22.5	43.9
1-2	3.3	5.0	4.5	5.0	5.9
2-3	2.1	7.0	5.0	6.5	7.9
3-4	5.2	7.2	7.7	6.8	8.9
4-5	5.0	5.2	7.8	6.6	6.7
	lb NO_3-N/A				
0-1'	63	76	79	90	176
0-5'	125	174	179	190	293

With this large difference in residual soil NO_3, each 1990 plot was split in 1991. Urea was applied in April at a rate of 75 lb N/A to one-half of each plot with the remaining half not receiving N. Soil samples were taken preplant (April 22) to a depth of 5' and to a depth of 3' at the V4 stage (corn 6 to 12" high) on June 6 from the plots that only received N in 1990. All samples were analyzed for nitrate and ammonium. In October soil samples were taken after harvest to a depth of 5' from the 0 and 75-lb N rates (1991) that received 0, 90 and 180 lb N/A in 1990 and analyzed for nitrate.

Corn (Pioneer 3751) was planted on May 3 at 30,600 plants/A. No starter fertilizer was applied. Force was used to control corn rootworms. Weeds were controlled with a preemergence application of Lasso (3.5 lb/A) plus Bladex (3.0 lb/A) on May 14. Each plot (4 rows or 10' wide X 25' long) was hand harvested in late September. Both silage and grain yields were taken from the center two rows each 20' long.

RESULTS

Residual soil NO_3 found in the 0-5' profile in April, 1991 was approximately 10% lower than in October 1990 (Table 2). Largest over-winter decline (28%) was found with the 180-lb N rate. The most striking finding was the substantial movement of NO_3 out of the 0-1' layer and into the 1-2' and 2-3' layers during this 6-month period.

Soil samples taken on June 6 revealed very low NO_3-N concentrations in the 0-1' layer with little accumulation in the 0-3' layer (Table 3). During this 45-day period, in which 9.71" of rain occurred, NO_3-N amounts in the 0-3' layer declined by 14% in the 0 lb N/A plots and an average of 38% in the plots that received fertilizer N in 1990. It is likely that a combination of denitrification and leaching occurred to cause this loss of NO_3.

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Table 2. Residual soil NO_3-N on April 22, 1991 as influenced by N rates applied to corn in June 1990.

Depth	N rate (lb/A) 0	60	90	120	180
feet	ppm NO_3-N				
0-1	5.5	6.0	8.7	9.3	9.6
1-2	8.0	10.5	12.3	11.7	14.0
2-3	4.6	8.3	9.1	10.5	11.5
3-4	4.2	7.8	8.7	9.9	9.4
4-5	4.5	6.6	6.7	7.3	8.4
	lb NO_3-N/A				
0-1'	22	24	35	37	38
0-3'	72	99	120	126	140
0-5'	106	157	182	195	211

Table 3. Soil NO_3-N on June 6, 1991 as influenced by N rates applied in June 1990.

Depth	N rate (lb/A) 0	60	90	120	180
feet	ppm				
0-1	4.3	4.1	4.9	5.7	5.1
1-2	5.0	6.1	5.4	6.6	5.7
2-3	6.3	7.1	7.6	7.5	9.0
	lb NO_3-N/A				
0-1'	17	16	20	23	20
0-3'	62	69	71	79	79

Table 4. Soil NO_3-N on October 11, 1991 as influenced by N rates applied in June 1990 and April 1991.

	June 1990			June '90 + April '91		
	N Rate (lb/A)					
Depth	0	90	180	0 + 75	90 + 75	180 + 75
feet	ppm NO_3-N					
0-1	5.2	5.9	7.0	5.3	5.6	6.1
1-2	2.8	2.5	3.1	2.6	2.7	3.2
2-3	2.4	2.2	3.0	1.9	1.9	2.3
3-4	3.8	3.5	4.5	4.6	3.4	4.6
4-5	4.6	6.7	5.7	5.6	4.9	5.7
	lb NO_3-N/A					
0-1'	21	23	28	21	22	24
0-3'	42	42	52	39	40	46
0-5'	75	83	92	80	74	88

Post-harvest samples showed very low concentrations of NO_3-N throughout the 0-5' profile regardless of 1990 or 1991 N rate applied (Table 4). Crop uptake and the very wet conditions during the year probably accounted for this lack of residual NO_3 in 1991.

Yields and N concentrations in the corn grain and stover in 1991 were not influenced by the 1990 N treatments (Table 5). Nitrogen uptake in the grain and silage was also not affected by the 1990 N rates. Corn production, however, was excellent in all of the plots, probably due to alfalfa in the rotation (1987-89).

Corn grain, stover and silage yields were increased by the 75-lb N treatment (1991) to all of the 1990 N treatments (Table 5). Grain moisture at harvest was also decreased while grain and stover N concentrations were not affected by the 1991 treatment. No interaction between the 1990 and 1991 N treatments was found for any plant parameter.

Table 5. Corn grain and silage yield, N concentration and N uptake as influenced by 1990 (residual) and 1991 N rates.

N Rate		Grain				Stover		Silage	
1990	1991	Yield	H_2O	N Conc.	N uptake	N	Yield	Yield	N uptake
lb/A	lb/A	bu/A	%	%	lb/A	%	TDM/A	TDM/A	lb/A
0	0	165.6	34.1	1.25	98.2	.68	2.02	6.38	125.5
60	0	164.0	34.4	1.24	96.8	.67	2.14	6.45	125.1
90	0	166.8	34.7	1.24	97.7	.61	2.14	6.52	123.7
120	0	169.6	34.9	1.21	97.3	.69	2.08	6.58	126.2
180	0	166.9	34.2	1.25	98.8	.63	2.25	6.67	127.3
0	75	193.2	31.6	1.24	113.4	.67	2.25	7.79	149.2
60	75	202.3	32.0	1.18	113.0	.58	2.68	8.18	146.1
90	75	200.2	31.5	1.12	105.0	.57	2.81	8.02	137.0
120	75	190.8	31.5	1.29	116.5	.65	2.85	7.90	153.8
180	75	206.2	31.4	1.25	122.2	.61	2.90	8.33	157.4
MAIN EFFECTS									
1990 N Rate (lb/A) - "Residual"									
	0	179.4	32.8	1.25	105.8	.67	2.35	7.08	137.3
	60	183.1	33.2	1.21	104.9	.62	2.48	7.32	135.6
	90	183.5	33.1	1.18	101.7	.59	2.44	7.27	130.4
	120	180.2	33.2	1.25	106.9	.67	2.46	7.24	140.0
	180	186.6	32.8	1.25	110.5	.62	2.58	7.50	142.3
Signif. Level (%):		42	32	56	61	72	79	60	69
1991 N Rate (lb/A)									
	0	166.6	34.4	1.24	97.8	.66	2.12	6.52	125.5
	75	198.5	31.6	1.22	114.2	.62	2.80	8.04	148.7
Signif. Level (%):		99	99	54	99	94	99	99	99
1990 N Rate x 1991 N Rate IA									
Signif. Level (%):		84	6	69	38	23	11	33	31
CV (%)	:	4.2	4.0	7.5	9.1	9.1	6.9	4.3	8.9

CONCLUSIONS

Even though substantial NO_3-N carried over into the 1991 season from 1990, it did not influence corn production in 1991 because most of it was lost from the 0-3' soil profile between late April and early June. Under these wet conditions residual NO_3 cannot be counted as a reliable N source. From this we can see the difficulty of obtaining accurate N rate recommendations from soil nitrate tests under high rainfall conditions.

DECLINE RATES OF SOIL TEST P AND K IN A CORN-SOYBEAN ROTATION[1]

1991

G. W. Randall and S. D. Evans[2]

ABSTRACT: Decline rates of soil test P and K are being measured following 12 years of various application rates of P and K at two locations. Soil test P declined by about 10% at Waseca and 14% at Morris. Soil test K increased by 30 and 35% at Waseca and Morris, respectively. Corn yields were increased 22 to 33% over the long-term control plots at the two sites when soil test Bray P_1 was greater than 24 lb/A. There appeared to be little effect of soil test K on corn yield at Waseca. Over the 5-year (1986-91) period soil test P declined by 1.1, 3.9 and 5.4 lb/A/yr when no fertilizer P was applied to soils testing 16, 48 and 89 lb/A initially at Waseca. Soil test K varied considerably from year to year and did not allow consistent decline rate calculations. At Morris soil P declined by 5.5 lb/A/yr when the initial Bray P_1 test was 67 lb/A.

With good fertilization practices over the last 20 to 30 years, many farmers throughout the Cornbelt have built their P and K soil tests to high and very high levels. Studies conducted over the last 12 years have not shown corn and soybean yield increases from additional broadcast P and K at these high to very high test levels. Consequently, a number of farmers have curtailed P and K fertilization on these high testing soils. Two commonly asked questions in this scenario are: (1) How fast will my soil test drop if I don't continue to add fertilizer P and K? and (2) At what test level should I begin to add P and K to maintain fertility at an optimum level for efficient and economical production? The purposes of this study are to determine (1) the decline rates of soil test P and K and (2) the optimum soil test level which should be maintained for economical corn and soybean production.

EXPERIMENTAL PROCEDURES

High rates of P and K were applied over a 12-year period (1973-84) in studies at the Southern Experiment Station at Waseca (Table 2) and the West Central Experiment Station at Morris (Table 3). These rates created a wide range of soil test values upon which we can evaluate the decline rates of soil test P and K when no additional fertilizer is added. Treatments 2, 3, and 4 have not received additional P since 1984 while treatments 6 and 7 at Waseca have not received K. The K treatments were not included at Morris because of very high native soil test K levels. Treatment 5, which had a moderately high level of fertilization prior to 1985, continues to receive P and K, and thus, serves as the high fertility control.

Table 1. Experimental procedures for corn on the high P and K rate study at the two branch stations in 1991.

Variable	Location: Morris	Location: Waseca
Planting date	4/25	5/14
Row spacing	30"	30"
Planting rate (plants/A)	27,500	30,200
Variety	Pioneer 3788	Pioneer 3578
Herbicide	3# Lasso + 2.2# Bladex/A (Bdct)	3.5# Lasso + 3# Bladex/A (Bdct)
Harvest date	9/18	10/10
Soil type	Aastad clay loam	Webster clay loam

The P and K materials (0-46-0 and 0-0-60) were broadcast on the soil surface and incorporated by chisel plowing the corn residue in the fall of 1990. Specific experimental procedures used for corn at the two locations are presented in Table 1. Management practices providing for optimum yields were employed at each location. Starter fertilizer was not used.

RESULTS AND DISCUSSION

Total phosphate (P_2O_5) and potash (K_2O) applied over the 12-year period ranged from 0 to 1200 lb/A (Tables 2 and 3). These application rates plus the 1985-86 rates resulted in highly significant differences in soil test P at both locations and soil test K at Waseca. At Waseca soil test P ranged from 10 to 95 lb/A (Table 2). Soil test P declined about 10% compared to 1990, but soil test K increased by 30% even though K was not applied. Corn yields were increased significantly by P but plateaued at soil P levels higher than 25 lb/A.

[1] Funding provided by the TVA-National Fertilizer Development Center.

[2] Soil scientists and professors at the Southern Experiment Station (Waseca) and West Central Experiment Station (Morris), respectively.

At Morris, Bray P_1 ranged from 12 to 71 lb/A while Olsen's $NaHCO_3$ test ranged from 11 to 62 lb P/A (Table 3). Soil test P values declined about 14% at Morris, while soil K values increased about 35%. Grain yields were increased 26 to 38 bu/A, but this was statistically significant at only the 85% level due to high variability. Grain moisture was decreased significantly by the P treatments.

Table 2. Soil test values, grain moisture, and grain yield as influenced by 18 years' application of P and K at Waseca.

	P and K Treatments				Soil Test[2]			Corn	
	Total								
No.	1973-84		1985-90[1]		pH	P	K	Moisture	Yield
	- - - - - - - lb P_2O_5 + K_2O/A - - - - - - -					- - - - lb/A - - - -		%	bu/A
2	0	+ 1200	0	+ 100	6.8	10	315	22.3	133.2
3	600	+ 1200	0	+ 100	6.6	25	295	22.3	176.7
4	1200	+ 1200	0	+ 100	6.8	60	299	21.7	165.2
5	600	+ 1200	100	+ 100	6.9	85	317	22.3	190.4
6	1200	+ 0	100	+ 0	7.0	95	225	21.0	175.5
7	1200	+ 600	100	+ 0	6.9	87	221	21.1	165.4
Signif. Level (%):					36	99	99	46	97
BLSD (.05) :					-	12	40	-	34.3
CV (%) :					3.8	12.	8.0	5.5	10.

[1] Treatments applied each fall. P was discontinued for treatments 6 & 7 in 1988.
[2] Samples were taken in October before 1991 treatments were applied.

Table 3. Soil test values, grain moisture, and grain yield as influenced by 18 years' application of P and K at Morris.

	P and K Treatments			Soil Test[2]				Corn	
	Total								
No.	1973-84		1985-90[1]		pH	P_1	P_{ol}	K	Moisture	Yield
	- - - - lb P_2O_5 + K_2O/A - - - - -					- - - - - - - lb/A - - - - - - -			%	bu/A
2	0	+ 1200	0	+ 100	7.9	12	11	564	24.9	150.4
3	600	+ 1200	0	+ 100	7.9	24	22	463	23.8	176.2
4	1200	+ 1200	0	+ 100	7.9	46	39	503	22.8	188.7
5	600	+ 1200	100	+ 100	7.8	71	62	498	22.8	181.5
Signif. Level (%):					66	99	99	99	95	85
BLSD (.05) :					-	8.7	6.6	27	1.8	-
CV (%) :					0.8	29.	26.	6.3	4.3	13.

[1] Treatments applied each fall.
[2] Samples were taken in October before 1991 treatments were applied.

FIVE-YEAR SOIL TEST DECLINE RATES

Regression analysis was used to assess the average decline rates for Bray P_1 and exchangeable soil test K at Waseca and Bray P_1 at Morris. Soil test data from each of the plots in treatments 2, 3 and 4, which have not received fertilizer P since 1984, were included for the 5-year period (1986-1991) for both sites. Similarly, soil test data for each of the plots in treatments 6 and 7, which have not received fertilizer K since 1984, were included for the 5-year period at Waseca. Both soil test P and K were included from all plots in treatment 5, which received 100 lb P_2O_5/A + 100 lb K_2O/A annually.

Soil Bray P_1 change over the 5-year period at Waseca is shown by each of the lines in Fig.1. Average soil P test for each of the treatments in any particular year is shown by the appropriate symbol. Coefficients of determination (R^2) indicate highly significant relationships (99% level) for the treatments where fertilizer P was not applied and a significant (95% level) relationship where P was applied (Table 4). Soil test P was shown to decline by 1.1 lb/A/yr when the initial soil test was 16 lb/A. At initial soil test values of 48 and 89 lb/A, soil Bray P_1 declined by 3.9 and 5.4 lb/A/yr, respectively, in this corn-soybean rotation. Annual additions of 100 lb P_2O_5/A increased the soil test an average of 4.6 lb/A/yr when the initial test was 61 lb/A.

No relationship was found between the exchangeable soil K test and time (years after 1986) when 100 lb K_2O/A was applied annually (trt 5) or with treatment 6 (Fig. 2). Soil test K was extremely variable over this period as shown by the symbols in Fig. 2. Very high K levels were found in 1988, 1989 and 1991 while K tests were much lower in 1987 and 1990. The relationship between soil K test and time was significant for treatment 7 and indicated a 11.0 lb/A/yr decline in soil K when the initial test was 254 lb/A.

At Morris, soil test P variability was high and decline rates could not be calculated from the regression equations, which were not significant, for treatments 2 and 3. However, soil P did decline by 5.5 lb/A/yr when P was not added to the plots that initially tested 67 lb P/A. This decline rate was almost identical to the rate found at Waseca where soil P test was also very high.

Table 4. Linear regression equation and coefficient of determination (R^2) for the various P and K treatments at Waseca and Morris.

Location	Nutrient	Treatment	Regression Equation[1/]	R^2
Waseca	P	2	ST = 15.8 - 1.13 X	39.4**
"	P	3	ST = 47.8 - 3.90 X	50.8**
"	P	4	ST = 88.8 - 5.43 X	80.8**
"	P	5	ST = 61.3 + 4.62 X	25.7*
"	K	5	ST = 284.0 + 2.45 X	1.1^{NS}
"	K	6	ST = 242.0 - 7.47 X	14.6^{NS}
"	K	7	ST = 253.6 - 11.09 X	25.9*
Morris	P	2	ST = 9.7 + 0.32 X	2.4^{NS}
"	P	3	ST = 34.9 - 1.59 X	3.1^{NS}
"	P	4	ST = 67.3 - 5.54 X	35.4**
"	P	5	ST = 34.3 + 5.58 X	15.4+

[1/] ST = Soil Test (lb/A), X = Years

CONCLUSIONS

Long term (12-yr) additions to these two soils created a wide range in soil test P levels. Corn yields were optimized over the no P treatments at soil test P levels of 25 lb/A at Waseca. Yields were not affected by K at Waseca. At Morris, corn yields were improved about 30 bu/A with the higher soil test P levels. Soil test P declined by about 10% at Waseca and 14% at Morris. Soil test K was increased by about 30% and 35% at Waseca and Morris, respectively, in 1991. Over the 5-year period (1986-91), soil Bray P_1 tests declined by 1.1, 3.9 and 5.4 lb/A/yr when no fertilizer P was applied to these soils initially testing 16, 48 and 89 lb/A, respectively, at Waseca. When 100 lb P_2O_5/A was added annually, soil Bray P_1 increased by 4.6 lb/A/yr when the initial test was 61 lb/A. At Morris, soil test P was more variable, but soil P declined by 5.5 lb/A/yr when the initial Bray P_1 was 67 lb/A.

Because of extremely high soil test K variability from year to year, it was difficult to show a consistent soil test change over time. One relationship, however, did show a 11.0 lb/A/yr decline in soil K when the initial test was 254 lb/A. This information on soil test decline rates when fertilizer is not applied should be very helpful to farmers who are considering omitting fertilizer P for a few years when their soils test high in P.

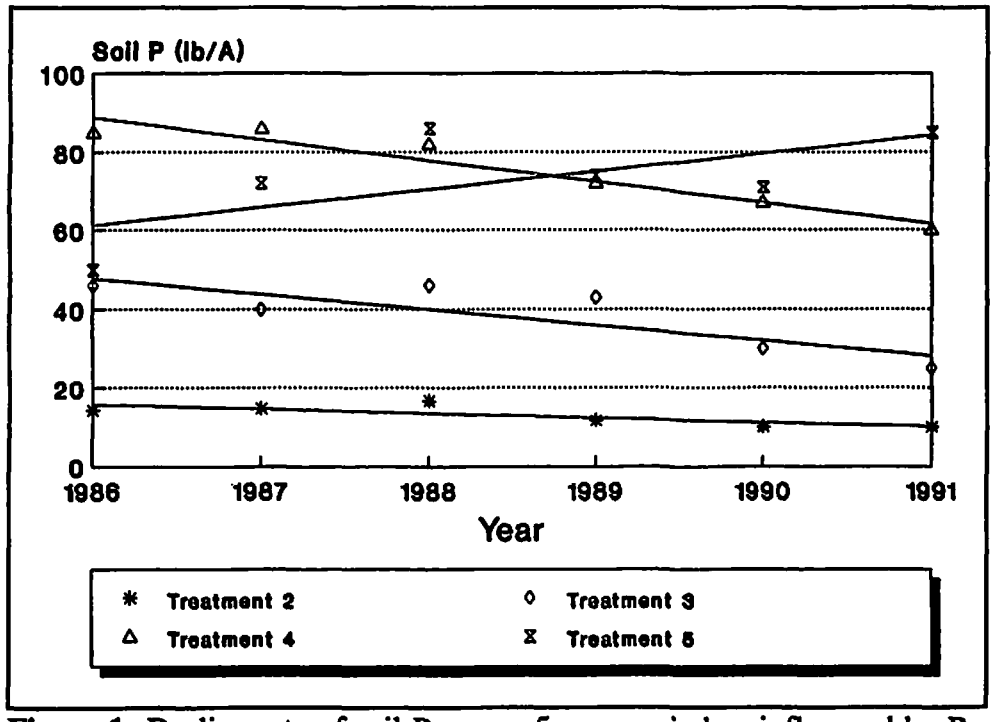

Figure 1. Decline rate of soil P over a 5-year period as influenced by P treatment at Waseca

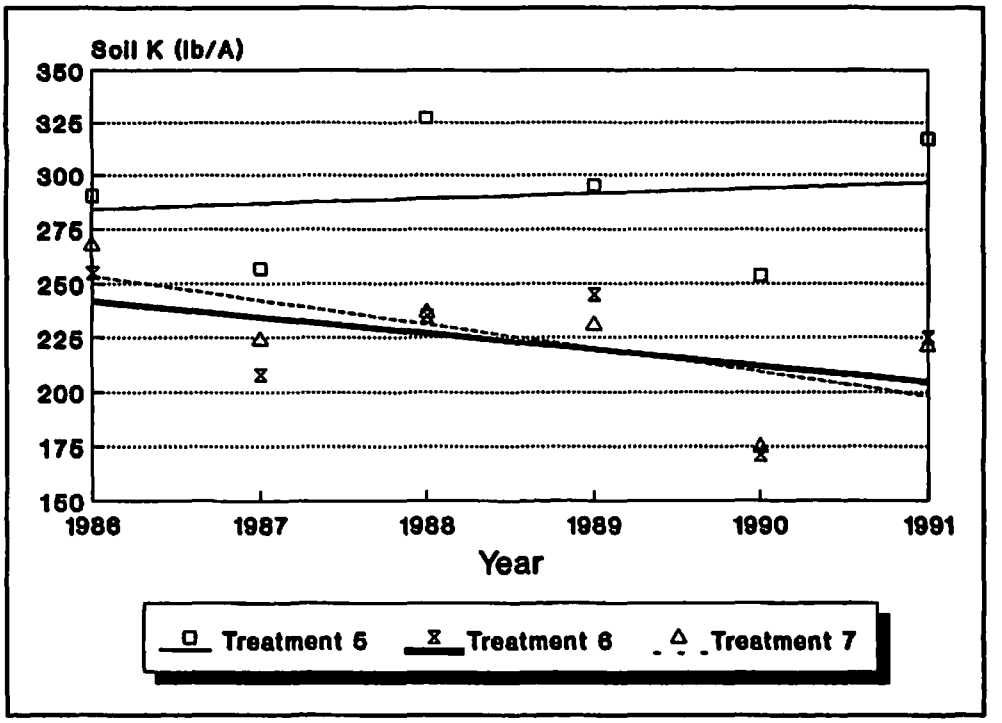

Figure 2. Decline rate of soil K over a 5-year period as influenced by K treatment at Waseca

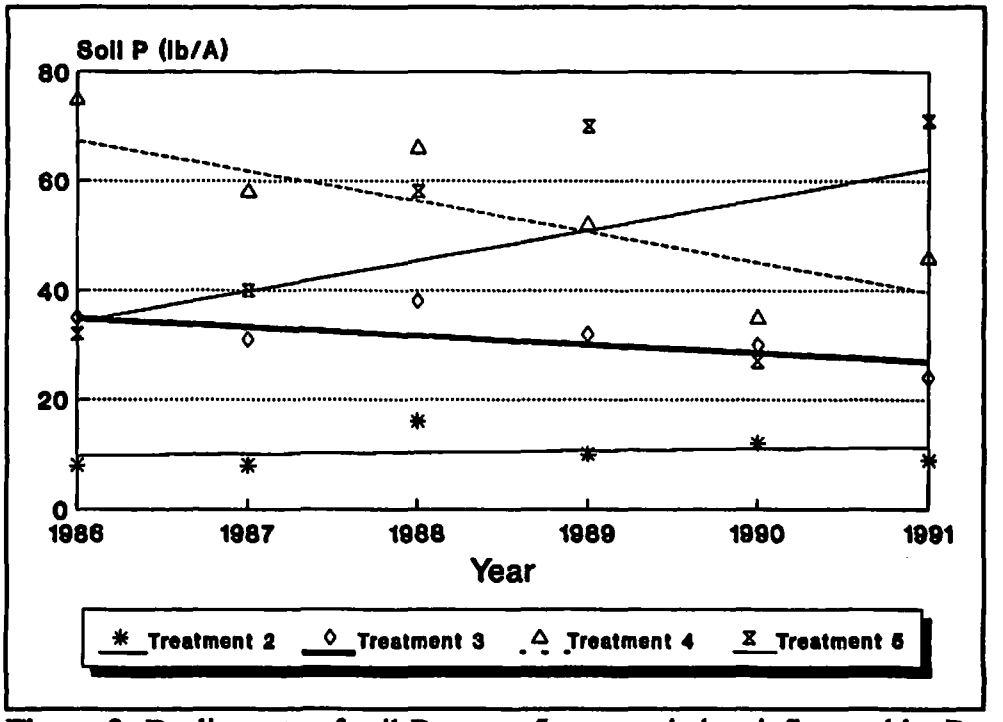

Figure 3. Decline rate of soil P over a 5-year period as influenced by P treatment at Morris

NITRATE AND PESTICIDE LOSSES TO TILE DRAINAGE, RESIDUAL SOIL N, AND N UPTAKE AS AFFECTED BY CROPPING SYSTEMS[1]

Lamberton, 1991

G. W. Randall, D. Fuchs, W. W. Nelson, D. D. Buhler,
M. P. Russelle, and J. L. Anderson

ABSTRACT: Four cropping systems (continuous corn, a corn-soybean sequence, alfalfa, and CRP) were established in 1988 to determine biomass yields, N uptake, residual soil NO_3 and NO_3 and pesticide losses to tile drainage water as influenced by cropping system. Corn and alfalfa yields in this fourth year of the study were excellent while soybean yields were average. Nitrogen removed by the corn, soybean, and alfalfa crops totaled 128, 202 and 339 lb/A, respectively. Residual soil NO_3-N remaining in the 0-5' profile in October totaled 84, 86, 56, 16 and 13 lb/A for the continuous corn, corn-soybean, soybean-corn, alfalfa and CRP systems, respectively. Available water in the 0-5' profile in late October with the row-crop systems ranged between 4.0 and 4.4 inches while the perennial crops only had 1.1" (alfalfa) and 2.2" (CRP). Tile water drainage from the row-crop system ranged from 7.0 to 10.8 acre-inches while only 1.6 to 1.7 acre-inches drained from the perennial crops. Flow-weighted NO_3-N concentrations ranged from 29 to 39 mg/L for the 3½ month drainage period with the corn and soybean systems but averaged only 4 mg/L with the alfalfa and CRP systems. Nitrate-N losses ranged from only 1.5 lb/A with the alfalfa and CRP systems to 72 lb/A with the corn-soybean rotation. Alachlor, cyanazine, Accent and Pursuit were not detected in any of the tile water samples.

Nitrate and pesticide losses to tile drainage water have been monitored in the last few years for continuous corn systems at the Lamberton and Waseca branch experiment stations. However, very little information exists on the N and pesticide losses from other cropping systems, especially those involving alfalfa or CRP grass:legume plantings. The purpose of this study was to determine the effect of four cropping systems on the:

1) above-ground biomass yields, N concentrations in the biomass, and N removal,
2) residual NH_4 and NO_3 in the 0 to 10' soil profile after harvest, and
3) NO_3 and pesticide losses in the tile drainage water.

Background

Fifteen tile drainage plots each measuring 45' x 50' surrounded with plastic sheeting to a depth of 6' were installed in 1972 at the Southwest Experiment Station at Lamberton. Nitrogen rates from 18 to 400 lb N/A were applied annually to corn from 1973 through 1979 on this Nicollet clay loam. Since 1979, continuous corn without N in 1980-1985 and with only 50 lb N/A in 1986-87 was grown to "erase" the effects of the previous treatments.

Experimental Procedures

Four cropping systems (continuous corn, corn-soybean sequence, continuous alfalfa, and continuous CRP (Conservation Reserve Program) species) were established on these drainage plots in the spring of 1988. Each cropping system was randomly assigned to the drainage plots in a randomized, complete-block design with three replications. The detailed experimental procedures are shown in Table 1.

Soil samples taken from the 0 to 8" layer in 1988 indicate high soil test P&K values. Consequently, no broadcast nor starter fertilizer was used for the corn, soybeans or CRP systems. Potassium was broadcast at a rate of 120 lb K_2O/A following the first cutting of alfalfa. Samples taken to a 5-foot depth in late-April were used to determine the N fertilizer rates needed for corn (Table 3). The 122-lb N rate used for continuous corn and the 109-lb N rate for corn after soybeans was based on the NO_3 concentration in the 0 to 24" and 24 to 48" layers and a yield goal of 140 bu/A. Due to a miscalculation, the 109-lb rate was used instead of the 135-lb rate suggested by the soil test.

Results and Discussion

Weather

Climatic conditions during the 1991 growing season were slightly wetter than normal (Table 2). Rainfall over the 7-month growing season was 3.9" above normal with greatest departure from normal in June and September. Monthly temperature averages were markedly above normal for April-June while the 7-month seasonal average was 1° F above normal. These conditions resulted in excellent corn and alfalfa yields and good soybean yield.

Spring Soil Nitrate

Residual NO_3 in the 0 to 5-foot soil profile in late-April was moderately low for both the corn-soybean and soybean-corn systems and high for the continuous corn system (Table 3). Nitrate-N distribution was relatively uniform throughout the profile for all systems, which is in contrast

[1] Funding provided by the North Central Regional Research Comm. (NC-201), Southwest Experiment Station, Southern Experiment Station, and Center for Agricultural Impacts on Water Quality.

to 1990 when most of the NO_3 was in the top two feet. Residual soil NO_3 decreased by 18 to 52% in the cropping systems between the October '90 sampling and the April '91 sampling. These changes between fall and spring sampling suggest sizeable over-winter "losses" of NO_3 probably through immobilization and perhaps leaching, and indicate that late-fall soil sampling to determine fertilizer N needs may not lead to sound fertilizer recommendations.

Crop Yields

Crop yields shown in Table 4 were above the yield goal for corn and were very good for alfalfa. Corn yields and N uptake by the corn were 16 and 10% higher, respectively, for the corn-soybean system compared to continuous corn. Nitrogen concentrations in the grain and stover were slightly higher for continuous corn, probably due to the lower yield. Nitrogen removal by the soybeans and alfalfa far exceeded that by corn. The CRP plots, which were dominated by alfalfa in 1989 and showed a 50:50 split between grass and alfalfa in 1990, had a 90:10 ratio between grass and alfalfa yield in 1991. The wetter conditions in 1990 and 1991 apparently led to the reestablishment of the grass species.

Fall Soil Nitrate

Soil NO_3 levels throughout the 10-foot profile were markedly lower for those cropping systems dominated by alfalfa and CRP compared to the corn and soybean systems (Table 5). Ranking from highest to lowest was: CC = C-Sb > Sb-C > A = CRP. Nitrate-N concentrations were highest in the 0-1' profile, usually lowest between 1 and 3' and were somewhat higher again below 3'. Distribution below 3' was very uniform for the CC and Sb-C systems but declined below 5' with the C-Sb system. The alfalfa and CRP systems exhibited very low NO_3-N concentrations down to 7 feet. From 7 to 10 feet, NO_3-N concentrations, although still low, more than doubled. Amounts of soil NO_3 in the top five feet in October ranged from -36% (continuous corn) to +17% (C-Sb) higher than in April. Absolute differences between the dates of sampling were -47, +17, and -25 lb NO_3-N/A for the CC, C-Sb and Sb-C systems, respectively. Even though 122 lb N/A was applied to the CC systems, soil NO_3-N decreased significantly. This was probably due to the wetter than normal conditions coupled with the high yield.

Soil Moisture

Soil moisture in the 0 to 5' profile in October was affected substantially by the cropping system (Table 6). This was especially true for alfalfa and CRP where soil water levels were considerably below those of the corn and soybean systems. Available water in the top five feet was below normal for the row crop systems and was close to deficit levels with the alfalfa and CRP cropping systems.

Tile Flow

Tile line discharge occurred from March 26 through July 5 for the corn and soybean systems, from March 26 through June 28 for CRP and from April 15 through June 30 for alfalfa. Discharge averaged 8.8" for the systems containing corn and soybean; this was 5.3x higher than the 1.7" for the alfalfa and CRP systems (Table 7). Flow-weighted NO_3-N concentrations for the season were highest for the CC and Sb-C (corn in 1990) systems and were approximately 10x higher than the alfalfa and CRP systems. The C-Sb system (soybean in 1990) showed average $NO_3$0-N concentrations about 9 to 10 mg/L less than those systems planted to corn in 1990. Temporal changes in NO_3-N concentration did not occur over the April-July flow period. Losses of NO_3-N in the tile drainage for the 1991 season were 48 and 41 times higher for the corn-soybean sequences and CC systems, respectively, compared to the two perennial crop systems. Losses averaged 72 lb/A for the two corn-soybean sequences, 62 lb/A for the CC system and only 1.5 lb/A for the alfalfa and CRP systems. These data indicate that N removal (alfalfa) and N cycling (CRP) along with high ET demand of the perennial crop are resulting in minimal NO_3 loss. Thus, we can speculate that NO_3 loss from native prairies to ground water prior to the adoption of cropping and tillage practices in southern Minnesota would have been extremely small.

Water samples were collected weekly throughout the 3½ month flow period and were submitted for pesticide analyses. No alachlor (Lasso) was found in any of the 128 samples collected from the corn and soybean systems. Cyanazine (Bladex) was not found in the 65 samples collected from the CC and Sb-C systems that received cyanazine in 1990 or in the 24 samples collected after May 9 (date Bladex applied) from the C-Sb system that received cyanazine in 1991. Detectable concentrations of Accent and Pursuit were not found in 25 samples collected from the C-Sb and Sb-C systems to which these herbicides had been applied in 1988-90. Detection limits were 0.10 ppb for all four herbicides. These data indicate very little need for concern regarding the leaching of these herbicides to tile discharge water in these high organic matter, fine-textured soils in southern Minnesota.

Conclusions

The slightly wetter than normal conditions in 1991 resulted in excellent corn and alfalfa yields and average soybean yield in this fourth year of the study. Nitrogen removal by soybean and alfalfa was 1.5x and 2.6x as high, respectively, as with corn. After two moist years, the grass species again dominated the CRP system. Over winter "loss" of soil NO_3 averaged 36% for the two cropping systems that received fertilizer N in 1990, indicating that spring soil sampling may be preferable to fall sampling to determine fertilizer N rate recommendations. Residual soil NO_3 in the fall, although not as high as in previous years, was approximately 3x higher with the row crop systems compared to the perennial crop systems. Tile flow occurred over a 3½-month period from late March through early July. Drainage averaged 8.8 acre-inches from the row crop systems and 1.7 acre-inches from the perennial crop systems. Nitrate-N concentrations also were 8 to 10x higher with the row-crop systems. Nitrate-N losses to the drainage water averaged 72 lb/A from the two row crop systems receiving fertilizer N in 1990, 62 lb/A in the C-Sb system, and only 1.5 lb/A in the alfalfa and CRP systems. Tile water samples analyzed for alachlor, cyanazine, Accent, and Pursuit showed no detectable amounts of any of these pesticides.

Table 1. Experimental procedures used in 1991 for the nitrate-pesticide movement study at Lamberton.

Cropping System	Procedures
Cont. Corn and Corn-"Sb"	
Hybrid	Pioneer 3615
Planting rate and date	27700 ppA on 5/10
Insecticide	Counter (1 lb/A), Pounce on 6/24
Herbicides	Lasso (4 lb/A) + Bladex (3½ lb/A)
Date	Both applied on 5/9 and incorporated 1X with field cultivator and 1x with a disk
N rate (Cont. corn only)	122 lb N/A as urea
Date	6/3 and cultivated in the same day
Cultivation date(s)	6/18
Harvest date	9/30
Fall tillage (kind and date)	Moldboard plow 10/28
Corn - "Sb"	
N rate	109 lb N/A as urea
Date	6/3
Soybeans	
Secondary tillage	Disked (5/9), Field cultivated (5/21)
Variety	Hardin
Planting rate and date	150,000 seeds/A on 5/22
Row width	30"
Herbicides	
Lasso	
Rate and date	4.0 lb/A on 5/21, incorporated with a field cultivator
Cultivation date(s)	6/27
Harvest date	10/7
Fall Tillage	None
Alfalfa	
Harvest date(s)	6/8, 7/12 and 8/27
Harvest area	3' x 20'
CRP	
Harvest date	9/18

Table 2. Growing season monthly air temperature averages and precipitation amounts during 1991 and the long-term normals for Lamberton.

	Avg. Temperature		Precipitation	
Month	1991	Normal	1991	Normal
	°F		inches	
April	59	46	4.33	2.73
May	61	59	4.06	3.16
June	72	68	6.69	3.55
July	72	73	1.37	3.88
Aug.	70	70	2.98	2.73
Sept.	58	60	5.64	3.34
Oct.	44	49	0.38	2.17
7-mo avg.	62	61	-	
Total	-	-	25.45	21.56

Table 3. Residual NO_3-N in the 0 to 5' soil profile of the cropping systems in April, 1991.

Depth	Cropping System in 1991		
	Cont. Corn	Corn-Sb	Soybean-C
feet	lb NO_3-N/A		
0 - 1	28.0	18.7	13.3
1 - 2	20.0	10.7	20.0
2 - 3	20.0	13.3	14.7
3 - 4	34.7	17.3	17.3
4 - 5	28.0	13.3	16.0
Total (0-5')			
Apr.'91	130.7	73.3	81.3
Oct. '90	160.1	151.1	138.7
% Change over winter	-18	-52	-41

Table 4. Crop yields, N concentration, and N uptake at Lamberton in 1991.

Cropping System	Yield	N Concentration	N Uptake
		%	lb/A
Cont. Corn			
Grain (bu/A)	146.7	1.59	110.4
Stover (lb DM/A)	2679.	.42	11.2
Total			121.6
Corn-Sb			
Grain (bu/A)	170.4	1.48	119.3
Stover (lb DM/A)	3635.	.41	15.1
Total			134.4
Soybean-C			
Seed (bu/A)	43.4	6.68	153.6
Stover (lb DM/A)	3840.	1.26	48.5
Total			202.2
Alfalfa			
1st Cut Forage (lb DM/A)	5191	3.19*	165.6
2nd Cut Forage (lb DM/A)	2828	3.09	87.4
3rd Cut Forage (lb DM/A)	2601	3.30	85.9
Total	5.31 T/A		338.9
CRP			
Grass (lb DM/A)	3214	2.32	74.5
Alfalfa (lb DM/A)	348	2.03	7.0
Total			81.5

* = Forage not analyzed, value is average of 2nd & 3rd cutting.

Table 5. Soil profile NO_3-N concentrations and amounts in October, 1991 as influenced by cropping system at Lamberton.

Depth	Cont. Corn Avg.	Cont. Corn SE	Cont. Corn Avg.	Corn-Sb Avg.	Corn-Sb SE	Corn-Sb Avg.
feet	------ ppm ------		lb/A	------ ppm ------		lb/A
0 - 1	6.9	0.75	27.5	5.9	2.61	23.6
1 - 2	2.8	0.52	11.3	4.8	3.25	19.2
2 - 3	2.9	0.27	11.7	4.5	2.97	18.0
3 - 4	4.2	0.94	16.7	3.4	0.99	13.7
4 - 5	4.2	1.02	16.7	2.8	0.20	11.2
5 - 6	3.8	0.86	15.3	2.2	0.20	8.9
6 - 7	3.5	0.82	14.1	1.8	0.32	7.1
7 - 8	4.0	1.40	16.1	1.8	0.46	7.1
8 - 9	3.7	1.21	14.9	2.0	0.46	8.0
9 - 10	5.1	2.28	20.5	2.2	0.43	8.9
Totals						
0 - 5			83.9			85.7
5 - 8			45.6			23.1
8 - 10			35.4			16.9
0 - 10			164.9			125.7

Depth	Soybean-C Avg.	Soybean-C SE	Soybean-C Avg.	Alfalfa Avg.	Alfalfa SE	Alfalfa Avg.
feet	------ ppm ------		lb/A	------ ppm ------		lb/A
0 - 1	4.3	0.50	17.3	1.2	0.20	4.9
1 - 2	1.5	0.12	6.1	0.8	0.17	3.1
2 - 3	1.6	0.18	6.5	0.7	0.22	2.7
3 - 4	3.0	0.23	12.1	0.6	0.15	2.4
4 - 5	3.4	0.44	13.7	0.6	0.19	2.5
5 - 6	2.7	0.24	10.9	0.6	0.25	2.4
6 - 7	2.5	0.22	10.1	0.9	0.35	3.6
7 - 8	3.2	0.22	12.9	1.8	0.40	7.2
8 - 9	4.0	0.17	15.9	2.2	0.27	8.9
9 - 10	4.3	0.29	17.3	2.4	0.38	9.7
Totals						
0 - 5			55.9			15.6
5 - 8			33.9			13.2
8 - 10			33.2			18.6
0 - 10			123.0			47.4

Depth	CRP Avg.	CRP SE	CRP Avg.
feet	---------- ppm ----------		lb/A
0 - 1	0.9	0.19	3.7
1 - 2	0.6	0.21	2.4
2 - 3	0.6	0.20	2.4
3 - 4	0.5	0.13	2.1
4 - 5	0.6	0.12	2.5
5 - 6	0.8	0.22	3.3
6 - 7	2.0	1.23	7.9
7 - 8	2.7	1.18	10.7
8 - 9	2.8	0.79	11.1
9 - 10	2.9	0.26	11.6
Totals			
0 - 5			13.2
5 - 8			21.9
8 - 10			22.6
0 - 10			57.7

Table 6. Gravimetric water content of the 0-10' profile and "available" water in the 0-5' profile as influenced by cropping system in October, 1991.

Profile depth	Cropping system				
	Cont. Corn	Corn-Sb	Soybean-C	Alfalfa	CRP
feet	Water Content (%)				
0 - 1	22.1	22.0	21.8	17.2	18.4
1 - 2	20.7	21.9	20.4	17.8	18.9
2 - 3	18.2	19.3	17.8	14.8	15.1
3 - 4	17.8	17.0	17.3	13.7	14.9
4 - 5	18.7	18.0	18.1	13.7	16.8
5 - 6	18.7	19.0	19.3	15.8	18.6
6 - 7	19.4	19.7	19.3	16.9	19.2
7 - 8	19.3	19.6	19.6	18.8	19.8
8 - 9	19.5	19.6	20.4	19.3	19.7
9 - 10	18.8	19.1	19.5	20.8	20.3
"Available" Water 0-5' (inches)	4.33	4.44	4.00	1.09	2.23

Table 7. Tile discharge, flow-weighted NO_3-N concentration, and NO_3-N loss via the tile lines as influenced by cropping system.

Month	Cont. Corn	Corn-Sb	Soybean-C	Alfalfa	CRP
	Tile Flow (acre-in)				
March	0.00	0.01	0.05	0.00	0.04
April	1.68	2.70	2.02	0.04	0.68
May	2.16	3.47	2.80	0.20	0.76
June	3.06	4.50	3.57	1.34	0.25
July	0.12	0.11	0.13	0.01	0.00
Total	7.02	10.79	8.57	1.59	1.73
	Flow-weighted NO_3-N Conc. (ppm)				
March	-	35.1	24.4	-	4.1
April	39.4	29.2	35.9	2.8	4.1
May	38.7	28.9	38.5	3.0	3.1
June	38.4	30.5	36.9	5.8	8.9
July	39.1	30.2	36.6	4.1	-
Season Avg.	39.1	29.0	37.5	4.1	3.9
	NO_3-N Loss (lb/A)				
March	0.0	0.1	0.3	0.00	0.04
April	15.3	17.2	16.6	0.02	0.49
May	19.2	22.0	24.4	0.09	0.44
June	26.6	30.6	30.0	1.36	0.52
July	1.1	0.8	1.1	0.01	0.00
Total	62.2	70.7	72.4	1.47	1.49

N CREDITS FOR MANURE AND ALFALFA

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ABSTACT: Farmers in southern Minnesota rarely obtain a yield response from fertilizer or manure N applications to first year corn following alfalfa and obtain limited yield response from N applications to second year corn following alfalfa. The overall objective of this series of experiments is to refine N credit methodology for alfalfa and manure. First year corn yields following alfalfa with no N applied were equivalent continuous corn yields at the optimum N rate. First year corn following alfalfa yielded an additional 18 bu/A in response to of 60 lb N/A at Waseca. Second year corn following alfalfa responded to fertilizer N applications of 60 lb N/A. The first year manure N credit for continuous corn closely matched the predicted manure N availability at Rosemount. In contrast, yield response was more limited to spring applied dairy manure to continuous corn at Waseca. There was no significant grain yield response to residual manure the second year after application to corn or alfalfa at both locations.

Many dairy farmers apply manure to alfalfa in the spring or fall before they plow down an old stand. This practice is not recommended because it creates an oversupply of N for the succeeding corn crop, potentially leading to losses of N from the soil profile. Portions of the manure and alfalfa N will not be available to corn until the second and third year after incorporation. Current N recommendations utilize estimated "N credits" to adjust fertilizer N rates downward to account for these sources of N. The first objective of this experiment is to compare the impact of over-application of fertilizer N and manure N on soil inorganic-N levels in both continuous corn and alfalfa-corn rotations. The second objective is to estimate first and second year N credits for 1)dairy manure applied in the spring to two previous crops (corn or alfalfa) and 2) alfalfa, using two methods of estimation (continuous-corn fertilizer response curve vs. corn following alfalfa fertilizer response curve).

The fertilizer and manure treatments in the study were initiated two different years (1990 and 1991) at two locations (Rosemount and Waseca) for a total of four site-years for each year of the experiment. The duration of the experiment is two years at each site. This report presents results based on the 1991 corn DM and N yields for all four sites. A previous report discussed the first year results of the study initiated in 1990.

Materials and Methods

Experimental plots were located on a Webster clay loam at the Southern Experiment Station, Waseca, MN, and on a Port Byron silt loam at Agronomy Hill, Rosemount Experiment Station, Rosemount, MN.

Plot history

Plots for all sites were established in spring of 1988 as a split-plot arrangement in a randomized block design with four replicates at each Waseca site, and three replicates at each Rosemount site. Establishment and previous management of the two sites where N treatments were initiated in 1990 were outlined in a previous report with the following exception. Plots designated for urea treatments in 1991 received 100 lb N/A in spring 1990 if corn was the previous crop and 0 lb N/A if alfalfa was the previous crop.

At the remaining two sites, alfalfa plots were seeded with variety DK120 (13 lb/A) with Nitragin inoculant in 1988. Weeds in alfalfa were controlled with 0.75 lb/A Treflan at Rosemount, and 1 gal/A Balan at Waseca. Plots were harvested once in the seeding year and on a 3-cut system in 1989 and 1990. The Rosemount seedling stand received 5 in. irrigation water in 1988 and alfalfa was seeded with a notill drill into the existing stand in spring 1990 to fill open patches in the stand from significant winter kill the previous winter. Corn plots at both sites were managed for corn grain production. Corn plots were chisel plowed and cultivated in spring at Rosemount and fall moldboard plowed and spring cultivated at Waseca in 1988, 1989, and 1990. Fertility levels of P and K were maintained at or above University Minnesota soil test recommendations. At Rosemount, 150, 120, and 100 lb N/A as urea was applied preplant incorporated in 1988, 1989, and 1990 respectively; at Waseca, 150 lb N/A as NH_4NO_3 was applied sidedress in 1988, 150 lb N/A as NH_4NO_3 was applied preplant in 1989, and 120 lb N/A as NH_4NO_3 was applied preplant in 1990.

Table 1. Nutrient content of applied dairy manure at Rosemount and Waseca, MN.

Location	Year Applied	DM	Total N	NH_4-N	P	K	S	Na	pH
		%	- - - - - - - -		lb / 1000 gal	- - - - - - - -			
Rosemount	1990	10.4	36.3	1.4	7.6	26.1	5.9	0.77	-
	1991	11.7	41.7	20.3	6.4	28.5	2.8	1.4	5.7
Waseca	1990	10.1	32.1	13.4	6.2	27.5	2.8	5.0	6.1
	1991	11.1	35.5	17.1	8.1	39.3	2.1	60.5	7.1

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Table 2. Effect of previous crop, dairy manure the second year after application, and urea on corn yield and N uptake at Rosemount, MN in 1991.

Cropping[1] sequence	N source	Rate		Grain Yield	Grain N uptake	Silage Yield	Silage N uptake
				bu/A	lb/A	T DM/A	lb/A
A-A-A-C-C		control		147	111	6.99	135
	Urea	60	lb/A	150	129	7.56	154
		100		174	148	8.36	182
		140		161	139	7.48	175
		180		176	152	8.48	204
			P>F	0.07	0.01	0.03	0.01
			MSD[2]	25	21	1.02	24
			CV (%)	6.6	7.1	5.9	6.7
	Manure[3]	3000	gal/A	164	125	7.62	151
		5000		167	134	7.61	164
		7000		168	135	7.83	164
			P>F	0.19	0.10	0.17	0.10
			MSD[2]	-	24	-	28
			CV (%)	7.0	8.6	5.4	8.6
A-C-C-C-C		control		131	93	5.75	108
	Urea	60	lb/A	164	127	7.12	149
		100		155	126	7.15	151
		140		167	143	7.81	179
		180		172	147	7.89	177
			P>F	0.08	0.06	0.05	0.02
			MSD[2]	32	39	1.34	43
			CV (%)	9.1	13.9	8.5	12.8
	Manure[3]	3000	gal/A	126	88	5.70	104
		7000		140	99	6.47	118
		11000		156	128	7.16	158
			P>F	0.14	0.06	0.02	0.02
			MSD[2]	-	-	0.64	26
			CV (%)	6.4	8.5	4.8	7.7

1 A = alfalfa, C = corn, and the 1991 crop is underlined
2 Minimum significant difference (0.10)
3 Manure applied spring 1990.

Procedures in 1991

At the two sites that received N treatments in 1990, all plots were spring moldboard plowed at Rosemount, and fall chisel plowed at Waseca. Five urea treatments (0, 60, 100, 140, 180 lb N/A) were applied in spring 1991 to the designated plots in each previous crop block and all plots were disked before planting corn. Plots receiving manure the previous year received no additional treatments.

At the two sites where treatments were initiated in 1991, 8 treatments were applied randomly to each previous crop block. Treatments in previous corn were 0 (control), 60, 100, 140, 180 lb N/A as urea, and 3330, 6660, 9990 gal/A dairy manure at Rosemount, and 3200, 6400, and 9990 gal/A dairy manure at Waseca. Treatments in previous alfalfa were 0 (control), 30, 60, 100, 140 lbs N/A as urea, and the same manure treatments as continuous corn. Liquid dairy manure was obtained from the Brand Farm in Farmington, MN, and from the Southern Experiment Station. The nutrient content of manure used at all sites is reported in Table 1. After manure application, all plots were moldboard plowed at Rosemount and disked twice at Waseca, incorporating the manure within 60 min. Manure was applied April 23 at Rosemount and May 14 at Waseca.

At Waseca, Pioneer 3751 was planted on both sites on May 21 at 30,600 seed/A and the stand was thinned to 27,500 plants/A on June 12. To control rootworms, Force insecticide (8.7 lb/A) was applied over the row at planting. Weeds were controlled with a preemergence application of Lasso (3.5 lb/A) and Bladex (3 lb/A). At Rosemount, Pioneer 3751 was planted on both sites May 21 at 26,100 seeds/A. To control rootworms, Force insecticide (8.7 lb/A) was applied over the row at planting. Lasso and Bladex (2 lb/A each) were applied preemergence to control weeds.

Table 3. Effect of previous crop, dairy manure the second year after application, and urea on corn yield and N uptake at Waseca, MN, in 1991.

Cropping[1] sequence	N source	Rate		Grain Yield	Grain N uptake	Silage Yield	Silage N uptake
				bu/A	lb/A	T DM/A	lb/A
A-A-A-C-C		control		174	100	6.88	122
	Urea	60	lb/A	200	124	8.13	155
		100		203	132	8.23	166
		140		206	141	8.25	177
		180		206	138	8.53	180
			P>F	0.07	0.01	0.02	0.01
			MSD[2]	29	17	1.06	19
			CV (%)	8.0	8.1	7.6	7.5
	Manure[3]	3000	gal/A	187	108	7.50	132
		5000		186	111	7.45	135
		7000		192	113	7.83	142
			P>F	0.11	0.11	0.05	0.08
			MSD[2]	-	-	0.70	17
			CV (%)	5.0	6.2	5.3	6.9
A-C-C-C-C		control		145	78	6.14	102
	Urea	60	lb/A	161	96	6.75	117
		100		190	119	7.94	149
		140		202	128	8.19	162
		180		193	130	8.02	166
			P>F	0.01	0.01	0.01	0.01
			MSD[2]	15	12	0.57	13
			CV (%)	5.8	7.7	5.3	6.7
	Manure[3]	3000	gal/A	136	71	5.74	87
		7000		141	75	5.73	92
		11000		158	84	6.49	104
			P>F	0.20	0.25	0.33	0.21
			MSD[2]	-	-	-	-
			CV (%)	9.2	11.4	10.5	12.2

1 A = alfalfa, C = corn, and the 1991 crop is underlined
2 Minimum significant difference (0.10)
3 Manure applied spring 1990.

At Waseca, grain and stover were harvested on September 27 in the 1990 plots and on October 2 in the 1991 plots plots. At Rosemount, all grain was harvested on September 25 and 26, and all stover was sampled on October 2. Grain and stover DM samples were harvested from 40 and 20 ft. of row, respectively. Plant samples were dried at 60° C and ground in preparation for analysis. Total N was determined using the salicylic acid predigest modification to the Kjeldahl total N digest.

Results and Discussion

Second year corn grain and silage yields following alfalfa responded to urea N at Rosemount and Waseca (Tables 2 and 3). Optimum yields were obtained with applications of 100 lbs N/A or less. Residual effects of the 1990 manure application on grain yield were not significant at both locations for manure applied to corn or alfalfa (Tables 2 and 3). At Rosemount, residual manure N consistently increased N-uptake of grain and silage (Table 2). The increases were consistent with the low estimates of mineralized manure N available the second year after application (Table 4).

First year corn grain and silage yields following alfalfa did not respond to additions of fertilizer at Rosemount (Table 5). Applications of manure to first year corn following alfalfa at Rosemount were associated with a significant increase in grain and stover yields compared to the control. This effect was due primarily to reduced yield variability on manured plots. At Waseca, first year corn grain and stover yields following alfalfa responded to low rates of fertilizer N, but manured plots did not differ from the 0 N control (Table 6). In contrast to Rosemount, N-uptake of corn following alfalfa was not affected by manure applications at Waseca.

Table 4. Estimated N availability and determined N credits in 1991 for dairy manure applied to continuous corn and corn following alfalfa at Rosemount and Waseca, MN.

Year of manure application	Location	Cropping[1] sequence	Rate	Available N in 1991[2] Estimated	Determined
			gal/A	- - lb / acre	- -
1990	Rosemount	A-A-A-C-C	3000	15	NM[3]
			5000	25	
			7000	35	
		A-C-C-C-C	3000	15	NM
			7000	35	
			11000	60	
	Waseca	A-A-A-C-C	3000	10	NM
			5000	15	
			7000	20	
		A-C-C-C-C	3000	10	NM
			7000	20	
			11000	30	
1991	Rosemount	A-A-A-C	3330	85	NR[4]
			6660	170	
			9990	255	
		C-C-C-C	3330	85	95
			6660	170	150
			9990	255	150
	Waseca	A-A-A-C	3200	75	NM
			6400	150	
			10660	240	
		C-C-C-C	3200	75	10
			6400	150	60
			10660	240	60

1 A = alfalfa, C = corn, and the 1991 crop is underlined.
2 Estimated available N based on 25% of organic N available the year of application, 100% of NH_4^+-N available the year of application, and 15% of organic N available the year after application. Determined available N based on the fertilizer response of grain yield on nonmanured plots with the same cropping sequence.
3 NM = no significant grain yield response to manure.
4 NR = no significant grain yield response to fertilizer N.

Manure N was effectively substituted for urea on continuous corn at Rosemount in 1991. Application of 6660 gal/A provided ample N for maximum grain yields, in agreement with estimates based on the manure N content (Table 4). No additional yield benefit was gained from a higher application (Table 5). At Waseca, corn response to manure was much lower than anticipated. Nitrogen was not the limiting factor since the grain yield of the two highest manure rates did not differ. Negative effects of the manure were probably related to high precipitation and wet soil in spring 1991, compaction problems associated with incorporating the manure into a limited soil volume with the disk, and the high salt content of the Waseca manure source.

This study compared two methods for determining alfalfa N credits, the indirect method with the less common direct method. The indirect method of determining N credits is based on the fertilizer response of continuous corn. The N credit is the quantity of fertilizer N required for continuous corn grain yield to equal the grain yield of corn following alfalfa with no fertilizer N applied. Direct determination of the N credit based on the fertilizer response of corn following alfalfa. A maximum N credit must be assumed to convert the direct method fertilizer N recommendation to an alfalfa N credit. We used the University of Minnesota maximum N credit recommendation of 150 lb N/A. With this assumption a direct method fertilizer recommendation of 60 lb N/A is equivalent to an N credit of 90 lb N/A (150 lb N/A - 60 lb N/A = 90 lb N/A).

The indirect method estimated lower N credits in second year corn following alfalfa compared to the direct method (Table 7). Determining an estimate by the direct method was made difficult by the limited N response of corn yield following alfalfa. It is easier to model the highly responsive continuous corn plots facilitating estimates of the second year N credit by the indirect method.

In first year corn following alfalfa, the direct method of determining N credits is more likely to identify responsive sites compared to the indirect method. For example, the indirect method failed to determine the potential yield response to fertilizer N of first year corn following alfalfa at Waseca (Table 7). This was probably due to the indirect method's inability to fully account for rotation effects.

Table 5. Effect of previous crop, spring incorporated dairy manure, and urea on corn yield and N uptake at Rosemount, MN in 1991.

Cropping[1] sequence	N source	Rate		Grain Yield	Grain N uptake	Silage Yield	Silage N uptake
				bu/A	lb/A	T DM/A	lb/A
A-A-A-C		control		168	129	7.79	156
	Urea	30	lb/A	181	150	8.35	179
		60		177	148	8.02	177
		100		190	162	8.56	206
		140		172	145	7.91	186
			P>F	0.23	0.08	0.41	0.01
			MSD[2]	-	24	-	24
			CV (%)	6.2	7.8	6.4	6.9
	Manure[3]	3330	gal/A	188	154	8.53	190
		6660		179	156	8.49	207
		9990		189	166	8.77	216
			P>F	0.01	0.01	0.01	0.01
			MSD[2]	5	14	0.48	20
			CV (%)	1.3	4.7	2.8	5.2
C-C-C-C		control		114	81	5.30	98
	Urea	60	lb/A	136	101	6.31	120
		100		159	123	7.40	150
		140		166	142	7.91	179
		180		165	147	7.90	183
			P>F	0.01	0.01	0.01	0.01
			MSD[2]	18	27	0.75	32
			CV (%)	6.6	12.0	5.9	12.0
	Manure[3]	3330	gal/A	148	112	7.13	136
		6660		164	140	7.58	166
		9990		165	145	7.90	188
			P>F	0.04	0.03	0.05	0.02
			MSD[2]	37	43	1.91	52
			CV (%)	11.9	17.0	12.9	17.2

1 A = alfalfa, C = corn, and the 1991 crop is underlined
2 Minimum significant difference (0.10)
3 Manure applied spring 1991.

Future reports in this series will discuss the second year grain and silage results from the two sites initiated in 1991 and soil inorganic N data collected in the spring and fall of each growing season at all four sites.

Table 6. Effect of previous crop, spring incorporated dairy manure, and urea on corn yield and N uptake at Waseca, MN in 1991.

Cropping[1] sequence	N source	Rate		Grain Yield	Grain N uptake	Silage Yield	Silage N uptake
				bu/A	lb/A	T DM/A	lb/A
A-A-A-C		control		162	95	6.35	113
	Urea	30	lb/A	173	108	6.59	127
		60		180	116	6.93	137
		100		187	125	7.39	154
		140		189	130	7.01	154
			P>F	0.04	0.01	0.04	0.01
			MSD[2]	20	12	0.75	15
			CV (%)	6.7	7.2	6.2	7.3
	Manure[3]	3200	gal/A	160	96	6.21	113
		6400		157	96	6.06	113
		9600		161	100	6.24	119
			P>F	0.70	0.26	0.86	0.48
			MSD[2]	-	-	-	-
			CV (%)	4.1	4.0	4.7	5.5
C-C-C-C		control		95	49	3.92	59
	Urea	60	lb/A	130	70	5.07	84
		100		144	80	5.68	96
		140		158	101	6.18	120
		180		174	118	6.63	140
			P>F	0.01	0.01	0.01	0.01
			MSD[2]	15	13	0.53	14
			CV (%)	7.8	10.8	6.7	10.2
	Manure[3]	3200	gal/A	104	53	4.05	63
		6400		126	71	5.04	85
		9600		125	72	4.48	82
			P>F	0.05	0.01	0.04	0.01
			MSD[2]	28	14	0.87	13
			CV (%)	14.0	14.1	11.3	11.4

1 A = alfalfa, C = corn, and the 1991 crop is underlined
2 Minimum significant difference (0.10)
3 Manure applied spring 1991.

Table 7. Nitrogen credit for first and second year corn following alfalfa in 1991 determined at at Rosemount and Waseca, MN.

Year of alfalfa incorporation	Cropping[1] sequence	Location	Nitrogen Credit[2] Direct	Nitrogen Credit[2] Indirect
			- - lb / acre	- -
1990	A-A-A-C-C	Rosemount	90	45
		Waseca	90	85
1991	A-A-A-C	Rosemount	150	150
		Waseca[3]	90	150

1 A = alfalfa, C = corn, and the 1991 crop is underlined.
2 See text for discussion of direct and indirect N credits
3 Alfalfa was incorporated fall 1990.

WATER QUALITY RESEARCH WITH NITROGEN AT THE HERMAN ROSHOLT WATER QUALITY RESEARCH FARM, WESTPORT, MN 1991 [1]

Large and Small plot phases

G.L. Malzer, T.J. Graff[2]

Abstract: The objective of the **small plot** water quality research phase is to evaluate and quantify the impact of a variety of agricultural practices on crop nitrogen utilization efficiency and the potential impact on water quality. Currently agricultural practices such as crop rotation, tillage, and fertilizer N management including, rates, sources, time of application, methods of application and use of nitrification inhibitors are being evaluated. Corn grain and soybean yields were not influenced by tillage systems (chisel-plow vs. ridge-till systems). Nitrogen fertilizer significantly increased corn grain yield when 105 lbs N/A was applied with continuous corn. No yield increase was obtained with N rates over 105 lbs N/A under continuous corn. Late sidedressed N application with chisel plow tillage system produced higher grain yields than early N application. High amounts of precipitation during 1991 apparently leached some of the fertilizer N which had been applied early. Nitrification inhibitors increased grain yield when used at the lower rates of fertilizer N. Rates of fertilizer N in excess of plant need resulted in higher concentrations of nitrate-N in the percolate water.

The objective of the **large plot** groundwater phase is to monitor the movement of nitrate-N through the soil profile into the underlying aquifer and to quantify subsequent impact on groundwater quality. Experimentation utilizes several sampling devices, including suction lysimeters, glass blocks, sheet metal (pan) containers, wick samplers, and wells established at three different levels in the aquifer. Three treatments replicated twice were established in 1987. Each plot area is in excess of one acre and the treatments include continuous corn at a moderate (160 # N/A) and high (215 # N/A) rate of N, and a corn-soybean rotation at the moderate N rate. Corn grain yields were not increased by the high N rate in 1987,1988, 1989,1990 but were in 1991. Concentration of nitrate-N in the percolate water increased as the rate of fertilizer N increased. Method of water collection influenced the actual concentration measured.

In 1987 three phases of nitrogen (N) research were started at the Herman Rosholt Water Quality Research Farm at Westport, MN. The three phases of research included a lysimeter phase, a large plot groundwater phase and a small plot N management/crop production phase. The large and small plot phases are reported here, the lysimeter phase will be reported separately.

The soil at the Rosholt farm is an Estherville sandy loam with 15-30 inches of sandy loam soil overlying glacial outwash composed mainly of coarse sand and gravel. Because of the coarse nature of these soils and the low water holding capacity, they are frequently irrigated to attain high yields. The higher yield potential along with higher fertilizer inputs, low water holding capacity, and shallow underlying aquifer create conditions which could result in groundwater contamination with nitrate N. Improper fertilizer N management can result in reduced yields, reduced fertilizer use efficiency, decreased profits, and increased groundwater contamination. The purpose of these phases of research was to determine the impacts of different N and crop management practices on crop yield, N utilization and their resulting impacts on groundwater quality.

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2. Professor and Asst. Scientist respectively, Dept. of Soil Science. University of MN.

Experimental Procedures

Small Plot N Management/Crop Production Phase: consisted of 25 N treatments randomized within a split-split plot design with three replications. The main plot consisted of two cropping sequences (continuous corn and corn following soybeans) with the sub-plots being tillage (ridge till and chisel plow). Ridges were constructed in 1987. In 1990 the entire experiment was planted to corn and in 1991 soybeans were planted in the corn-soybean rotation. The 25 N treatments within each sub-plot consisted of a control (zero N) plus four N rates (60, 120, 180, and 240 kg N/ha -- these will be reported as 50, 105 160, and 215 # N/A), two nitrification inhibitors (none and N-Serve) and three times/methods of application (all N early-6 leaf growth stage, all N late-8 leaf growth stage, and split with 2/3 N early and 1/3 N late). All fertilizer N treatments were applied as anhydrous ammonia. Early application was applied on June 10th and late application was applied on June 19th. The nitrification inhibitor N-Serve was applied with an in-line injection pump which inserted the chemical in front of a bidirectional flow integrator and the manifold. N-Serve was applied at a rate of 0.5 #/A active ingredient.

Soil samples were taken from 0-1 and 1-2 ft depth from 13 of the 25 treatments on April 25th before planting and on September 19th before harvest. The soil samples were analyzed for ammonium and nitrate concentration and the data is reported in tables 2 and 3. Spring samples were taken on corn following corn and the corn following soybeans. Fall samples were taken from corn following corn and the soybean check plots.

Corn (Pioneer 3790 - 95 day R.M.) was planted on May 9th in 30 inch rows at a population of 29,900 seeds/A using a four-row Buffalo planter. Starter fertilizer was applied to the corn plots at the rate of 10 gal/A of 7-22-5 as a band below the seed and Counter was banded in the row at planting. Lasso (3 #/A) and AAtrex 90 DF (1 #/A) was applied on May 20th for weed control in the corn. For additional weed control the corn was cultivated twice. The first cultivation was on June 17th, and second on July 5th, ridges were also built on July 5th. Soybeans were planted on May 22nd at the rate of 63 #/A. A tank mix of Basagran (1 qt/A), Blazer (.5 pt/A), Poast (1.5 pt/A) and oil concentrate (1 qt) applied June 5th at the rate of 20 gal/A. For additional weed control the plots were cultivated twice. The irrigation program (traveling boom) was started on August 18th with 1 inch of water being applied through irrigation. An additional 21.89 inches of water was obtained during the growing season as rainfall.

Soybean yields were taken October 2nd with a plot combine harvesting two 50 ft rows. Corn grain yields were obtained on October 9th by hand harvesting 100 ft^2 of plot area. All corn grain yields were adjusted to 15.5% and soybeans to 13%. Grain yields and N concentration are reported in table 1.

Large Plot Groundwater Phase:

In 1987 six large plots (approximately one acre) were established at the Rosholt farm. The experiment area consisted of three treatments with two replications. Two treatments are continuous corn with N rates of 160 and 215 lbs N/A. The third treatment is in a corn following soybeans sequence with 160 lbs N/a applied during the corn year. In 1987 all treatments were planted to corn. In 1988 soybeans were planted into the corn-soybean rotation treatment. Soybean have been present in the rotation on even number years. Nitrogen was applied as anhydrous ammonia in split application of two-thirds of the N rate with a nitrification inhibitor (N-Serve) at an early growth stage 6-leaf (June 10), and one-third at the 8-leaf growth stage (June 19th). N-Serve was applied only at the 6-leaf stage utilizing an in-line injection pump which inserted the chemical in front of a bidirectional flow integrator and the manifold. N-Serve was applied at a rate of 0.5 #/A a.i.

Corn (Pioneer 3790 - 95 day R.M.) was planted on May 10 in 30 inch rows at a population of 29,900 seeds/A using a four-row Buffalo planter. Starter fertilizer was applied at the rate of 10 gal/A of 7-22-5 as a band below the seed. Counter was banded in the row at planting. Lasso (3.0 #/A) and AAtrex 90 DF (1#/A) were sprayed on May 14th for weed control. The irrigation program (traveling boom) consisted of 1.0 inch of water being applied through irrigation on August 18th and an additional 21.89 inches of water coming through rainfall during the growing season. Grain yields were obtained on October 9th by hand harvesting 800 ft^2 of plot area. Corn grain yields were adjusted to 15.5% moisture. Grain yields results are presented in table 5.

Chemical movement through soils to groundwater

The movement of nitrate-N through soils to the groundwater is being evaluated utilizing several types of soil water sampling devices. These include suction lysimeters, glass blocks, sheet metal pans, wick samplers, and wells. The wells were installed by the United States Geological Survey.

Data from the wells and suction lysimeters will not be presented at this time. The glass blocks did not collect enough water in 1991 to present the data in tabular form.

Glass block samplers are made from glass building blocks,(12" X 12"X 4" - L X W X D). Holes were drilled into the blocks to allow water to enter and permit access for removing the water collected. Three glass blocks were installed in plots at a soil depth of 18-24 inches (depth where soil becomes very coarse). Three blocks were installed side by side, one directly under a crop row and one on either side.

Suction lysimeters were installed at depths of 4 and 7 feet during 1987. The ceramic cup of the suction sampler was cast into a silica slurry which hardens in the soil to insure continuous contact between the soil and the ceramic cup. Outflow tubes were run to the soil surface for sampling. This type of sampler allows for the collection of soil water samples at the aforementioned depths.

Pan sheet metal samplers consist of 18-gauge sheet metal, cut, bent, and spot welded into a trough-like collection box. The samplers are 30" long 12" wide and 3" deep and made watertight by soldering along seams. Holes were drilled into the top of the sampler to allow entry of water. Access tubes were installed to the soil surface to facilitate extraction of the water collected.

Wick samplers are a one-half inch glass plate, 12 inches X 30 inches. A hole was drilled in the center of the glass plate and a 2 inch length of PVC pipe was attached to it. A braided glass rope was inserted through the PVC pipe and onto the glass plate. The strands of glass rope were unraveled over the surface of the glass plate and epoxied to the edges of the plate, forming a spider web-like pattern. The glass rope thus acted as a wicking device to draw water from the surface of the plate into a one gallon collection jar. These also have outflow tubes going to the surface. The pan sheet metal and wick samplers were installed at approximately the same depth as the glass blocks.

General Results

Small Plot N Management/Crop Production Phase:

When no fertilizer N was applied corn yields were about 65 bu/A and soybeans yields were about 35 bu/A. Tillage systems had relatively little influence on corn and soybean grain yields.

Yield increases were obtained with fertilizer N up to 105 #/A although 85% of the yield increase was obtained with the first 50 # N/A. The wet growing season created conditions for some very interesting responses to fertilizer management. Fertilizer use efficiency and grain yields increased when the time of fertilizer N application was delayed there by minimizing N loss. In the dryer years 1988 and 1989 highest yields were obtained when the fertilizer was applied early (4-leaf) rather than in split or 8-leaf applications. In 1991 the yields response associated with delaying time of fertilizer N would indicate that substantial N losses occurred during the early portion of the growing season. The chisel plow tillage system appeared to be more prone to N loss than did the ridge-till system. A significant yield increase (12 bu/A) was obtained with the use of N-Serve on corn. N-Serve is a chemical additive used with N fertilizer to minimize N loss from the soil. Although the overall yield increase due to N-Serve was not high, substantial yield increases (10-15 bu/A) were obtained at the lower rates of N in the chisel plow system. Previous N management practices had no influence on soybean yields.

The soil nitrate-N concentration in the spring, before planting, and in the fall, following harvest, were similar. Since the concentrations were relatively low at both samplings it would suggest that the NO_3-N not used by the plant was probably moved out of the root zone by the high rainfall in 1990 and 1991. The highest rate of fertilizer N tended to have higher concentrations of nitrate-N in the soil profile. The NO_3-N concentration of water collected in the pan lysimeters tended to be high in the corn following soybeans plots than in the continuous corn plots (table 4). Water samples collected by the wick lysimeters had higher NO_3-N concentrations than the water collected in the pan lysimeters.

Large Plot Groundwater Phase:

Results displayed in table 5 suggest that there was a yield advantage to the highest rate of fertilizer N in 1991. This is contrary to any results obtained in the preceding four years of research. Corn yields following soybeans were higher than yields following corn. Application of more fertilizer N in 1991 did not compensate for the rotation effect in 1991. Higher rates of fertilizer N resulted in higher concentration of NO_3-N in the water samples collected in the pan and wick samplers (table 6). Concentration of NO_3-N was higher under continuous corn than the corn-soybean sequence. The pan samplers provided lower estimates of the concentration of NO_3-N in the soil water than the wick samplers.

Table 1. Influence of N-rate, nitrification inhibitors, method of application and tillage on continuous corn grain yields, N-concentration, and N removal. Influence of treatments applied in 1990 on soybeans yields (soybeans following corn). Westport, MN. 1991

Total N-Rate	Early N	Inh.	Late N	Tillage	Corn Grain Yield	Corn Grain N-content	Corn Grain N-removal	Soybean Yield
#/A	#/A		#/A		Bu/A	%	#/A	Bu/A
Control	----	--	----	C	63.7	1.23	37.09	36.5
50	50	--	----	C	100.7	1.19	56.90	41.4
50	----	--	50	C	113.4	1.37	73.73	34.2
50	35	--	15	C	110.2	1.27	66.17	37.3
50	50	NS	----	C	116.3	1.37	75.33	34.5
50	----	NS	50	C	124.9	1.36	80.32	34.4
50	35	NS	15	C	118.8	1.41	79.45	36.8
105	105	--	----	C	107.8	1.40	71.39	32.1
105	----	--	105	C	128.8	1.36	82.57	32.9
105	70	--	35	C	120.6	1.37	78.14	37.2
105	105	NS	----	C	111.0	1.37	71.91	30.8
105	----	NS	105	C	117.7	1.34	74.58	36.3
105	70	NS	35	C	120.5	1.50	85.51	38.8
160	160	--	----	C	108.8	1.37	70.63	39.6
160	----	--	160	C	118.2	1.45	81.13	43.3
160	105	--	55	C	116.3	1.39	76.76	36.6
160	160	NS	----	C	120.5	1.42	81.19	33.6
160	----	NS	160	C	117.7	1.42	78.99	36.3
160	105	NS	55	C	125.0	1.49	87.76	42.3
215	215	--	----	C	105.3	1.54	76.80	33.8
215	----	--	215	C	109.9	1.44	74.68	35.9
215	145	--	70	C	115.5	1.45	79.13	38.5
215	215	NS	----	C	110.5	1.49	78.00	38.8
215	----	NS	215	C	115.9	1.43	78.61	35.8
215	145	NS	70	C	110.3	1.46	76.45	38.4
Control	----	--	----	R	68.4	1.18	38.20	34.8
50	50	--	----	R	116.3	1.24	68.39	32.9
50	----	--	50	R	113.1	1.37	73.43	31.9
50	35	--	15	R	107.1	1.41	71.28	34.8
50	50	NS	----	R	121.4	1.30	74.54	37.4
50	----	NS	50	R	118.7	1.33	74.92	33.5
50	35	NS	15	R	118.0	1.39	77.41	33.2
105	105	--	----	R	125.6	1.42	84.51	31.3
105	----	--	105	R	127.9	1.28	77.59	36.6
105	70	--	35	R	124.0	1.46	85.70	32.8
105	105	NS	----	R	125.1	1.42	84.02	36.5
105	----	NS	105	R	128.2	1.38	83.53	36.1
105	70	NS	35	R	122.6	1.32	76.10	33.9
160	160	--	----	R	124.6	1.41	83.43	37.8
160	----	--	160	R	125.8	1.50	89.29	26.0
160	105	--	55	R	119.4	1.45	82.16	41.4
160	106	NS	----	R	120.4	1.57	89.17	39.3
160	----	NS	160	R	119.9	1.41	79.60	36.2
160	105	NS	55	R	117.5	1.38	76.22	29.4
215	215	--	----	R	121.0	1.45	83.23	37.0
215	----	--	215	R	121.8	1.40	80.80	34.9
215	145	--	70	R	126.1	1.41	84.48	37.0
215	215	NS	----	R	117.3	1.48	81.98	38.7
215	----	NS	215	R	124.5	1.39	81.81	36.6
215	145	NS	70	R	120.5	1.49	84.87	33.3

Table 1. continued. Continuous Corn Split Plot Statistical Analysis
Corn Soybean Rotation Split Plot Statistical Analysis

	Corn Grain			Soybean
	Yield	N-Content	N-Removal	Yield
	Bu/A	%	#/A	Bu/A
Tillage				
Chisel	115.2	1.40	76.5	36.6
Ridge Till	121.1	1.40	80.3	34.8
P-Value	84	19	83	60
N-Rate X Method X Inhibitor				
N-Rate #/A				
50	114.9	1.33	72.6	35.0
105	121.6	1.38	79.6	34.6
160	119.4	1.43	81.3	36.8
215	116.5	1.45	80.0	36.5
P-Value	99	99	99	82
BLSD (.05)	2.5	0.02	2.2	
Method				
1. 4 leaf	115.7	1.40	79.6	36.0
2. 8 leaf	120.4	1.38	79.0	35.0
3. Split 2/3 1/3	118.2	1.41	79.2	36.2
P-Value	99	89	95	52
BLSD (.05)	2.3		2.2	
Inhibitor				
None	117.0	1.39	77.1	35.7
N-Serve	119.3	1.41	79.6	35.7
P-Value	98	94	98	4
N-Rate X Method	57	99	87	42
N-Rate X Inhibitor	99	61	99	36
Method X Inhibitor	55	94	96	57
N-Rate X Method X Inhibitor	71	97	89	8
N-Rate X Method X Inhibitor X Tillage				
N-Rate X Tillage	99	81	68	63
Method X Tillage	99	50	99	94
Inhibitor X Tillage	97	93	99	48
N-Rate X Method X Tillage	69	86	94	62
N-Rate X Inhibitor X Tillage	85	90	87	26
Method X Inhibitor X Tillage	85	99	91	99
N-Rate X Method X Inhibitor X Tillage	18	95	95	97

Table 2. Influence of N-rates, nitrification inhibitors, method of application and tillage in **continuous corn** on soil ammonium and soil nitrate from spring and fall soil samples depth 1 (0-1 ft) and depth 2 (1-2 ft) Westport, MN 1991.

Total N-Rate	Early N	Inh.	Late N	Tillage	Depth	Ammonium Spring	Ammonium Fall	Nitrate Spring	Nitrate Fall
#/A	#/A		#/A			------ppm-----		------ppm-------	
Control	---	---	---	C	1	4.5	1.7	1.7	3.2
					2	3.9	2.0	1.6	1.3
50	50	---	---	C	1	5.4	1.9	1.0	3.3
					2	4.1	2.0	1.5	1.3
50	---	---	50	C	1	4.7	2.0	2.0	3.7
					2	4.1	1.7	1.9	1.8
105	105	---	---	C	1	5.6	1.8	1.6	3.5
					2	4.1	1.6	1.8	2.3
105	---	---	105	C	1	4.6	1.8	2.5	3.7
					2	3.8	1.6	2.4	2.3
160	160	---	---	C	1	5.1	1.9	4.3	4.3
					2	4.1	1.7	4.2	3.4
160	---	---	160	C	1	5.0	2.4	2.2	4.3
					2	4.0	1.9	3.0	2.8
160	105	---	50	C	1	3.9	3.1	2.7	4.2
					2	3.5	2.0	2.9	3.6
160	160	NS	---	C	1	6.0	4.7	2.1	6.4
					2	4.4	3.1	3.6	6.9
160	---	NS	160	C	1	4.7	2.1	3.2	3.6
					2	6.5	1.9	3.9	3.9
160	105	NS	50	C	1	5.5	3.3	1.7	7.3
					2	4.1	2.1	2.1	3.0
215	215	---	---	C	1	7.4	9.0	3.1	10.2
					2	5.3	3.3	4.1	15.0
215	---	---	215	C	1	5.3	5.7	1.7	10.8
					2	6.0	1.9	2.4	10.3
Control	---	---	---	R	1	4.1	1.8	3.0	3.1
					2	3.8	1.6	2.4	1.3
50	50	---	---	R	1	4.8	2.0	4.0	2.9
					2	4.1	2.1	3.2	2.2
50	---	---	50	R	1	5.2	2.0	3.1	3.7
					2	4.3	2.0	2.9	2.0
105	105	---	---	R	1	5.2	1.9	4.6	3.9
					2	3.3	1.8	3.9	2.9
105	---	---	105	R	1	4.6	2.1	3.9	4.4
					2	3.7	1.8	4.1	3.4
160	160	---	---	R	1	5.1	2.6	2.8	4.6
					2	3.7	2.2	3.1	4.1
160	---	---	160	R	1	5.0	1.7	4.0	4.8
					2	3.8	1.6	4.5	2.5
160	105	---	50	R	1	4.6	2.2	4.0	4.2
					2	4.1	1.2	3.9	2.9
160	160	NS	---	R	1	4.8	2.6	5.6	4.7
					2	3.6	1.9	5.7	3.5
160	---	NS	160	R	1	5.7	2.5	3.7	4.9
					2	8.2	1.9	6.8	3.2
160	105	NS	50	R	1	4.9	2.3	3.3	3.2
					2	4.1	1.8	3.1	1.4
215	215	---	---	R	1	4.6	1.5	5.2	5.1
					2	3.8	1.7	3.9	3.4
215	---	---	215	R	1	7.5	2.5	6.7	5.2
					2	5.5	1.9	6.4	4.5

Table 3. Influence of N-rate, nitrification inhibitors, methods of application and tillage in **soybeans following corn** on soil ammonium and soil nitrate from spring and fall soil samples depth 1 (0-1 ft) and depth 2 (1-2 ft) Westport, MN 1991.

Total N-Rate	Early N	Inh.	Late N	Tillage	Depth	Ammonium Spring	Ammonium Fall	Nitrate Spring	Nitrate Fall
#/A	#/A		#/A			-----ppm-----		-----ppm------	
Control	---	---	---	C	1	4.1	1.9	2.1	2.5
					2	3.3	2.1	1.8	1.1
50	50	---	---	C	1	4.7		1.9	
					2	3.5		1.4	
50	---	---	50	C	1	3.7		1.0	
					2	3.4		0.8	
105	105	---	---	C	1	4.5		1.4	
					2	3.6		2.0	
105	---	---	105	C	1	3.9		2.1	
					2	3.3		2.1	
160	160	---	---	C	1	4.2		2.2	
					2	4.2		3.0	
160	---	---	160	C	1	5.1		3.0	
					2	3.9		3.1	
160	105	---	50	C	1	4.7		1.7	
					2	2.9		1.8	
160	160	NS	---	C	1	4.8		1.9	
					2	3.6		1.8	
160	---	NS	160	C	1	4.9		2.5	
					2	5.3		3.3	
160	105	NS	50	C	1	4.7		2.8	
					2	3.5		4.5	
215	215	---	---	C	1	4.9		3.0	
					2	3.2		3.0	
215	---	---	215	C	1	7.8		2.5	
					2	3.7		4.2	
Control	---	---	---	R	1	3.9	2.1	2.5	3.1
					2	3.4	1.8	2.4	1.3
50	50	---	---	R	1	4.3		2.5	
					2	3.7		2.5	
50	---	---	50	R	1	4.1		4.4	
					2	3.2		3.5	
105	105	---	---	R	1	4.3		2.9	
					2	3.1		2.8	
105	---	---	105	R	1	3.5		2.9	
					2	3.1		3.2	
160	160	---	---	R	1	4.6		4.9	
					2	3.7		4.3	
160	---	---	160	R	1	4.6		3.9	
					2	4.3		3.7	
160	105	---	50	R	1	4.5		3.8	
					2	3.4		4.6	
160	160	NS	---	R	1	6.4		4.9	
					2	4.6		5.3	
160	---	NS	160	R	1	4.5		2.9	
					2	3.8		4.3	
160	105	NS	50	R	1	4.4		3.0	
					2	3.9		3.3	
215	215	---	---	R	1	4.2		2.6	
					2	3.2		3.7	
215	---	---	215	R	1	4.6		3.5	
					2	4.5		3.4	

Table 4. Nitrate-N concentration of water collected in pan and wick lysimeters in the small plot area, Westport, MN 1991.

N rate #/A		Pan corn-corn	Pan corn-beans	Wick corn-corn	Wick corn-beans
		ppm NO_3-N			
0		1.4	12.9	--	12.4
105	early	1.9	4.2	--	20.3
105	late	3.1	5.8	10.9	--
215	early	2.8	79.3	--	148.8
215	late	0.2	13.2	--	125.9

Table 5. Corn grain yields from large plot area Westport, MN 1991.

Total N-Rate #/A	Early N #/A	Late N #/A	Crop Rotation	Grain Yield Bu/A	Grain N-Content %	Grain N-Removal #/A
160	105	55	Corn-Corn	112.0	1.40	74.4
215	140	75	Corn-Corn	136.2	1.43	82.6
160	105	55	Corn-Soybeans	121.7	1.44	82.9

Table 6. Nitrate-N concentration of water collected from the pan and wick lysimeters in large plot area, Westport, MN 1991.

N rate lb N/A	Rotation	NO_3-N ppm
Pan		
160	corn-corn	30.1
215	corn-corn	38.0
160	corn-soybean	1.9
Wick		
160	corn-corn	24.1
215	corn-corn	84.8
160	corn-soybean	21.7

USE OF THE SPAD 502 CHLOROPHYLL METER TO MONITOR THE NITROGEN STATUS OF CORN[1]

L. A. Kotilinek, G. L. Malzer, and T. J. Graff[2]

Abstract: Nitrogen management decisions which improve fertilizer efficiency should decrease the potential for nitrate contamination of ground water and increase profitability for corn producers. The use of a chlorophyll meter which quantifies leaf greenness could rapidly and effectively monitor N requirements of the crop and thus improve N management programs for those producers with sidedress or fertigation capabilities. In 1991, a study was initiated to determine if the Minolta SPAD 502 chlorophyll meter could be utilized to predict N deficiency in corn. Meter readings and leaf nitrogen concentrations from plants at 4-, 8-, 12-leaf, blister, and milk growth stages were compared for their ability to predict nitrogen deficiencies in corn. The correlation between meter readings and leaf N concentrations and grain yield increased with increasing age of the plant. Correlation coefficients (r) increased by analysis of relative values as compared to actual measurements. Correlation of relative yield x relative meter readings was comparable to that of relative yield x relative leaf N concentrations (r=0.65, 0.50, 0.81, 0.94, 0.95, and 0.68, 0.49, 0.84, 0.98, 0.99 respectively). While it is not possible to recommend rates of N fertilization via chlorophyll meter readings at this time, the data would suggest that the meter and leaf tissue analysis are comparably effective in monitoring the N status of corn.

Tissue analysis may be an effective method for predicting the N status of corn, but cost and time involved prevent such methods from being widely accepted as tools to improve nitrogen management. The chlorophyll meter rapidly and non-destructively measures the degree of leaf greenness and thus has potential for contributing to greater nitrogen fertilizer efficiency for producers that apply nitrogen by sidedress application or through irrigation water. The objective of this study was to compare the chlorophyll meter with leaf N concentrations for their ability to predict nitrogen deficiencies of corn.

Experimental Procedures: This study was conducted at the Herman Rosholt Water Quality Research Farm, Westport, MN, during the 1991 growing season. The soil is an Estherville sandy loam and the crop sequence was continuous corn (Pioneer 3902 - 90 day R.M.). Corn, under chisel and ridge tillage systems was planted on May 9th, at 29,900 seeds per acre. Starter fertilizer 7-22-5 was applied as a band below the seed at a rate of 10 gal/A. Nitrogen fertilizer in the form of anhydrous ammonia was applied at rates of 0, 50, 105, 160, and 215 lbs N/A on June 10th (4-leaf stage) or June 19th (8-leaf stage). Weed control was accomplished with Lasso, Atrazine-90DF, and cultivation.

At 4-leaf(June 8th), 8-leaf(June18th), 12-leaf(July 1st), blister(July 23rd), and milk(August 8th) growth stages, chlorophyll meter readings were taken from 20-30 different plants from one row of each plot. Leaf samples were taken from 10-15 plants in the adjacent row, dried, ground, and analyzed for N concentrations. For the 4, 8, and 12-leaf stages, the youngest leaf with a collar was measured, while the leaf opposite and below the developing ear was used at blister and milk stages. Meter readings (one per plant) were taken at a location approximately midleaf, from base to tip and from the midrib to outer leaf margin. Corn was hand harvested from 100 sq.ft. of plot area on October 9th. Shelled grain was dried and values reported at 15.5% moisture.

General Results: Chlorophyll meter readings, leaf N concentrations, and grain yield are presented in Table 1. Meter readings were highly correlated with yield at all growth stages while leaf N concentrations did not significantly correlate with yield at the 8 and 12-leaf growth stages. Relative values for meter readings, N concentrations, and yield are shown in Table 2. These values were obtained using the following formula: relative value = observed value/highest value obtained for the equivalent tillage and time of fertilizer application. Relative meter readings and relative leaf N concentrations were well correlated with relative grain yield at 4-leaf, 12-leaf, blister, and milk growth stages. Lower correlation was observed at the 8-leaf stage.

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2. Graduate Research Asst., Professor, Asst. Scientist, respectively, Dept. of Soil Science, University of MN.

Since as much as 90% of the yield response was obtained with the lowest rate of fertilizer, the highest coefficients obtained at the later stages of growth should be interpreted with caution. Preliminary data suggests that the chlorophyll meter and leaf N analysis, when standardized to relative values, are equivalent with regards to their ability to monitor the N status of corn.

Table 1. Chlorophyll meter readings, leaf N concentrations, and grain yield for continuous corn. Westport, MN 1991.

Tillage	N Rate (# N/A)	Application Time	Chlorophyll Meter Readings^ 4-leaf	8-leaf	12-leaf	blister	milk	Yield^ Bu/A
Chisel	0		42.3	42.6	36.8	32.7	31.2	63.7
	50	4-leaf	43.8	44.4	47.1	51.8	48.8	100.7
	105		44.5	45.5	48.8	57.2	53.5	113.4
	160		43.5	45.3	48.3	57.9	55.7	107.8
	215		45.1	46.9	49.8	56.9	53.8	128.8
	50	8-leaf	43.4	46.2	43.8	54.0	51.7	108.8
	105		43.7	45.3	41.8	55.3	53.6	118.2
	160		43.4	47.0	45.9	56.6	54.6	105.3
	215		44.4	49.7	48.2	57.7	54.6	109.9
Ridge	0		43.7	44.8	37.1	34.2	31.4	68.4
	50	4-leaf	43.3	42.9	45.9	53.5	51.1	116.3
	105		45.8	45.2	47.5	57.6	56.3	113.1
	160		45.2	46.6	48.0	58.2	56.3	125.6
	215		44.7	46.6	48.0	57.3	56.9	127.9
	50	8-leaf	43.8	44.0	41.8	54.8	52.8	124.6
	105		44.4	46.3	42.8	54.0	54.9	125.8
	160		46.2	47.7	43.8	56.2	55.1	121.0
	215		45.9	48.7	47.5	58.0	55.7	121.8
	(yield x meter) r=		0.60**	0.45~	0.67**	0.90**	0.92**	
				Leaf N Concentration (%)^				
Chisel	0		3.91	2.72	2.42	1.36	1.32	
	50	4-leaf	3.95	2.76	2.67	2.63	2.29	
	105		4.18	3.27	2.94	2.92	2.77	
	160		4.26	2.79	2.81	2.95	2.87	
	215		4.20	3.02	2.85	2.99	2.94	
	50	8-leaf	4.10	2.78	2.55	2.84	2.54	
	105		4.00	2.79	2.49	2.88	2.91	
	160		3.95	2.90	2.58	3.06	2.75	
	215		4.01	2.91	2.76	2.87	2.81	
Ridge	0		4.00	2.66	2.20	1.41	1.39	
	50	4-leaf	4.13	2.61	2.50	2.39	2.32	
	105		4.45	2.85	2.72	2.92	2.80	
	160		4.46	2.95	2.66	2.92	2.97	
	215		4.36	2.85	2.48	3.08	2.89	
	50	8-leaf	4.38	2.62	2.49	2.56	2.60	
	105		4.16	2.85	2.40	2.95	2.88	
	160		4.28	2.91	2.65	2.97	2.78	
	215		4.25	3.11	2.53	2.85	2.92	
	(yield x leaf N) r=		0.64**	0.37	0.40	0.87**	0.91**	

^ Rep Means.

~,*,** Significant at the 0.10, 0.05, and 0.01 level respectively.

Table 2. Relative meter readings, relative leaf N concentrations, relative grain yield. Westport, MN 1991.

Tillage	N Rate (# N/A)	Application Time	Relative Meter Readings^ 4-leaf	8-leaf	12-leaf	blister	milk	Rel. Yield^
Chisel	0		0.94	0.91	0.74	0.56	0.56	0.49
	50	4-leaf	0.97	0.95	0.95	0.90	0.88	0.78
	105		0.99	0.97	0.98	0.99	0.96	0.88
	160		0.97	0.97	0.97	1.00	1.00	0.84
	215		1.00	1.00	1.00	0.98	0.97	1.00
	0		0.95	0.86	0.76	0.57	0.57	0.54
	50	8-leaf	0.98	0.93	0.91	0.94	0.95	0.92
	105		0.98	0.91	0.87	0.96	0.98	1.00
	160		0.98	0.95	0.95	0.98	1.00	0.89
	215		1.00	1.00	1.00	1.00	1.00	0.93
Ridge	0		0.95	0.96	0.77	0.59	0.55	0.53
	50	4-leaf	0.95	0.92	0.96	0.92	0.90	0.91
	105		1.00	0.97	0.99	0.99	0.99	0.88
	160		0.99	1.00	1.00	1.00	0.99	0.98
	215		0.98	1.00	1.00	0.98	1.00	1.00
	0		0.95	0.92	0.78	0.59	0.56	0.54
	50	8-leaf	0.95	0.90	0.88	0.94	0.95	0.99
	105		0.96	0.95	0.90	0.93	0.99	1.00
	160		1.00	0.98	0.92	0.97	0.99	0.96
	215		0.99	1.00	1.00	1.00	1.00	0.97
(Rel. Yield x Rel. Meter) r=			0.65**	0.50*	0.81**	0.94**	0.95**	
				Relative Leaf N Concentration^				
Chisel	0		0.92	0.83	0.82	0.46	0.45	
	50	4-leaf	0.93	0.84	0.91	0.88	0.78	
	105		0.98	1.00	1.00	0.98	0.94	
	160		1.00	0.85	0.96	0.99	0.98	
	215		0.99	0.92	0.97	1.00	1.00	
	0		0.95	0.93	0.88	0.45	0.45	
	50	8-leaf	1.00	0.96	0.92	0.93	0.87	
	105		0.98	0.96	0.90	0.94	1.00	
	160		0.96	1.00	0.94	1.00	0.95	
	215		0.98	1.00	1.00	0.94	0.97	
Ridge	0		0.90	0.90	0.81	0.46	0.47	
	50	4-leaf	0.93	0.89	0.92	0.78	0.78	
	105		1.00	0.97	1.00	0.95	0.94	
	160		1.00	1.00	0.98	0.95	1.00	
	215		0.98	0.97	0.91	1.00	0.97	
	0		0.91	0.86	0.83	0.47	0.48	
	50	8-leaf	1.00	0.84	0.94	0.86	0.89	
	105		0.95	0.92	0.91	0.99	0.99	
	160		0.98	0.93	1.00	1.00	0.95	
	215		0.97	1.00	0.95	0.96	1.00	
(Rel. Yield x Rel. Leaf N) r=			0.68**	0.49*	0.84**	0.98**	0.99**	

^ Rep Means.

*, ** Significant at the 0.05 and 0.01 level respectively.

Impact of Turkey Manure Application on Corn Production and Potential Water Quality Concerns on Estherville Sandy Loam[1]

Manjula V. Nathan, Gary L. Malzer and James L. Anderson[2]

Abstract

A field study was conducted at Westport, Minnesota to study the impact of turkey manure application on irrigated corn production and potential water quality concerns on Estherville sandy loam. Two rates of turkey manure (4 and 8 tons per acre on wet weight basis; these rates were computed to provide 70 and 140 lb of available N per acre respectively), were compared with two rates of commercial fertilizer (used at the rates of 70 and 140 lb N/A) and untreated check. Dry matter production and N uptake at 8-leaf and silking stages were estimated. Grain and stover yields and N uptake were measured at maturity. Water percolation and N leached were measured periodically throughout the growing season. Soil samples were collected at planting, 8-leaf, silking and harvest and analyzed for inorganic N (NH_4^+-N + NO_3^--N). As expected manure and fertilizer treatments increased the dry matter production and grain yield. Grain yield was increased almost by 100 bu/A when fertilizer rate of 140 lb N/A was applied. The low rate of manure was comparable in yield to the high rate of fertilizer, while the high rate of manure produced yield (142 bu/A) higher than the high fertilizer rate (128 bu/A). Treatments applied in 1991 had no influence on the amount of water that percolated through the soil, or the concentration and amount of N lost in the percolate water. Residual impacts of 1991 treatments will be evaluated in 1992. Soil inorganic N levels were significantly higher with high manure rate treatment at 8-leaf, silking and harvest stages. This elevated concentration of inorganic N may be reflected in the leachate water next spring. Considering the grain yield uptake turkey manure at 4T and 8T/A performed equally well or better than the 140 lb N/A fertilizer treatment.

Introduction

Turkey production in Minnesota is ranked second in the nation (Minnesota Statistics, 1990). In 1990, Minnesota's turkey farms boosted their output to a new record of 43.6 million turkeys. A large portion of the turkey production is concentrated in the West Central and Northwest regions of the state. Many turkey producers have limited agricultural production areas available to them for manure disposal. As production increases there will be an increased concern about manure disposal and potential water quality contaminations.

Turkey manure is rich in several nutrients. Recent survey done by University of Minnesota researchers (Moncrief et al. 1991, unpublished date) revealed the nutrient composition of poultry manure on dry weight basis is 5.1% N, 2.2% P and 2.3% K respectively. It is estimated that the 860,000 tons (dry wt.) of turkey manure produced per year will supply 87, 86 and 48 million pounds of N, P_2O_5 and K, respectively.

Increased emphasis on protection of surface water and ground water, and the farmers desire to reduce fertilizer costs have increased the need to evaluate the use of turkey manure in corn production. The objectives of this field study was to compare two rates of turkey manure (4 and 8 T/A on wet weight basis) and two rates of fertilizer N (70 and 140 lb N/A) on dry matter production, N uptake and grain yield, and leaching loss of NO_3-N.

Materials and Methods

In 1975, 30 non-weighing lysimeters were installed on the Rosholt farm at Westport, Minnesota. Each lysimeter was 5.75 ft in diameter, and 4 ft deep and constructed of 12-gauge galvanized steel coated with coal tar epoxy enamel. At the bottom of each lysimeter a sintered stainless steel filter candle was

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[1] Funding provided by the University of Minnesota Agricultural Experiment Station and the Center for Agricultural Impacts on Water Quality.

[2] Postdoctoral Associate and Professors respectively, Dept. of Soil Science, University of Minnesota.

installed and connected to the soil surface by polyethylene tubing. Each lysimeter was placed in the center of 30′ x 30′ plots. Soil at the experimental site was an Estherville sandy loam (Typic Hapludoll) and the lysimeters were backfilled with that soil by depth. Selected chemical and physical properties of the soil are presented in Table 1.

This site did not have any previous history of manure application. Cropping history was corn following corn in a corn-corn-soybean rotation. In 1990, corn was grown at this site without any fertilizers.

Table 1. Some chemical and physical properties of the Estherville sandy loam.

Soil Depth	Gravel	Sand	Silt	Clay	Organic Matter	pH
in.	%					
0-6	0.8	57.9	23.8	18.3	4.8	5.7
6-15	8.0	69.0	16.8	14.1	1.1	5.8
15-30	5.4	66.8	16.1	17.1	0.7	6.2

Irrigation was provided to all plots through a drip-type irrigation system. Drippers were 30 inches apart on a 0.5 inch plastic irrigation line. An irrigation line was placed along each row of corn. Water was pumped through the irrigation system at 13.8 kPa pressure. The emission rate for each dripper was 0.35 gal/h. Each lysimeter contained 4 drippers. Irrigation water was applied when less than 2 inches of water were available in the soil profile. Irrigation water was metered through 3 main irrigation lines.

Treatments consisted of two rates of turkey manure (4 and 8 T/A, wet weight basis) and two rates of commercial fertilizer N (70 and 140 lb N/A applied as urea) and a control with no N. The turkey manure treatments were incorporated, immediately after application. The nutrient composition of turkey manure is presented in Table 2. Estimate of manure N availability was based on the assumption that 80% of the inorganic N and 30% of the organic N will be available during the first year of application. The manure rates applied were expected to provide approximately 70 and 140 lb. of available N/A. The experimental design was a randomized complete block design with three replications. The three blocks (5 plots/block) which were in roto-till during the previous years have been used for this year of the study. The other three blocks which have been in no-till in the past have been roto-tilled this and were left untreated. These untreated blocks will be used in 1992 to study the effect of turkey manure application on soybean production. The plots which were treated this year will be used to study the residual effects of manure application on soybeans following corn in 1992. The entire study area was planted with corn (Pioneer 3790) on May 8 at the seed density of 28,500 seeds per acre. Blanket application of P and K were made at the rate of 50 and 150 lb of P_2O_5 and K_2O per acre respectively to all 30 plots.

Table 2. Turkey Manure Composition.

Nutrients	lb/T*
Total N	48
Inorg. NH_4^--N	12
NO_3^--N	2
Organic N	34
P_2O_5	69
K_2O	50
Moisture %	52

*Nutrient composition presented in wet weight basis.

Dry matter production and N uptake were determined at the 8-leaf and silking stages by hand harvesting four feet of row. Grain and stover yields were determined by harvesting two 20 feet of rows at maturity. Subsamples from stover, cob and grain were analyzed for total Kjeldahl N. Corn grain yields were reported at 15.5% moisture.

Soil water percolate was collected throughout the growing season from the bottom of the lysimeters following rainfall events. The amount percolated and the NO_3^--N in the leachate was measured to quantitate concentration, flow rate and total N lost by leaching.

Soil samples collected (0 to 12 in. depth) at the time of planting, 8 leaf, silking and harvest time were analyzed for inorganic N (NH_4^+-N + NO_3^--N).

Results and Discussion

The manure and commercial fertilizer treatments significantly increased dry matter production and grain yield.

Table 3. Dry matter production and N uptake as influenced by manure and fertilizer treatment at the 8-leaf growth stage and silking.

Treatment	Dry matter		N Concentration		N Uptake	
	8-leaf	silking	8-leaf	silking	8-leaf	silking
	T/A		%		lb/A	
Control	0.49	1.89	0.99	0.65	9	24
Urea 70 lb N/A	0.84	4.11	0.80	0.56	13	45
Urea 140 lb N/A	1.16	4.54	2.55	1.37	59	124
TM 4 T/A	1.16	4.67	0.93	1.44	22	133
TM 8 T/A	1.27	4.76	2.12	1.62	54	154
LSD 0.05	0.45	1.05	0.67	0.30	20	26

Low rates of fertilizer and manure did not influence N concentration and N uptake at the 8-leaf growth stage, but the low rate of manure did increase dry matter production (Table 3). The high rates of fertilizer and manure produced comparable yield and uptake (1.16, 1.27 T/A and 59 and 54 lb/A respectively for high fertilizer and manure treatments) which were significantly higher than the control. At the silking stage, the dry matter production for all fertilizer and manure treatments were similar and were significantly higher than the control (Table 3). The N concentration in the corn plant and total N uptake at silking were significantly reduced at the low fertilizer rate (Table 3). The N concentration in plant and N uptake at 8-leaf and silking suggests that the low rates of fertilizer and manure did not supply sufficient N at the 8-leaf stage. At silking, however the low manure was comparable to the high rates of manure and fertilizer.

A severe wind storm on June 27 (around 14-leaf stage) reduced the plant stands in the manure treated plots. The succulent plant material was broken at the base of the stalk resulting in a 15-20% stand reduction. Grain yield data has been adjusted for the reduced population in the manure treated plots. Significant yield increase was observed with all fertilizer or manure treatments rather than the control (Table 4). Grain yield was increased by almost 100 bu/A when a fertilizer rate of 140 lb N/A was applied. The low rate of manure was comparable in yield to the high rate of fertilizer, while the high rate of manure produced yields (142 bu/A) higher than the high fertilizer rate (128 bu/A).

Table 4. Grain and Stover yield and N uptake as influenced by manure and fertilizer treatment.

Treatment	Grain		Stover		Total N
	yield	N uptake	yield	N uptake	uptake
	bu/A	lb/A	T/A	lb/A	lb/A
Control P	31	18	1.31	11	28
Urea 70 lb N/A	91	48	2.09	15	63
Urea 140 lb N/A	128	87	2.36	20	107
TM 4 T/A	133	88	2.23	20	108
TM 8 T/A	142	104	3.18	39	143
LSD (0.05)	13	21	0.66	10	25

As expected, grain N uptake increased with all fertilizer and manure treatments than the control. Grain N uptake increased by almost 40 lb/A when fertilizer rate was increased from 70 to 140 lb N/A. The lower rate of manure was comparable in grain N uptake to the higher rate of fertilizer. However, increasing manure rate did not result in significant grain N uptake (Table 4). Total N uptake followed somewhat similar pattern as grain N uptake, with the exception of significant increase in total N uptake with increase in manure rates.

The leachate collected from the bottom of the lysimeters has been grouped into two time periods (before planting and planting to harvest, Table 5). Post-harvest leaching data has not been summarized. Concentration of NO_3-N in the leachate before planting ranged from 6 to 11 ppm. Leachate collected during the growing season had NO_3-N concentration in the range of 10 to 12 ppm. Treatments applied in 1991 had no influence on the amount of water that percolated through the soil, or the concentration and amount of N lost in the percolate water. Residual impacts of 1991 treatments will be evaluated in 1992.

Table 5. Water percolation amount and concentration of NO_3^--N in the leachate as influenced by fertilizer and manure treatments.

	Before planting			Planting to harvest		
Treatment	H_2O in	N lb/A	NO_3^--N ppm	H_2O in	N lb/A	NO_3^--N ppm
Control	3.4	5	6	4.0	10	11
Urea 70 lb N/A	3.5	7	9	4.2	10	12
Urea 140 lb N/A	3.6	8	11	4.7	11	10
Manure 4 T/A	4.2	10	11	4.4	12	11
Manure 8 T/A	3.4	6	8	5.7	13	10
LSD (0.05)	NS	NS	NS	NS	NS	NS

Table 6. Soil inorganic N as influenced by manure and fertilizer.

	Inorganic N			
Treatment	Planting*	8-leaf	Silking	Harvest
	lb/A			
Control	20	25	20	21
Urea 70 lb N/A	18	30	21	21
Urea 140 lb N/A	20	33	30	22
Manure 4 T/A	20	35	30	27
Manure 8 T/A	21	40	52	48
LSD (0.05)	NS	11	19	17

*Before treatment application.

Soil inorganic N (NH_4 + NO_3-N) in surface 12" of soil before planting averaged to 20 lb/A (Table 6). The high manure treatment resulted in significantly higher amounts of soil inorganic N as measured at 8-leaf, silking and harvest. This elevated concentration of inorganic N may be reflected in the leachate water next spring.

CALIBRATION AND CORRELATION OF SOIL N TESTS FOR IMPROVED N RECOMMENDATIONS[1]

M.A. Schmitt and G.W. Randall[2]

Soil testing, which allows site specific fertilizer recommendations, offers a means of improving nitrogen (N) management for corn production for a given soil/crop/climate. Research throughout the Corn Belt has shown that soil N tests have great potential for refining N rate decisions.

The primary objective of this project is to develop an N soil test that will enable farmers to apply optimum rates of N for corn under a wide variety of soil, crop, and climatic conditions. To meet this objective, an evaluation of different tests or combination of tests, based on sampling time and depth as well as form of N, will be made for measuring and/or assessing available N before and during the growing season for use in predicting fertilizer N requirements for corn.

Methods and Materials

Experiments were established during March and early April at 15 locations throughout southern and central Minnesota in 1991. Ten sites were on farmer-cooperator fields with five being located at experiment stations. The sites represented three major parent materials with seven being on glacial till, four on loess and four on outwash soils. A range of previous crops was also obtained with corn at four sites, soybeans at six, alfalfa at three, and small grains at two. Soil texture ranged from loamy sand to clay. This wide array of soil, previous crop, and climatic conditions should provide an excellent opportunity to evaluate various soil N tests and their ability to predict available N.

There were nine treatments at most locations. The treatments included a control plot, five preplant N rates (30, 60, 90, 120, 150 lb N/acre) and three split-applied N rates (60 lb N/acre preplant with 30, 60, 90 lb N/acre sidedressed). Where alfalfa was the previous crop, only sidedress treatments of 0, 30, 60 and 90 lb N/acre were included. Preplant applications used broadcast urea and the sidedress applications used subsurface bands of urea. Sidedressing occurred when the corn was 6-12 inches tall.

Soil samples were collected four times each year: 1) preplant, approximately two weeks before planting, 2) about 10-14 days after planting, when the corn had 1-2 leaves (V1 stage), 3) about 5 weeks after planting, when the corn was 6-12 inches tall (V4 stage), and 4) after harvest. Only control plots and two treatments receiving preplant N were sampled throughout the year. Soil samples were collected in 1-foot increments to a depth of five feet for the preplant and postharvest samplings and to a depth of three feet for the in-season samplings.

Stover and grain yields were measured from each plot after physiological maturity. Total Kjeldahl N was measured in the stover and grain, and nitrate-N was measured in the basal stalk section of the corn plants from selected treatments after maturity. Rainfall and temperature data were recorded through July at each site.

Samples were analyzed for ammonium-N and nitrate-N using a Wescan Autoanalyzer. Selected samples were also analyzed for hydrolyzable N using a phosphate-borate buffer extractant. A randomized complete-block design with four replications was used at all sites. Plot size ranged from 10 to 15 feet wide (all with 30" rows) by 40 to 60 feet long.

All analysis of variance and correlation data conducted from 1991 data were performed by PC-SAS software. Data from 1989-1991 were used when regression equations were determined. The dependent variable in all regression models was relative grain yield. Relative grain yield was determined by dividing plots' grain yields by the average grain yield of all plots from treatments that were from the optimum (or greater) N treatments. Optimum N rate was determined by using least significant differences of the treatment means--no economic considerations were included.

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Results and Discussion

Soil Nitrate-N

Soil nitrate data from the first three sampling times are shown in Table 1. Preplant sample data indicated a large range in residual nitrate remaining in the soil profile. The absence of any concentrations greater than 14.1 ppm in the top one foot indicates that high amounts of carryover from 1990 were not present. At most sites, nitrate accumulation in the deeper profiles closely paralleled the nitrate concentration in the top foot.

Soil samples taken at the 1-2 leaf stage should represent residual (carryover) nitrate as well as N mineralized from the soil organic matter and previous legume sources if applicable. Sites with loess or glacial outwash had marked increases in nitrate compared to the preplant measurements. Most of the glacial till soils either had a decrease in nitrate or no change.

When the corn was 6-12 inches tall, soil nitrate values in the 3-foot profile did not change significantly from the previous sampling values when glacial till was the parent material. With sites on glacial outwash, nitrate tended to decrease from the previous sampling. These data suggest that mineralization and potential N losses early in the growing season can be highly related to soil parent material.

When alfalfa was the preceding crop, nitrate accumulation in the 3-foot profile at the 1-2 leaf stage was significantly higher than at preplant sampling, most probably due to the mineralization of the N pool associated with the alfalfa root system. This same increase was seen when sampled at the presidedress time. In addition, when alfalfa was grown two years previously, there was a marked increase in nitrate at all sampling times. Thus, there appears to be a potential interaction of previous crop with time of sampling for nitrate.

Soil N correlations

When correlating various soil N tests to each other varying sampling times, depths and N forms, there does not appear to be strong correlation among N forms or sampling times (Table 2). Contrasts of nitrate and ammonium measurements between two times of sampling at the two-foot depth resulted in coefficients of 0.11 and 0.30. Comparing nitrate and hydrolyzable N in four contrasts never showed coefficients greater than 0.20. Hydrolyzable N did give highly significant correlations when contrasted between different dates of sampling.

Correlation coefficients for nitrate analyses from different times and depths are listed in Table 3. The issue of sampling time can be evaluated for the two-foot nitrate samplings. The preplant sample is significantly, but not highly, correlated to the 1-2 leaf sampling ($r=0.43$) and to the 6-12 inch corn sampling ($r=0.39$). In comparing sampling time between the middle and late sampling, the correlation for the 1' and 2' depths are much higher ($r=0.67$ and $r=0.68$, respectively).

Table 3 also provides correlation information for depths of sampling. The correlation between the 0-2 ft preplant nitrate and the 2-3 ft value is 0.58. At the 1-2 leaf stage and when corn is 6-12 in. tall, the correlation of the second foot to the first foot in sampling depth are 0.53 and 0.51, respectively. Thus, it is unclear how much additional information is gained by including the additional foot at each of the sampling times.

Fertilizer N recovery

Preplant fertilizer rates were applied at all sites except when alfalfa was the previous crop. Ammonium concentrations did increase in the top foot of soil but only at the 1-2 leaf stage as the rate of preplant applied urea-N was increased (Table 4). Nitrate concentrations increased at both in-season sampling times proportionally to the amount of preplant N applied. While the nitrate increases were greatest in the top foot, there were proportional increases of nitrate in the second foot as well.

Grain yields

Grain yield results shown in Table 5 indicate significant yield responses to applied fertilizer N at 12 of the 15 sites. Alfalfa was the previous crop at the three non-responsive sites. The three sites with second-year corn following alfalfa responded to N rates of 30 lb/A (two sites) and 60 lb/A (one site). Yield responses following small grains (three sites) ranged from 37 to 107 bu/A with optimum N rates of 60 to 120 lb N/A. When following soybeans (five sites), corn yield responses ranged from 9 to 93 bu/A with optimum N rates of 30 to 150 lb N/A. However, the site that optimized yield with only 30 lb N/A (a

9 bu/A response) was planted to alfalfa in 1989. One site (E) experienced relatively low yields due to very wet conditions and late planting (June 7).

Grain yields and soil N

A preliminary relationship between grain yield and soil N parameters can be assessed by calculating correlation coefficients between soil N variables and relative grain yields. In Table 6, the influences of parent material and N form can be related to sampling time and depth. In almost every situation, the correlation between sampling parameters and N forms is affected by the soil's parent material. However, there is consistency when nitrate-N sampled at the 1-2 leaf stage is correlated to yield (r's of 0.75 to 0.81) for the three parent materials and the two depths of sampling. Ammonium-N and hydrolyzable N data resulted in higher or similar correlation values in only limited instances--those situations being generally with outwash parent materials.

Because it is common practice to add some or all fertilizer N before planting, similar correlations between soil nitrate and ammonium variables measured at the 1-2 leaf stage or when the corn is 6-12 inches tall can be calculated for plots that received preplant N (Table 7). Grain yield correlations to ammonium are always significantly less than with nitrate for all conditions.

Regression of relative grain yield and soil N tests is more appropriate for determining the predictive ability of a specific N test for grain yield. In order to increase confidence in the regression analysis, research data from 1989 and 1990 were combined with the 1991 dataset (all data from the same soil N testing project). Unless otherwise noted, data are from the control (0# N/A) plots and their relative grain yields as compared to a non-limiting grain yield at each site.

The model that should be used to fit the data is not always easy to determine. Neither linear nor quadratic models are used in this report because of the principles associated with them. While either models may seem to fit at a given site, theoretically, yields should plateau at increasing soil N test levels. Therefore, the models of linear-plateau and quadratic-plateau are evaluated.

There are three comparisons possible in Table 8 comparing linear- and quadratic-plateau models. The most obvious difference between models is the critical value--the value where the linear or quadratic curve intersects with the plateau line. Simply stated, this is where the responsive sites' data intersects with the nonresponsive sites' data. The quadratic-plateau model's critical value is approximately 12-13 ppm greater than the linear-plateau's. Each model's R^2 is almost identical and the error rates are comparable.

Although the error rates are comparable, the difference in the type of errors are noteworthy. Errors can either be where there is a response and one predicts no N response (R-PNR) or where there is no response when one predicted a response (NR-PR). Errors of R-PNR nature are of greatest concern to the crop producer because yields may have been limited because of underfertilizing. The NR-PR errors will result in fertilizing without a yield response.

Linear-plateau models consistently have a higher R-PNR error rates when compared to quadratic-plateau models--a response to the shift in critical values (Table 8). Conversely, the NR-PR error rates are very high (87-100%) when the quadratic-plateau model is used. Thus, the appropriate model from this dataset is primarily dependent on the type of error one will accept.

The factor of depth of sampling is compared in Table 8 with the V1 and V4 stage of growth. The error rates are similar for the 1-foot and 2-foot sampling depths, whereas, the R^2 is slightly higher for the 2-foot samples. Therefore, the deeper sampling does provide some benefit to the model. This is in agreement with an earlier statistical summary (Table 3) that documents a significant correlation between the two depths.

Sampling time is an important factor in developing a soil N test. Three times of sampling can be compared for either the 1-foot depth or the 2-foot depths in Table 8. Error rates among sampling times had a range of 9%--probably no significant difference. The R^2 values increased with later samplings for the 1-foot samplings and increased from the preplant sampling to the in-season samplings with the 2-foot samples. Based on these regression models, taking samples from the 2-foot depth at either the V1 or V4 stage of growth is the best N test situation.

From earlier soil data (Table 6), there was a distinct effect on nitrate concentrations and fluxes based on the site's parent material. When the V4, 2-foot sampling data were separated by parent material, the model's R^2 were significantly different for the parent materials. From the combined data, the R^2 is 48%, when separated by parent material, the range is from 32-57%.

When separation by parent material is made, the database for each model is significantly reduced, thus more observations are desired. To better compare parent materials, the database was expanded by including plots that received preplant N. In Table 8, the V1, 2-foot samples were analyzed to evaluate the effects of parent material on models. The combined model's R^2 is 45%. When sorted by parent material, the poorest model was from outwash sites (R^2=21%) and the strongest model was from the loess sites (R^2=71%).

Other N forms, such as ammonium and hydrolyzable N were also evaluated in this project. From a regression perspective, the phosphate-borate buffer extraction for hydrolyzable N did not provide data that fit either regression model. Ammonium data, while it did fit the models, was significantly inferior to the nitrate-only models. Combinations of N forms may be tested in the future.

Summary

Grain yield response to N, either from the soil or fertilizer, differs greatly depending on many factors--including soil parent material, previous crop, and previous crop management. Soil N analyses indicate that time of sampling and form of measured N do not correlate well amongst each other. Depth of sampling did correlate well for a given date of sampling. Soil parent material did influence the inorganic N increases (decreases) among sampling dates.

When preplant fertilizer was added, proportional increases were measured in the ammonium and nitrate soil N components. Ammonium N increased at the 1-2 leaf stage of sampling while nitrate N increased at both in-season samplings for both the 1- and 2-foot depths of sampling.

Regression analysis was made on a database from 1989-1991 (43 site-years). Using either the linear-plateau or quadratic-plateau model, error rates were commonly in the 25-40% range. The types of error being somewhat controlled by selection of the model.

Based on the fit of the models (R^2) between relative grain yield and soil nitrate-N concentrations, taking a soil sample from a 2-foot depth at the 1-2 leaf stage or at the 6-12 inch corn stage appears to be superior. From a logistical perspective, the earlier that one can sample, the less risk the user will experience relative to sidedress applications. There is potential for better fitting models when parent materials are separated.

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Table 1. Soil NO_3-N prior to planting, at the 1-2 leaf stage, and when the corn is 6-12 inches tall in the control plots at each site, 1991.

Site Code	Parent Material	Soil Texture[1/]	Previous Crop[2/]	Preplant 0-1'	Preplant 0-3'	Preplant 0-5'	1-2 leaf 0-1'	1-2 leaf 0-3'	6-12" tall 0-1'	6-12" tall 0-3'
				ppm	- - lb/A - -		ppm	lb/A	ppm	lb/A
A	Till	CL	C,A	14.1	130	187	7.7	87	9.7	91
B	Till	CL	Sb	5.9	48	68	3.8	45	4.6	46
C	Till	CL	Sb	4.1	85	173	3/	3/	3/	3/
D	Till	C	Sg	3.6	55	96	6.3	69	7.9	73
E	Till	CL	C	4.7	46	84	4.8	50	2.3	42
F	Till	SiCL	C,A	13.0	124	163	10.9	110	10.5	108
G	Till	CL	Sb	2.2	18	30	0.0	19	4.4	65
H	Outwash[4/]	L	A	10.9	52	54	25.3	158	13.7	97
I	Outwash	SL	Sb	7.2	68	88	13.8	95	9.0	61
J	Outwash	LS	Sg	2.0	14	23	4.2	24	4.3	34
K	Outwash	L	Sb,A	7.2	65	84	12.8	81	5.9	55
L	Loess	SiL	Sg	4.4	27	28	8.0	54	5.8	39
M	Loess[4/]	SiL	C,A	10.8	118	138	17.3	121	12.3	101
N	Loess	SiL	A	8.6	46	54	17.6	88	18.5	99
O	Loess	SiL	A	5.3	68	90	13.7	119	17.9	138

[1/] Abbreviations are: clay (C), loam (L), silt (Si), sand (S)
[2/] Abbreviations are: corn (C), alfalfa (A), soybeans (Sb), and small grain (Sg). The second crop, when listed, is from 1989.
[3/] Samples not collected.
[4/] Samples taken to a 4-foot depth only.

Table 2. Correlation between selected soil N variables from treatments receiving no fertilizer N at 15 sites in 1991.

Variables Contrasted[1/]	r	Pr>r
Pre 0-2′ NO_3 vs Pre 0-2′ NH_4	.11	.41
Pre 0-2′ NO_3 vs Pre 0-1′ PB	.05	.69
V1 0-2′ NO_3 vs V1 0-2′ NH_4	.30	.03
V1 0-2′ NO_3 vs V1 0-1′ PB	.20	.14
V4 0-1′ NO_3 vs Pre 0-1′ PB	.06	.66
V4 0-2′ NO_3 vs Pre 0-1′ PB	.10	.44
V4 0-1′ PB vs V1 0-1′ PB	.85	.00
V1 0-1′ PB vs Pre 0-1′ PB	.83	.00

[1/] Abbreviations used in describing variables are: preplant (Pre), 1-2 leaf stage (V1), and 6-12 inch tall corn (V4) sampling time, sampling depth in feet (0-1 or 0-2), and nitrate (NO_3), ammonium (NH_4), or hydrolyzable N using a phosphate borate extraction (PB) N forms.

Table 3. Correlation coefficients of soil nitrate-N variables affected by time an depth of sampling from plots receiving no fertilizer at 15 sites in 1991.

		Stage of corn growth and depth of sampling							
		Preplant		1-2 leaf (V1)			6-12" tall (V4)		
		0-2′	2-3′	0-1′	1-2′	0-2′	0-1′	1-2′	0-2′
		r[1]							
Preplant	0-2′	-	.58	.31	.59	.43	.33	.39	.39
	2-3′		-	.04[NS]	.44	.16[NS]	.16[NS]	.36	.25
V1	0-1′			-	.53	.97	.67	.31	.62
	1-2′				-	.73	.48	.62	.59
	0-2′					-	.68	.44	.68
V4	0-1′						-	.51	.95
	1-2′							-	.75

[1/] All coefficients are statistical significant at the 10% probability level except those designated with a NS.

Table 4. The effect of time and depth of soil sampling on nitrate-N and ammonium-N concentrations from preplant fertilizer applications averaged across all sites.

		Preplant N applied (lb N/A)								
Sampling Time	Sampling Depth	0			60			150		
		NO_3-N	NH_4-N	Total	NO_3-N	NH_4-N	Total	NO_3-N	NH_4-N	Total
	- ft -	lb N/A								
1-2 leaf	0-1	38	25	63	67	28	95	112	39	151
	1-2	26	13	39	38	14	52	49	16	65
	0-2	64	38	102	105	42	147	161	55	216
6-12" tall	0-1	35	31	77	59	32	90	98	35	133
	1-2	27	19	46	35	19	54	51	20	71
	0-2	62	50	112	93	51	144	149	55	204

Table 5. Corn grain yield response to N fertilizer additions for each of the sites, 1991.

Site Code	Previous Crop[1/]	Soil O.M.	Yield with 0 N/A bu/A	Optimum N Rate[2/] lb N/A	Yield Increase bu/A
A	C, A	High	153	60	33
B	Sb	High	84	150	93
C	Sb	High	96	90	50
D	Sg	High	136	60	37
E	C	High	42	90	15
F	C, A	High	161	30	13
G	Sb	High	104	120	74
H	A	Med	175	0	0
I	Sb	Low	149	90	24
J	Sg	Low	99	120	51
K	Sb, A	Low	177	30	9
L	Sg	Med	115	120	107
M	C, A	Med	159	30	16
N	A	Med	174	0	0
O	A	Med	207	0	0

[1/] Abbreviations used are: corn (C), alfalfa (A), soybeans (Sb), and small grain (Sg). The second crop, when listed, is from two years ago.
[2/] Optimum N rate is determined using statistical separation of N rate treatment means.

Table 6. Correlation coefficients of three N forms affected by sampling time, depth, and parent material correlated to relative grain yield of plots receiving no fertilizer N at 15 sites in 1991.

Sampling Time	Depth -ft-	Parent Material	Nitrate-N	Ammonium-N	Hydrolyzable N
			r[1/]		
Preplant	0-2	Till	0.61	-0.16^{NS}	-0.39
		Loess	0.35^{NS}	0.44*	0.21^{NS}
		Outwash	0.79	0.34^{NS}	0.63
Preplant	0-3	Till	0.67	-0.14^{NS}	-0.37
		Loess	0.35^{NS}	0.19^{NS}	0.24^{NS}
		Outwash	0.70	0.32^{NS}	0.61
1-2 leaf	0-1	Till	0.77	-0.10^{NS}	0.11^{NS}
		Loess	0.75	0.67	-0.13^{NS}
		Outwash	0.80	0.33^{NS}	0.62
	0-2	Till	0.76	-0.19^{NS}	-0.09^{NS}
		Loess	0.81	-0.74	-0.06^{NS}
		Outwash	0.81	0.56	0.60
6-12" tall	0-1	Till	0.62	0.38	0.11^{NS}
		Loess	0.85	-0.20^{NS}	-0.29^{NS}
		Outwash	0.65	0.73	0.73
	0-2	Till	0.71	-0.43	-0.24^{NS}
		Loess	0.86	-0.34^{NS}	-0.14^{NS}
		Outwash	0.78	0.77	0.69

[1/] All correlation coefficients are statistically significant at the 95% level or greater except those designated with a *, which denotes significance at the 90% level, or a ^{NS}, which denotes not significant at the 90% level or greater.

Table 7. Correlation coefficients of relative grain yield and nitrate-N and ammonium-N from selected N sampling parameters for sites that received preplant N at 15 sites in 1991.

Sampling Time	Depth	NO_3	NH_4
	-ft-	- - - - r[1/] - - -	
1-2 leaf	0-1	0.55	0.23
	1-2	0.55	0.12[NS]
	2-3	0.43	0.03[NS]
6-12" tall	0-1	0.47	-0.04[NS]
	1-2	0.55	0.15*
	2-3	0.47	0.13[NS]

[1/] All correlation coefficients are statistically significant at the 95% level or greater except those designated with a *, which denotes significance at the 90% level, or a [NS], which denotes not significant at the 90% level or greater.

Table 8. Selected regression model parameters as affected by soil sampling time and depth, parent material, and model for soil nitrate values and relative grain yield on control plots at 43 sites in Minnesota, 1989-91.

Parent Material	Sampling Time[1/]	Sampling Depth	Model[2/]	R^2	Critical Value	Error Rate[3/] All	Error Rate[3/] R-PNR	Error Rate[3/] NR-PR
		-ft-		%	ppm	- - - - - - - -	%	- - - - - - - -
Combined	Pre	0-1	LP	26	17.2	30		
Combined	Pre	0-2	LP	35	17.9	37	29	50
Combined	Pre	0-2	QP	34	31.1	33	4	87
Combined	V1	0-1	LP	38	15.8	35		
Combined	V1	0-2	LP	49	23.7	33	21	53
Combined	V1	0-2	QP	49	36.1	37	4	100
Combined	V4	0-1	LP	42	13.0	28		
Combined	V4	0-2	LP	48	20.3	28	18	47
Combined	V4	0-2	QP	49	33.3	35	7	87
Till	V4	0-2	LP	51	21.7	18		
Loess	V4	0-2	LP	57	16.3	40		
Outwash	V4	0-2	LP	32	20.1	36		
All[4/]	V1	0-2	LP	45	27.7	26		
Till[4/]	V1	0-2	LP	46	26.7	38		
Loess[4/]	V1	0-2	LP	72	28.4	7		
Outwash[4/]	V1	0-2	LP	21	28.5	25		

[1/] Sampling time abbreviations are preplant (Pre), 1-2 leaf stage (V1), and 6-12 inches tall (V4).
[2/] Models are either linear-plateau (LP) or quadratic plateau (QP).
[3/] Error rates are based on lack-of-fit for models. Errors are sometimes partitioned into responsive-predicted nonresponsive (R-PNR) or nonresponsive-predicted responsive (NR-PR).
[4/] These regression models included plots that received preplant N applications.

FERTILIZER N RESPONSE IN A CONTINUOUS CORN SYSTEM

M.A. Schmitt, G.W. Randall, and C.C. Sheaffer[1/]

ABSTRACT

The optimum fertilizer N rate for corn following corn is dependent on the year. In 1989, at Waseca and Rosemount, there were no statistical differences in corn grain yield among N rates. In 1990, the optimum fertilizer N rate was 90 lb at Rosemount and 60 lb at Waseca. For the 1991 cropping season, 60 lb. N was optimum at Rosemount and 150 lb N was optimum at Waseca. While an overall optimum N rate can be determined over several years for a location, this rate may underapply or overapply N fertilizer when only previous response curves are used to make this decision.

Introduction

Nitrogen equivalency plots are established to develop a response curve for N fertilizer. Normally, these plots are used to determine the fertilizer replacement value of a N source of unknown quantity. For example, if manure of an unknown N quantity were applied to a field, the yield could be placed on the equivalency plot response curve to estimate how much fertilizer N was replaced by the manure.

Long-term alfalfa/manure plots are being established at Rosemount and Waseca, and, in conjunction with these plots, a series of fertilizer N response trials are being conducted. The objective of these plots are to establish N response curves so that multiyear trends can be established.

Methods

Plots were established on a Waukegan silt loam at Rosemount and a Webster clay loam at Waseca from 1989 through 1991. Continuous corn in a conventional tillage system was the cropping history. Fertilizer N rates of 0, 30, 60, 90, 120, 150, and 180 lb N/acre were applied preplant as broadcast urea and incorporated soon thereafter.

Corn planting was conducted during recommended planting periods at populations sufficient for optimum production. Weeds were controlled with a preplant herbicide program. All management was conducted to ensure high yielding corn.

Corn was hand picked at Rosemount and then shelled, whereas a combine/sheller was used to harvest corn at Waseca. Shelled grain samples were dried and bushel weights were calculated for 15.5% grain moisture basis.

Plots were 20-30 feet long and 10 feet wide. A randomized complete block experimental design was used. Each block was replicated four times. Statistical analysis was performed by PC-SAS software. Different plot areas were used each year to avoid residual N effects from the differing N rate treatments.

Results

The grain yield responses to fertilizer N from Waseca are reported in Table 1. While the 1989 average treatment yields ranged from 105 to 115 bu/A, this variation was not significantly different. Thus, there was no response to fertilizer N this year. It is important to note that a major drought occurred the previous year (1988) and there was probably some residual N in the soil that contributed to the lack of response to fertilizer N.

In 1990 at Waseca, the optimum N rate was 60 lb N/acre according to statistical delineation. The optimum N rate increased to 150 lb. N/acre in 1991. Based on long-term N response studies at Waseca, the 150 lb N/acre is in line with the predicted amount of N from other studies for continuous corn.

At Rosemount, there was no grain yield response to fertilizer N in 1989 (Table 2). Again, factors contributing to this were relatively high amounts of N added in 1988 and low yields due to a dry growing season. However, in 1990, grain yield responses were higher with an optimum of 90 lb N/acre. The optimum N rate was 60 lb N/acre in 1991.

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Summary

Previous fertilizer management, crop yields, and the weather during the growing season all affect corn yield response to fertilizer N. Therefore, optimum fertilizer N rates are difficult to predict based simply on the previous years' optimum N rate.

These results emphasize the fact that years are not independent when dealing with N fertilizer. Nitrogen fertilizer recommendations that do not account for preceding environmental information or the results of the past environment (soil N test) may be overrecommending fertilizers.

Table 1. Corn grain yields as affected by n fertilizer rates at Waseca from 1989-1991.

N Rate	Year			
	1989	1990	1991	1989-91
lb N/acre	bu/acre			
0	105.6[1]	95.8	59.4	86.9
30	111.4	117.6	72.7	100.6
60	115.2	125.5[1]	100.6	113.8
90	112.8	127.5	117.9	119.4
120	110.7	139.9	128.4	126.3[1]
150	110.4	135.0	144.5[1]	129.9
180	113.0	136.9	158.9	136.3

[1] The designated yields indicate the N treatment at which yields were not statistically increased using least significant difference procedures.

Table 2. Corn grain yields as affected by N fertilizer rates at Rosemount from 1989-1991.

N Rate	Year			
	1989	1990	1991	1989-91
lb N/acre	bu/acre			
0	150.5[1]	100.7	129.9	127.1
30	141.8	114.7	149.0	135.2
60	150.8	129.2	169.2[1]	149.7
90	151.2	146.1[1]	178.0	158.5[1]
120	144.9	146.8	174.6	158.7
150	159.6	159.7	178.5	165.9
180	161.0	157.8	172.6	163.6

[1] The designated yields indicate the N treatment at which yields were not statistically increased using least significant difference procedures.

NITROGEN SPECIFIC MANAGEMENT BY SOIL CONDITION[1]

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Abstract: Recent advances in technology has brought about considerable interest in developing the methodology for making variable N rate applications within a field. The objectives of this study were to evaluate yield variability within production fields, determine yield response to applied fertilizer N and differential N loss as influenced by soil conditions. Results are being evaluated to determine what measurable soil conditions are best suited for making site specific N recommendations. Experimental locations of 36 and 44 acres were established at Lamberton and Becker, respectively. Different N management treatments were applied in replicated strips across the fields. Yields obtained from segmented harvest areas from control strips (zero N) indicate extreme yield variability. Preliminary results would suggest that variable N rate application can reduce N inputs, maintain or improve yield and increase net return for the producer.

Introduction: Nitrogen Specific Management by Soil Condition (NSMSC) has the potential to increase yields by better evaluating yield potentials of fields, increase profits by lowering inputs and improve water quality by identifying areas of potential N loss. NSMSC originated from recent advances in Geographic Information System (GIS) technology and continued interest in improving Best Management Practices (BMP) for nitrogen. Nitrogen specific recommendations, based on yield goal and soil conditions of production fields, are stored on a computer as digitized maps. The applicator's computer reads the digitized map and applies the specific N rate. An experiment was initiated in 1990 to evaluate site specific application of anhydrous ammonia on corn. The objectives of this study were to evaluate the variability in yield potentials within production fields, determine yield response to applied fertilizer N and differential N loss as influenced by soil conditions and ascertain what measurable soil conditions are best suited for making site specific N recommendations.

Materials and Methods: Experimental sites of 36 and 44 acres were chosen at the Southwest Experiment Station, Lamberton (Dryland) and the Malcolm and Steve Olson Farm, Becker (Irrigated). The sites selected represented soil variability common to their respective areas. Experimental measurements for both sites include: an intensive soil survey (1:5000 scale) and grid soil sampling (analyzed for NO_3-N, NH_4-N, total N, carbon, mineralizable N and soil water). Soil sample grid size was 90 by 100 and 100 by 100 feet and samples were taken to a depth of 4 and 3 feet in early November and mid May at Lamberton and Becker, respectively. Soil samples were separated into one foot increments for analysis. A summary of the sites soil characteristics are presented in Tables 1 and 2. Response measurements include: corn grain yield, grain moisture and N accumulation in grain.

Table 1. Soil data for Nitrogen Specific Management by Soil Condition Lamberton 1991.

Soil Series	Symb.	Acres	Text.	Slope	O. M.	NO_3-N	Subgroup
				%	%	lbs/A	
Canisteo	86	7.2	cl	0-2	5.4	54	Mollic Haplaquoll
Webster	113	7.2	cl	0-2	4.2	47	Typic Haplaquoll
Normania	446	1.1	l	0-2	4.0	50	Aquic Haplustoll
Okoboji	134	2.4	sicl	0-2	6.4	71	Cumulic Haplaquoll
Terril	94	0.8	l	2-6	3.8	38	Cumulic Hapludoll
Ves A	421A	3.3	l	0-2	3.4	40	Udic Haplustoll
Ves B	421B	11.4	l	2-6	3.4	40	Udic Haplustoll
Ves C	421C	2.8	l	6-12	3.1	35	Udic Haplustoll

Symb. Soil series symbol, Text. Soil texture
O.M. Organic matter (values for one foot depth)
NO_3-N Residual Nitrate (value for zero to two foot depth)

[1] The assistance and financial support of the Minnesota Agricultural Experiment Station, USDA-CSRS, Dow Elanco and Soil Teq Inc. is greatfully acknowledged.

[2] Graduate assistant, Professor and Assistant Professor, Department of Soil Science, and Superintendent, Southwest Experiment Station, respectively.

Table 2. Soil data for Nitrogen Specific Management by Soil Condition Becker 1991.

Soil Series	Symb.	Acres	Text.	Slope	O. M.	NO_3-N	Subgroup
				%	%	lbs/A	
Hubbard A	7A	6.4	ls	0-2	1.9	15	Udorthentic Haploboroll
Hubbard B	7B	11.1	ls	2-6	2.4	19	Udorthentic Haploboroll
Hubbard C	7C	1.2	ls	6-12	4.2	27	Udorthentic Haploboroll
Monticello A	768A	7.8	sl	0-2	2.6	19	Udic Haploboroll
Monticello B	768B	7.7	sl	2-6	2.0	16	Udic Haploboroll
Sandberg	256C	2.4	lcos	6-12	2.4	17	Udorthentic Haploboroll
Fill		7.4	s/p	0-2	3.9	23	

Symb. Soil series symbol, Text. Soil texture
O.M. Organic matter (values for one foot depth)
NO_3-N Residual Nitrate (value for zero to two foot depth)
s/p Sand over peat

Lamberton: Pioneer 3615 was planted on May 11 at a population of 27,700 S/A on 30 inch rows. Starter fertilizer was applied as a side banded application of 100 lbs/A of 12-30-10. Weed control was accomplished by using Lasso at 3 lbs/A on May 13 and cultivation on June 12 and 13. Twelve treatments consisting of eight constant N rates paired with N-Serve (60, 90, 120 and 150 lbs N/A), two variable N rates (soil and residual nitrate) and two checks (zero N) were applied sidedress as anhydrous ammonia on May 22 and 23 (emergence). Treatments were applied in 15 foot strips (6 rows) across the field in a randomized complete block design with 7 replications. Rates for the variable rate by soil treatment were based on yield goal, previous cropping history, and the Crop Equivalency Rating (CER) of each mapping unit. Rates for the variable by residual nitrate were calculated from the grid soil samples using the nitrogen credit equation (AG-BU 0519). The previous crop was soybeans in a corn-soybean rotation. Grain was harvested on October 4, 5 and 6 in 40 foot segments across the field.

Becker: Pioneer 3569 was planted on April 29 at a population of 31,500 S/A on 38 inch rows. Starter fertilizer was applied as a side banded application of 240 lbs/A of a 12-10-30. Weed control was accomplished by using a tank mix of Prowl at 2 pts/A and Aatrex at 1.75 lbs/A and cultivation on June 4. Ten treatments consisting of eight constant N rates paired with N-Serve (120, 150, 180 and 210 lbs N/A), one variable rate (soil), and a check (zero N) were applied sidedress as anhydrous ammonia on June 5 and 6 (sixth leaf Stage). Treatments were applied in 25 foot strips (8 rows) across the field in a randomized complete block design with 4 replications. Rates for the variable by soil treatment were based on yield goal, previous cropping history and the CER of each mapping unit using existing extension recommendations. The previous crop was corn in a corn-corn-soybean rotation. Grain was harvested on October 14, 15 and 18 in 40 foot segments across the field.

Results and Discussion Lamberton: Grain yields on check plots ranged from 66 to 174 bu/A. Variability in grain yield from the check areas was high on all soils except Terril which ranged from 132 to 161 bu/A. This suggests that soil map unit may not be the only parameter needed to describe soil variability. The yield averages for treatments by soil map unit are presented in Table 3. All soil map units responded to fertilizer N, only Okoboji and Terril responded to rates higher than 60 lbs N/A. This implies differential N response to fertilizer N between soil map units. Early indications suggest limited yield response to N-Serve within mapping units, except on Okoboji and terril soil map units, however, statistical analysis has not been performed. The nitrogen fertilizer return (NFR) showed no economic benefit for either of the site specific treatments (VSoil and VNO_3) compared with conventional application (Table 4), but the calculated economic optimum rate of fertilization saved $15 per acre over conventional application. This suggests that significant improvements can be made with site specific application over conventional fertilization. Both variable treatments and calculated economic optimum had lower average rates of N for the field, thus reducing the risk of N contamination to groundwater. The VNO_3 treatment could have been affected by considerable N losses, resulting from cool wet weather conditions experienced after soil samples were obtained in the fall of 1990. Such losses would limit the effectiveness of the fall soil Nitrate test.

Table 3. Grain yield by soil map units for Nitrogen Specific Management by Soil Condition, Lamberton 1991.

NRate lbs/A	NServe	86	113	446	134	94	421A	421B	421C
		bu/A							
60	NI	139	131	150	128	157	142	137	120
90	NI	135	137	136	122	162	144	148	126
120	NI	148	148	---	140	159	142	146	132
150	NI	139	136	---	118	160	142	140	137
0		123	126	120	109	147	125	124	111
60		140*	144*	163*	113	151	144*	142*	143*
90		136	139	148	142*	156*	142	144	135
120		138	139	---	131	157	142	143	137
150		132	144	137	137	157	145	144	130
VSoil	NI^	135	135	141	130	164	144	144	135
VNO_3N		118	129	131	121	153	142	134	118

NI = Nitrification Inhibitor N-Serve.
VSoil Variable by soil.
VNO_3N Variable by residual NO_3.
* Significant Economic optimum rate (LSD 0.05).
--- No Data.
^ N-Serve applied to soils 86, 113 and 134 on VSoil.

Table 4. Economics of Farming by Soil Lamberton 1991.

Treatment Method	N-Rate lbs N/A	N-Cost $/A	N-Serve $/A	Avg Yield bu/A	NFR $/A
Conventional	120	16	0	140	27
VSoil	98	13	3	139	24
VNO_3	42	5	0	135	25
Optimum	64	8	0	143	42

N-Cost 13 cents per pound.
Corn Value $2.45 per bushel @ 15.5% moisture.
Rates and yields averaged for 36 acre field.
NFR = Nitrogen Fertilizer Return.
Additional application cost of Variable treatment over conventional application = $2 per acre.

Results and Discussion Becker: Grain yields on check plots varied from 58 to 162 bu/A. Variability in grain yield from the check areas was high on all soils. This suggests that soil map unit may not be the only parameter needed to describe soil variability. The average yields for treatments by soil map unit are presented in Table 5. All soil map units responded to fertilizer N, only Hubbard C responded to a N rate higher than 120 lbs N/A. This implies differential N response to fertilizer N between soil map units. Early indications show a potential yield response to N-Serve in the Fill area. This area is a sand marsh, it is very wet and frequently has a perched water table, thus the potential for N loss is high. The NFR for the Becker site is presented in table 6. The site specific application (VSoil) returned $9 more than conventional and the calculated economic optimum was $18 better than conventional. The apparent economic success in the VSoil treatment came from lowering N rates while maintaining or increasing grain yield. The optimum and the variable treatment resulted in lower average rates of N applied to the field. Data from this site supports trends and conclusions at Lamberton, in that considerable improvement can be made over conventional application.

Table 5. Grain yield by soil map unit for Nitrogen Specific Management by Soil Condition, Becker 1991.

NRate	NServe	7A	7B	7C	768A	768B	256C	Fill
lbs/A		bu/A						
120	NI	153	157	154	168	161	145	162
150	NI	153	155	158	159	144	---	157
180	NI	165	152	167	166	147	160	162
210	NI	163	158	168	163	156	167	156
0		98	102	138	111	97	105	106
120		162*	158*	156	171*	171*	155*	152*
150		159	158	164*	161	148	---	161
180		160	153	154	156	146	157	140
210		162	160	174	163	153	158	155
VSoil	NI	172	162	160	171	158	150	164

NI Nitrification Inhibitor N-Serve.
VSoil Variable by soil.
* Significant optimum rate (LSD 0.05).
--- No Data.

Table 6. Economics of Farming by Soil Becker 1991.

Treatment Method	N-Rate lbs N/A	N-Cost $/A	N-Serve $/A	Avg Yield bu/A	NFR $/A
Conventional	210	27	0	159	108
VSoil	177	23	7	164	117
Optimum	121	16	0	162	126

N-Cost 13 cents per pound.
Corn Value $2.45 per bushel @ 15.5% moisture.
Rates and yields averaged for 44 acre field.
NFR = Nitrogen Fertilizer Return.
Additional application cost of Variable treatment over conventional application = $2 per acre.

AGRICULTURAL UTILIZATION OF NUTRALIME: ON FARM DEMONSTRATION PLOTS

Carl Rosen, Dave Birong, Mark Zumwinkle, and Peter Bierman

NutraLime is a product made from two waste materials: sewage sludge incinerator ash from the Metropolit Waste Control Commission in St. Paul and spent lime from municipal water treatment plants. Land application of these waste products has been studied individually in previous research. The sewage sludge ash was found to supply phosphorus and micronutrients for crop production. At realistic application rates, heavy metals were not found to be taken up by corn plants nor did the metals move significantly in the soil. Spent lime was found to an effective liming amendment. By combining these two waste products, both nutrients and lime could be recycled onto cropland alleviating, the need to rely on landfills for disposal. The objectives of these demonstration plots were to inform growers and the public about NutraLime, monitor crop growth at various rates of applied NutraLime, monitor plant uptake of elements supplied by NutraLime, and follow movement of elements supplied by NutraLime in soil.

PROCEDURES

Three field sites, all used for commercial crop production, were selected for the demonstration plots. The sites were located in Dakota Co. (Wadena loam), Isanti Co. (Hayden silt loam), and Washington Co. (Antigo silt loam). Selected soil characteristics of each site are presented in Table 1. The same basic procedure was followed at each site. Treatments consisted of a control and three rates (0.5X, 1.0X, 2.0X) of NutraLime, replicated three times in strips. The strips were 25-30 feet wide and 300 feet in length. Prior to NutraLime application, 14" suction tubes were buried so that the ceramic tip was at about 2.5' deep. These suction tubes were intended to be used for the duration of the demonstration without having to reinstall them each year. Plastic line from the suction tubes was laid along a 5' trench so that soil above the suction tube would not be disturbed when water samples were collected and the line was buried to allow for tillage operations. The NutraLime was applied as a slurry using a terragator set at the 0.5X rate. To obtain the 1X and 2X rate, the terragator travelled 2 and 4 more times, respectively, over the plots at the same speed. Preweighed plastic trays (3ft x 2ft) were placed in the middle of each 0.5X strip to catch the applied material. The trays were weighed again after application and a subsample was collected in plastic bottles for moisture determination and elemental content. The actual rates applied varied with each site and are presented on a wet and dry weight basis in Table 2. Elemental content of the NutraLime at each site was determined on concentrated nitric acid/perchloric acid digests (Table 3).

At the Dakota Co. site, NutraLime was applied on April 26, 1991 and then chisel plowed in to a depth of 1 inches. The previous crop was potatoes and the crop tested for response to Nutralime was Jacques seed corn - Code 84 was the pollinator and Code 67 was the seed parent. The seed corn was planted May 20, 1991 at a rate of 26,500 seeds/A (2.5' between rows). Anhydrous ammonia was applied preplant at the rate of 140 lb N/A. Irrigation was used to supplement rainfall when needed.

At the Isanti Co. site, NutraLime was applied on November 7, 1990 and then disked in to a depth of 6 inches. The previous crop was soybeans and the crop tested for response to Nutralime was Pioneer 3790 field corn. The corn was planted May 10, 1991 at a rate of 29,000 seeds/A (2.5' between rows). Starter fertilizer was applied at a rate of 30 lb N/A, 30 lb P_2O_5/A, 40 lb K_2O/A, and 10 lb S/A. No additional fertilizer was applied during the season. The site was nonirrigated.

At the Washington Co. site, NutraLime was applied on October 25, 1990 and then chisel plowed in to a depth of 10 inches. The previous crop was corn and the crop tested for response to Nutralime was Jacques 6770 field corn. The corn was planted May 8, 1991 at a rate of 28,000 seeds/A (2.5' between rows). Anhydrous ammonia was applied preplant at the rate of 160 lb N/A. Starter fertilizer was applied at a rate of 23 lb N/A, 58 lb P_2O_5/A, and 75 lb K_2O/A. Irrigation was used to supplement rainfall when needed.

Soil water samples were collected 2-3 times during the growing season. At the Washington Co. site, insufficient water percolated to the 2.5 ft depth and therefore water samples could not be obtained at this site. Water samples were analyzed for multiple elements using ICP procedures. Whole plant samples (8 per replication) were collected at the 10 - 12 leaf stage and 8 ear leaf samples per replication were collected at 50% silk. Two - 40 ft rows were hand harvested to obtain an estimate of final yield. For the seed corn, both male and female parents were harvested. Samples of stover and ears (grain and cob) were collected. Samples were dried at 60 C, moisture content was determined and then the samples were ground to pass through a 30 mesh screen. Samples were ashed, dissolved in 1 N HCl and then analyzed for elemental content using ICP procedures. Tissue nitrogen concentrations were determined following Kjeldahl digestion using

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[1]Funding for this project was provided by the Metropolitan Waste Control Commission.
[2]Extension Soil Scientist, Junior Scientist, and Research Assistants, respectively, Soil Science Department, University of Minnesota.

conductimetric procedures. Soil samples were collected after harvest. Eight subsamples from each replication were taken at one foot intervals down to three feet. Samples were air dried and then ground. Multiple elements were determined on 1 N nitric acid extracts. Other analyses included soil pH and soluble salts (1:1 soil:water), ammonium acetate extractable cations, and DTPA extractable metals.

RESULTS

Plant Growth and Yield. Effects of NutraLime on corn growth are presented in Tables 4-7. Early plant growth at the 10-12 leaf stage decreased at the highest application rate of NutraLime in Washington County, but had no effect on early plant growth at the other locations. NutraLime had no effect on final stand count at any of the locations. Stover yield significantly increased with Nutralime application at the Isanti Co. location, but had no effect at the other sites. NutraLime increased seed corn yield at the Dakota Co. site at the lowest application rate. In Isanti Co., field corn yield increased linearly with NutraLime application. NutraLime increased yield by 32 bu/A over the control treatment. In Washington Co., the highest rate of NutraLime had a depressing effect on grain yield. These results indicate that when applied at realistic rates, NutraLime can have a beneficial effect on plant growth. However, when excessive applications were applied as in the highest rate at Washington County, some negative effects on growth may occur.

Elemental Concentrations in Soil Water. Elemental concentrations in water collected from suction tubes at the 2.5' depth are presented in Tables 8 and 9. Samples were not obtained from Washington County due to insufficient water movement in this soil. Concentrations of Al, B, Cd, Cr, Cu, Fe, Ni, and Pb were generally below detection limits of the ICP. Concentrations of P and K were below detection limits at the Isanti Co. site. At the Dakota Co. site P and K concentrations were generally above detection limits, but did not show any trend with NutraLime treatment. Concentrations of Ca, Mg, Mn, Na, S, and Zn were above detection limits at both sites; however, they did not show any trend with NutraLime treatment.

Elemental Concentrations in Soil. Soluble salts, soil pH, Bray and Olsen P, ammonium acetate extractable cations and DTPA extractable metals are presented in Tables 10-12. Soil pH increased substantially (1.2-1.8 units) in the top 6 inches with the 0.5X NutraLime rate. With higher NutraLime rates, soil pH increased by an additional 0.1-0.4 units. Soil pH was not affected by NutraLime treatment at the 12-24 inches depth at any site. At the 6-12 inch depth, soil pH increased by 0.8 units with the 2X rate at one site. Soluble salts in the top 6 inches increased with NutraLime application; however, none of the soluble salt levels were in a range considered to be high enough to cause salt toxicity. In the 6-12 inch depth, soluble salts increased with Nutralime application at two of the three sites and in the 12-24 inch depth, increased at one of the three sites. Bray and Olsen P increased with NutraLime application in the top 6 inches at all sites. At the Isanti county site soil P was unaffected by NutraLime application at the lower depths, which probably indicates shallow tillage practices. At the other two sites, soil P increased in the 6-12 inch depth and only slightly at one of the sites in the 12-24 inch depth. Extractable K was not affected by NutraLime application. Extractable Na increased only at the Dakota Co. site in the top 6 inches. Extractable Ca and Mg tended to increase with NutraLime application in the top 6 inches, but not in the lower depths. DTPA extractable Fe and Mn decreased with NutraLime application in the top 6 inches and were unaffected in the lower depths. DTPA extractable Cu increased in the top 6 inches at all sites and was generally unaffected in the lower depths. DTPA extractable Zn was not affected by NutraLime application at the Dakota and Isanti Co. sites, but did increase in the top 12 inches at the Washington Co. site. DTPA extractable Pb and Ni did not increase with NutraLime application at any of the sites and in some cases actually decreased with NutraLime application. DTPA extractable Cd was not significantly affected by NutraLime application. DTPA extractable Cr was generally not affected by NutraLime application; although at the Dakota Co site there was a slight increase in extractable Cr in the 12-24 inch depth.

Nitric acid extractable soil elements are presented in Tables 13-15. All elements tested except Be, Co, Li, K, and S increased with NutraLime application in the top 6 inches at all sites. Li was frequently below detection limits, K increased with NutraLime application at one of the three sites and Co increased at two of the three sites. Interestingly, S did not significantly increase with NutraLime application in the top 6 inches; however, significant increases in S were observed in the 6-12 and 12-24 inch depths. These results indicate that some leaching of S from the NutraLime was occurring. At the Isanti Co. site higher concentrations of elements, other than S, at the lower depths were not observed. Background concentrations at these lower depths indicate that minimal leaching occurred and that tillage operations were relatively shallow. At the other two sites, where deeper tillage was used, Cd, Ca, Cr, Cu, P, Na, and Zn concentrations increased in the 6-12 inch depth with NutraLime application. Except for S, NutraLime had no consistent effect on elemental concentrations in the 12-24 inch depth.

Elemental Concentrations in Plant Tissue. Elemental concentrations in whole plant, ear leaf, stover, husk (seed corn only), kernel, and cob tissue from all sites are presented in Tables 16-37. Of all the elements determined, only Mo consistently increased with NutraLime application at all sites. Concentrations of Mo were below levels (10 ppm) that would cause Mo toxicity (molybdenosis) in cattle. Tissue concentrations of

trace metals such as Cd, Ni, Cr, and Pb were generally not affected by NutraLime application and in some cases decreased with NutraLime application.

In Dakota Co., Cu concentrations increased slightly with NutraLime application in whole plant and cob tissue. The reason for the increase in yield with the low rate of NutraLime at this site is not clear from the nutrient status of the plant. Nutrient levels in ear leaf tissue were in the satisfactory range for plants grown in all treatments, including the control.

In Isanti Co., P concentrations in whole plant and ear leaf tissue significantly increased with NutraLime application. Surprisingly, N concentrations also increased in ear leaf tissue with NutraLime applications. The N content of NutraLime is only about 1 lb N/dry ton, which is probably not enough at the rates applied to affect N nutrition of the plant. It is possible that Mo, which is involved with N metabolism, may be associated with improved N nutrition. The reason for the increase in yield with NutraLime at this site may be due to a number of factors including improved N, P, Mo, and B.

In Washington Co., N concentrations in whole plant and ear leaf tissue increased with NutraLime application. Yields at this site did not increase with NutraLime application and actually decreased at the highest rate. Reasons for the decrease in yield at the highest rate could not be associated with any specific element.

GENERAL SUMMARY

NutraLime application increased corn yield at two of three sites. Improved N, P, and Mo nutrition appeared to be involved, although other factors not measured may also have played a role. High rates of NutraLime (> 30 dry tons/A) may decrease corn yields. Accumulation of heavy metals in plant tissue as a result of NutraLime application was not observed. Heavy metals applied with NutraLime were confined to the top 12 inches of soil and did not leach. NutraLime effectively increased soil pH and plant available P. Results from this first year show that NutraLime does appear to have an agronomic benefit. This study will be continued at the same sites without additional applications to monitor residual metal movement in the soil, metal availability to crop plants, and overall crop performance.

Table 1. Selected initial soil chemical characteristics of the demonstration sites.

Chemical Characteristic	Demonstration sites		
	Dakota Co.	Isanti Co.	Washington Co.
pH	6.3	5.5	5.7
Bray P1 (ppm)	120	40	81
Ammonium Acetate K (ppm)	256	170	214

Table 2. NutraLime treatments applied at each site prior to planting.

Demonstration sites					
Dakota Co.		Isanti Co.		Washington Co.	
NutraLime applied					
Wet tons/A	Dry tons/A	Wet tons/A	Dry tons/A	Wet tons/A	Dry tons/A
0.0	0.0	0.0	0.0	0.0	0.0
9.8	4.3	13.1	5.1	18.6	7.8
19.6	8.6	26.2	10.2	37.2	15.6
39.2	17.2	52.3	20.4	74.4	31.2

Table 3. Selected chemical characteristics of NutraLime used at each site (means of 4 or 5 samples).

Chemical Characteristic	Dakota Co.		Isanti Co.		Washington Co.	
Moisture (%)	55.9		61.1		58.2	
Calcium Carbonate Equivalent (%)[1]	33.3		41.7		45.7	
Soluble Salt (mmhos/cm)	4.5		5.3		4.9	
Chloride (ppm)	201		218		232	
Mercury (ppm)	-		0.007		0.011	
Total nitrogen (%)	-		0.05		-	
Acid Digestible Elements[2]	**ppm**	**lb/dry ton**	**ppm**	**lb/dry ton**	**ppm**	**lb/dry ton**
Aluminum	42543	85	35722	71	33183	66
Arsenic	44	0.09	36	0.07	34	0.07
Barium	1260	2.5	815	1.6	960	1.9
Beryllium	0.7	0.001	0.8	0.002	0.7	0.001
Boron	39	0.08	36	0.07	34	0.07
Cadmium	32	0.06	37	0.07	35	0.07
Calcium	137573	275	159544	319	171478	343
Chromium	769	1.5	648	1.3	638	1.3
Cobalt	4.9	0.01	1.9	0.004	1.7	0.003
Copper	2270	4.5	2205	4.4	2011	4.0
Iron	19982	40	18500	37	17546	35
Lead	412	0.82	417	0.83	383	0.77
Lithium	11	0.02	10	0.02	10	0.02
Magnesium	13566	27	15579	31	15108	30
Manganese	3008	6.0	1809	3.6	1994	4.0
Molybdenum	38	0.08	27	0.05	26	0.05
Nickel	209	0.42	210	0.42	200	0.40
Phosphorus	39010	78	33171	66	29719	59
Potassium	3324	6.6	2766	5.5	2565	5.1
Rubidium	<105	-	<105	-	<105	-
Silicon	366	0.73	433	0.87	401	0.80
Sodium	2038	4.1	1994	4.0	1839	3.7
Strontium	273	0.55	273	0.55	272	0.5
Sulfur	2231	4.5	2543	5.1	2554	5.1
Titanium	318	0.64	312	0.62	266	0.5
Vanadium	38	0.08	33	0.07	32	0.06
Zinc	1591	3.2	1769	3.5	1673	3.3

[1] Calcium carbonate equivalent, chloride, mercury, total nitrogen, and acid digestible elements are expressed on a dry weight basis.

[2] Acid digestible - boiling concentrated nitric acid and concentrated perchloric acid. After 6 hours, 34-41% remained undigested.

Table 4. Effect of NutraLime on whole plant dry weight at the 10-12 leaf stage, final stand count, stover yield, husk yield, and seed corn yield (female parent) - Dakota County.

NutraLime Treatment	Plant yield 10-12 leaf	Final stand count	Stover yield	Husk yield	Seed corn yield
	g dw	plants/A	T/A	T/A	bu/A
0	145	26,523	1.98	0.20	35.4
0.5X	144	31,847	2.31	0.26	45.1
1.0X	143	30,105	2.22	0.20	39.3
2.0X	116	30,976	2.12	0.20	38.8
Significance	NS	NS	NS	NS	*
BLSD (0.05%)	--	--	--	--	4.6
Linear NutraLime	NS	NS	NS	NS	NS
Quad. NutraLime	NS	NS	NS	NS	*

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 5. Effect of NutraLime on whole plant dry weight at the 10-12 leaf stage, final stand count, stover yield, husk yield, and grain yield (male parent) - Dakota County.

NutraLime Treatment	Plant yield 10-12 leaf	Final stand count	Stover yield	Husk yield	Grain yield
	g dw	plants/A	T/A	T/A	bu/A
0	70	43,947	3.06	0.27	13.4
0.5X	50	42,204	2.76	0.35	12.8
1.0X	59	40,656	2.87	0.27	13.5
2.0X	89	41,430	2.93	0.26	14.3
Significance	NS	NS	NS	NS	NS
BLSD (0.05%)	--	--	--	--	--
Linear NutraLime	NS	NS	NS	NS	NS
Quad. NutraLime	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 6. Effect of NutraLime on whole plant dry weight at the 10-12 leaf stage, final stand count, stover yield and grain yield - Isanti County.

NutraLime Treatment	Plant yield 10-12 leaf	Final stand count	Stover yield	Grain Yield
	g dw	plants/A	T/A	bu/A
0	203	25,264	2.70	148.7
0.5X	206	25,264	3.42	172.3
1.0X	211	25,120	3.44	180.5
2.0X	204	24,684	3.05	180.2
Significance	NS	NS	*	*
BLSD (0.05%)	--	--	0.40	18.9
Linear NutraLime	NS	NS	*	**
Quad. NutraLime	NS	NS	*	*

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 7. Effect of NutraLime on whole plant dry weight at the 10-12 leaf stage, final stand count, stover yield and grain yield - Washington County.

NutraLime Treatment	Plant yield 10-12 leaf	Final stand count	Stover yield	Grain Yield
	g dw	plants/A	T/A	bu/A
0	324	23,958	2.57	177.8
0.5X	289	24,394	2.38	185.5
1.0X	279	24,829	2.56	178.5
2.0X	282	24,248	2.32	163.8
Significance	NS	NS	NS	*
BLSD (0.05%)	--	--	--	13.1
Linear NutraLime	*	NS	NS	*
Quad. NutraLime	NS	NS	NS	*

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 8. Effect of NutraLime on elemental composition of soil water collected from suction tubes - Isanti County.

NutraLime Treatment	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Pb	S	Zn
	ppm															
Aug. 8, 1991																
0	<0.19	<0.026	25	<0.006	<0.015	<0.028	<0.02	<0.8	9	0.02	6	<0.024	<0.08	<0.09	6	0.03
0.5X	<0.19	<0.025	28	<0.006	<0.015	<0.028	<0.22	<0.8	9	0.05	6	<0.027	<0.04	<0.09	7	0.04
1.0X	<0.19	<0.025	26	<0.006	<0.015	<0.028	<0.04	<0.8	9	0.05	5	<0.028	<0.05	<0.09	9	0.05
2.0X	<0.19	<0.025	35	<0.006	<0.015	<0.028	<0.04	<0.8	12	0.05	6	<0.028	<0.04	<0.09	10	0.05
Significance	--	--	NS	--	--	--	--	--	NS	NS	NS	---	--	--	NS	NS
Oct. 2, 1991																
0	<0.19	<0.028	25	<0.006	<0.015	<0.028	<0.15	<0.8	9	0.02	6	<0.025	<0.06	<0.09	10	0.06
0.5X	<0.19	<0.025	29	<0.006	<0.015	<0.028	0.03	<0.8	9	0.03	6	<0.029	<0.04	<0.09	12	0.06
1.0X	<0.19	<0.025	21	<0.006	<0.015	<0.028	0.02	<0.8	6	0.02	4	<0.024	<0.05	<0.09	13	0.05
2.0X	<0.19	<0.026	34	<0.006	<0.015	<0.028	0.02	<0.8	11	0.06	6	<0.035	<0.04	<0.09	11	0.06
Significance	--	--	NS	--	--	--	--	--	NS	NS	NS	---	--	--	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 9. Effect of NutraLime on elemental composition of soil water collected from suction tubes - Washington County.

NutraLime Treatment	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Pb	S	Zn
	ppm															
July 25, 1991																
0	<0.19	0.052	82	<0.006	<0.015	<0.028	0.26	5.0	21	0.02	11	<0.030	0.15	<0.09	26	0.12
0.5X	<0.19	0.031	45	<0.006	<0.015	<0.028	<0.03	1.6	8	0.01	5	<0.025	0.12	<0.09	24	0.07
1.0X	<0.19	0.032	51	<0.006	<0.015	<0.028	<0.07	1.9	11	0.02	6	<0.024	0.11	<0.09	21	0.11
2.0X	<0.19	<0.028	105	<0.006	<0.015	<0.028	<0.06	2.0	22	0.04	14	<0.052	0.07	<0.09	31	0.09
Significance	--	--	NS	--	--	--	--	NS	NS	NS	NS	---	NS	--	NS	NS
Aug. 30, 1991																
0	<0.19	<0.044	52	<0.006	<0.015	<0.028	<0.10	4.0	13	0.01	7	<0.030	<0.11	<0.09	26	0.08
0.5X	<0.19	<0.032	74	<0.006	<0.015	<0.032	0.07	2.5	16	0.05	7	<0.049	0.09	<0.09	26	0.25
1.0X	<0.19	<0.026	62	<0.006	<0.015	<0.028	0.09	1.8	14	0.02	5	<0.031	<0.06	<0.09	17	0.15
2.0X	<0.19	<0.029	79	<0.006	<0.015	<0.028	0.27	1.7	17	0.03	14	<0.037	<0.06	<0.09	33	0.50
Significance	--	--	NS	--	--	--	--	NS	NS	NS	NS	---	--	--	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 10. Effect of NutraLime on soil pH, soluble salts, Bray P1, Olsen P, ammonium acetate extractable cations and DTPA extractable metals - Dakota County.

Depth inches	Treatment	pH	Soluble Salts mmhos/cm	Bray P1	Olsen P	NH_4OAc Extractable K	Ca	Mg	Na	DTPA Extractable Fe	Mn	Zn	Cu	Pb	Ni	Cd	Cr
				ppm													
0-6	0	6.2	0.33	131	61	273	1576	384	5.2	86	17.9	1.9	0.82	1.72	1.62	0.06	0.04
	0.5x	7.4	0.40	253	83	233	2814	426	7.5	64	9.5	1.6	2.90	1.70	0.90	0.09	0.05
	1.0x	7.2	0.60	265	87	225	3244	439	9.9	75	11.0	2.0	4.12	2.31	1.37	0.14	0.05
	2.0x	7.5	0.47	348	137	258	4048	485	11.3	59	8.1	1.9	5.05	1.93	1.16	0.10	0.05
Significance		**	*	**	*	NS	*	NS	*	**	*	NS	*	NS	**	NS	NS
BLSD (0.05)		0.38	0.17	93	37	-	1570	-	3.6	14	6.7	-	2.67	-	0.35	-	-
Contrasts																	
Linear																	
NutraLime		**	NS	**	**	NS	**	*	**	**	*	NS	**	NS	NS	NS	NS
Quadratic																	
NutraLime		**	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
6-12	0	5.7	0.43	53	27	99	1512	354	6.3	83	13.5	2.4	0.77	1.61	1.15	0.03	0.04
	0.5x	6.2	0.43	77	35	133	1630	362	8.7	82	13.0	1.1	1.02	1.12	0.99	<0.02	0.06
	1.0x	6.0	0.60	105	36	92	1638	342	8.7	97	15.2	1.2	1.11	2.45	1.30	0.03	0.05
	2.0x	6.5	0.57	167	68	118	1783	373	9.4	90	13.1	1.2	1.19	1.67	1.23	0.03	0.05
Significance		*	NS	**	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS
BLSD (0.05)		0.5	-	54	20	-	-	-	-	-	-	-	-	-	-	-	-
Contrasts																	
Linear																	
NutraLime		*	NS	**	**	NS	*	NS	NS	NS	NS	NS	*	NS	NS	-	NS
Quadratic																	
NutraLime		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS
12-24	0	6.1	0.27	12	6	59	1068	232	7.9	37	1.3	0.2	0.61	0.55	0.52	<0.02	0.03
	0.5x	6.2	0.27	17	8	64	1128	241	8.7	35	1.2	0.1	0.72	0.52	0.41	<0.02	0.03
	1.0x	6.1	0.40	19	8	64	1265	258	8.8	41	1.5	0.2	0.72	0.42	0.57	<0.02	0.03
	2.0x	6.2	0.37	24	9	61	1158	254	9.9	41	1.6	0.2	0.76	0.60	0.78	<0.03	0.06
Significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	-	*
BLSD (0.05)		-	-	-	-	-	-	-	-	-	-	-	0.10	-	-	-	0.02
Contrasts																	
Linear																	
NutraLime		NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	-	*
Quadratic																	
NutraLime		NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS

NS = not significant, * = significant at 5%, ** = significant at 1%

Table 11. Effect of NutraLime on soil pH, soluble salts, Bray P1, Olsen P, ammonium acetate extractable cations, and DTPA extractable metals - Isanti County.

Depth inches	Treatment	pH	Soluble Salts mmhos/cm	Bray P1	Olsen P	NH_4OAc Extractable K	Ca	Mg	Na	DTPA Extractable Fe	Mn	Zn	Cu	Pb	Ni	Cd	Cr
				ppm													
0-6	0	6.0	0.17	41	19	151	737	78	3.5	85	24.8	1.5	0.62	1.40	1.28	0.10	0.03
	0.5x	7.5	0.37	172	34	159	1907	125	5.5	57	11.0	1.5	2.48	1.35	0.80	0.11	0.04
	1.0x	7.5	0.37	175	34	158	2321	151	8.2	52	9.9	1.6	2.73	1.36	0.78	0.07	0.05
	2.0x	7.7	0.33	220	54	167	3416	192	8.9	54	8.7	1.8	4.11	1.69	0.79	0.12	<0.02
Significance		**	**	**	**	NS	**	*	NS	*	**	NS	**	NS	*	NS	-
BLSD (0.05)		0.4	0.10	38	14	-	1048	60	-	19	4.9	-	1.36	-	0.31	-	-
Contrasts																	
Linear																	
Nutralime		**	*	**	**	NS	**	**	*	*	**	NS	**	NS	*	NS	-
Quadratic																	
Nutralime		**	**	**	NS	NS	NS	NS	NS	*	**	NS	NS	NS	*	NS	-
6-12	0	6.0	0.10	30	17	115	967	154	5.9	77	9.8	1.8	0.58	1.41	1.05	0.05	0.03
	0.5x	6.3	0.20	32	16	116	1013	154	9.2	67	8.1	0.5	0.59	0.59	0.86	0.05	0.03
	1.0x	6.8	0.33	78	22	105	1361	120	7.1	60	9.1	0.8	1.09	1.12	0.92	0.08	<0.02
	2.0x	6.5	0.33	35	16	96	1039	119	7.3	70	7.9	0.6	0.59	1.38	1.13	0.11	0.03
Significance		NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	-
BLSD (0.05)		-	0.19	-	-	-	-	-	-	-	-	-	-	0.54	-	-	-
Contrasts																	
Linear																	
Nutralime		NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-
Quadratic																	
Nutralime		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	-
12-24	0	5.7	0.10	30	28	125	1327	325	14.1	83	6.9	0.31	0.83	0.79	1.03	0.07	0.05
	0.5x	5.8	0.20	33	25	118	1307	277	15.6	81	8.2	0.35	0.90	0.85	1.25	0.03	0.04
	1.0x	6.1	0.20	32	23	108	1432	280	13.7	70	5.6	0.22	0.78	0.95	1.03	0.07	0.04
	2.0x	6.0	0.23	35	27	113	1460	282	13.8	87	4.4	0.28	0.82	0.89	1.30	0.04	0.05
Significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BLSD (0.05)		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Contrasts																	
Linear																	
Nutralime		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Quadratic																	
Nutralime		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%

Table 12. Effect of NutraLime on soil pH, soluble salts, Bray P1, Olsen P, ammonium acetate extractable cations and DTPA extractable metals - Washington County.

Depth inches	Treatment	pH	Soluble Salts mmhos/cm	Bray P1	Olsen P	NH_4OAc Extractable K	Ca	Mg	Na	DTPA Extractable Fe	Mn	Zn	Cu	Pb	Ni	Cd	Cr
				ppm													
0-6	0	5.4	0.20	75	38	168	1741	250	2.4	135	35.9	2.1	1.30	3.39	2.27	0.12	0.12
	0.5x	7.2	0.43	195	83	206	3780	329	5.1	100	14.7	2.9	3.81	2.62	1.73	0.19	0.07
	1.0x	7.3	0.40	208	100	202	4728	362	8.4	93	11.6	2.4	5.20	3.16	1.57	0.20	0.06
	2.0x	7.6	0.40	247	120	207	4835	434	9.0	75	9.1	3.3	7.62	3.10	1.27	0.19	0.05
Significance		**	**	**	**	NS	*	**	NS	**	**	**	**	*	**	NS	**
BLSD (0.05)		0.2	0.10	29	33	-	495	74	-	20	5.7	0.5	1.46	0.48	0.41	-	0.03
Contrasts																	
Linear																	
NutraLime		**	**	**	**	NS	**	**	*	**	*	**	**	NS	**	NS	**
Quadratic																	
NutraLime		**	**	**	NS	NS	**	NS	NS	NS	**	NS	NS	NS	NS	NS	*
6-12	0	5.7	0.23	27	17	108	1912	311	5.8	83	13.0	0.9	0.96	1.62	1.79	<0.02	0.08
	0.5x	5.8	0.37	41	22	144	2023	309	6.0	95	14.0	1.2	1.04	2.31	1.97	0.05	0.06
	1.0x	5.5	0.37	44	23	119	1969	270	5.4	110	20.6	1.1	1.16	2.08	2.41	0.04	0.09
	2.0x	6.3	0.47	58	23	127	2249	343	5.6	79	10.3	1.0	1.28	2.14	1.55	0.06	0.06
Significance		*	NS	*	*	NS	NS	NS	NS	NS	NS	*	NS	NS	*	-	NS
BLSD (0.05)		0.5	-	20	4	-	-	-	-	-	-	0.2	-	-	0.56	-	-
Contrasts																	
Linear																	
NutraLime		*	*	**	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS
Quadratic																	
NutraLime		NS	NS	NS	**	NS	NS	NS	NS	*	*	*	NS	NS	*	-	NS
12-24	0	6.2	0.10	14	8	104	1997	402	8.1	39	1.8	0.3	0.92	1.18	0.75	0.03	0.09
	0.5x	6.0	0.20	13	8	126	2072	407	7.4	45	2.1	0.3	0.82	1.29	0.89	<0.02	0.05
	1.0x	5.9	0.20	11	8	124	2154	396	8.9	48	2.5	0.3	0.92	1.18	0.96	<0.02	0.07
	2.0x	6.3	0.26	20	9	122	2085	429	6.7	38	1.7	0.5	0.93	1.37	0.66	0.04	0.07
Significance		*	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	-	NS
BLSD (0.05)		0.3	0.06	-	-	-	-	-	-	-	-	-	0.07	-	0.29	-	-
Contrasts																	
Linear																	
NutraLime		NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS
Quadratic																	
NutraLime		*	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	*	-	NS

NS = not significant, * = significant at 5%, ** = significant at 1%

Table 13. Effect of NutraLime on nitric acid extractable elements - Dakota County.

Treatment	1 N Nitric Acid Extractable																									
	Al	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Mo	Ni	P	K	Si	Na	Sr	S	Ti	V	Zn
	ppm																									
Depth: 0-6 inches																										
0	1507	1.58	111	0.36	1.1	0.38	2481	1.25	1.02	3.1	630	9.12	<0.20	639	124	0.69	3.39	166	337	451	8	10.4	16.5	8.3	2.98	5.1
0.5x	2101	2.24	128	0.37	1.6	0.86	4857	3.21	1.35	25.3	943	15.15	<0.20	847	199	0.96	3.68	775	325	745	27	14.1	5.8	13.9	4.13	11.5
1.0x	2405	2.53	141	0.37	1.9	1.19	6206	4.51	1.38	41.6	1067	19.25	0.24	908	232	1.17	4.97	1224	309	871	42	17.0	17.6	16.6	4.42	16.5
2.0x	2796	3.12	153	0.36	2.4	1.71	9251	6.66	1.63	69.9	1249	24.83	0.32	1166	303	1.49	5.78	2065	390	1068	63	21.4	12.4	20.7	5.11	24.1
Significance	*	*	NS	NS	*	*	*	*	*	*	*	NS	-	NS	NS	NS	NS	*	NS	*	*	*	NS	*	*	*
BLSD(0.05)	876	0.88	-	-	0.9	0.89	4416	3.38	0.42	44.7	317	-	-	-	-	-	-	1205	-	405	36	7.6	-	7.3	1.26	13.0
Contrasts																										
Linear NutraLime	**	**	*	NS	**	**	**	**	*	**	**	*	-	*	*	**	*	**	NS	**	**	**	NS	**	**	**
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depth: 6-12 inches																										
0	1648	1.58	109	0.27	0.9	0.31	2077	1.33	0.64	2.8	610	8.37	0.21	550	70	0.73	2.53	68	131	495	12	11.5	8.4	9.9	2.73	4.2
0.5x	1790	1.69	114	0.38	1.0	0.38	2352	1.63	0.77	5.0	703	8.53	<0.20	568	94	0.76	2.50	138	145	548	13	11.7	13.1	10.4	3.02	5.0
1.0x	1776	1.67	118	0.38	1.0	0.39	2423	1.68	0.75	5.7	731	9.06	<0.20	576	95	0.75	2.96	163	127	567	15	12.1	25.6	11.0	3.05	5.4
2.0x	1762	1.75	116	0.37	1.2	0.44	2718	1.81	0.80	7.9	718	9.58	0.21	609	101	0.77	2.96	278	149	540	16	12.3	27.4	10.7	3.07	5.9
Significance	NS	NS	NS	NS	NS	NS	NS	*	NS	*	*	NS	-	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS
BLSD(0.05)	-	-	-	-	-	-	-	0.30	-	2.7	86	-	-	-	-	-	-	97	-	-	-	-	-	-	-	-
Contrasts																										
Linear NutraLime	NS	NS	NS	NS	NS	*	*	**	NS	**	*	NS	-	NS	NS	NS	NS	**	NS	NS	*	NS	*	*	*	*
Quadratic NutraLime	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	-	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
Depth: 12-24 inches																										
0	1229	1.26	67	0.22	0.6	0.24	1422	1.04	0.32	2.1	555	4.31	0.22	398	24	0.61	1.59	56	63	424	14	10.3	4.5	13.4	2.29	3.0
0.5x	1366	1.26	72	0.23	0.5	0.21	1491	1.17	0.24	2.6	598	4.99	<0.20	402	28	0.55	1.34	64	65	456	13	10.8	6.7	13.0	2.40	3.0
1.0x	1401	1.42	78	0.25	0.6	0.25	1621	1.39	0.26	3.0	703	5.43	0.21	471	30	0.61	1.92	49	69	535	15	12.0	7.0	15.3	2.73	3.8
2.0x	1249	1.37	69	0.23	0.6	0.26	1521	1.20	0.34	2.9	577	5.47	0.29	421	27	0.58	2.01	70	64	447	15	10.3	10.5	13.2	2.33	3.3
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BLSD(0.05)	-	-	-	-	-	-	-	0.30	-	0.5	136	-	-	-	-	-	-	-	-	-	-	-	5.8	2.2	-	-
Contrasts																										
Linear NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	*	NS	*	*	NS	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%

Table 14. Effect of NutraLime on nitric acid extractable elements - Isanti County

Treatment	1 N Nitric Acid Extractable																									
	Al	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Mo	Ni	P	K	Si	Na	Sr	S	Ti	V	Zn
	ppm																									
Depth: 0-6 inches																										
0	766	1.27	38	0.15	0.5	0.36	1006	0.95	0.54	2.0	827	6.40	0.22	143	136	0.42	2.79	87	241	195	11	3.8	6.5	14.5	2.94	4.4
0.5x	1041	1.79	52	0.16	0.9	0.84	3121	2.40	0.67	19.9	1025	10.43	0.26	295	190	0.57	3.23	533	267	341	25	6.7	9.2	19.2	3.54	10.7
1.0x	1167	2.00	56	0.16	1.1	1.01	4073	2.95	0.74	26.4	1046	12.30	0.31	397	201	0.66	4.17	691	250	371	30	8.2	12.7	20.2	3.65	13.3
2.0x	1525	2.56	70	0.17	1.5	1.59	6714	4.90	0.78	47.4	1348	19.35	0.34	567	252	0.87	4.40	1201	271	550	45	11.9	12.0	25.2	4.50	20.8
Significance	**	*	*	NS	**	**	**	**	NS	**	**	**	NS	**	*	**	*	**	NS	**	**	**	NS	**	*	**
BLSD(0.05)	285	0.63	18	-	0.3	0.44	2309	1.45	-	19.0	231	5.43	-	188	66	0.18	1.10	460	-	111	14	3.2	-	3.9	0.75	6.6
Contrasts																										
Linear NutraLime	**	**	**	NS	**	**	**	**	NS	**	**	**	NS	**	**	**	**	**	NS	**	**	**	NS	**	**	**
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depth: 6-12 inches																										
0	957	1.33	33	0.18	0.5	0.35	1276	1.61	0.31	1.9	1025	6.11	0.36	327	62	0.50	2.80	82	150	375	15	4.6	2.8	20.7	3.77	3.7
0.5x	923	1.29	34	0.16	0.5	0.36	1296	1.54	0.30	2.2	961	5.78	0.38	321	57	0.49	2.41	83	144	360	18	4.6	12.3	20.1	3.57	3.5
1.0x	888	1.44	39	0.15	0.6	0.51	1886	1.66	0.41	8.2	871	7.43	0.31	261	94	0.48	2.80	115	157	289	18	5.3	13.9	18.3	3.21	3.5
2.0x	852	1.32	37	0.16	0.5	0.40	1376	1.43	0.21	3.2	1000	5.96	0.27	233	69	0.46	2.81	99	125	296	17	4.7	21.5	19.0	3.59	3.7
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts																										
Linear NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depth: 12-24 inches																										
0	1317	1.68	35	0.22	0.6	0.41	1755	2.34	0.21	2.5	1328	6.06	0.66	661	32	0.65	3.06	140	143	665	25	6.1	0.9	25.3	4.73	4.8
0.5x	1330	1.68	36	0.22	0.6	0.44	1786	2.36	0.29	3.2	1350	6.57	0.69	653	38	0.68	3.39	117	145	661	27	6.2	4.6	25.4	4.72	5.1
1.0x	1276	1.69	35	0.20	0.6	0.39	1825	2.07	0.28	2.9	1129	6.38	0.66	609	30	0.62	3.71	96	140	596	24	6.6	5.7	26.0	4.27	4.6
2.0x	1314	1.77	36	0.21	0.6	0.43	1839	2.32	0.21	3.5	1322	6.63	0.58	578	28	0.65	3.48	122	138	561	23	6.5	9.6	23.3	4.92	4.6
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrasts																										
Linear NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%

Table 15. Effect of NutraLime on nitric acid extractable elements - Washington County.

Treatment	1 N Nitric Acid Extractable																									
	Al	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Li	Mg	Mn	Mo	Ni	P	K	Si	Na	Sr	S	Ti	V	Zn
	ppm																									
Depth: 0-6 inches																										
0	1632	1.80	114	0.39	1.2	0.42	2432	1.79	0.95	4.0	685	9.24	0.23	405	119	0.65	4.70	113	206	481	8	12.6	11.8	9.2	3.09	6.6
0.5x	2034	2.14	137	0.39	1.7	0.97	6002	3.45	1.09	25.5	866	13.88	0.25	656	180	0.73	4.91	659	246	751	22	18.3	16.0	12.3	4.01	15.1
1.0x	2450	2.79	148	0.41	2.2	1.52	8877	5.29	1.32	43.8	1048	18.57	0.31	828	223	1.02	5.70	1102	269	945	37	22.0	20.2	15.4	4.65	21.3
2.0x	2819	3.02	149	0.38	2.3	2.06	10944	7.04	1.59	69.4	1213	22.97	0.36	1043	255	1.22	5.85	1756	296	1132	55	24.3	20.4	19.4	5.11	29.7
Significance	**	*	NS	NS	**	**	**	**	**	**	**	**	NS	**	**	**	NS	**	*	**	**	**	NS	**	**	**
BLSD(0.05)	469	0.66	-	-	0.3	0.42	2671	2.15	0.25	17.0	203	4.02	-	167	50	0.17	-	395	60	204	11	4.9	-	2.9	0.69	6.4
Contrasts																										
Linear NutraLime	**	**	*	NS	**	**	**	**	**	**	**	**	*	**	**	**	*	**	**	**	**	**	NS	**	**	**
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depth: 6-12 inches																										
0	1780	1.83	111	0.39	1.0	0.31	2472	1.65	0.58	3.31	764	7.61	0.34	573	60	0.70	3.66	34	133	681	11	14.3	5.1	14.5	3.32	5.6
0.5x	1705	1.56	114	0.39	0.9	0.32	2611	1.52	0.50	4.09	703	7.13	0.27	530	62	0.65	3.60	65	137	598	10	14.7	13.3	13.5	3.14	5.9
1.0x	1755	1.85	121	0.40	1.1	0.37	2638	1.64	0.53	4.98	759	7.88	0.31	503	72	0.66	4.30	79	133	623	12	15.1	17.8	13.9	3.20	6.1
2.0x	1856	1.80	112	0.38	1.1	0.41	3038	1.95	0.64	7.04	789	8.29	0.30	595	73	0.66	3.62	126	146	694	14	14.6	32.6	14.3	3.48	6.8
Significance	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS
BLSD(0.05)	-	-	-	-	-	-	-	0.31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.3	-	-	-
Contrasts																										
Linear NutraLime	NS	NS	NS	NS	NS	*	*	*	NS	*	NS	NS	NS	NS	*	NS	NS	*	NS	NS	*	NS	**	NS	NS	*
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depth: 12-24 inches																										
0	1931	1.98	96	0.32	0.9	0.32	2453	2.07	0.27	3.65	1049	7.11	0.51	784	34	0.77	2.82	51	119	903	15	16.8	3.0	21.4	4.09	6.6
0.5x	1858	1.65	101	0.34	0.8	0.28	2380	1.79	0.23	3.45	939	6.31	0.42	736	27	0.69	2.09	25	115	805	14	17.6	6.3	21.5	3.74	6.4
1.0x	1922	1.85	108	0.34	0.8	0.34	2465	2.00	0.28	3.73	1058	6.95	0.51	774	30	0.74	2.44	22	123	890	15	18.3	7.6	22.7	4.08	7.0
2.0x	1932	1.76	96	0.32	0.9	0.34	2522	1.88	0.33	4.51	958	7.28	0.43	756	35	0.74	2.09	70	125	847	16	16.7	12.7	19.2	3.82	6.6
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
BLSD(0.05)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	37	-	-	-	-	-	-	-	-
Contrasts																										
Linear NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Quadratic NutraLime	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%

Table 16. Effect of NutraLime on the elemental composition of female whole plant samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	3.00	0.39	2.97	5744	3828	35.5	86	14.8	56.9	30	6.7	6.7	<2.7	1.1	1.2	0.2	0.5
0.5	2.91	0.41	3.21	5979	4111	42.3	87	16.8	68.7	34	7.8	7.0	4.4	1.5	1.4	0.4	1.5
1.0	3.08	0.43	3.02	5933	4151	44.4	93	18.0	69.4	34	8.1	7.7	5.4	1.8	1.6	0.4	1.7
2.0	3.02	0.41	3.32	5757	3729	42.4	95	16.0	67.0	32	8.0	7.3	<2.8	1.1	1.2	0.2	1.6
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	—	NS	NS	NS	*
BLSD (0.05	—	—	—	—	—	—	—	—	—	—	0.9	—	—	—	—	—	0.7
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	—	NS	NS	NS	*
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	—	*	*	*	*

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 17. Effect of NutraLime on the elemental composition of female ear leaf samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	3.32	0.35	1.81	8094	3408	19.8	99	11.4	68.9	25	9.6	7.6	<2.5	<0.8	0.9	<0.2	0.5
0.5	3.33	0.37	1.83	8478	3743	24.0	105	14.6	54.7	24	10.2	8.6	<4.3	<1.2	1.2	<0.3	2.1
1.0	3.42	0.37	1.84	8559	3518	24.5	107	11.2	68.9	29	10.7	9.1	<3.3	1.0	1.0	<0.2	2.5
2.0	3.59	0.38	1.91	7817	3607	22.5	102	13.4	62.9	27	10.0	8.8	4.3	1.3	1.2	0.8	2.7
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	—	NS	—	**
BLSD (0.05)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.1
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	—	NS	—	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	—	NS	—	*

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 18. Effect of NutraLime on the elemental composition of female stover samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.40	0.23	2.05	5364	3836	38.1	60	34.5	54.0	27	5.8	5.9	3.8	1.4	1.2	0.2	0.6
0.5	1.14	0.19	2.00	5196	4027	50.0	66	30.0	62.4	21	5.2	5.7	4.4	1.5	1.3	0.3	1.2
1.0	1.18	0.22	2.07	5104	4011	44.1	62	25.7	51.9	21	5.8	6.2	4.3	1.6	1.3	0.3	1.5
2.0	1.39	0.24	1.81	5509	3634	46.3	67	24.7	65.2	25	6.3	6.3	4.4	1.6	1.3	0.3	0.1
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.4
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 19. Effect of NutraLime on the elemental composition of female kernel samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.71	0.31	0.52	71	1064	8.4	21	<3.7	6.2	20	1.2	2.3	2.5	0.7	0.5	0.6	0.3
0.5	1.70	0.31	0.52	69	1054	6.5	20	<3.7	6.3	20	1.2	2.4	2.5	0.7	0.5	0.5	0.5
1.0	1.77	0.32	0.55	80	1095	6.4	21	<3.7	6.8	21	1.2	2.4	<2.5	0.7	0.5	0.5	0.5
2.0	1.83	0.31	0.52	71	1086	6.8	21	<3.7	6.4	21	1.2	2.4	2.4	0.8	0.6	0.4	0.6
Significance	NS	NS	NS	NS	NS	**	NS	--	NS	NS	NS	NS	NS	NS	NS	NS	NS
BLSD (0.05)	--	--	--	--	--	1.1	--	--	--	--	--	--	--	--	--	--	--
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	*	NS	--	NS	NS	NS	NS	NS	NS	NS	NS	**
Quad Nutra	NS	NS	NS	NS	NS	**	NS	--	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 20. Effect of NutraLime on the elemental composition of female cob samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.54	0.16	1.08	196	658	10.3	14.6	4.4	8.9	22	2.6	3.0	2.4	1.6	1.0	0.2	0.4
0.5	0.56	0.17	1.11	201	660	9.3	13.7	5.4	9.1	19	2.8	3.3	3.4	1.3	1.1	0.2	0.6
1.0	0.53	0.16	1.11	191	650	9.0	13.7	4.8	9.3	21	2.8	3.1	3.2	1.4	1.1	0.3	0.6
2.0	0.60	0.18	1.21	224	737	10.6	17.2	5.6	11.1	19	3.0	3.6	2.6	1.3	<0.8	0.2	0.6
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*	NS	NS	--	NS	*
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	*	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 21. Effect of NutraLime on the elemental composition of female husk samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.86	0.24	1.46	997	1467	23.4	39	16.2	18.3	21	4.0	5.1	<2.3	1.3	1.5	<0.2	0.4
0.5	0.77	0.24	1.83	1103	1451	22.3	44	14.9	21.0	22	4.6	5.2	2.3	1.5	2.0	0.2	0.7
1.0	0.91	0.26	1.81	1261	1537	23.4	41	13.5	22.6	23	4.5	6.3	<2.2	1.3	1.8	<0.2	0.8
2.0	0.85	0.21	1.44	1004	1340	19.7	39	16.1	22.4	19	4.4	5.4	<2.4	1.3	1.7	<0.2	0.9
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	--	*
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.3
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	--	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	--	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 22. Effect of NutraLime on the elemental composition of male whole plant samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	3.56	0.45	4.33	4556	3469	51.1	114	21.1	81.5	38	8.0	6.0	4.2	1.4	1.4	0.3	0.4
0.5	3.41	0.44	4.63	5166	4248	46.2	111	19.2	49.1	38	9.2	5.3	3.0	1.3	1.3	0.3	1.1
1.0	3.52	0.45	4.39	4852	3662	88.1	154	23.8	62.6	39	9.9	6.0	3.5	1.6	1.5	0.3	1.5
2.0	3.37	0.43	4.45	4812	3615	67.2	126	22.5	57.0	33	9.1	6.2	3.7	1.3	1.3	0.3	1.8
Significance	NS	NS	NS	NS	NS	**	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	*
BLSD (0.05)	--	--	--	--	--	19.2	--	2.9	--	--	--	--	--	--	--	--	0.7
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
Quad Nutra	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 23. Effect of NutraLime on the elemental composition of male ear leaf samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	3.11	0.46	2.89	5641	2851	21.1	114	20.7	65.4	25	10.8	5.9	<2.1	0.7	0.9	<0.1	0.4
0.5	3.08	0.45	2.93	5563	2934	20.7	112	18.6	37.9	22	12.5	5.5	<1.7	0.6	0.9	<0.1	1.9
1.0	3.08	0.45	2.94	5493	2836	19.5	114	16.8	54.8	25	12.5	6.0	<1.8	1.0	0.9	<0.1	2.3
2.0	3.07	0.43	2.85	5598	2943	22.5	112	22.2	46.7	23	11.7	6.1	<2.2	0.8	0.9	<0.2	2.3
Significance	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	--	NS	NS	--	**
BLSD (0.05)	--	--	--	--	--	--	--	3.8	--	--	--	--	--	--	--	--	0.7
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	--	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	--	NS	NS	--	**

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 24. Effect of NutraLime on the elemental composition of male stover samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.16	0.18	1.85	2757	2411	35.3	62	19.0	32.8	19	4.0	5.4	3.6	1.2	1.0	0.2	0.5
0.5	1.19	0.21	1.79	3197	2742	39.0	66	24.4	27.6	22	5.4	6.7	3.2	1.1	1.0	<0.2	1.3
1.0	1.14	0.18	1.85	2879	2578	36.7	62	19.6	38.2	17	4.7	5.9	3.5	1.2	1.1	0.2	1.4
2.0	1.01	0.16	1.66	2461	2290	28.3	55	18.6	22.4	14	4.2	4.9	3.5	1.1	0.9	<0.2	1.1
Significance	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	*
BLSD (0.05)	—	—	—	507	—	—	—	—	—	—	—	—	—	—	—	—	0.7
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS
Quad Nutra	NS	NS	NS	*	*	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	—	*

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 25. Effect of NutraLime on the elemental composition of male kernel samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.89	0.34	0.59	126	1299	5.7	24	5.3	6.2	28	3.8	2.2	2.1	0.7	0.5	0.4	0.3
0.5	1.97	0.35	0.65	148	1368	9.6	24	5.3	6.4	30	4.4	2.6	2.9	0.9	0.6	0.5	0.8
1.0	1.89	0.33	0.62	146	1297	7.4	23	6.4	7.0	29	5.4	2.5	<2.4	1.1	0.5	0.4	0.8
2.0	1.95	0.34	0.62	132	1319	10.8	22	5.9	6.1	27	4.4	2.4	2.5	0.8	0.5	0.5	0.8
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
BLSD (0.05)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.2
Contrasts																	
Linear Nutri	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
Quad Nutri	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 26. Effect of NutraLime on the elemental composition of male cob samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.86	0.18	1.02	391	1110	10.2	24	9.1	9.6	24	6.0	3.2	2.0	1.2	1.2	0.2	0.3
0.5	0.94	0.19	1.00	390	1111	9.0	21	6.5	8.4	22	6.4	3.3	2.2	1.2	1.1	0.2	0.5
1.0	0.80	0.15	0.83	340	964	8.8	22	6.5	8.4	20	6.0	2.8	2.0	1.3	1.2	0.2	0.6
2.0	0.93	0.18	1.03	392	1173	12.4	25	8.1	8.9	21	6.3	3.5	2.1	1.3	1.3	0.2	0.6
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.2
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*	NS	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 27. Effect of NutraLime on the elemental composition of male husk samples - Dakota county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.83	0.16	0.79	663	1153	20.6	45	12.0	15.6	17	3.1	3.9	<2.7	1.2	1.4	0.2	0.4
0.5	0.75	0.15	0.67	468	995	16.8	38	12.8	8.9	14	2.9	3.3	3.1	1.4	1.5	0.2	0.7
1.0	0.85	0.16	0.77	708	1230	15.4	35	13.5	15.5	17	3.9	4.0	<2.6	1.1	1.3	0.2	0.8
2.0	0.74	0.16	0.93	654	1087	16.5	34	9.8	14.3	15	3.1	3.8	<2.6	1.1	1.1	0.2	0.7
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	*
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.2
Contrasts																	
Linear Nutra.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	NS
Quad Nutra.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	**

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 28. Effect of NutraLime on the elemental composition of whole plant samples - Isanti county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	2.29	0.29	0.46	3130	1618	31.4	76	20.8	75.0	25	8.1	6.8	5.3	1.7	1.4	0.4	0.6
0.5	2.35	0.36	0.55	3677	2105	<31.4	85	15.9	48.6	26	9.4	7.7	4.4	1.5	1.2	0.4	2.2
1.0	2.97	0.35	0.51	3514	2083	28.1	80	14.6	48.2	27	9.3	7.5	3.8	1.4	1.2	0.4	2.6
2.0	3.15	0.35	0.42	3655	2092	32.8	91	16.0	48.0	26	10.2	7.9	4.2	1.5	1.2	0.4	3.2
Significance	NS	*	NS	*	NS	—	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
BLSD (0.05)	—	0.04	—	221	—	—	—	—	—	—	—	—	—	—	—	—	1.0
Contrasts																	
Linear Nutra.	*	*	NS	**	NS	—	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
Quad Nutra.	NS	*	NS	*	NS	—	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 29. Effect of NutraLime on the elemental composition of ear leaf samples - Isanti county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	2.46	0.27	2.06	4866	1712	30.9	108	25.2	77.8	25	12.1	5.8	5.9	1.9	1.2	0.4	1.0
0.5	2.75	0.33	2.16	5546	1971	28.5	108	15.9	50.1	26	13.4	6.5	5.8	1.7	1.3	0.4	4.5
1.0	2.91	0.32	2.13	5334	1959	28.6	113	17.2	58.4	27	14.0	6.5	5.0	1.6	1.3	0.4	5.2
2.0	2.98	0.33	2.14	5347	2063	23.5	111	13.5	57.2	28	13.8	6.1	<3.0	1.1	0.9	0.3	5.0
Significance	**	**	NS	NS	NS	**	NS	NS	*	NS	NS	**	—	NS	NS	*	**
BLSD (0.05)	0.22	0.03	—	—	—	3.0	—	—	19.9	—	—	0.2	—	—	—	0.1	1.1
Contrasts																	
Linear Nutra	**	**	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	—	**	*	**	**
Quad Nutra	*	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	—	NS	NS	NS	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 30. Effect of NutraLime on the elemental composition of stover samples - Isanti county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.26	0.04	1.61	1705	926	56.8	79	12.2	51.7	9	4.8	4.0	2.3	0.8	0.9	0.2	0.3
0.5	0.25	0.05	1.28	1647	1019	44.3	55	9.6	33.4	8	5.8	4.1	<1.8	0.8	0.7	0.2	1.1
1.0	0.29	0.06	1.39	1666	926	28.1	35	7.6	33.0	9	7.1	4.1	<1.9	0.6	0.7	0.2	1.4
2.0	0.25	0.05	1.53	1284	811	35.8	44	10.5	27.3	7	6.2	4.1	2.4	0.9	1.1	0.2	1.3
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	NS	*
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.6
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	--	NS	NS	NS	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	NS	*

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 31. Effect of NutraLime on the elemental composition of kernel samples - Isanti county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.05	0.27	0.32	30	932	<3.6	16	<3.6	5.2	17	0.5	1.5	<1.7	<0.4	<0.3	0.1	<0.2
0.5	1.35	0.29	0.32	30	964	<3.6	16	<3.8	4.9	16	0.5	1.7	<1.7	<0.4	<0.3	0.1	<0.3
1.0	1.32	0.30	0.33	28	1029	<3.6	16	<3.6	5.3	17	0.5	1.4	<1.7	<0.4	<0.3	0.1	<0.2
2.0	1.30	0.30	0.33	27	1019	<3.6	16	<3.6	5.3	17	0.5	1.5	<1.7	<0.4	<0.3	0.1	<0.2
Significance	NS	NS	NS	NS	NS	--	NS	--	NS	NS	--	NS	--	--	--	NS	--
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	--	NS	--	NS	NS	--	NS	--	--	--	NS	--
Quad Nutra	*	NS	NS	NS	NS	--	NS	--	NS	NS	--	NS	--	--	--	NS	--

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 32. Effect of NutraLime on the elemental composition of cob samples - Isanti county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.21	0.03	0.42	77	206	<4.1	12	<3.6	3.7	52	3.0	1.5	<1.7	1.2	1.3	0.1	<0.2
0.5	0.24	0.03	0.29	91	249	<3.8	8	<3.6	3.6	26	3.2	1.4	<1.7	1.1	1.2	0.1	0.3
1.0	0.25	0.04	0.33	90	205	<3.6	8	<3.6	4.6	24	3.5	1.3	<1.7	0.8	0.9	0.1	<0.3
2.0	0.27	0.04	0.33	86	204	<3.6	8	<3.6	4.0	26	3.4	1.3	<1.7	0.9	0.9	0.2	<0.3
Significance	NS	NS	NS	NS	NS	--	NS	--	NS	NS	NS	NS	--	NS	NS	NS	--
BLSD (0.05)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Contrasts																	
Linear Nutra	NS	NS	NS	NS	NS	--	NS	--	NS	NS	NS	NS	--	NS	NS	NS	--
Quad Nutra	NS	NS	NS	NS	NS	--	NS	--	NS	NS	NS	NS	--	NS	NS	NS	--

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 33. Effect of NutraLime on the elemental composition of whole plant samples - Washington county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	2.41	0.30	3.63	5235	3270	28.7	73	18.0	73.4	34	7.7	7.0	3.4	1.5	1.2	0.3	0.4
0.5	2.62	0.36	3.94	5891	3544	32.7	83	17.4	64.2	42	8.2	8.4	3.3	1.5	1.3	0.3	1.0
1.0	2.72	0.35	3.50	5647	3510	32.9	86	17.4	70.0	38	9.3	7.5	<2.7	1.9	1.1	<0.2	1.5
2.0	2.87	0.37	4.17	5634	3312	39.0	93	17.1	57.0	40	8.9	7.9	4.1	1.7	1.5	0.4	1.9
Significance	*	NS	NS	NS	NS	*	*	NS	NS	NS	NS	NS	--	NS	NS	--	**
BLSD (0.05)	0.28	--	--	--	--	6.6	14	--	--	--	--	--	--	--	--	--	0.4
Contrasts																	
Linear Nutra	**	NS	*	NS	NS	**	*	NS	NS	NS	*	NS	--	NS	NS	--	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	--	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 34. Effect of NutraLime on the elemental composition of ear leaf samples- Washington county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	2.95	0.34	2.25	7502	2989	46.3	102	22.3	92.5	38	10.8	8.3	4.9	1.5	1.4	0.3	0.6
0.5	2.83	0.34	2.35	7890	2746	34.2	102	19.7	73.8	37	10.7	9.2	4.6	1.5	1.5	<0.3	2.2
1.0	3.12	0.35	2.24	7739	2912	34.7	104	18.5	80.0	36	11.3	8.6	<3.8	1.3	1.3	<0.3	3.1
2.0	3.11	0.35	2.43	7679	3050	36.9	104	26.6	57.3	33	11.3	9.8	5.3	1.7	1.6	0.4	4.4
Significance	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	—	**
BLSD (0.05)	0.20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.8
Contrasts																	
Linear Nutra	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	—	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	—	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 35. Effect of NutraLime on the elemental composition of stover samples - Washington county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.55	0.04	1.69	3175	1614	56.9	60	12.1	49.1	7	4.8	3.9	3.4	1.5	1.6	0.3	0.5
0.5	0.58	0.04	1.84	3228	1690	53.7	61	9.5	33.4	7	4.2	3.6	<2.3	1.0	1.3	0.2	0.8
1.0	0.65	0.07	1.66	3908	1960	88.4	90	13.9	48.3	9	6.1	3.9	2.7	1.2	1.4	0.2	1.1
2.0	0.78	0.08	1.81	3492	2016	79.8	81	15.0	29.7	8	7.6	3.9	3.8	1.4	1.4	0.3	1.4
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	—	NS	NS	NS	**
BLSD (0.05)	—	—	—	—	—	—	—	—	—	—	1.5	—	—	—	—	—	0.4
Contrasts																	
Linear Nutra	NS	*	NS	NS	NS	NS	NS	NS	NS	*	**	NS	—	NS	NS	NS	**
Quad Nutra	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 36. Effect of NutraLime on the elemental composition of kernel samples - Washington county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	1.31	0.27	0.35	39	1104	<3.6	21	<3.6	7.1	22	1.7	1.5	<1.7	<0.6	0.4	<0.2	<0.2
0.5	1.35	0.28	0.36	41	1140	<3.6	21	<3.6	6.8	23	1.5	1.7	<1.7	0.5	<0.4	<0.1	0.4
1.0	1.33	0.27	0.35	41	1173	<3.6	20	<4.3	6.6	21	1.6	1.6	<1.7	<0.5	<0.3	<0.1	0.4
2.0	1.43	0.29	0.36	39	1132	<3.6	21	<4.7	6.4	22	1.6	1.7	<1.7	<0.5	<0.4	<0.2	0.6
Significance	NS	NS	NS	NS	NS	—	NS	—	NS	NS	NS	NS	—	—	—	—	**
BLSD (0.05)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.1
Contrasts																	
Linear Nutra	*	NS	NS	NS	NS	—	NS	—	NS	NS	NS	NS	—	—	—	—	**
Quad Nutra	NS	NS	NS	NS	NS	—	NS	—	NS	NS	NS	NS	—	—	—	—	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 37. Effect of NutraLime on the elemental composition of cob samples - Washington county.

Treatment	N	P	K	Ca	Mg	Al	Fe	Na	Mn	Zn	Cu	B	Pb	Ni	Cr	Cd	Mo
	%			ppm													
0	0.27	0.02	0.77	102	129	<3.8	12	8.1	6.7	9	2.7	1.6	<1.7	1.5	1.8	<0.2	<0.3
0.5	0.35	0.03	0.77	116	164	<4.1	16	14.2	7.8	13	3.5	2.1	<1.7	1.7	2.0	<0.3	0.4
1.0	0.35	0.03	0.75	121	156	4.2	13	12.6	8.1	10	3.3	1.9	<1.7	1.4	1.6	0.2	0.4
2.0	0.30	0.02	0.60	121	155	<4.5	14	15.4	6.7	8	3.4	2.1	<1.7	1.6	1.8	0.3	0.5
Significance	NS	NS	**	NS	NS	—	NS	NS	NS	NS	NS	NS	—	NS	NS	—	NS
BLSD (0.05)	—	—	0.08	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Contrasts																	
Linear Nutra	NS	NS	**	NS	NS	—	NS	NS	NS	NS	NS	NS	—	NS	NS	—	NS
Quad Nutra	*	*	NS	NS	NS	—	NS	NS	NS	NS	NS	NS	—	NS	NS	—	NS

NS = nonsignificant, * = significant at 5%, ** = significant at 1%.

IMPACT OF NITROGEN AND TILLAGE MANAGEMENT PRACTICES ON CROP YIELD AND POTENTIAL GROUNDWATER CONTAMINATION IN SOUTHEASTERN MINNESOTA[1]

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ABSTRACT: Studies are being conducted on the silt loam soils of southeastern Minnesota to evaluate specific N and tillage practices for their role in providing profitability (BENEFIT) while minimizing NO_3 occurrences in the water below the root zone (RISK). In Olmsted Co. continuous corn yield was optimized at 150 lb N/A with no advantage for split application over a preplant application. Nitrate-N concentrations were highest with split application of N and considerably lower for no tillage (NT) compared to chisel plow (CP) tillage. One-third of each plot that did not receive fertilizer N in 1991 responded to residual NO_3 remaining in the soil profile with CP but not NT. Under these conditions, a portion of the N applied in excess of crop needs in prior years became available for corn in 1991. In Goodhue Co. soybean yields were not affected by the previous N or tillage treatments applied to continuous corn even though large differences in residual NO_3 existed in the soil profile in May. Nitrate-N concentrations in the soil water at 5' did not change from May to November, which indicates that soybean did not remove sufficient NO_3 from the 0-5' profile in one growing season to impact NO_3 concentrations in water below the root zone. In Winona Co. oat responded to carryover NO_3 from the previous CP treatments but alfalfa did not. Nitrate-N concentrations in the soil water in May ranged from 18 to 54 mg/L and reflected the very high amounts of residual NO_3 in the soil profile. By November 20, NO_3-N concentrations at the 5' depth ranged from 0.2 to 17 mg/L. This suggests that establishment-year alfalfa can remove excess NO_3 from the soil profile and reduce the NO_3 concentration in water moving out of the 0-5' root zone.

Current agricultural production systems are being linked closely to the occurrence of agricultural chemicals in the groundwater. This concern is especially prevalent in southeastern Minnesota where agriculture is quite intensive and the soils are rather shallow over a fractured limestone and sandstone bedrock geology (karst). The purposes of these studies are to: (1) determine the cause and effect relationship of specific N and tillage management practices on crop production and NO_3 and pesticide accumulation/movement through the soil and (2) identify best management practices that minimize groundwater contamination while maintaining economic profitability.

EXPERIMENTAL PROCEDURES

Three sites were continued for the 1991 studies. The primary site with the most intensive investigation is being conducted in Olmsted Co. on the Lawler Farm. The other sites are in Goodhue Co. on the Foss Farm and in Winona Co. on the Kalmes Farm.

Olmsted County - Lawler Farm

In April of 1986 a 6.5 acre site of Port Byron soil was identified on the Richard Lawler and Sons Farm approximately 6 miles east of Rochester. A very comprehensive field history for the last 7 years was provided. Corn was grown in 1986. No herbicides and no nitrogen (N) fertilizer were applied to the corn which was cultivated three times.

Nitrogen Study

A randomized, complete-block with four replications was established in the fall of 1986 and was continued in 1991. Ten N treatments including both anhydrous ammonia and manure were established for a total of 40 plots (Table 1). Each plot was 30' wide and 65' long. The fall N treatments were applied on November 14, 1990. Spring N fertilizer treatments were applied on May 20 and again on June 19, 1991. Liquid hog manure was not applied in 1989, 1990 or 1991. All plots except the no-till treatment were disked on May 20.

Corn (Pioneer 3751) was planted on May 22 at 30,200 plants/A. Lasso (3 lb/A) and Bladex (2.5 lb/A) were applied preemergence. Force was applied in the furrow at a rate of 8 oz/1000' of row to control rootworms. All chisel plow plots were cultivated on June 26.

Whole plants were harvested from selected rows at silking and were weighed, dried, ground and analyzed for total N to determine pre-silk N uptake. Stover yields were taken from 20' of row at physiological maturity (Sept. 26). Grain yields and moisture were determined by combine harvesting two rows, each 60' long on Oct. 15. All samples were weighed, dried, ground and analyzed for total N.

Soil samples were obtained from each plot on May 13 and Oct. 30 by taking two 2-inch cores in 1-foot increments to the bedrock and then compositing the cores from each increment. The samples were forced-air, oven-dried at 120°F, ground and analyzed for inorganic N (NH_4-N and NO_3-N).

Suction porous cup samplers installed in 1987 at the 5 and 7.5-foot depths in each plot were used to extract soil water from these depths to measure NO_3 concentrations in the soil water. Samples were collected on May 10, July 15, August 14, and November 15.

[1] Funding provided by the Legislative Commission on Minnesota Resources, Center for Agricultural Impacts on Water Quality, and the Minnesota Agricultural Experiment Station.

Pesticide Study

An area adjacent to the N study was established in the fall of 1986 to accommodate a study to evaluate the movement of Lasso, atrazine, Banvel, and Counter through the soil profile as influenced by four tillage systems. The four tillage treatments (moldboard plow, chisel plow, ridge tillage, and no tillage) were initiated in November, 1986. Nitrogen was applied on May 20 at a rate of 180 lb N/A as anhydrous ammonia. All other planting operations were the same as in the N study. The herbicides were applied using specialized plot equipment. The corn was cultivated on June 26 with the ridge plots being ridged at that time.

Each plot was intensively soil sampled throughout the season to monitor herbicide movement. Stainless steel suction porous cup samplers installed at 5' and 7.5' depths were used to extract soil water. Grain and stover yields were taken at physiological maturity (PM).

Goodhue County - Foss Farm

In May of 1986 an area of 5.1 acres of Port Byron soil was identified on the Selmer Foss and Sons (James Foss) farm in Goodhue County. A good field history was provided for the past 6 years. Corn was grown in 1986 and received a minimal amount of N (75 lb N/A) because it was in continuous corn. Weeds were controlled with 4 lb atrazine/A. Due to wet conditions no primary tillage was performed in the fall of 1986.

A randomized, complete-block design with 4 replications was established at this site in April, 1987 and was continued in 1991. Sixteen N and tillage treatments were applied to continuous corn over the four-year period (1987-90). In 1991, the experiment was converted to a corn-soybean rotation to determine (1) if soybean responded to carryover NO_3 in the soil profile and (2) the extent to which excess residual NO_3 could be removed from the soil. Chisel plowing was done with a John Deere Mulch Tiller on November 14, 1990. All chisel plots were disked on May 22.

Soybean (Hardin) was seeded at 9-10 seeds/foot on May 22. Lasso (3.5 lb/A) was applied preemergence on May 24. The chisel plowed plots were cultivated to remove weeds and volunteer corn on June 26. Poast Plus was applied to all no till (NT) plots on July 2 to control wild proso millet and giant foxtail. Seed yield and moisture were determined by combine on October 1.

Soil sampling to the 8-foot depth on May 14 and November 12 was accomplished using the same procedures as in Olmsted Co. Suction samplers installed in six treatments (24 plots) to a 5' depth in 1987 were sampled on May 14, July 18, Aug. 20, and Nov. 12 to determine the NO_3 concentrations in the extracted soil water.

Winona County - Kalmes Farm

A 3.0 acre contour strip of Seaton soil was identified in early April, 1987. This farm is owned by Eugene Kalmes and son, Robert Kalmes. A field history was provided for the last 4 years. Corn was grown in 1986 and received 70 lb N/A and 2 lb atrazine/A. Alfalfa was grown in 1983-85 and received manure in the fall of 1985.

A randomized, complete-block design with 4 replications was established at this site in mid-April, 1987 and was continued through 1990. Twelve N treatments were established for a total of 48 plots. Each plot measured 20' wide by 65' long and were planted to continuous corn.

After four years of continuous corn and because substantial amounts of NO_3 had accumulated in the soil profile with some of the N treatments, this experiment was changed to determine if alfalfa could reduce the amount of residual NO_3 in the soil. Fall chiseling of all plots was conducted on November 15, 1990. A field cultivator was used as secondary tillage just prior to planting. Alfalfa was companion seeded with oats to the whole experimental area on May 13. The oat was harvested as oatlage on July 8. Alfalfa yields were determined from selected plots on August 26 prior to harvesting the whole experimental site by the Kalmes.

Stainless steel and PVC porous cup suction samplers were installed in 1987 at the 5' depth in six treatments (24 plots). PVC suction samplers were installed in 1988 at the 5' depth in three additional treatments and at the 7.5' depth in six treatments. These were sampled on May 10, July 10, Aug. 20, and Nov. 20 to determine NO_3 concentrations in the extracted soil water.

RESULTS AND DISCUSSION

Olmsted County

Corn grain yields in 1991 were increased significantly by the fertilizer N treatments (Table 1). The addition of 75 lb N/A increased yield by 61 bu/A resulting in very high fertilizer N efficiency. Yields were optimized at the 150-lb N rate. In contrast to 1990, yields were not decreased with the fall-applied treatments and with the NT treatment. Yields were not increased by split applying N. Even though manure had not been applied for three years, yields were 25 to 32 bu/A higher with the previous manure treatments compared to the control. This was surprising since very low amounts of NO_3 remained in the 0-5' profile in November, 1990. Grain moisture at harvest was reduced significantly by the fertilizer N treatments. Grain N concentration was increased linearly with increasing fertilizer N rate. Even though the manure treatments produced slightly higher grain yields, grain N concentration was not markedly affected. Grain N removal was highly related to N rate but was not influenced by tillage system or time/method of fertilizer N application; except the fall application plus N-Serve treatment which was slightly higher. Average 5-year yields show a 70 bu/A yield increase with the 75-lb rate of application, but the greatest yield/return with the 150-lb preplant application. Use of higher N rates or split application did not increase yield over the single spring application of anhydrous ammonia.

Nitrate-N amounts in the 0-5' and 0-7' soil profile were closely related to rate of N application for the chisel plow (CP) treatments (Table 2). Somewhat less NO_3 was found in the soil profile with NT compared to CP. A substantial amount of NO_3 was found between 5' and 7' with the annual 150 and 225-lb N rates. Nitrate-N concentrations in the soil water extracted in mid July and mid November from the 5-foot depth were not as closely related to rate of N application as in past years. The NO_3-N concentrations in the 150-lb spring preplant plots seemed abnormally high compared to the other treatments. When applied at 150 lb N/A, NO_3-N concentrations were highest when the N was split applied and lowest when applied to the NT system. The low concentrations with NT were probably due to reduced mineralization. The November 15 sampling showed significantly lower NO_3-N concentrations at the 5' depth than the July 15 sampling, especially when the N rate was limiting (0 and 75-lb and former manure treatments). Samples from the 7.5' depth indicated high NO_3-N concentrations with the 150- and 225-lb N rates and the former 9200 gal/A manure rate. Loss of NO_3-N from the 7.5' depth during the July-November period was likely due to leaching.

Table 1. Effect of N treatments on corn yields, grain moisture, grain N concentration and grain N removal in Olmsted Co. in 1991.

Treatment				Grain				1987-91 Grain
No.	Tillage	N rate	Time/Method	Yield	H_2O	N	N Removal	Yield
		lb N/A		lb/A	%	%	lb/A	bu/A
1	CP	0	-	73.8	19.5	0.98	34.2	81.6
2	CP	75	Spr., preplant	135.1	18.0	1.22	78.3	151.4
3	CP	150	"	152.0	16.9	1.38	99.5	168.4
4	CP	225	"	152.2	16.9	1.56	112.5	164.1
5	CP	150	Fall	153.0	17.5	1.38	100.0	166.1
6	CP	150 + NI[1/]	Fall	158.7	17.0	1.47	110.2	167.0
7	CP	150 Split	50% Spr., preplant					
			50% SD, 8-leaf	152.6	16.7	1.43	103.4	165.2
8	NT	150	Spr., preplant	152.8	17.2	1.34	96.4	165.0
9	CP	315[2/]	Spr., disked in	98.7	18.7	1.03	48.3	-
10	CP	490[2/]	Spr., disked in	105.6	18.8	1.06	53.2	-
Significance level (%) :				99	99	99	99	
BLSD (.05) :				12.5	0.6	.07	8.7	
CV (%) :				7.1	2.3	4.2	8.0	

[1] N-Serve

[2] Liquid swine manure was applied annually at an average rate of 6050 and 9200 gal/A, respectively, in 1987 and 1988. No manure was applied in 1989, 1990 or 1991. Total N rates were 315 and 490 lb N/A/yr or approximately 175 and 265 lb "available" N/A/yr.

Table 2. Amount of NO_3-N in the soil profile in May 1991 and NO_3-N concentrations in the soil water at 5' and 7.5' as influenced by N rate and tillage in Olmsted Co. in 1991.

Treatment				Nitrate-N in soil profile		Nitrate-N Conc in Water[1/]			
						5'		7.5'	
No.	Tillage	N rate	Time/Method	0-5'	0-7'	7/15	11/15	7/15	11/15
		lb N/A		lb/A		mg/L			
1	CP	0	-	22	28	1[3]	1	-	2[3]
2	CP	75	Spr., preplant	52	68	13	3	12[2]	8
3	CP	150	"	97	148	25[3]	24[3]	21[2]	20
4	CP	225	"	110	200	22[3]	16[3]	48[2]	44[3]
5	CP	150	Fall			16[3]	11		
6	CP	150 + NI[1/]	Fall			20[2]	18		
7	CP	150 Split	50% Spr., preplant						
			50% SD, 8-leaf	90	133	45[2]	27[3]		
8	NT	150	Spr., preplant	68	102	9	6[3]		
9	CP	315[2/]	Spr., disked in			6[2]	2	6[2]	5[3]
10	CP	490[2/]	Spr., disked in			9[2]	1[2]	28[2]	5[3]

[1/] On July 15 and November 15. All values are an average of four replications unless noted by the superscript which denotes number of samples in average.

Because of the consistent increase in residual soil NO_3 found in November 1990 associated with higher N rates, all plots were split in 1991 with the north four rows of each plot not receiving any additional N. The purpose of this was to determine the impact of residual NO_3 on N uptake and yield of corn and NO_3 removal from the soil profile. Corn production and N uptake parameters from these unfertilized plots are shown in Table 3. Residual NO_3 significantly increased yields, N concentrations and N removal/uptake of the grain, fodder and silage. A linear response to the 1987-90 N rates was clearly shown for all parameters with the CP tillage system. However, there was no response with the

150-lb N rate over the 0-lb rate when NT was used. This suggests that the annual 150-lb N rate for NT may have been optimum, due to reduced mineralization, whereas the annual 150-lb rate for CP exceeded crop demand and resulted in carryover of N for the succeeding crop. Grain:stover ratios were increased from 1.15 with the 0-lb rate, to 1.31 with the 75-lb rate, to 1.49 with the 150-lb rate to 1.57 with the 225-lb N rate. Apparently, higher levels of residual NO_3 enhanced N utilization efficiency and thus increased grain yield substantially while only having a small effect on fodder yield. Comparison of the yields from the plots receiving N in 1991 (Table 1) with those not receiving N (Table 3), shows a 42.6, 35.8, and 25.9 bu/A response to N applied in 1991 with the 75, 150 and 225-lb N rates, respectively, and 73.1 bu/A response to the 150-lb rate applied with NT. These responses clearly suggest that N applied in excess of crop needs in prior years can contribute to the N available for corn in following years under these soil/climate conditions. This was not true in a somewhat similar study on the poorly drained soil at Waseca in 1991.

Table 3. Influence of residual N rates on grain and silage yield, N uptake and N concentration in Olmsted Co. in 1991.

Treatment			Grain			Fodder		Silage	
No.	Tillage	Residual N Rate	Yield	N	Removal	Yield	N	Yield	N uptake
		lb/A	bu/A	%	lb/A	TDM/A	%	TDM/A	lb/A
1	CP	0	75.5	1.01	36.5	1.55	.36	3.34	47.6
2	CP	75	92.5	1.05	45.9	1.70	.37	3.89	58.5
3	CP	150	116.2	1.13	62.0	1.86	.47	4.60	79.5
4	CP	225	126.3	1.20	71.7	1.93	.46	4.92	89.4
5	CP	150	121.8	1.14	65.6	1.90	.44	4.78	82.5
6	CP	150 + NI[1]	99.4	1.08	51.1	1.71	.43	4.06	65.8
7	CP	150 Split	106.1	1.18	59.6	1.88	.48	4.39	77.9
8	NT	150	79.7	1.07	40.2	1.45	.41	3.33	52.2
9	CP	315[2]	99.3	1.06	50.1	1.84	.37	4.19	63.6
10	CP	490[2]	93.7	1.05	46.7	1.79	.36	4.00	59.6
Signif. Level (%) :			99	96	99	98	99	99	99
BLSD (.05) :			17.0	0.14	11.0	0.31	0.08	0.55	13.4
CV (%) :			12.	7.1	15.	11.	12.	9.5	14.

1/ N-Serve.

2/ Liquid swine manure was applied annually at an average rate of 6050 and 9200 gal/A, respectively, in 1987 and 1988. No manure was applied in 1989 or 1990. Total N rates were 315 and 490 lb N/A/yr or approximately 175 and 265 lb "available" N/A/yr.

Corn yields in the pesticide study were not affected by tillage (Table 4). The 5-year average shows approximately an 8-10 bu/A advantage for the moldboard and chisel plow treatments.

Table 4. Effect of tillage treatments on the 1991 corn yields in Olmsted Co.

Tillage	Grain Yield 1991	Grain Yield 1987-91 Avg.
	bu/A	
Moldboard plow	145.4	162.0
Chisel plow	145.1	160.5
Ridge till	141.8	152.9
No tillage	146.4	151.0
Significance level (%):	6	
CV (%) :	7.5	

Goodhue Co.

Soybean seed yields N concentrations in the seed and N removal by the seed were not significantly affected (P = 90% level) by the previous N treatments even though there were substantial accumulations of residual NO_3-N in the 0-5' soil profile (Table 5). Approximately 40 to 60 lb NO_3-N/A resided in the 5 to 7' zone and is likely to be leached toward the groundwater. Nitrogen removal with the seed averaged about 200 lb N/A which is markedly larger than one would expect with corn and should have removed some of the residual NO_3 from the soil profile. Nitrate-N concentrations in the soil water at the 5' depth in mid-May increased with increasing N rate used in prior applications, but was especially high when the N was sidedress-applied. Changes in NO_3-N concentration over the 6-month growing season were small except for the 150-lb sidedress treatment where the very high concentration in May was reduced to concentrations similar to the other 150-lb treatments. These data indicate that soybean did not have a large "cleansing effect" on the NO_3 levels in water at the 5' depth over this growing season. However, soil samples taken in November 1991 indicate very low NO_3-N amounts in the top three feet of all plots (data not shown). Thus, soybean may be somewhat effective at removing excess NO_3 from the upper part of the soil profile, but this study cannot exclude the possibility of leaching as a contributing loss mechanism.

Table 5. Soybean production, residual NO_3-N in the soil profile, and NO_3-N concentration in the soil water at 5' as affected by the 1987-90 treatments in Goodhue Co. in 1991.

1987-90[1/] N Rate	Tillage	Seed Yield	Seed N Conc.	Seed N Removal	Nitrate-N in soil profile 0-5'	Nitrate-N in soil profile 0-7'	Nitrate-N in soil soil water at 5' [2/] 5/14	Nitrate-N in soil soil water at 5' [2/] 11/12
		bu/A	%	lb/A	----- lb/A -----		----- mg/L -----	
0	CP	56.8	6.65	195.8	33	45	5	7
50	CP	60.3	6.48	203.1				
100	CP	59.0	6.81	208.8			19[3]	23[2]
150	CP	57.3	6.36	189.5	96	134	38	43[3]
200	CP	56.9	6.82	201.6	173	239		
0	NT	54.4	6.67	188.2				
100	NT	58.4	6.56	199.4			12	9[2]
150	NT	58.5	6.54	198.8	87	127	26	19
200	NT	59.8	6.65	206.5	142	201		
50 + 50	CP	60.5	6.51	204.3				
50 + 100	CP	59.0	6.64	203.4				
100 + 50	CP	58.8	6.84	208.5				
100 (SD)	CP	57.0	6.61	196.5				
150 (SD)	CP	59.7	6.61	204.8			57	33[3]
150 + NS (SD)	CP	58.9	6.87	209.8				
150 + NS (SD)	CP	57.4	6.56	195.4				
Signif. Level (%) :		24	41	27				
CV :		6.4	4.5	7.6				

[1/] See 1991 Bluebook article for a complete description of treatments.

[2/] On May 14 and November 12. All values are an average of four replications unless noted by the superscript which denotes number of samples in average.

Winona Co.

Similar to the Goodhue Co. study, the experiment in Winona Co. was converted from continuous corn to alfalfa established with oat. Although oat yield was low due to high infestation of leaf rust, a dry matter response to carryover N associated with the previous N treatments applied to chisel plow tillage was found (Table 6). Nitrogen concentration in the dry matter was increased significantly over the control by the 100-, 150-, and 200-lb N rates with no difference among these three treatments. Total N removal by the oat was increased by 10 to 20 lb/A with previous N rates of 100 lb/A or greater.

Table 6. Influence of previous N rates on oat yield and N removal by the crop at Winona Co. in 1991.

Previous N Rate	Oat Yield	Whole Plant N	N Removal
lb/A	TDM/A	%	lb/A
0	1.22	1.43	34.7
50	1.18	1.58	37.5
100	1.31	1.70	44.3
150	1.43	1.79	51.2
200	1.52	1.81	54.7
Signif. Level (%) :	92	99	99
BLSD (.05) :	-	0.21	10.8
BLSD (.10) :	0.25	0.18	9.1
CV (%) :	13.	8.	15.

In contrast to the oat, no effect of either the previous tillage system nor N rate was observed on seeding year alfalfa yield (Table 7). Whole plant N concentration, however, was increased about 0.50% N (3.1% protein) by the previous CP tillage treatment compared to the previous NT system. The previous N rates did not influence N concentration in the alfalfa. Nitrogen removal was increased about 10 lb/A with the CP system.

Table 7. Effect of previous tillage and N rates on alfalfa yield and N uptake at Winona Co. in 1991.

Previous Tillage	Previous N Rate	Whole Plant N	Alfalfa Yield	N removal by crop
	lb/A	%	TDM/A	
CP	0	3.69	1.210	89.4
CP	100	3.85	1.132	87.4
CP	200	3.98	1.124	88.4
NT	0	3.27	1.185	77.2
NT	100	3.50	1.088	77.1
NT	200	3.30	1.164	77.2
MAIN EFFECTS				
Tillage				
CP		3.84	1.155	88.4
NT		3.36	1.146	77.2
Signif. Level (%):		98	18	95
N Rate				
0		3.48	1.197	83.3
100		3.67	1.110	82.2
200		3.64	1.144	82.8
Signif. Level (%):		30	80	1
INTERACTION				
Tillage x N Rate				1
Signif. Level (%):		24	36	
CV (%) :		13.	8.1	15.

Nitrate-N amounts in the soil profile prior to oat-alfalfa establishment were highly related to the past N and tillage treatments (Table 8). Nitrate-N increased with increasing N rate but was consistently lower with NT compared to CP. High levels of NO_3-N were found between 5 and 7' especially with the 200-lb preplant and 150-lb sidedress rates.

Nitrate-N concentrations in the soil water at 5' and 7.5' in mid-May reflected the NO_3 amounts in the soil profile (Table 8). However, by November 20, NO_3-N concentrations at 5' were reduced to levels as low as 0.2 mg/L. The only concentration above 10 mg/L was with the previous 150-lb sidedress treatment that showed extremely high carryover amounts of residual NO_3. Concentrations of NO_3-N at 7.5' were not reduced consistently over this 6-month period. These data suggest that the alfalfa in this seeding year and perhaps some leaching were responsible for the substantial removal of NO_3 from the 0-5' zone resulting in very low NO_3-N concentrations in the soil water at 5'. Considering that water samples taken in mid-August still showed high NO_3 concentrations (data not shown), that seeding year alfalfa would have established a root system to a 5- depth by October, and that rainfall amounts from August thru October were less than normal at this site, it becomes evident that alfalfa in its establishment year has a tremendous capability of scrubbing NO_3 from the rooting zone. Leaching of NO_3 was not likely to have occurred under these conditions.

Table 8. Nitrate-N content in the soil profile in May 1991 and NO_3-N concentration in the soil water at 5' and 7.5' as influenced by previous tillage and N rates in Winona Co. in 1991.

Treatment				Nitrate-N in soil profile		Nitrate-N Conc in Water[1/]			
						5'		7.5'	
No.	Tillage	N rate	Time/Method	0-5'	0-7'	5/10	11/20	7/10	11/20
		lb N/A		lb/A		mg/L			
1	CP	0	Spr., preplant	32	38	-	1^2		
3	CP	75	"	101	151	23	2	-	22^2
4	CP	150	"	198	281	41^3	9	26^2	24^2
5	CP	200	"	262	390	54^3	5^2	38^2	42^2
7	NT	100	"	68	100	-	1^2	-	-
8	NT	150	"	141	201	23^2	0.2^2	21^2	6^2
9	NT	200	"	195	292	42^2	1^2	19^3	-
10	CP	50 + 50	Spr. PP + SD	128	197				
11	CP	50 + 100	"	217	309	18^3	6^3	58^2	34^2
12	CP	150	Sidedress	284	417	37^2	17^2		

[1/] Superscript indicates the number of samples in the mean if less than four.

EFFECTS OF NUTRIENT SOURCES, APPLICATION TIMING AND RATE ON ALFALFA (AND SUBSEQUENT CORN) PRODUCTION

M.A. Schmitt, C.C. Sheaffer and G.W. Randall[1/]

Farmers often have questions regarding the effect of manure application on alfalfa. Although alfalfa is grown on fewer acres than corn in Minnesota, alfalfa removes more nutrients on a per acre basis. However, because alfalfa can produce its own nitrogen (N), many livestock producers are reluctant to apply manure to alfalfa fields.

This report is an update of a long-term research project investigating the effects of manure and fertilizer on alfalfa establishment and production, soil N contents, and the resulting credits the alfalfa/manure treatment combinations provide for subsequent corn crops. The 1991 growing season was the third year of the study. The specific objectives are:

1. Evaluate the effects of plowdown and topdress fertilizer applications, commercial and manure fertilizer sources, and rates of nutrient applications on alfalfa nutrient uptake, forage quality, stand density, and dry matter production.

2. Monitor soil N forms from the manure treatments while the alfalfa was actively growing to assess potential for excessive nitrate accumulation.

3. Determine the N fertilizer replacement equivalent (credit) that should be recommended for alfalfa/manure treatment combinations for the corn crops grown in the years after the alfalfa is plowed.

Materials and Methods

Trials were established at University of Minnesota Agricultural Experiment stations at Rosemount and Waseca. At Rosemount, hog manure was used on a shallow Waukegan silt loam soil lying on outwash gravel subsoil. Soil P and K tests at Rosemount were categorically "high" (Bray P at 35 ppm and K at 200 ppm). At Waseca, dairy manure was used on a Nicollet clay loam soil, which tested "low" for both P (8.5 ppm) and K (94 ppm). Two adjacent plot areas were established at Rosemount to offset potential confounding effects of years.

Nutrient application rates were based on the estimated two-year nutrient needs of alfalfa and the prevalent range of manure application rates commonly used by farmers. Three rates of manure (3000, 6000, and 12000 gallons per acre) were broadcast and incorporated immediately prior to establishment of the alfalfa. Three inorganic commercial fertilizer treatments were also used--applied to give equivalent phosphorus (P) and potassium (K) application rates as contained in the three rates of manure. A control treatment was also included, thus, seven treatments were replicated four times in a randomized, complete-block design. Specific nutrient amounts are listed in Table 1 and associated production information is given in Table 2.

Along with measures of overall dry matter yield at each harvest, plant samples were collected at each harvest for nutrient analysis. Stand density measurements and weed pressure estimates also were made. After the second year, before the alfalfa was plowed, subplots were undercut and crown counts, crown and taproot dry matter yields and N contents measured. The plots were also subdivided at this time, with one half of the plot having its last cut of alfalfa harvested and the other half of each plot having its late summer regrowth plowed under. Thus, the plot design is now a split plot.

Corn production practices were followed according to optimum management principles. No N fertilizers are added to the plots at any time. Broadcast applications of P and K were made to approximate crop removal amounts. The corn was harvested from 2-20 foot rows within each subplot.

During the alfalfa's growing season, soil samples were collected to a depth of two feet in one-foot increments. These samples were analyzed for nitrate-N and ammonium-N. When corn was being grown, soil samples were collected at various times and depths.

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Results

Production Year Yields

The application of manure did significantly increase alfalfa dry matter yields at Rosemount (South) in 1990 compared to the unfertilized control treatment (Table 3). Despite slight yield increases with the inorganic fertilizer rates at Rosemount, there was no statistically significant difference between the control treatment and the inorganic fertilizer treatment means. The relatively high soil test values for P and K would provide justification for this lack of fertilizer response.

For the Rosemount (North) plots in 1991, statistical analysis of the data results in none of the treatments being statistically different from each other, however, the treatment means (Table 3) show the same trends that occurred in 1990. The control plot had the lowest yields and with each increment of manure added, a yield increase was noted--the highest manure rate treatment yielding 0.55 ton dry matter more per acre than the control. At the same time, the commercial fertilizer treatments did increase yields, but there was no difference among the rates nor was this increase as great as with the manure.

At Waseca, the yield response to both commercial fertilizer and manure was statistically significant (Table 3). While the lowest rate of inorganic fertilizer did not result in a significant increase in alfalfa yield, the low rate of fertilizer produced 0.44 tons of dry matter more than the control. The middle and high fertilizer rate each produced a significant increase in dry matter production. The increase in tonnage was almost a direct linear correlation with the rate of fertilizer application. With the low soil test levels for P and K at this site, the increase in yield was predictable.

Soil Nitrate Levels

Nitrate-N concentrations measured in the soil provide an indicator as to the amount of N that can potentially be lost. Nitrate-N quantities in manure-treated plots above the quantities in the control plots represent nitrate contributions from the manure.

Throughout the 1989 growing season at Rosemount, there were statistically significant differences in soil nitrate-N due to manure rate differences--these differences being somewhat related to the relative application rates of the manure (Table 4). In July and thereafter, the low manure rate nitrate-N concentrations were not different from the control and after August, the medium manure rate was not different from the control.

For the second set of plots at Rosemount initiated in 1990, nitrate concentrations were significantly increased above the control plot concentrations for all manure rates with the spring samplings after application (Table 4). The low and medium manure rate treatments (3000 and 6000 gal/acre) nitrate levels were never significantly higher than the control plots' nitrate concentrations at later samplings.

The higher manure rate treatment did result in higher nitrate levels during the first year of the study, but after the initial flush of N release the second year, the nitrate levels were statistically equal to the control plots. The wide fluctuations in the control plots' nitrate levels indicate how environmental conditions affect the biological processes in the soil.

At Waseca, fewer samplings were taken, yet the same results were observed. In 1989, there was a significant effect of the manure rate on soil nitrate-N. The first sampling in 1990 showed significant nitrate-N differences in the medium and high manure rates, but subsequent samplings resulted in no statistical differences among treatments.

Corn Production after Alfalfa

Two of the three sites had corn grown in 1991. Average corn yields measured in 1991 had no statistically significant differences due to preplant manure and fertilizer treatments that were made to the preceding alfalfa crop (Table 5). Based on current corn N fertilizer recommendations, no response to N fertilizer is expected after alfalfa. Therefore, this first year of corn following various treatment combinations of alfalfa and manure is not surprising. Any residual effects of the manure and/or alfalfa would be more noticeable in subsequent years.

Presidedress nitrate tests were also conducted on the corn plots to ascertain the sufficiency of N according to Iowa State University guidelines. The results indicate that higher nitrate-N was present in early June with increasing manure rates. However, these results are all below the critical level (21 ppm) that Iowa State University recommends where no response to fertilizer will be measured. Thus, the alfalfa/manure treatments are either releasing sufficient amounts of nitrate-N later in the season and/or the nitrate-N may be moving below the sampling depth.

Summary

The application of either manure or inorganic fertilizer can be used to supply the fertilizer requirements of a planned alfalfa crop. Both nutrient sources will increase dry matter production, although there is a consistent trend that manured treatments produced more dry matter than an equivalent amount of P and K fertilizer. Manure does supply a substantial amount of inorganic N to the soil--with its persistence in the soil being a function of the rate of application. Corn yields after the alfalfa is plowed were not significantly affected by the manure treatments on the alfalfa plot. This is consistent with other research supporting the recommendation that first-year corn after alfalfa do not require additional N fertilizer.

Table 1. Nutrient sources and application rates for preplant applications of nutrients at Rosemount and Waseca.

Treatment Code	Nutrient Source	Application Rate	
		Rosemount	Waseca
		- gal/acre or $N-P_2O_5-K_2O$ lb/acre -	
1	None	-	-
2	Manure	3000	3000
3	Manure	6000	6000
4	Manure	12000	12000
5	Fertilizer	0-90-69	0-33-69
6	Fertilizer	0-180-138	0-66-138
7	Fertilizer	0-360-276	0-132-276

Table 2. Calendar dates of manure applications and harvests of alfalfa at two Rosemount sites and at Waseca.

Operation	North Rosemount	South Rosemount	Waseca
Manure application	April 17,1990	April 21,1989	May 10,1989
Harvests-seeding year	July 5,1990 August 16,1990	July 11,1989 August 28,1989	July 27,1989
Harvests-production year	June 3,1991 July 1,1991 August 8,1991 October 10,1991	June 6,1990 July 5,1990 August 8,1990 October 29,1990	June 15,1990 July 23,1990 August, 1990 November 1,1990

Table 3. Alfalfa dry matter yield means for the first full year of production as influenced by preplant manure and fertilizer applications.

Treatment	DM Yields		
	Rosemount-North	Rosemount-South	Waseca
	T/A		
1	4.67	3.81	2.84
2	4.72	4.31	3.40
3	5.09	4.60	4.12
4	5.22	4.55	4.49
5	4.89	3.87	3.28
6	4.83	3.97	3.71
7	4.80	4.17	4.57
Pr.>F	0.1824	0.0001	0.0001
$LSD_{(.10)}$	-	0.36	0.45

Table 4. Two-foot soil nitrate-N concentrations from plots receiving preplant incorporated manure applications in 1989 and 1990.

Location	Date	Manure Rate (GPA) Control	3000	6000	12000	$LSD_{(.10)}$
		ppm NO_3-N				
Rosemount	May 1, 1989	14.2	17.6	16.9	17.8	-
	May 31 "	16.9	41.4	79.5	106.2	31.5
	June 22 "	17.2	42.5	68.8	103.3	17.2
	Aug. 3 "	3.5	4.3	14.1	38.4	3.9
	Nov. 1 "	1.6	1.7	2.1	15.4	4.8
	April 12, 1990	15.6	14.2	27.3	39.1	-
	May 3 "	12.7	14.9	18.1	40.7	15.0
	May 31 "	9.8	9.9	15.3	19.6	-
	July 18 "	11.8	9.7	8.6	13.7	-
	Aug. 20 "	5.9	7.1	7.1	7.3	-
Waseca	June 5, 1989	18.1	25.2	38.1	48.1	5.7
	June 27 "	17.1	24.6	36.1	55.0	7.3
	Sept. 11 "	7.3	15.7	32.8	47.4	12.5
	April 27, 1990	14.5	14.0	21.8	28.9	4.3
	May 23 "	10.2	11.2	16.0	17.7	-
	June 22 "	6.9	7.9	7.2	10.0	-
	July 23 "	3.9	2.8	4.1	5.0	-
Rosemount	May 31, 1990	20.8	47.9	58.6	81.1	20.9
	June 25 "	15.9	17.5	23.5	38.9	-
	July 18 "	12.2	17.2	24.4	34.2	8.7
	Aug 20 "	6.7	6.8	7.8	15.7	6.8
	April 17, 1991	7.2	7.7	8.1	8.3	-
	June 3 "	7.7	8.2	9.4	11.7	1.4
	July 16 "	4.6	4.7	5.1	6.6	-
	Sept 5 "	3.5	4.3	4.6	3.8	-

Table 5. Effects of preplant manure and fertilizer applications on the following corn grain yields and presidedress nitrate levels (PSNT) at Rosemount and Waseca, 1991.

Treatment Code	Rosemount Corn Yields PSNT	No Fall Cut	Fall Cut	Ave	Waseca Corn Yields PSNT	No Fall Cut	Fall Cut	Ave
	ppm	bu/A			ppm	bu/A		
1	17.2	175.1	166.7	170.9	7.2	155.8	156.5	156.2
2	15.2	177.0	167.2	172.1	7.8	170.1	158.6	164.3
3	18.9	188.5	187.9	188.2	8.1	173.4	169.7	171.5
4	19.3	175.7	172.7	174.2	9.3	177.3	163.4	170.3
5		173.4	172.3	172.8		160.8	148.8	154.8
6		176.6	172.1	174.3		172.2	157.1	164.6
7		177.5	176.5	177.0		176.4	170.4	173.4
Pr.>F				0.319				0.335

RESIDUAL EFFECTS OF POTASH AND ALFALFA MANAGEMENT ON CORN PRODUCTION

M.A. Schmitt, M.P. Russelle, and C.C. Sheaffer[1/]

ABSTRACT

Fertilizer management for a previous crop can have a residual effect on following crops. Potassium additions of 0, 375, 750, and 1500 lb K_2O/A were applied to alfalfa from 1985-87. The alfalfa was managed in both 3- and 4-cutting schedules. Although the cutting schedule did not have an effect on corn grain yields in 1990-91, the previous potash rates did. Yields in 1990 and 1991 ranged from less than 14 bu/A for the 0 lb K_2O rate to over 180 bu/A for the 1500 lb K_2O rate. Soil test levels from the topsoil ranged from 53-87 ppm K. Within this relatively narrow soil K test range, yield correlated well with soil K levels.

Introduction

Potassium (K) deficiency in corn is characterized by a marginal necrosis on the leaves. It was this visual symptom that identified a previous research field at the Rosemount research station as one that had a K deficiency and that some of the residual fertilizer treatments were alleviating this problem in some plots. The contrast between the "good" corn and "poor" corn in this bulk corn field in 1990 initiated the process collecting yields and measuring soil tests in the plot area.

The plot area had been part of a previous alfalfa study. That study, initiated in the spring of 1985, investigated the interacting effects of K fertilization, alfalfa cutting management schedules, and alfalfa varieties, which differed in winter hardiness ratings.

The K fertilization rates consisted of 0, 125, 250, and 500 lb of K_2O per acre. This fertilizer was added as a plowdown treatment in 1985 and applied in split, topdressed application in 1986 and 1987.

The initial soil K test was 100 ppm. Oats were grown in 1989 and corn was grown in 1990 and 1991. The field has received no fertilizer since the project ended in 1987.

The objective of this trial was to link current corn growth differences with previous alfalfa treatments as well as current soil test results.

Methods

The soil at this site was a Waukegan silt loam with approximately 28 inches of loam over outwash sand and gravel. Because the symptoms were a residual effect of the beforementioned alfalfa study, no treatments were applied. Top management practices were implemented regarding cultural practices and pest management. Extremely wet conditions in the spring of 1991 delayed corn planting until the first week in June.

At harvest time, plots were flagged according to the original 1985 plot design. One exception was that the effect of alfalfa varieties was not delineated due to the hypothesis (and observation) that this factor was not influencing the current corn crop. Thus, the cutting managements were the main plots and the K treatments were the subplots. There were three replications.

Corn grain was harvested by hand-picking four 10-foot rows. After weighing this, six ears were selected, weighed, dried, weighed again, shelled, and reweighed. This allowed for grain moisture, shelling percentage, and grain yield determinations. In the fall of 1990, soil samples were collected from each plot to a depth of six inches and analyzed for exchangeable K according to standard (ammonium acetate extraction) procedures.

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Results

A summarization of the statistical analyses is listed in Table 1. The factor of alfalfa cutting management had no effect on potassium deficiency and grain yields of the corn in either year. The effect of the potash rates was highly significant, whereas the interaction of cutting management and potash rates
was not significant. Note that there was a highly significant difference between the two years. This difference can mainly be attributed to the lower yields measured in 1991 due to the very late date of planting.

Table 1. Analysis of variance table for individual and combined years for selected sources of variation.[1/]

Source of Variation	1990	1991	Combined
Year	-	-	395.82***
Alfalfa cuts	0.35NS	1.26NS	0.09NS
Potash Rate	150.73***	95.14***	43.20***
Cuts x Potash	0.42NS	1.83NS	0.18NS

[1/] Statistical significance is designated at probability levels of a greater F or 0.001, 0.01, 0.10 and less than 0.10 by ***, **, *, and NS, respectively.

Corn grain yields ranged from 3.8 - 187.5 bu/A in 1990 and from 8.0 - 82.8 bu/A in 1991 (Table 2). In plots that had received no K fertilizer, yields did not exceed 10 bu/A. Corn in these plots did not grow taller than 2 feet and exhibited severe K deficiency symptoms soon after emergence. As the previous K rates increased, so did the height, yield, and overall appearance of the crop. At the highest K rate, no deficiency symptoms were observed and the corn was 6-8 feet tall.

Table 2. Corn grain yields as affected by alfalfa cutting management and potash applications.

Potash Applied 1985-1987	Alfalfa Mgmt 1985-1987	Grain Yields 1990	1991	1990-91
lbs K_2O/A/Yr	- Cuts/Yr -	- - - - - - - -	bu/A	- - - - - - - - - -
0	3	3.8	8.0	5.9
	4	8.3	8.8	8.5
125	3	76.2	27.2	51.7
	4	71.3	36.9	54.1
250	3	160.4	50.8	105.6
	4	160.8	68.1	114.5
500	3	187.5	82.8	135.2
	4	172.3	80.6	126.4

Soil K tests measured 53, 61, 62, and 87 ppm K/A for the K treatments ranging from the lowest K rate (control) to the highest K rate. Except for the two middle means, these values were significantly different from each other. Grain yield was well correlated with soil K tests for each plot (r=0.72 in 1990 and r=0.80 in 1991). According to University of Minnesota fertilizer recommendations, all soil K tests would be in the medium to medium-low range, thus, the resulting range in yields is surprising.

Summary

Results from this trial have led to more questions than answers, and the number of questions continues to grow. While the refinement of soil K tests and the resulting K recommendations can be a future goal from this trial, a broader issue may be the development of fertilization plans for entire rotations. It is important to use a fertilizer management plan that meets current needs and that is adaptable for future needs as well.

EFFECTS OF TILLAGE AND FREQUENCY OF LIQUID DAIRY MANURE ON N AVAILABILITY TO CORN[1]

J. R. Joshi and J. F. Moncrief[2]

Abstract: A study to determine the influence of tillage and manure application on corn production in Goodhue Co., MN was continued in 1991. Results from this long-term experiment showed generally depressed yield levels in 1991. Manure applied annually had greater yields (137 bu/A) than urea (114 bu/A) applied at 163 lb N/A. Manure applied biennially produced 119 bu/A in the year of application of manure and 85 bu/A in the following year. Manure applied triennially in chisel plowing system produced 110, 99, and 76 bu/A yield in the first, second, and third year, respectively. Check yields were 11 and 63 bu/A in no-tillage and chisel plowing systems, respectively. The amount of surface cover provided by various tillage and N treatments were similar to the previous years.

Total amount of N applied through manure was comparable to the previous three years but the amount in mineral form was about 40% smaller. In addition, delayed planting, greater seeding rate, and a change in hybrid may have been responsible for the yield decline.

INTRODUCTION

The objectives of this study are to determine the effects of tillage and frequency of manure application on corn yield, N uptake, and soil nitrogen levels. The site is located on a Seaton silt loam (Typic hapludalf, fine-silty, mixed, mesic) soil on the Dale Flueger Farm near Red Wing in Goodhue Co., MN. The study was initiated in 1982.

Liquid dairy manure is injected either annually, biennially or triennially on chisel-plowed treatments and annually or biennially on no-tillage treatments. A zero-N check treatment and a fertilized check treatment are also included in the study. In 1991, the fertilized check received broadcast urea, instead of ammonium nitrate or anhydrous ammonia applied in previous years. The hybrid used this year was NK 3624. Other cultural practices are listed in Table 1.

From 1982-1986 the manure treatments were split with 0 and 200 lbs K_2O/A and the fertilizer treatments with 0, 200, and 400 lbs K_2O/A. The application of this extra potassium has been stopped since 1987. To evaluate residual effects of additional potassium, data in this report are presented on split basis with respect to K_2O whenever applicable.

The experiment is laid out in a randomized complete block split-split plot design with three replications. Tillage is the main plot and N source is the subplot. Manure as N source is further split by the year of N application as a sub-sub plot.

RESULTS AND DISCUSSION

Residue Cover. Residue measurements were made both in and between the rows in duplicate in manure, fertilizer and check treatments in both tillages on June 6, 1991. A table of significance of treatment effects on residue cover is given in Table 2. Residue cover in between the rows in the no-tillage system without manure was above 80% (Table 3). The injection of manure reduced the residue cover in between the rows to 27 in the year of manure application in the biennial manure and 39% in annual manure treatments. Chisel plowing with or without manure had a cover between 23 to 29%. The amount of cover in the rows was generally below 25% in all treatments except in the biennial manure (53%) in the year following manure application.

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Plant Population, Grain Yields, and Grain Moisture: Biennial Study. The effects of various annual and biennial treatments on plant population, grain yield, and grain moisture are given in Table 4. Average plant population at harvest was about 37,000 plants/A, an increase by about 30% from the previous years. This is because of a higher seeding rate this year. Grain yields were reduced this year by about 25% from the 1990 yield levels. However, the relative magnitude among the N treatments was similar: Annual manure > biennial manure in the application year > fertilizer > biennial manure in the year following the manure application. Fertilizer was applied at 163 lb/A, about 12 lb/A lower than in 1990. Average grain moisture at harvest was about 21%. Greater moisture levels were associated with smaller yields (fertilizer and biennial manure in the year after manure).

Plant Population, Grain Yields, and Grain Moisture: Triennial Study. The effects of various triennial treatments on plant population, grain yield, and grain moisture are given in Table 5. Final plant stand was more in the second year after the application of manure. Grain yield in the year of application of manure was 110 bu/A, about 20% lower than the annual manure treatment. The yield levels declined in the second year by 11 bu/A and in the third year by 24 bu/A. The third year yields were 13 bu/A more than the check treatment. Although the yield levels were reduced compared to the previous years, the general trend between the years was similar. Grain moisture at harvest was uniform among the years.

Table 1. Cultural practices at the Flueger Farm in Goodhue County, MN in 1991.

Tillage

No Till

Chisel Plowed and field cultivated on May 23, 1991.

Cropping History

Corn since 1981-P 3906

1989 Corn Pioneer 3737

1990 Corn Pioneer 3751

1991 Corn NK3624

Manure Application

Injected liquid dairy manure at the following rate and analysis on May 20, 1991.

		1991 rate	
		Mean	Std. Dev.
Manure	(gal/A)	8500	500
Total-N	(lbs/A)	202	12
NH_4-N	(lbs/A)	78	5
P_2O_5	(lbs/A)	119	7
K_2O	(lb/A)	149	9
Solids	(%)	6.4	2.3

Planting Information : A four row 38 inch John Deere Maxi-Emerge planter with 2" fluted coulters was used to plant on May 24, 1991. Corn was harvested on October 12, 1991.

Fertilizer

Material Analysis	Tillage	Actual N -lbs/A-	Date Applied	Method of Application
46-0-0	Both	163	June 19, 1991	Broadcast after planting
9-23-30	Both	111	May 24, 1991	As a starter

Soil: Seaton silt loam (mixed, mesic, fine-silty Typic hapludalf), well drained, 2 to 12% slope.

Insect Control: 5.7 lbs/A Timet 20G applied in furrow on May 24, 1991.

Weed Control: Cultivated all treatments on June 27, 1991.

Table 2. Significance table for surface residue cover in Goodhue Co., MN on 6/6/91.

Till(T)	N Freq(F)	T*F	K(K)	T*K	F*K	T*F*K	Row(R)	T*R	F*R	K*R	T*F*R	T*K*R	F*K*R	T*F*K*R
.033	.000	.000	.987	.916	.700	.707	.000	.001	.005	.660	.001	.736	.736	.453

Table 3. Surface residue cover as affected by tillage, N source and row position in Goodhue Co.,MN on 6/6/91.

N Source And Frequency	Row Position	Residue (%)	
		No Till	Chisel
Manure (Year of)	In	17.0	12.7
	Between	26.7	29.3
Manure (Year After)	In	53.3	16.7
	Between	82.0	23.7
Manure (Annual)	In	18.8	14.0
	Between	38.9	29.2
Urea	In	25.0	8.7
	Between	81.0	25.3
Pr > F (T X F X R)		.001	

Table 4. Corn plant population, grain yield, and grain moisture at harvest as influenced by tillage, and N source and frequency of application in Goodhue Co., MN in 1991.

Frequency & Source of N	K_2O lb/A	PLANT POPULATION No Till	Chisel	Mean	GRAIN YIELD No Till	Chisel	Mean	GRAIN MOISTURE No Till	Chisel	Mean
		-- plants/A*10^{-3} ---			---------bu/A--------			---------%----------		
Manure[1]	0	36.2	33.8	35.0	85	105	95	25.6	20.9	23.2
(Yr after)	200	34.4	31.8	33.1	52	98	75	24.0	20.8	22.4
	Mean	**35.3**	**32.8**	**34.1**	**68**	**102**	**85**	**24.8**	**20.9**	**22.8**
Manure	0	41.1	38.7	39.9	97	124	111	20.4	18.1	19.3
(Yr of)	200	36.6	40.3	38.1	121	128	124	17.9	15.4	16.9
	Mean	**38.1**	**39.6**	**38.8**	**113**	**126**	**119**	**18.7**	**16.6**	**17.8**
Manure	0	35.2	41.0	36.5	126	142	130	19.9	17.0	19.2
(Annual)	200	37.8	34.2	36.6	152	126	143	18.6	19.0	18.7
	Mean	**36.4**	**36.9**	**36.5**	**138**	**133**	**137**	**19.3**	**18.2**	**19.0**
Urea	200	42.6	35.2	38.9	113	115	114	22.4	26.4	24.4
Overall Mean		**37.8**	**36.2**	**37.1**	**115**	**119**	**116**	**20.6**	**20.5**	**20.6**
Check (0 N)[2]		33.6	40.5	37.0	11	63	37	27.3	20.0	23.6

Pr>F	Till(T)	Freq.(F)	T*F	K rate(K)	K*T	K*F	K*F*T
Plant population	.281	.038	.103	.199	.680	.976	.070
Grain Yield	.155	.000	.111	.922	.296	.058	.068
Grain moisture	.471	.022	.356	.556	.669	.778	.921

[1]Manure applied in the spring of 1990 (year after) and 1991 (year of).
[2]Check (0 N) treatments were not included in the statistical analysis.

Table 5. Corn plant population, grain yield, and grain moisture at harvest in triennially-applied manure with chisel plowing system in Goodhue Co., MN in 1991.

YEAR OF MANURE APPLICATION	K_2O lb/A	PLANT POPULATION -- plants/A*10^{-3} --	GRAIN YIELD ---bu/A---	GRAIN MOISTURE ---%---
First Year	0	36.9	106.2	21.1
	200	37.2	113.8	20.4
	Mean	**37.1**	**110.0**	**20.8**
Second Year	0	38.2	98.7	20.2
	200	38.8	99.7	21.2
	Mean	**38.5**	**99.1**	**20.7**
Third Year	0	36.9	77.1	21.5
	200	36.8	74.2	19.6
	Mean	**36.9**	**75.5**	**20.4**

TILLAGE EFFECTS ON CORN AND SOYBEAN PRODUCTION, AND WATER QUALITY IN MEEKER COUNTY (KUECHLE FARM), MINNESOTA[1]

A. Bhattacharjee, J.F. Moncrief, S.C. Gupta, M.B. Kells, and B.J. Johnson[2]

Abstract

Experiments are being conducted for six years to demonstrate the effects of tillage and methods of fertilizer P placement in minimizing the P losses to water bodies. Results of the experiment conducted in 1991 show that the soil cover by soybean residue was adequate for erosion control with no tillage system but inadequate with other systems. The soil P content was maximum in the surface layer (0-2") and decreased steeply with the increase in depth for no tilled, ridge tilled and chisel plowed treatments. But with moldboard plowed treatment the difference between the soil P content at surface layer and sub-surface layers was absent. Corn grain moisture content analysis suggested that Corn with row applied P matured earlier to the broadcasted P. The maximum of tissue N was observed in no tillage system (3.04%) and the minimum of tissue N was observed in moldboard plowed treatment (2.63%).

A higher yield of 105.9 bu/ac was recorded for the row applied P when compared with broadcast which recorded 94.2 bu/ac. The increase in Corn yield was 12% in row applied P. In Soybean the maximum grain yield of 50.9 bu/ac was obtained in the treatment with moldboard plow.

Introduction

The water quality in the Clearwater River Chain of lakes is considered to be deteoriating due to the entry of phosphorus from various sources. It is suggested that agricultural activities in these areas have also contributed due to soil erosion. Erosion control in conjunction with better phosphorus management could prevent the contamination of surface water with phosphorus. A good management strategy would be to control erosion with crop residue and place phosphorus below the soil surface.

The present experiment is being conducted in Meeker County, MN, involving various tillage practices and methods of fertilizer P placement. This study is in its sixth year. The objective of this study is to demonstrate the effects of tillage and method of fertilizer P placement to minimize P losses to water bodies.

Materials and Methods

The experimental design is a randomized complete block split-plot design with tillage as the main plots and method of fertilizer application as sub-plots. The management practices are given in table 1. The initial soil tests are given in tables 2 and 3.

Crop residue was measured on 6/13/91 using a line transect technique. Crop residue was characterized in and between the rows. "In row" is defined as four inches centered over the row and "between row" the remainder.

Soil samples were collected on 6/11/91 from 0-2", 2-4" and 4-6" depths; in row and between row. The samples were analyzed for soil P content by Bray-1 method.

Corn ear leaf samples were taken at 50% silk emergence and were analyzed for N, P, and K.

Stand estimates were made on two ten-foot row samples from adjacent rows at two randomly selected monitoring sites in each tillage plot.

Results and Discussion

Soil Residue Cover. Soil cover by soybean residue in corn resulting from the tillage systems evaluated is shown in table 4 (Fig. 1A). There were significant differences of soybean residue between the tillage

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systems. The maximum residue cover was observed in the no tillage treatment followed by the chisel plow, ridge till and moldboard plow treatments respectively. The soil cover by soybean residue was adequate for erosion control with the no tillage system but inadequate with the other systems. As expected the soil cover was greater in 'between rows' than 'in rows',as the clearing disc on the planter clears residue from the row area.

The soil cover in the row by soybean residue should be less than 20% to minimize detrimental effects on the early development of corn. The chisel plowed treatment is adequate in this respect. Although the soybean residue in corn was greater in the no tillage treatment, it did not influence the corn stand .

The tillage effects on corn residue in soybeans also showed the same trend as the soybean residue in corn (table 5, Fig. 1B). There were significant differences between the treatments with maximum soil cover in no tillage treatment and the lowest soil cover in moldboard plowed treatment. The soil cover in the chisel plowed treatment is greater than that of ridge plowed treatment.

Soil P Distribution. The effect of tillage system, row position, and depth on soil P content is shown in table 6 (Fig. 2). There were no significant difference between no tillage, ridge tilled and chisel plowed treatments. The moldboard plowed treatment had the least soil P test and 40% less soil P than the ridge tilled treatment. However moldboard plowed treatment did not have any significant difference with other types of tillage.

There was a significant tillage and soil depth interaction on soil P content (table 7, Fig. 3). The soil P content was maximum in the surface layer (0-2") and decreased steeply with the increase in depth for no tilled, ridge tilled and chisel plowed treatments. But with the moldboard plowed treatment the difference between the soil P content at surface layer and sub-surface layers was absent. The ridge tillage system had the highest soil P content throughout the profile as compared to the other tillage systems.

The interaction of tillage, phosohorus application methods, and row position on soil profile P is shown in table 8 (Fig. 4). In no tillage system when P was broadcasted, the soil P content between the rows was greater at surface layer than in the rows. In case of row application, 'in row' soil P was greater at the surface layer. In both the cases, soil P either in the row or between the row was similar at the depths below 2". With ridge till system with broadcast phosphorus application the soil P content in between the rows were more than in the rows up to the 4" depth. The reason attributed for this fact is that when tillage is done in the ridge plots the soil from the ridge carrying the P fertilizer is removed in between the rows and thus shows up high P content upto 4" depth of the soil. In chisel plowed and moldboard plowed treatments, the P distribution was fairly uniform throughout the depth of sampling.

Earleaf Analysis. The effect of tillage and method of phosphorus application on tissue N, P, and K content is shown in table 9. Though tillage system had a significant effect on tissue N, it did not on tissue P and K. The maximum of tissue N was observed in no tillage system (3.04%), and the minimum of tissue N was observed in moldboard plowed treatment (2.63%). Method of fertilizer application did not have any significant effect on tissue N, P, and K composition.

Corn Population. The tillage and method of phosphorus application effects on corn stand at vegetative stage of the crop are shown in table 10. Neither treatments affected stands.The tillage and method of Phosphorus application interaction effects on corn stand at the harvest is shown in table 11.Though there no significant difference in stand due to main effects oftillage and method of P application,there were significant effects of tillage and method of Phosphorus application interaction on corn stand. There were no significant effects of tillage and soil types on the corn stand (table 12).

Soybean Population. There were no significant differences between the soybean stand in broadcast and row applied P treatments with ridge tillage system (table 13). There were significant differences due to other tillage systems on soybean stand (table 14). The maximum stand was observed in the moldboard plowed treatment. The method of fertilizer application did not influence the soybean stand. There were no significant differences between row applied and broadcast fertilizer treatments.

Corn grain yield . There was no significant interaction between effects of tillage and methods of phosphorus application on the grain yield of corn(table 15). The highest grain yield of 106.2 bu/ac was recorded for the moldboard plow and 91.6 bu/ac for the no tillage system. The method of phosphorus application had significant influence on the grain yield. A higher yield of 105.9 bu/ac was recorded for the row applied phosphorus when compared with broadcast which recorded 94.2 bu/ac. The increase in corn yield was approximately 12% in row applied phosphorus. There were no significant interaction of tillage systems and the soil types on the yield of the corn(table 16). However there were significant difference in corn yield for the different soil types. The highest corn yield (112.2 bu/ac) was obtained in Koronis fine sandyloam and the lowest was obtained in Delft clay loam. Though yield of corn in Marcellon loam type of soil was 106.7

bu/ac, it was on par with Koronis fine sandy loam.

Corn grain moisture content. There were no significant differences in grain moisture percent for the different tillage systems(table 17). However the method of phosphorus application had an influence over the grain moisture content. The grain moisture percent aws higher in the row applied phosphorus than broadcast suggesting early maturity of the crop when phosphorus was row applied. There were no significant tillage and method of application of phosphorus interaction effect on the grain moisture percent. There were no significant interaction effect of tillage and soil type on the corn grain moisture content (table 18).

Soybean grain yield . There were no significant interaction effect of tillage and method of phosphorus application on the soybean grain yield (table 19). However there were significant difference in yield for the tillage systems (excluding ridge tillage). Highest grain yield of 50.9 bu/ac was obtained in the treatment with moldboard plow. There were no significant differences in grain yield between the methods of phosphorus application for the ridge plow(table 19).

Soybean grain moisture.There were no significant differences in grain moisture for either of the treatments (table 20). The two methods of phosphorus application in the ridge plow treatment had no significant effect on the grain moisture.

Table 1. Cultural practices at Meeker County, MN, in 1991.

Tillage

No Till
Ridge Till
Fall Chisel Plowed-Field cultivated prior to planting
Fall Moldboard Plowed-Field cultivated prior to planting

Cropping History

Corn-soybean rotation since 1978.

1991 Crop

Corn- Northup King N 3624
Soybeans- Northrup King B 095

Planting and Harvest Dates

Corn - was planted with a two row Hiniker Series 1 EconoTill planter with 30 inch row spacing.

Soybeans - ridge till was planted with a two row Hiniker Series 1 EconoTill planter with 30 inch row spacing and all other tillage treatments were planted with a Tye no till drill with 7 inch row spacing equipped with 2 inch fluted coulter ahead of the double disc openers.

Crop	Planting Date	Planting Planter	Planting Rate	Harvested
Corn	May 16,1991	Row	32,000 seeds/A	October 9,1991
Soybeans	May 22, 1991	Drill	225,000 seeds/A	October 17,1991
Soybeans	May 16, 1991	Row	225,000 seeds/A	October 17,1991

Fertilizer History 1985-1990

Crop	Material Analysis	Rate	Actual N	Actual P_2O_5	Actual K_2O	Date Applied
			---- lb/A ----			
Corn:	82-0-0	183 lb/A	150	0	0	Spring 1985
	4-15-40[1]	250 lb/A	10	38	100	Planting 1985
Corn:	4-15-40	300 lb/A	12	45	120	October 27, 1986
	7-21-7[1]	17 gal/A	13	40	13	April 28, 1987
	82-0-0	159 lb/A	130	0	0	May 15, 1987
Soybeans:	4-15-40	300 lb/A	12	45	120	October 27, 1986
	0-46-0[2]	45 lb/A	0	21	0	May 5, 1987
Corn:	10-34-0[3]	19 gal/A	22	76	0	April 28, 1988
	10-34-0[1]	9 gal/A	11	36	0	May 5, 1988
	82-0-0	183 lb/A	150	0	0	June 7, 1988
Soybeans:	10-34-0[3]	10 gal/A	12	40	0	April 28, 1988
	10-34-0[1]	5 gal/A	6	20	0	May 5, 1988
	0-46-0[2]	358 lb/A	0	165	0	May 5, 1988

Crop	Material Analysis	Rate	Actual N	Actual P_2O_5	Actual K_2O	Date Applied
			---- lb/A ----			
Corn:	7-21-7[4]	15 gal/A	12	35	12	May 10, 1989
	82- 0-0	183 lb/A	150	0	0	May 31, 1989
Soybeans	7-21-7[5]	15 gal/A	12	35	12	May 22, 1989
Corn :	7-21-7[4]	18 gal/A	14	42	14	May 10, 1990
	82-0-0	220 lb/ A	180	0	0	July 5, 1990
Soybean :	7-21-7[5]	18 gal/A	14	42	14	May 10, 1990

1. Planter placement 2" beside and 2" below row.
2. Drill soybeans were split with row fertilizer which was surface banded ahead of and incorporated by the fluted coulters.
3. Broadcast applied.
4. Planter placement 2" x 2" on 1/2 the plots.
5. Planter placement 2" x 2" on 1/2 the plots, Ridge Till only.

1991 Fertilizer

Crop	Material Analysis	Rate	Actual N	Actual P_2O_5	Actual K_2O	Date Applied	Method of Application
			---- lb/A ----				
Corn:	10-34-0	5 gal/ac	6 -	20	- 0	5/16/91	Row placement 2"x2" below row.
	0-46-0	87lb/ac	0 -	40	- 0	5/13/91 5/15/91	Broadcast.
	83-0-0	260lb/ac	217	-	-	6/25/91	Injected
Soybeans :	10-34-0	5 gal/ac	6 -	20	- 0	5/16/91	Row placement 2"x2" below row.
	0-46-0	87lb/ac	0 -	40	- 0	5/13/91 5/15/91	Broadcast.

Soil

The soils present at this site are as follows: 29% of plot area is Delft clay loam (Cumulic Haplaquolls, fine-loamy, mixed, mesic), 43% is Koronis fine sandy loam (Mollic Haplaudalfs, fine-loamy, mixed, mesic), and the remaining 28% is Marcellon loam (Aquic Argiudolls, fine-loamy, mixed, mesic).

Weed Control

Corn

3.0 qt/A (3.0 lb/A) Lasso + 2.0 qts (4.0 l/A) Bladex 90 DF applied on May 23, 1991.

Soybeans

1.5 pt/A (0.188 lb/A) Fusilade 2000 + 1 pt/A (0.459 lb/a) Galaxy a premix of (0.375 lb/A Basagran + 0.084 lb/a Blazer) + 2 qt/A oil concentrate on June 14,1991. 11pt/A (0.5 lb/A) Basagran + 2 pt/A (0.375 lb/A) Poast + 1 qt/A Dash oil concentrate + 2 qt/A 28% UAN on June 26,1991.

Soil Test

Table 2. Soil test results for corn following soybeans on April 7, 1987.

Nutrient	Tillage: No Till	Ridge	Chisel	Moldboard	Avg.	Sig.
	lb/A					
P	21.2	25.2	27.9	22.8	24.4	.862
K	182.7	177.6	173.1	146.2	169.9	.258

Table 3. Soil test results for soybeans following corn on April 7, 1987.

Nutrient	Tillage: No Till	Ridge	Chisel	Moldboard	Avg.	Sig.
	lb/A					
P	26.0	20.6	32.7	23.7	25.5	.262
K	208.7	234.9	200.1	173.1	204.2	.016

Table 4. Effect of tillage and row position on soybean residue in corn at Meeker Co.(Kuechle farm) on 6/13/91.

Tillage	Residue(%)		
	In row	Between row	Means
No Tillage	10.7(9.9)	30.7(16.3)	20.7a
Ridge Tillage	4.0(4.6)	7.2(5.1)	5.6bc
Chisel Plow	12.0(12.8)	11.0(7.2)	11.5b
Moldboard Plow	2.0(2.1)	1.8(2.1)	1.8b
Mean	7.2 a	12.7 b	

1.The p value for tillage,row position and tillage by row position interaction are 0.002(n=32), 0.006(n=64)and 0.002(n=16) respectively. Means within same row or column with same letter are not significantly different (α=0.10).

Table 5. Effect of tillage on corn residue in soybeans at MeekerCo. (Kuechle farm) on 6/13/91.

Tillage	Residue(%)		
	In row	Between row	Means
No tillage	55.8(25.6)	46.0(27.8)	50.9a
Ridge Tillage	16.3(14.6)	17.0(17.9)	16.6b
Chisel Plow	24.8(16.0)	17.5(15.1)	21.1c
Moldboard Plow	10.5(8.9)	6.0(7.6)	8.3d
Mean	26.8	21.6	

1.The p value for tillage,row position and tillage by row position interaction are <0.001(n=32), 0.146 (n=64) and 0.718(n=16) respectively. Means within same column with same letter are not significantly different (α = 0.10).

Table 6. Effect of tillage and row positon on soil P content (ppm) in Meeker County, MN, on 6/11/91[1].

Tillage	In Row	Between Row	Mean
No Tillage	14.3 (8.7)	15.0 (9.0)	14.7 ab
Ridge Till	17.3(10.0)	23.7(14.6)	20.4 a
Chisel Plow	16.4 (8.7)	13.7 (7.0)	14.7 ab
Moldboard Plow	12.3 (3.9)	12.3 (2.6)	12.3 b
Mean	*15.2 a*	*15.9 a*	------

1.The P value for tillage, row position and tillage by row position interaction are 0.175 (n=24), 0.386 (n=48) and 0.025 (n=12) respectively. Means within same row and column with the same letter are not significant different (α = 0.10).

Table 7. Effects of Tillage and depth on soil P content (ppm) in Meeker Co., MN,on 6/11/91[1].

Depth	No Till	Ridge Till	Chisel Plow	Moldboard Plow	Mean
0-2	22.5	31.2	23.3	13.2	22.5 a
2-4	11.9	20.1	12.9	12.8	14.4 b
4-6	9.6	10.1	8.3	11.0	9.8 c
Mean	*14.7 ab*	*20.4 a*	*14.7 ab*	*12.3 b*	----

1.The P value for tillage, depth and tillage by depth interactions are 0.175 (n=24),< 0.001(n=12) and 0.002 (n=08) respectively. Means within same row and column with the same letter are not significantly different (α = 0.10).

FIG. 1 EFFECT OF TILLAGE AND ROW POSITION ON SOIL COVER AT MEEKER CO . (KUECHLE FARM) 6/13/91

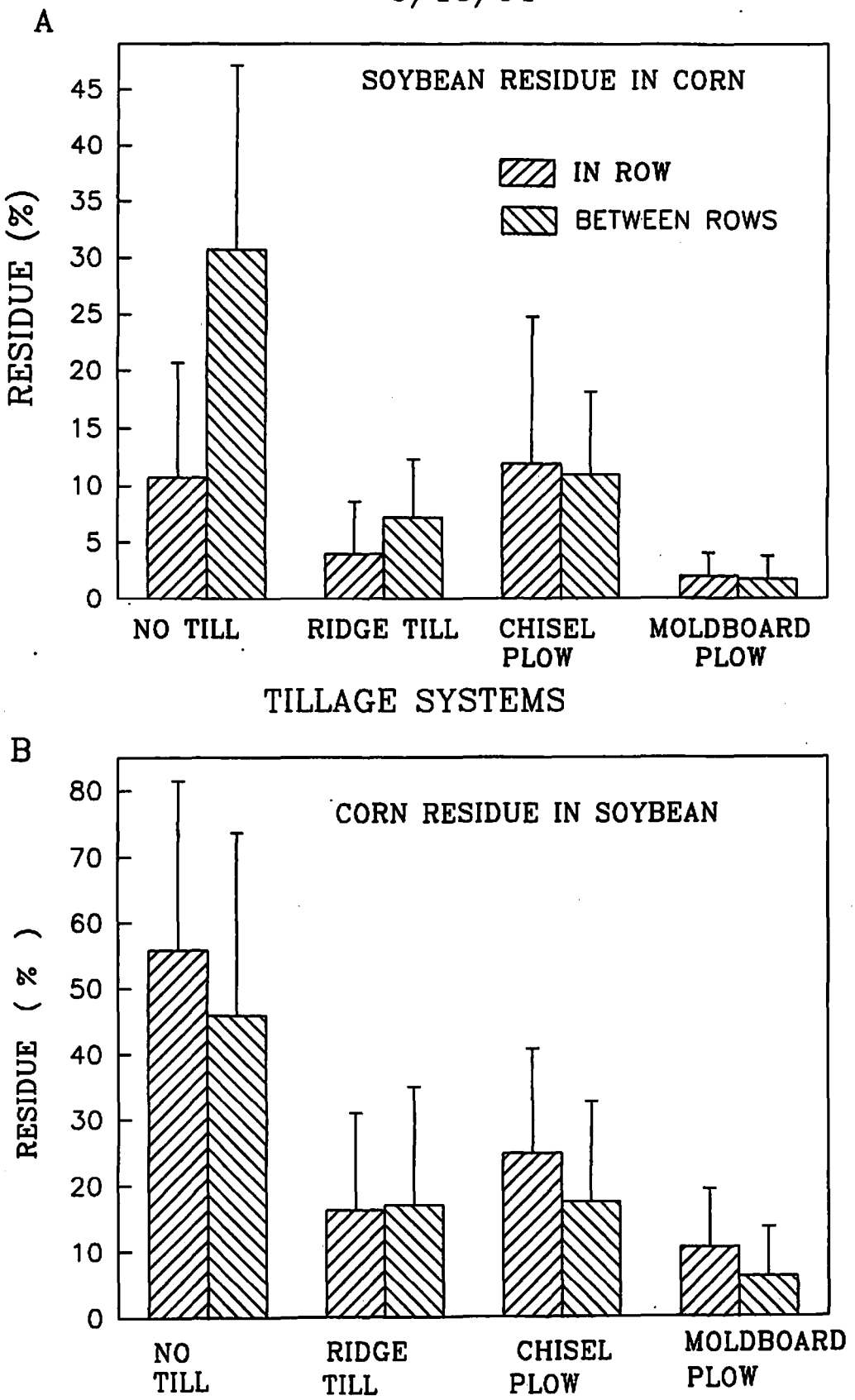

FIG .2 EFFECT OF TILLAGE AND ROW POSITION ON SOIL PHOSPHORUS AT MEEKER CO (KUECHLE FARM)
6/11/91

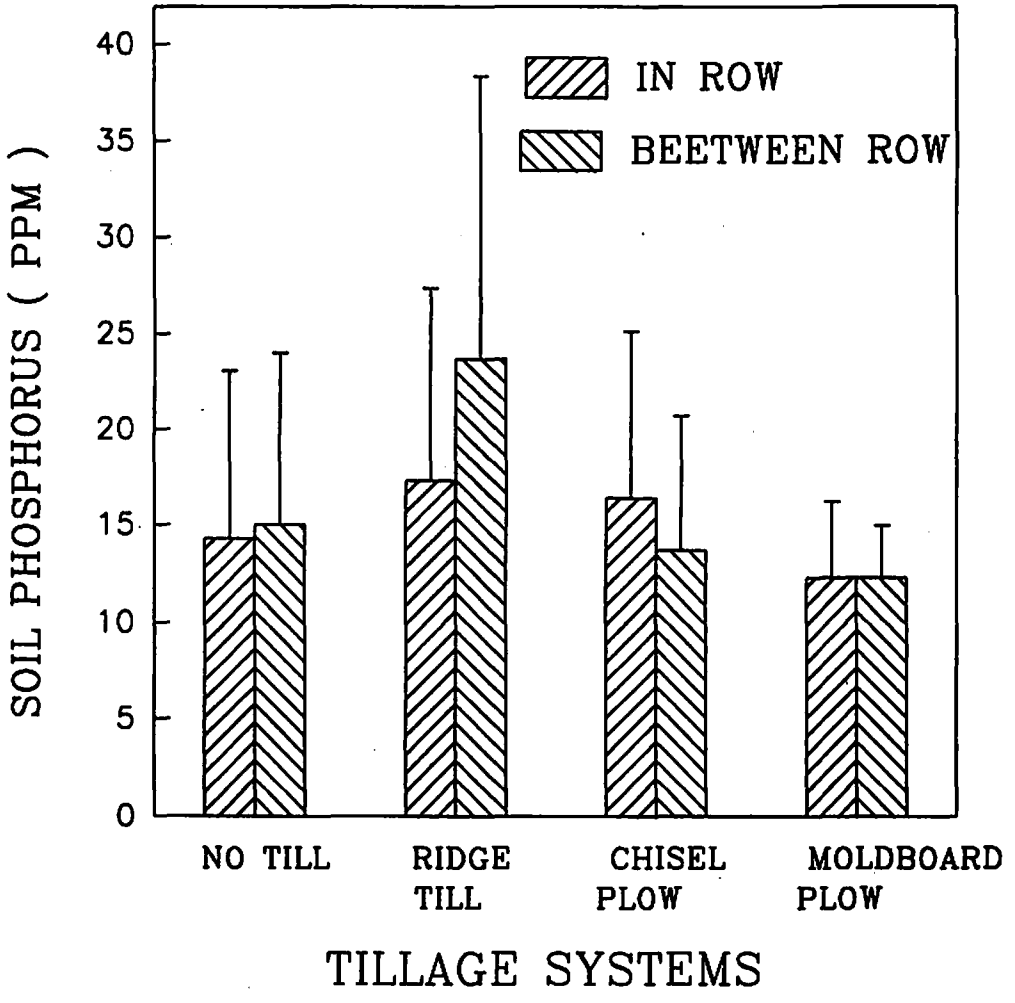

FIG. 3 EFFECT OF TILLAGE ON SOIL P IN SOIL PROFILE IN MEEKER (KUECHLE) CO.

6/11/91

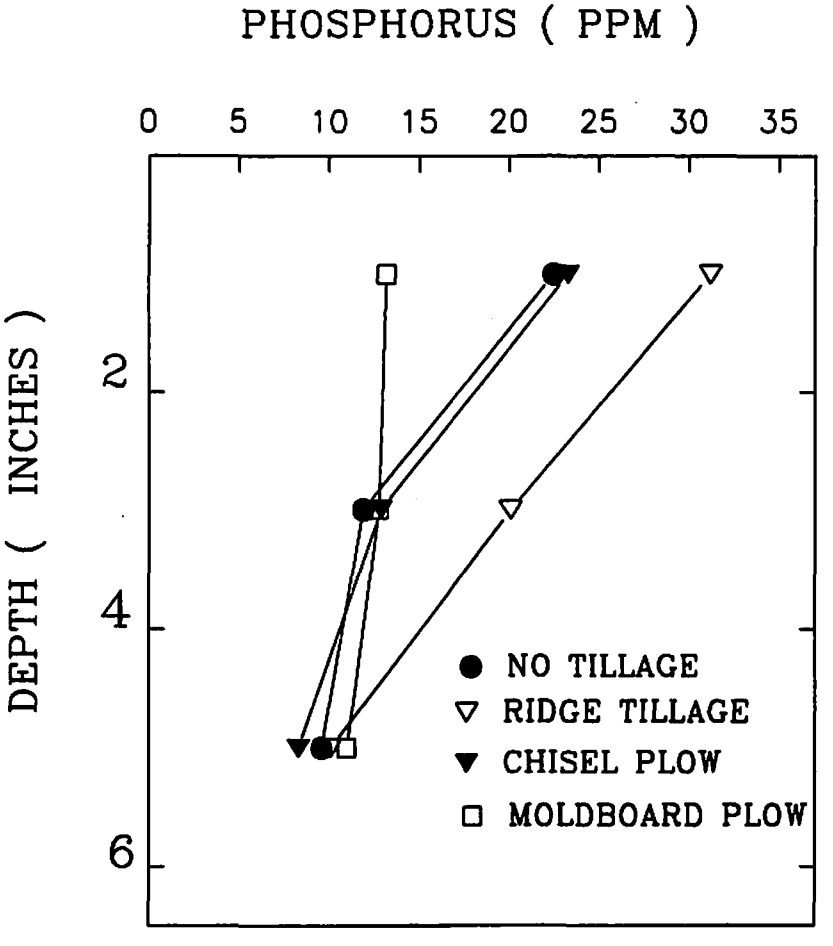

Table 8. Effect of tillage, method of phosphorus application, row postiton and soil depth on soil P content (ppm) in Meeker Co., MN, on 6/11/91[1].

Tillage	Fertilizer	Soil P (ppm)			
		Depth(in.)	In row	Between row	*Mean*
No Till	Broadcast	0-2	14.1	23.0	*18.5*
		2-4	8.3	9.2	*8.7*
		4-6	7.2	6.3	*6.8*
	Row application	0-2	31.8	21.3	*26.6*
		2-4	12.2	17.7	*14.9*
		4-6	12.0	12.8	*12.5*
Ridge Till	Broadcast	0-2	21.6	30.0	*25.8*
		2-4	11.0	20.4	*15.6*
		4-6	11.4	11.3	*11.3*
	Row application	0-2	24.3	48.8	*36.6*
		2-4	27.8	21.2	*24.5*
		4-6	7.4	10.4	*8.9*
Chisel Plow	Broadcast	0-2	22.1	17.9	*20.0*
		2-4	11.0	10.7	*10.8*
		4-6	8.6	7.5	*8.9*
	Row application	0-2	28.4	24.8	*26.6*
		2-4	20.6	10.5	*15.5*
		4-6	7.5	8.5	*8.3*
Moldboard	Broadcast	0-2	8.0	14.4	*12.8*
		2-4	14.3	10.5	*12.5*
		4-6	10.8	10.5	*10.7*
	Row application	0-2	12.0	15.2	*13.5*
		2-4	15.3	10.8	*13.1*
		4-6	11.0	11.6	*11.3*

1.The P value for tillage, fertilizer, depth and row position interaction is 0.068 (n=02) .

FIG. 4 EFFECTS OF TILLAGE, PHOSPHORUS APPLICATION METHODS AND ROW POSITION ON SOIL PROFILE P

6/11/91

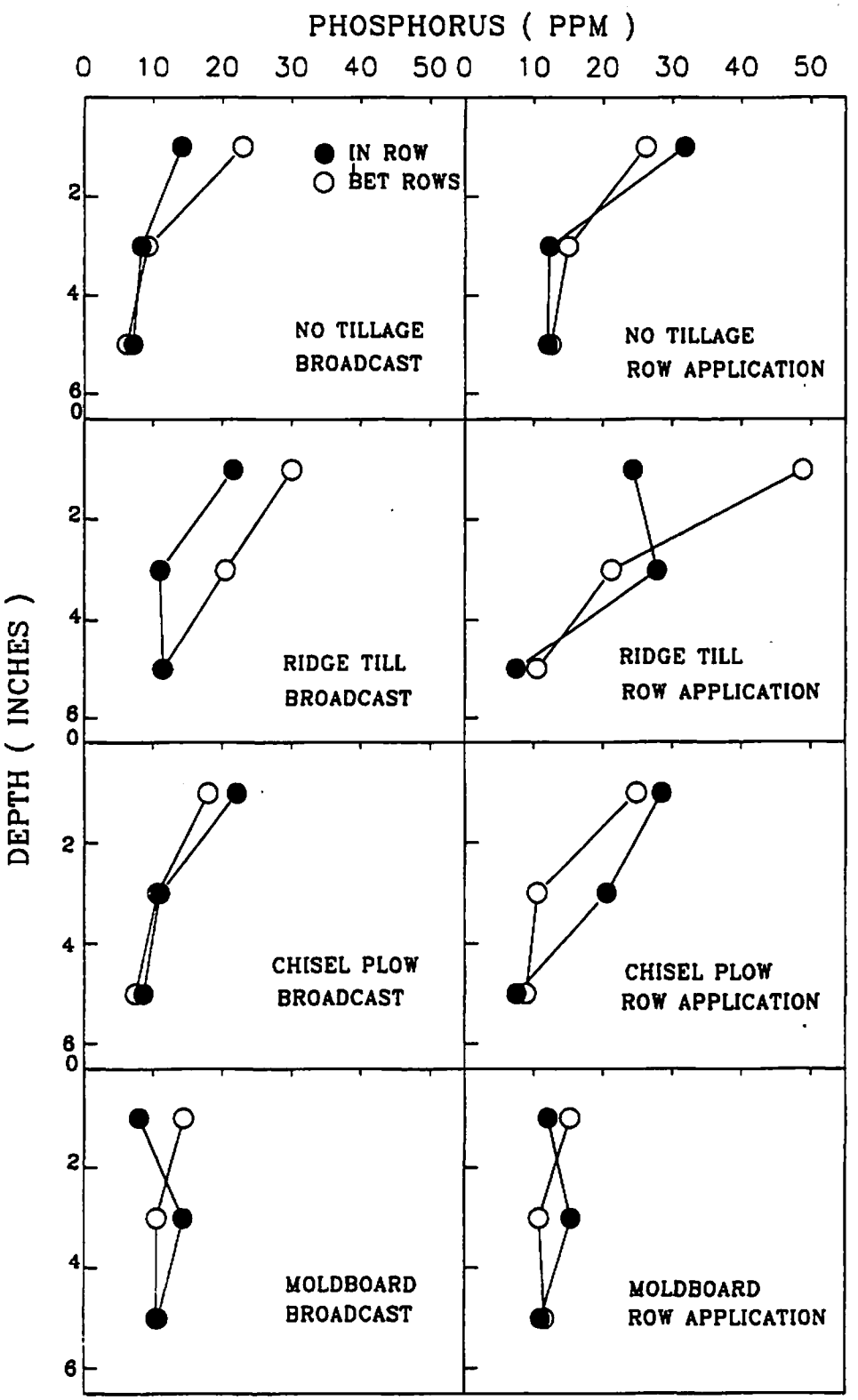

Table 9. Effect of tillage and method of phosphorus application on corn tissue N , P and K in Meeker Co. (Kuechle farm) on 7/26/91[1].

Fertilizer	TILLAGE SYSTEMS				
	No Tillage	Ridge Tillage	Chisel Plow	Moldboard Plow	Mean[2]
			N (%)		
Broadcast	3.10	2.96	2.86	2.56	2.87 a
Row applied	2.98	2.67	2.90	2.71	2.81 a
Mean	3.04 a	2.81 bc	2.88 ab	2.63 c	
			P (%)		
Broadcast	0.29	0.30	0.29	0.23	0.28 a
Row applied	0.28	0.26	0.27	0.26	0.26 a
Mean	0.29 a	0.28 a	0.28 a	0.24 b	
			K (%)		
Broadcast	1.18	1.29	1.46	1.42	1.34 a
Row applied	1.32	1.34	1.46	1.55	1.42 a
Mean[2]	1.25 a	1.31 a	1.46 a	1.48 a	

1. Pr > F value for main effects and interactions are

	N	P	K
Tillage	0.082 (n=8)	0.141 (n=8)	0.130 (n= 8)
Fertilizer	0.581 (n=16)	0.371 (n=16)	0.295 (n=16)
Tillage x Fertilizer	0.437 (n=4)	0.355 (n=4)	0.873 (n=4)

2. Means within same row or column with the same letter are not significantly different at $\alpha = 0.1$.

Table 10.Effect of tillage and method of Phosphorus application on corn stand (Plants/ac x 10^{-3}) in Meeker Co.(Kuechle Farm), MN , on 6/17/1991[1].

Method of P appln	Tillage				
	No Till	Ridge Till	Chisel Plow	Moldboard Plow	Mean
Broadcast	28.6	29.7	30.3	29.8	29.7 a
Row applied	29.9	30.9	30.7	30.6	30.5 a
Mean	29.2 a	30.3 a	30.6 a	30.2 a	

1 The p value for tillage,method of P application and tillage by method of P application for stand are 0.0.452 (n=32), 0.159 (n= 64), and 0.871 (n=16) respectively. Means within the same row or column with the same letters are not significantly different ($\alpha = 0.10$).

Table 11.Effect of tillage and method of Phosphorus application on corn stand (Plants/ac x 10^{-3}) at harvest(10/9/91) in Meeker Co. (Kuechle Farm), MN , 1991[1].

Method of P appln	Tillage				
	No Till	Ridge Till	Chisel Plow	Moldboard Plow	Mean
Broadcast	25.8	27.1	30.2	29.4	28.2 a
Row applied	28.9	28.8	28.2	28.7	28.7 a
Mean	27.5 a	28.0 a	29.2 a	29.1 a	

1. The p value for tillage,method of P application and tillage by method of P application for stand are 0.162, 0.674 and 0.050 respectively. Means within the same row or column with the same letters are not significantly different (α = 0.10).

Table 12. Effect of tillage and soil type on corn stand (Plants/acx10^{-3} per ac) in Meeker county (Kuechle Farm), MN 1991[1].

Soil	Tillage				
	No Till	Ridge Till	Chisel Plow	Moldboard Plow	Mean
Delft clayloam	26.4	27.5	28.7	29.2	27.9 a
Marcellon loam	30.2	27.8	29.6	28.3	29.2 a
Koronis fine sandyloam	27.5	32.6	29.9	29.4	28.8 a
Mean	27.5 a	28.1 a	29.2 a	29.1 a	

1.The p value for tillage, soil and tillage by soil type for corn stand are 0.205, 0.099 and 0.903 respectively. Mean with the same letters are not significantly different (α = 0.10).

Table 13. Effect of method of phosphorus application in ridge tillage on soybean population at MeekerCo. kuechle farm) on 6/17/91[1].

Method of fertilizer Application	Population(Plants/Ac x 10^{-3})
Broadcast	196.8 a (n= 14)
Row applied	226.7 a (n= 12)
Mean	211.8

1 The p value for method of phosphorus application in ridge till is 0.284. Means within same column with same letter are not sinificantly different (α = 0.10).

Table 14. Effect of tillage on soybean population in Meeker Co.(Kuechle farm) on 6/17/91[1].

Tillage	Population (Plants/Ac x 10^{-3})
No Tillage	80.5 a
Ridge tillage	211.8 b
Chisel Plow	87.4 a
Moldboard Plow	146.6 c

1.The p value for tillage on soybean population is 0.001 (n=16). Means within same column with same letter are not significantly different at α = 0.1.

Table 15. Effect of tillage and method of Phosphorus application on corn yield (bu/ac) in Meeker Co. (Kuechle Farm),MN, 1991[1].

Method of P application	Tillage				
	No Till	Ridge Till	Chisel Plow	Moldboard Plow	Mean
Broadcast	91.2	89.5	102.1	92.0	94.2 a
Row applied	91.9	105.9	107.2	120.4	105.9 b
Mean	91.6 a	98.4 a	104.7 a	106.2 a	

1.The p value for tillage,method of P application and tillage by method of P application for yield are 0.375, 0.119 and 0.414 respectively. Means within the same row or column with the same letters are not significantly different (α = 0.10).

Table16. Effect of tillage and soil types on corn yield (bu/ac) in Meeker Co.(Kuechle Farm), MN , 1991[1].

Soil	Tillage				
	No Till	Ridge Till	Chisel Plow	Moldboard Plow	Mean
Delft clayloam	85.4	90.3	88.8	102.6	91.9 a
Marcellon loam	111.1	99.3	122.4	90.4	106.7b
Koronis fine sandyloam	89.4	140.7	118.7	121.3	112.2 b
Mean	91.6 a	98.4 a	104.7 a	106.2 a	

1 The p value for tillage, soil and tillage by soil type for corn yield are 0.342, 0.022 and 0.612 respectively. Mean within the same row or column with the same letters are not significantly different (α = 0.10).

Table 17.Effect of tillage and method of Phosphorus application on corn grain moisture (per cent) in Meeker Co.(Kuechle Farm), MN , 1991[1].

Method of P appln	Tillage				
	No Till	Ridge Till	Chisel Plow	Moldboard Plow	Mean
Broadcast	21.1	20.0	20.4	21.5	20.8 a
Row applied	20.3	17.9	19.0	17.1	18.7 b
Mean	20.7 a	18.8 a	19.7 a	19.3 a	

1 The p value for tillage,method of P application and tillage by method of P application for grain moisture are 0.396, 0.017 and 0.347 respectively. Means within the same row or column with the same letters are not significantly different (α = 0.10).

Table 18. Effect of tillage and soil type on corn grain moisture (in percent) in Meeker Co.(Kuechle Farm), MN , 1991.

Soil	Tillage				
	No Till	Ridge Till	Chisel Plow	Moldboard Plow	Mean
Delft clayloam	20.5	20.3	21.3	20.5	20.7 a
Marcellon loam	18.4	17.6	17.7	16.6	17.6 a
Koronis fine sandy loam	22.8	17.6	18.6	18.3	19.7 a
Mean	20.7 a	18.8 a	19.7 a	19.3 a	

1 The p value for tillage, soil and tillage by soil type for grain moisture are 0.602, 0.102 and 0.891 respectively. Mean with the same letters are not significantly different (α = 0.10).

Table 19 Effect of tillage[1] and method of P application[2] on soybean yield (Bu/Ac) at Meeker Co.(kuechle farm) MN., 1991[3]

Method of P application	Tillage				
	No Till	Ridge Till	Chisel Plow	Moldboard Plow	Mean[4]
Broadcast	39.0	35.8 a	31.7	53.2	42.2 a
None	34.3	—	29.6	48.5	38.2 a
Row applied	—	39.9 a	—	—	
Mean[4]	36.7 a	37.9	30.7 a	50.9 b	

1 The statistical analysis for ridge tillage was carried out separately considering the main effect of only the methods of P application.
2 With no till,chisel plow and moldboard plow as main plot treatments the subplot treatments were broadcast and none.
3 The p value for tillage(except ridge till), method of P application and tillage by method of P application for grain yield are 0.003, 0.263 and 0.933 respectively. The p value for method of application of P application in ridge till is 0.386
4 Means within the row or column with the same letters are not significantly different (α = 0.10)

Table 20 Effect of tillage[1] and method of P fertilizer[2] application on soybean grain moisture (in percent) at Meeker Co.(Kuechle farm) MN., 1991[3]

Method of P application	Tillage				
	No Till	Ridge Till	Chisel Plow	Moldboard Plow	Mean[4]
Broadcast	6.6	6.3a	6.4	6.5	6.5 a
None	6.4	--	6.6	6.5	6.5 a
Row applied	—	6.3a	--	--	
Mean[4]	6.5 a	6.3	6.5 a	6.5 a	

1 The statistical analysis for ridge tillage was carried out separately considering the main effect of only the methods of P application.
2 With no till,chisel plow and moldboard plow as main plot treatments the subplot treatments were broadcast and none.
3 The p value for tillage(except ridge till), method of P application and tillage by method of P application for grain moisture content are 0.964, 0.977 and 0.415 respectively. The p value for method of application of P application in ridge till is 0.961

Table 18. Effect of tillage and soil type on corn grain moisture (in percent) in Meeker Co.(Kuechle Farm), MN , 1991.

Soil	Tillage				
	No Till	Ridge Till	Chisel Plow	Moldboard Plow	Mean
Delft clayloam	20.5	20.3	21.3	20.5	20.7 a
Marcellon loam	18.4	17.6	17.7	16.6	17.6 a
Koronis fine sandy loam	22.8	17.6	18.6	18.3	19.7 a
Mean	20.7 a	18.8 a	19.7 a	19.3 a	

1 The p value for tillage, soil and tillage by soil type for grain moisture are 0.602, 0.102 and 0.891 respectively. Mean with the same letters are not significantly different (α = 0.10).

Table 19 Effect of tillage[1] and method of P application[2] on soybean yield (Bu/Ac) at Meeker Co.(kuechle farm) MN., 1991[3]

Method of P application	Tillage				
	No Till	Ridge Till	Chisel Plow	Moldboard Plow	Mean[4]
Broadcast	39.0	35.8 a	31.7	53.2	42.2 a
None	34.3	—	29.6	48.5	38.2 a
Row applied	—	39.9 a	—	—	
Mean[4]	36.7 a	37.9	30.7 a	50.9 b	

1 The statistical analysis for ridge tillage was carried out separately considering the main effect of only the methods of P application.
2 With no till, chisel plow and moldboard plow as main plot treatments the subplot treatments were broadcast and none.
3 The p value for tillage(except ridge till), method of P application and tillage by method of P application for grain yield are 0.003, 0.263 and 0.933 respectively. The p value for method of application of P application in ridge till is 0.386
4 Means within the row or column with the same letters are not significantly different (α = 0.10)

Table 20 Effect of tillage[1] and method of P fertilizer[2] application on soybean grain moisture (in percent) at Meeker Co.(Kuechle farm) MN., 1991[3]

Method of P application	Tillage				
	No Till	Ridge Till	Chisel Plow	Moldboard Plow	Mean[4]
Broadcast	6.6	6.3a	6.4	6.5	6.5 a
None	6.4	--	6.6	6.5	6.5 a
Row applied	—	6.3a	--	--	
Mean[4]	6.5 a	6.3	6.5 a	6.5 a	

1 The statistical analysis for ridge tillage was carried out separately considering the main effect of only the methods of P application.
2 With no till, chisel plow and moldboard plow as main plot treatments the subplot treatments were broadcast and none.
3 The p value for tillage(except ridge till), method of P application and tillage by method of P application for grain moisture content are 0.964, 0.977 and 0.415 respectively. The p value for method of application of P application in ridge till is 0.961
4 Means within the row or column with the same letters are not significantly different (α = 0.10)

Tillage and Time of Manure Application Effects on Corn Response and Losses of Manure N and P at Meeker County, MN[1]

D. Ginting, J.F. Moncrief, S.C. Gupta, M.B. Kells, and B.J. Johnson[2]

Abstract

Two sources of manure applied fall and spring were compared to spring applied anhydrous ammonia. Nitrogen source comparisons were evaluated with two tillage systems (chisel and moldboard plowing). Application of dairy manure increased soil residue cover. The spring application provided more residue than the fall application due to fall primary tillage. Residue cover between plant rows was higher than residue in the rows. Chisel plowing resulted in higer residue cover. Corn stand was similar across the tillage and manure treatments. P concentration of the soil under chisel plowing is higher than P concentration under moldboard plowing. Spring application of manure increased soil P mainly on the top 3 inch depth.
Soil pH did not change with different tillage and manure treatment. Pig manure and dairy manure application resulted in similar earleaf N and K concentration. Spring application of dairy manure, resulted in higher P concentration of earleaf, however, grain yield was 15 bu/acre lower. Grain N and protein concentration is higher when soil is treated with manure. Soil type and tillage interacted significantly in influencing grain yield and number of corn ears. Poorly drained soil, Cordova soils, resulted in higher yield when moldboard plowed compared to chisel plowed.

Materials and Methods

Tillage ,source of nutrients (dairy manure, pig manure and anhydrous ammonia) and time of application of the manures (Fall and Spring) were compared to evaluate corn response and loss of N and P. This experiment was a continuation of the same experiment conducted in 1990. For both-year experiments, corn was grown.

Anhydrous ammonia was applied (5/13/91). At planting time (5/20/91), 150 lb/A starter (9-23-30) was applied. Time of application of manure in 1991 experiments were Fall (9/11/90) and Spring (5/10/91 or 5/15/91) prior to corn planting. Control plots were not treated with either anhydrous ammonia or manure.

The agronomic practices and composition of manures applied in 1990 and 1991 are shown in Table 1. In 1991, the rate of manure applied in fall and spring were similar. However, the rate of manure-N, P or K of dairy and pig manure sources are different due to the differences in nutrient concentration.

Measurements. Measurements taken were soil residue cover (6/11/91), corn stands (6/11/91), soil P and pH (6/11/91) and earleaf N, P and K concentration (7/19/91).

Residue cover was estimated by the line transect method and characterized in and between the rows within each plot. Soil cover measurements were made over 10 feet of row with a line consisting of 25 points. "In row" is defined as a four inch strip centered over the row and "between row" as the remainder.

Corns stands were estimated from the numbers of plants within the 10 foot row from each plot. Soil sample was taken in the row and between the rows at three depths (0-2, 2-4 and 4-6 inch). Soil P and pH, and corn earleaf N, P, and K concentration was determined using standard analysis.
Grain yield was harvest from rows of 40 feet long (Oct, 10, 1991).

Experimental Design. The experiment was arranged in split plot with tillage(chisel plowing and moldboard plowing) as main plots and nutrient sources (fall pig, fall dairy, spring pig, spring dairy, anhydrous ammonia, and none) as subplots. The design was extended to split-split-split plot to evaluate the influences of row position and soil depth in soil pH.

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Results and Discussions

Residue Cover. Tillage significantly influenced residue cover measured in spring 1991 (Table 2). The chisel plowing system resulted in higher soil cover than moldboard plowing. Soil inversion with moldboard plowing incorporated more residue. However, both chisel and moldboard plowing resulted in less than 30% soil residue cover, which is considered necessary for soil conservation. Lower than 30% residue cover was mainly due to excessive secondary tillage.

The application of pig manure, dairy manure and anhydrous ammonia resulted in higher soil residue cover compared to control plots. Dairy manure provide more residue cover than pig manure, because of the straw content in dairy manure. Spring application of dairy manure provide significantly more residue cover than fall dairy application. Loss of residue from the fall application is due to fall primary tillage. Residue from plots treated with anhydrous ammonia was higher than residue from fall pig or spring pig sources. Control plots resulted in the lowest residue cover.

Residue was significantly greater between the rows than in the rows, especially in the chisel plowed plots (Fig. 1). This indicated that straw from manure and corn residue was concentrated between the row. Row position interacted significantly with tillage or nitrogen source. Variability among samples (Fig. 1) within a treatment was high. Distribution of manure or plant residue is quite variable.

Corn Stands. Tillage or nitrogen source did not influence corn plant population. The time of application or manure source did not influence corn population (Table 3).

Soil Phosphorous. Tillage influenced soil phosphorus content significantly (Table 4). Chisel plowing consistently resulted in higher soil P levels on plots treated with anhydrous ammonia or spring pig manure (Figure 2).

Spring pig manure application increased soil phosphorous significantly. This was also shown by a higher P concentration of corn earleaves when treated with manure (Table 6). The increase of soil P concentration with manure application was consistent across the tillage treatments (Fig. 2). Manure P application increase soil P about 7.5 ppm in moldboard plowed treatment and or 19.6 ppm in the chisel plowed treatment.

The soil P concentration gradient was steep with depth especially on the plot treated with manure and chisel plowed (Fig. 2). The gradient decreased significantly from 3 inch deep. The gradient was negligible when no phosphorous was applied. The tillage, nutrient source, and soil depth interaction was significant at $P < 0.004$.

Soil pH. Soil pH was not influenced by tillage, nutrient source or soil depth (Table 5). However, tillage and soil depth, also tillage, nutrient source and soil depth interacted significantly at $P < 0.009$ and $P < 0.057$, respectively. At 0-2 inch deep, chisel plowing resulted in higher pH compared to moldboard plowing, especially when treated with anhydrous ammonia (Fig. 3). It may be that ammonium did not nitrify as rapidly with chisel plowing producing hydrogen ion, which reduce the pH.

Corn Earleaf N, P, K. Tillage did not influence N, P, or K of corn earleaf. Pig manure and dairy manure resulted in the same earleaf N concentration (Table 6). Control plots resulted in the lowest N concentration. Time of manure application did not affect corn earleaf N concentration.

Spring dairy manure application resulted in significantly higher corn earleaf P compared to other time and manure source applications. Corn earleaf K was not influenced by manure application.

Grain Yield. Yield was significantly influenced by manure treatment (table 8). The spring applied dairy manure resulted in 15 bu/a lower yield than the other manure and time of application combinations. No nitrogen application resulted in the lowest yield, 74 bu/a. Grain moistures are similar across tillage, nutrient sources (Table 7). Grain N and protein concentration is significantly influenced by manure treatments (Table 11 and 12).

A change in tillage system from moldboard plow to chisel plowing on Cordova soil, poory drained soil resulted in a decrease of yield and number of corn ears (Fig.4 and 5). Koronis sandy loam and Marcellon sandy loam resulted in similar yields and number of corn ears (Table 10). Corn population at harvest is significantly influenced by tillage. On Cordova soil, moldboard plowing resulted in higher plant population (Table 9) compared to chisel plowing, however on Koronis and Marcellon corn population at harvest are similar (Table 8).Precipitation data is presented in Fig. 6.

Table 1. Cultural practices at Meeker County, MN. 1991.

Tillage

Fall Chisel Plowed, spring field cultivated
Fall Moldboard Plowed, spring field cultivated

Crop

1990 Corn-Pioneer 3751
1991 Corn-Northrop King

Planting and Harvest Dates

Plots were planted with a four row John Deere Maximerge planter equipped with spring tine row cleaners at a 38 inch row spacing.

Crop	Planting Date	Planting Rate	Harvested
Corn	May 20,1991	30,000 seeds/A	

1990 Fertilizer and Manure Analysis

Crop	Material Analysis	Rate	Actual N	Actual P_2O_5	Actual K_2O	Date Applied
			---- lb/A ----			
Corn	9-23-30[1]	150 lb/A	14	35	45	May 8, 1990
	82-0-0[2]	85 lb/A	70	0	0	April 24, 1990

1. Planter placement 2" beside and 2" below row.
2. Anhydrous ammonia was applied on selected plots.

Chemical composition of dairy and pig manure from barn gutters and an anaerobic pit from farrowing house at Meeker County, Fall-1989.

Manure Type and Rate of Application		Nitrogen					Phosphorus		Potassium	
		Mineral	Organic	Total	$	Available	P_2O_5	$	K_2O	$
Source	Rate	------- lb/A --------				- lb/A -	lb/A		lb/A	
Dairy	13.2 t/A	62	97	159	15.90	86	107	21.40	134	13.40
Pig	4,100 g/A	120	75	195	19.50	146	212	46.68	100	10.00

1. It is assumed that fertilizer cost .10, .20, and .10 per pound of N, P_2O_5, and K_2O respectively. All mineral N and 25% of organic N are available.

Chemical composition of dairy and pig manure from barn gutters and an anaerobic pit from farrowing house at Meeker County, Spring-1990 (4/5/90 for liquid and 5/18/90 for dairy).

Manure Type and Rate of Application		Nitrogen					Phosphorus		Potassium	
		Mineral	Organic	Total	$	Available	P_2O_5	$	K_2O	$
Source	Rate	------- lb/A --------				- lb/A --	lb/A		lb/A	
Dairy	11.6 t/A	149	61	210	21.00	164	89	17.80	217	21.70
Pig	4,100 g/A	93	43	136	13.60	108	127	25.40	82	8.20

1. It is assumed that fertilizer cost .10, .20, and .10 per pound of N, P_2O_5, and K_2O respectively. All mineral N and 25% of organic N are available.

1991 Fertilizer and Manure Analysis

Crop	Material Analysis	Rate	Actual N	Actual P_2O_5	Actual K_2O	Date Applied
			---- lb/A ----			
Corn	8-23-30[1]	150 lb/A	12	35	45	May 20, 1991
	82-0-0[2]	100 lb/A	82	0	0	May 13, 1991

1. Planter placement 2" beside and 2" below row.
2. Anhydrous ammonia was applied on selected plots.

Chemical composition of dairy and pig manure from barn gutters and an anaerobic pit from farrowing house at Meeker County, Fall-1990 and Spring-1991.

Manure Type and Rate of Application		Nitrogen					Phosphorus		Potassium		Date
		mineral	Organic	Total	$	Available	P_2O_5	$	K_2O	$	Applied
Source	Rate	------- lb/A --------				- lb/A --	lb/A		lb/A		
Fall Pig	3250 g/A	65	60	125	12.5	80	65	13.0	75	7.5	11/9/90
Fall Dairy	13.9 t/A	4	155	159	15.9	43	12	2.4	11	1.1	11/9/90
Spring Pig	3700 g/A	74	68	142	14.2	91	75	15.0	85	8.5	5/10/91
Spring Dairy	13.9 t/A	6	134	140	14.0	40	41	9.2	25	2.5	5/15/91

1. It is assumed that fertilizer cost .10, .20, and .10 per pound of N, P_2O_5, and K_2O respectively. All mineral N and 25% of organic N are available.

Soil

The soils present at this site are as follows: 60% is Koronis fine sandy loam (Mollic Haplaudalfs, fine-loamy, mixed, mesic) with good internal drainage; 20% Cordova loam (Typic Argiaquolls, fine-loamy, mixed, mesic) with poor internal drainage; and the remaining 20% is Marcellon loam (Aquic Argiudolls, fine-loamy, mixed, mesic) with somewhat poor internal drainage.

Weed Control: - 0.25 lb a.i./A Buctril + 0.5 lb a.i./A Atrazine as postemergence herbicide.
- 1.5 lb a.i./A Lasso as preemergence herbicide.

Insect Control: - 8.0 oz/A Lorsban 15G.

Table 2. Effects of tillage, nutrient source and row position on residue cover (%) at Meeker County, (Ecker Farm), MN (June 11, 1991).

N Source	Tillage						Overall Mean
	MOLDBOARD			CHISEL			
	In Row	Between Row	Mean	In Row	Between Row	Mean	
	%						
Fall Hog	2.5 (4.8)	2.3 (2.9)	2.4 (3.9)	12.3 (10.3)	21.0 (9.5)	16.7 (10.7)	**9.5 bc** **(10.7)**
Spr Hog	2.8 (3.2)	4.8 (5.3)	3.8 (4.4)	14.8 (11.8)	18.0 (11.1)	16.4 (11.4)	**10.1 bc** **(10.7)**
Fall Dairy	2.5 (2.5)	5.3 (5.0)	3.9 (4.1)	15.1 (11.2)	23.8 (10.0)	19.4 (11.4)	**11.6 bc** **(11.5)**
Spr Dairy	14.0 (10.8)	29.5 (22.1)	21.8 (18.8)	19.5 (20.7)	32.5 (9.6)	26.0 (17.6)	**23.9 a** **(18.0)**
Anhydrous	4.0 (4.6)	6.0 (4.4)	5.0 (4.5)	17.0 (15.6)	26.3 (11.0)	21.6 (14.1)	**13.3 b** **(13.3)**
None	2.8 (4.3)	2.0 (4.1)	2.4 (4.2)	9.5 (10.4)	18.8 (10.6)	14.1 (11.3)	**8.3 c** **(10.3)**
Mean	*4.8* *(7.0)*	*8.3* *(13.6)*	*6.5 b* *(11.0)*	*14.7* *(13.9)*	*23.4* *(11.2)*	*19.0 a* *(13.3)*	-----

- Numbers in parenthesis are Standard deviations.
- P>F value for main effects and significant extractions are:
- tillage = 0.001 (n=192)
- nutrient source = 0.001 (n=064)
- row position = 0.001 (n=192)
- tillage x row position= 0.007 (n=96)
- nutrient source x row position= 0.009 (n=32)
- tillage x nutrient source x row position=0.379 (n=16)
* Means at the same row or column with the same letters are not significantly different at $\alpha = 0.1$.

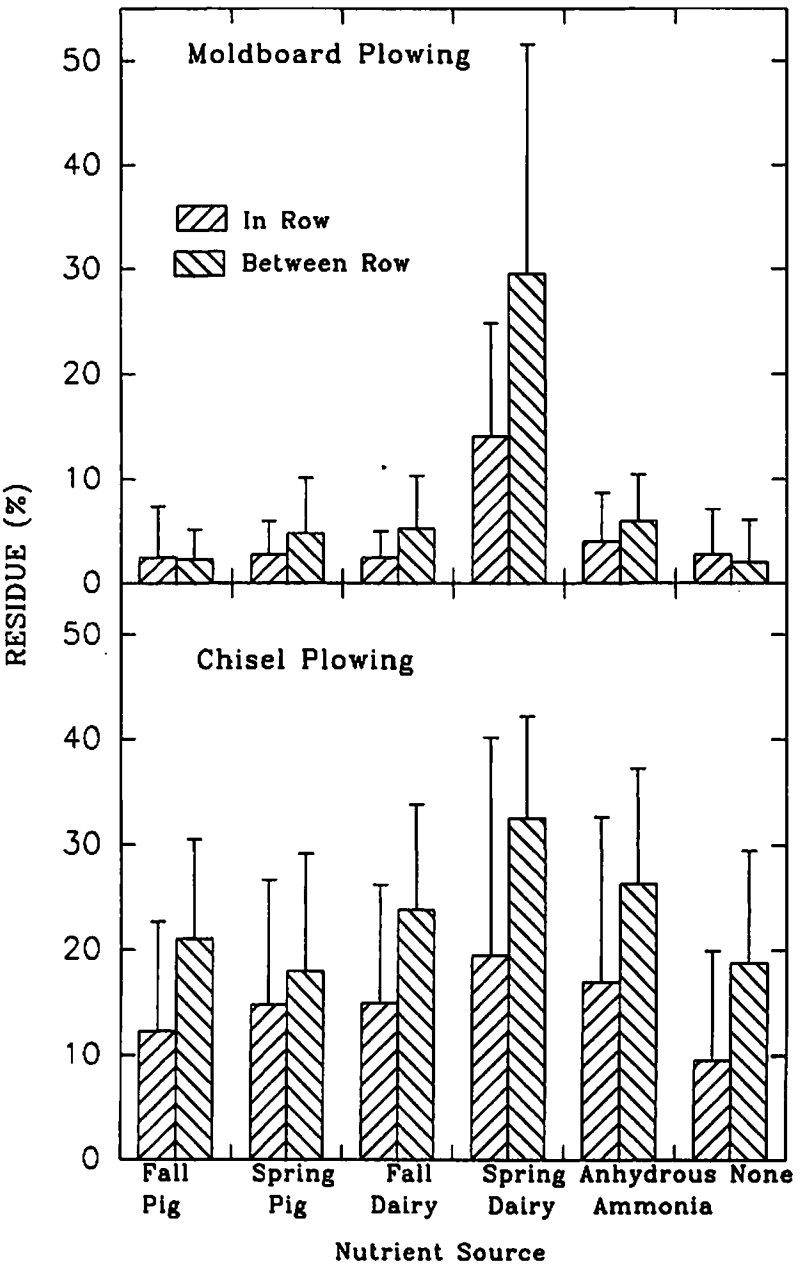

Fig. 1. Effects of tillage, nutrient source, and row position on soil cover by residue in Meeker Co., MN, 1991.

Table 3. The effects of tillage and nutrient source on corn population at Meeker County (Ecker Farm), MN (June 11,1991).

Nitrogen Source	Tillage		
	Moldboard	Chisel	Mean
	----------1000 plants/a----------		
Fall Pig	31.6 (1.8)	31.8 (2.9)	31.7 a (2.2)
Spring Pig	30.7 (2.3)	31.6 (2.9)	31.1 a (2.6)
Fall Dairy	30.3 (2.3)	31.9 (2.8)	31.1 a (2.6)
Spring Dairy	30.6 (2.2)	31.1 (2.6)	30.9 a (2.3)
Anhydrous	31.0 (3.1)	31.0 (2.1)	31.0 a (2.6)
None	30.7 (2.9)	31.6 (2.7)	31.1 a (2.8)
Mean	*30.8 a* *(2.4)*	*31.5 a* *(2.6)*	----

Number in parenthesis are Standard Deviations.
Means at the same row followed the same letters are not significantly different.
at $\alpha = 0.1$.

Table 4. Effects of tillage, nutrient source and soil depth on soil P concentration (ppm) at Meeker County (Ecker Farm), MN (June 11, 1991).

Soil depth (inches)	Tillage						Overall Mean
	MOLDBOARD			CHISEL			
	Spring Pig	Anhydrous	Mean	Spring Pig	Anhydrous	Mean	
	ppm						
0-2	36.6 (9.6)	24.2 (2.3)	30.5 (9.3)	70.8 (24.3)	30.6 (12.5)	50.7 (27.9)	**40.5 (22.7)a**
2-4	27.3 (8.9)	21.0 (3.5)	24.8 (6.8)	42.5 (13.4)	29.6 (8.6)	36.0 (12.5)	**30.3 (11.3)b**
4-6	28.5 (9.6)	23.1 (3.3)	25.8 (7.2)	37.2 (9.3)	31.2 (17.0)	33.0 (13.1)	**30.0 (11.1)b**
Mean	*30.8 (9.5)*	*23.3 (3.0)*	----	*50.1 (21.8)*	*30.5 (11.9)*	----	
Overall Mean	----	----	**27.0 (7.8)b**	----	----	**39.5 (19.8)a**	

- Numbers in parenthesis are Standard deviations.
- P value of main effect and significant interactions.
- tillage = 0.017 (n=24) - nsource x depth = 0.005 (n=08)
- nutrient source = 0.063 (n=24) - tillage x nutrient source x soil depth = 0.084 (n=04)
- soil depth = 0.003 (n=16)

Means at the same row or column with the same letters are not significantly different.

Table 5. Effects of tillage, nutrient source and soil depth on soil pH at Meeker County (Ecker Farm), MN, (6/11/91).

Soil depth (inches)	Tillage						Overall Mean
	MOLDBOARD			CHISEL			
	Spring Pig	Anhydrous	Mean	Spring Pig	Anhydrous	Mean	
0-2	5.9 (0.3)	5.8 (0.2)	5.9 (0.2)	6.1 (0.3)	6.5 (0.6)	6.3 (0.5)	**6.1 a (0.4)**
2-4	6.0 (0.1)	5.9 (0.1)	6.0 (0.1)	6.1 (0.3)	6.2 (0.7)	6.1 (0.5)	**6.0 a (11.3)**
4-6	6.0 (0.1)	6.3 (0.5)	6.2 (0.4)	6.0 (0.4)	6.1 (0.6)	6.1 (0.5)	**6.1 a (0.4)**
Mean	*6.0 (0.2)*	*6.0 (0.4)*	----	*6.0 (0.3)*	*6.3 (0.6)*	----	
Overall Mean	----	----	**6.0 a (0.3)**	----	----	**6.2 a (0.5)**	

- Numbers in parenthesis are Standard deviations.
- P value of main effect and significant interactions.
- tillage = 0.428 (n=24) - tillage x soil depth = 0.009 (n=08)
- nutrient source = 0.566 (n=24) - tillage x nutrient source x soil depth = 0.057 (n=04)
- soil depth = 0.653 (n=16)

* Means at the same row or column with the same letters are not significantly different at $\alpha = 0.1$.

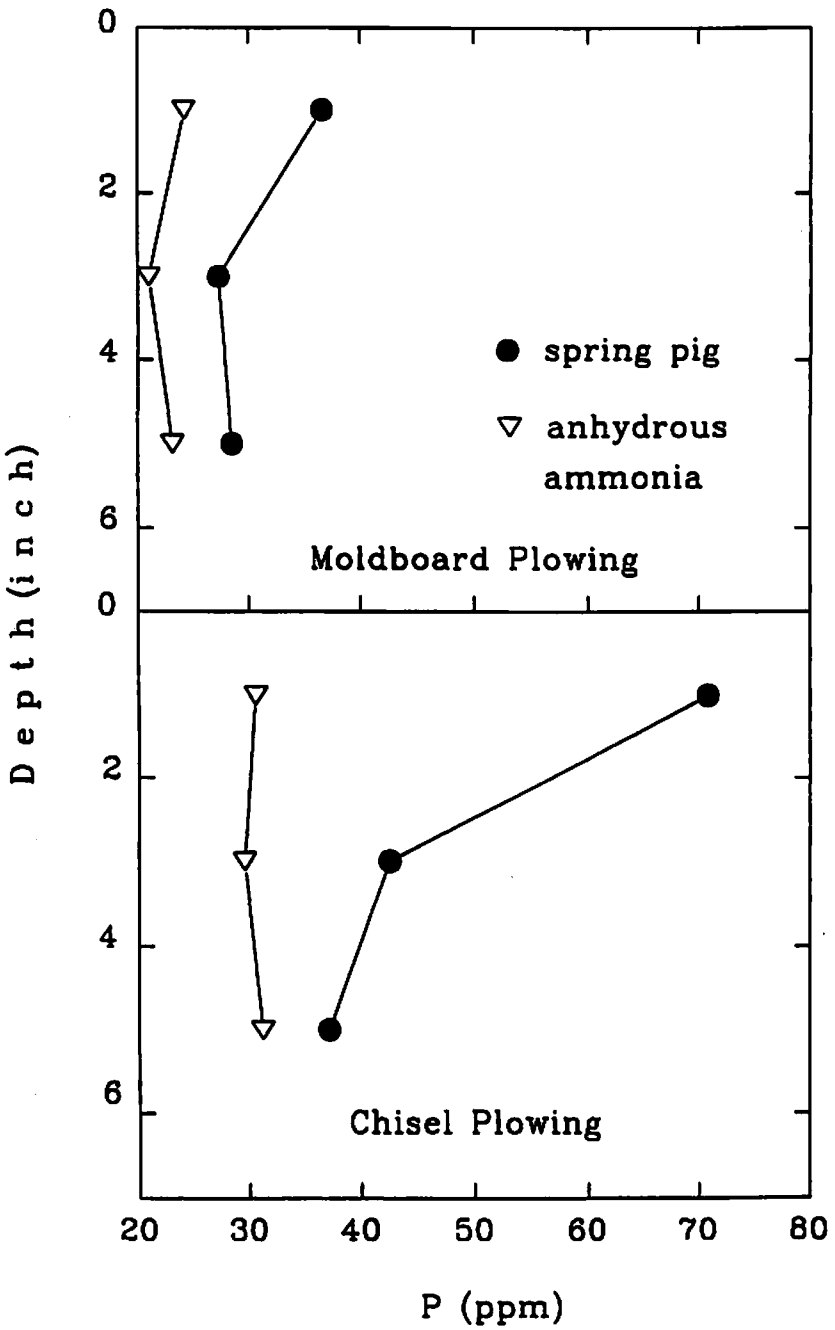

Fig. 2. Effects of tillage, N source and soil depth on soil P concentration

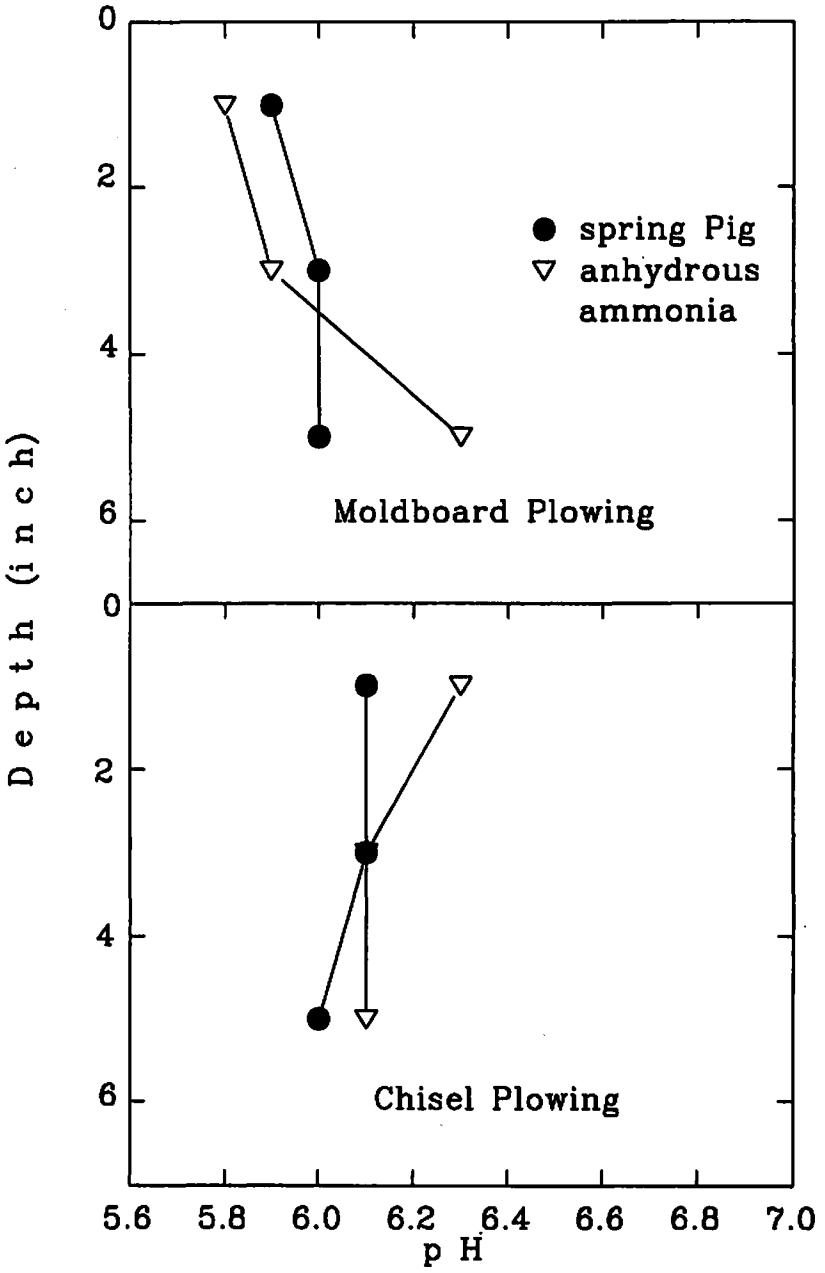

Fig. 3. Effects of tillage, N source and soil depth on soil pH at Meeker County, MN, in 1991

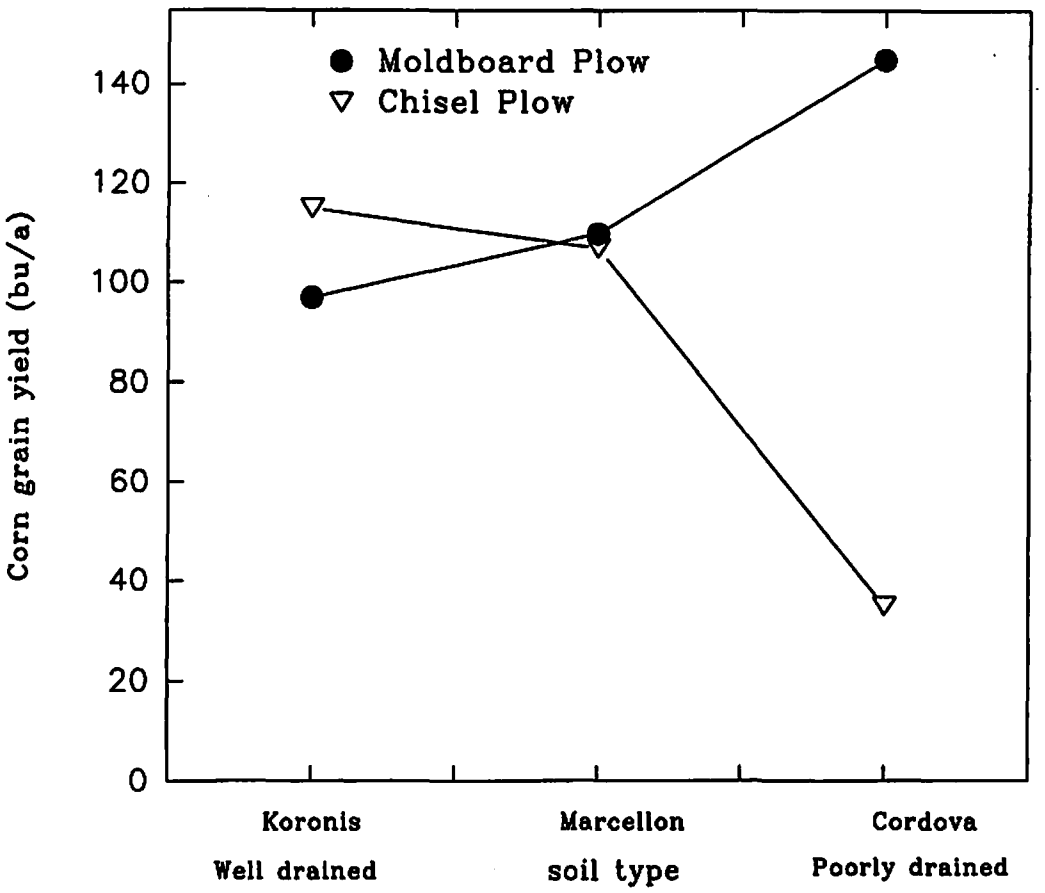

Fig. 4. Tillage system and soil type interaction on corn grain yield at Meeker Co. (Ecker farm), Oct. 10. 1991.

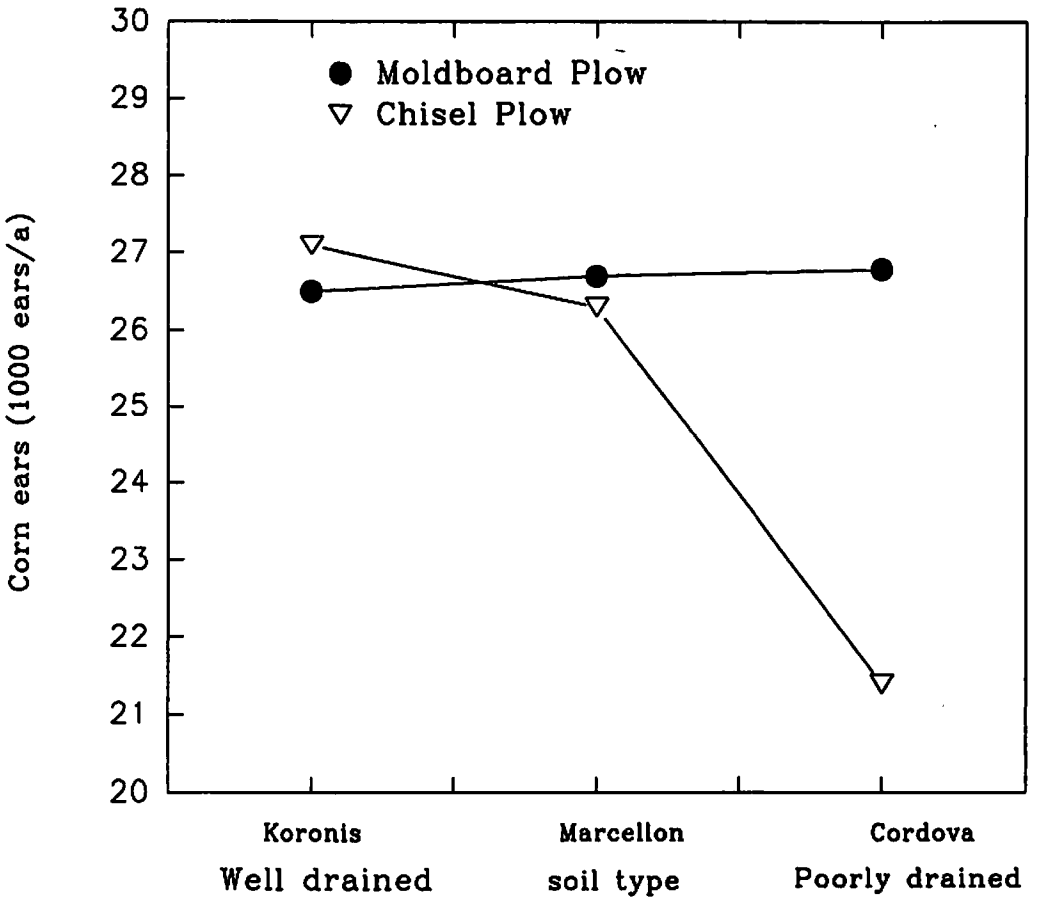

Fig. 5. Tillage system and soil type interaction on number of corn ears at Meeker Co. (Ecker farm), Oct. 10. 1991.

Table 6. The effects of nutrient source on corn earleaf N, P & K at Meeker Ecker County (Ecker Farm), MN (July 19, 1991).

Nitrogen Source	Plant Tissue		
	N (%)	P (%)	K (%)
Fall Pig	1.9 b (0.2)	0.18 b (0.03)	2.5 a (0.4)
Spring Pig	2.1 ab (0.3)	0.19 b (0.02)	2.4 a (0.2)
Fall Dairy	2.0 ab (0.3)	0.20 b (0.03)	2.5 a (0.3)
Spring Dairy	1.9 ab (0.5)	0.22 a (0.02)	2.3 a (0.2)
Anhydrous	2.2 a (0.3)	0.18 b (0.03)	2.3 a (0.2)
None	1.4 c (0.2)	0.18 b (0.03)	2.3 a (0.2)
P > F	*0.0009*	*0.001*	*0.142*

- Number in parenthesis are Standard Deviations.

* Means at the same row followed the same letters are significantly different.

Table 7. Effect of tillage systems, soil type and nutrient sources on corn grain moisture at Meeker County (Ecker farm), MN (Oct. 10, 1991).

Nutrient Source	Tillage System		Mean
	Moldboard Plow	Chisel Plow	
	%		
Fall Hog	13.6(1.2)	17.0(12.7)	15.3(8.9)a
Spring Hog	14.1(2.1)	15.8(4.1)	15.0(3.3)a
Fall Dairy	12.5(1.2)	13.3(4.1)	12.9(2.9)a
Spring Dairy	13.5(1.7)	13.7(1.6)	13.6(1.6)a
Anhydrous Ammonia	14.0(3.6)	17.4(10.5)	15.7(7.7)a
None	18.6(12.0)	13.8(3.22)	16.2(8.8)a
Mean	14.4(5.3)a	15.2(7.0)a	

The p value of Tillage (n=42-43) : 0.329
Nutrient Source (n=14-15) : 0.681
Tillage x Nutrient Source interactions (n=7-8) : 0.497

Nutrient Source	Soil			Mean
	Koronis	Marcellon	Cordova	
	%			
Fall Hog	13.1(1.7)	12.9(1.4)	29.1(23.6)	15.3(8.0)a
Spring Hog	14.9(3.7)	14.0(3.1)	17.9(0.4)	15.0(3.3)a
Fall Dairy	12.2(0.9)	12.0(1.4)	17.5(7.1)	12.9(2.9)a
Spring Dairy	13.6(1.8)	13.1(1.4)	14.7(0.2)	13.6(1.6)a
Anhydrous Ammonia	17.4(9.9)	12.6(0.8)	15.0(4.6)	15.7(7.7)a
None	17.6(11.5)	12.8(1.3)	17.4(3.7)	16.2(8.8)a
Mean	14.8(6.5)a	12.9(1.7)a	18.6(9.2)a	

The p value of Nutrient Source (14-15) : 0.745
soil (n=12-48) : 0.413
Nutrient source x soil interactions (n=2-8) : 0.214

Tillage System	Soil			Mean
	Koronis	Marcellon	Cordova	
	%			
Moldboard Plow	15.2(6.8)	12.9(1.4)	14.1(2.4)	14.4(5.3)b
Chisel Plow	14.4(6.2)	12.9(2.1)	23.1(11.4)	15.2(7.0)a
Mean	14.8(6.5)a	12.9(1.7)a	18.6(9.2)a	

The p value of Tillage (n=42-43) : 0.001
soil (n=12-48) : 0.751
Tillage systems x soil interactions (n=6-24) : 0.004

Table 8. Effect of tillage systems, soil type and nutrient sources on corn grain yield at Meeker County, (Ecker Farm), Oct. 10, 1991.

Nutrient Source	Tillage System		Mean
	Moldboard Plow	Chisel Plow	
	bu/a		
Fall Hog	114(33)	101(40)	108(36)a
Spring Hog	133(34)	100(40)	116(40)a
Fall Dairy	118(34)	119(46)	119(39)a
Spring Dairy	101(35)	97(18)	99(27)a
Anhydrous Ammonia	122(29)	106(47)	114(38)a
None	58(19)	85(42)	72(34)b
Mean	108(38)a	101(39)a	

The p value of Tillage (n=42-43) : 0.455
Nutrient Source (n=14-15) : 0.005
Tillage x Nutrient Source interactions (n=7-8) : 0.304

Nutrient Source	Soil			Mean
	Koronis	Marcellon	Cordova	
	bu/a			
Fall Hog	108(24)	115(23)	92(102)	108(36)a
Spring Hog	122(35)	120(34)	79(78)	116(40)a
Fall Dairy	122(29)	117(41)	108(94)	119(39)a
Spring Dairy	92(19)	103(34)	116(50)	99(27)b
Anhydrous Ammonia	111(25)	132(28)	89(99)	114(38)a
None	81(37)	62(27)	57(46)	72(34)c
Mean	106(31)a	109(36)a	90(63)b	

The p value of Nutrient Source (14-15) : 0.001
soil (n=12-48) : 0.047
Nutrient source x soil interactions (n=2-8) : 0.963

Tillage System	Soil			Mean
	Koronis	Marcellon	Cordova	
	bu/a			
Moldboard Plow	97(35)	110((38)	145(31)	108(38)a
Chisel Plow	115(25)	107(36)	35(24)	101(39)b
Mean	106(31)a	108(36)a	90(63)a	

The p value of Tillage (n=42-43) : 0.046
soil (n=12-48) : 0.127
Tillage Systems x soil interactions (n=6-24) : 0.001

Table 9. Effect of tillage systems, soil type and nutrient sources on corn population at harvest at Meeker County (Ecker Farm) Oct. 10, 1991.

Nutrient Source	Tillage System		Mean
	Moldboard Plow	Chisel Plow	
	---------- 1000 plants/a ----------		
Fall Hog	29.2(3.1)	28.1(3.0)	28.6(7.6)a
Spring Hog	29.8(1.7)	27.7(3.5)	28.7(2.9)a
Fall Dairy	29.5(1.8)	27.5(1.3)	28.5(1.8)a
Spring Dairy	27.2(2.6)	27.3(1.3)	27.2(6.6)a
Anhydrous Ammonia	28.0(1.2)	27.5(3.2)	27.8(2.4)a
None	28.1(2.1)	28.3(1.5)	28.2(1.7)a
Mean	28.7(1.4)a	27.7(7.8)b	

The p value of Tillage (n=42-43) : 0.039
Nutrient Source (n=14-15) : 0.499
Tillage x Nutrient Source interactions (n=7-8) : 0.660

Nutrient Source	Soil			Mean
	Koronis	Marcellon	Cordova	
	---------- 1000 plants/a ----------			
Fall Hog	28.0(3.5)	29.5(2.7)	29.4(0.7)	28.6(3.0)a
Spring Hog	29.4(3.0)	28.3(3.1)	26.8(1.9)	28.7(2.9)a
Fall Dairy	28.4(2.2)	29.1(1.3)	27.5(1.5)	28.5(1.8)a
Spring Dairy	27.8(1.6)	25.7(2.5)	28.2(0.5)	27.2(2.0)a
Anhydrous Ammonia	28.2(1.3)	28.3(1.1)	25.1(6.3)	27.8(2.4)a
None	28.6(1.6)	27.4(1.8)	28.2(2.9)	28.2(1.7)a
Mean	28.4(2.3)a	28.1(2.4)a	27.5(2.6)a	

The p value of Nutrient Source (14-15) : 0.473
soil (n=12-48) : 0.392
Nutrient source x soil interactions (n=2-8) : 0.572

Tillage System	Soil			Mean
	Koronis	Marcellon	Cordova	
	---------- 1000 plants/a ----------			
Moldboard Plow	28.7(2.3)	28.4(2.6)	29.1(0.9)	28.7(2.2)a
Chisel Plow	28.1(2.2)	27.8(2.2)	25.9(2.9)	27.7(2.4)b
Mean	28.4(2.3)a	28.1(2.4)a	27.5(2.6)a	

The p value of Tillage (n=42-43) : 0.030
soil (n=12-48) : 0.466
Tillage Systems x soil interactions (n=6-24) : 0.716

Table 10. Effect of tillage systems, soil type and nutrient sources on number of corn ears at harvest at Meeker County (Ecker Farm) ,Oct. 10, 1991.

Nutrient Source	Tillage System		Mean
	Moldboard Plow	Chisel Plow	
	---------- 1000 ears/a ----------		
Fall Hog	26.1(4.4)	25.9(3.0)	26.0(3.6)bc
Spring Hog	27.8(2.0)	27.0(2.7)	27.4(2.3)ab
Fall Dairy	28.8(2.2)	27.4(1.4)	28.1(1.9)a
Spring Dairy	25.5(2.9)	25.1(1.6)	25.3(2.3)c
Anhydrous Ammonia	26.3(1.7)	25.7(4.8)	26.0(3.5)bc
None	25.0(3.2)	25.2(3.0)	25.1(3.0)c
Mean	26.6(3.0)a	26.0(2.9)a	

The p value of Tillage (n=42-43) : 0.446
Nutrient Source (n=14-15) : 0.039
Tillage x Nutrient Source interactions (n=7-8) : 0.979

Nutrient Source	Soil			Mean
	Koronis	Marcellon	Cordova	
	----------1000 ears/a----------			
Fall Hog	25.5(3.9)	28.0(2.1)	24.1(4.9)	26.0(3.6)a
Spring Hog	28.2(1.9)	27.0(2.9)	24.9(1.2)	27.4(2.3)a
Fall Dairy	28.3(2.0)	28.4(2.1)	26.8(1.5)	28.1(1.9)a
Spring Dairy	26.1(2.2	24.2(2.4)	23.9(1.2)	25.3(2.3)a
Anhydrous Ammonia	26.6(1.9)	27.1(1.1)	21.5(9.0)	26.0(3.5)a
None	26.0(3.0)	23.9(1.5)	23.6(5.1)	25.1(3.0)a
Mean	26.8(2.7)a	26.5(2.6)a	24.1(3.9)b	

The p value of Nutrient Source (14-15) : 0.126
soil (n=12-48) : 0.015
Nutrient source x soil interactions (n=2-8) : 0.544

Tillage System	Soil			Mean
	Koronis	Marcellon	Cordova	
	----------1000 ears/a ----------			
Moldboard Plow	26.5(3.4)	26.7(2.9)	26.8(1.3)	26.6(3.0)a
Chisel Plow	27.1(2.2)	26.3(2.3)	21.4(3.8)	26.0(2.9)b
Mean	26.8(2.7)a	26.5(2.6)a	24.1(3.9)b	

The p value of Tillage (n=42-43) : 0.019
soil (n=12-48) : 0.056
Tillage System x soil interactions (n=6-24) : 0.059

Table 11. Effect of tillage systems, soil type and nutrient sources on corn grain N concentration at Meeker County (Ecker Farm) ,Oct. 10, 1991.

Nutrient Source	Tillage System		Mean
	Moldboard Plow	Chisel Plow	
	----------%----------		
Fall Hog	0.95(0.09)	0.98(0.06)	0.96(0.08)a
Spring Hog	1.02(0.08)	1.04(0.13)	1.02(0.10)a
Fall Dairy	0.99(0.13)	0.99(0.09)	0.99(0.11)a
Spring Dairy	1.02(0.14)	0.97(0.04)	0.99(0.10)a
Anhydrous Ammonia	1.00(0.12)	0.9790.09)	0.98(0.10)a
None	0.95(0.13)	0.91(0.06)	0.93(0.09)a
Mean	0.99(0.11)a	0.98(0.09)a	

The p value of Tillage (n=42-43) : 0.975
Nutrient Source (n=14-15) : 0.184
Tillage x Nutrient Source interactions (n=7-8) : 0.871

Nutrient Source	Soil			Mean
	Koronis	Marcellon	Cordova	
	----------%----------			
Fall Hog	0.96(0.08)	1.01(0.06)	0.89(0.00)	0.97(0.08)ab
Spring Hog	1.02(0.09)	1.05(0.12)	0.99(0.19)	1.02(0.10)a
Fall Dairy	0.97(0.07)	1.00(0.11)	1.08(0.21)	0.99(0.11)ab
Spring Dairy	0.96(0.07)	0.99(0.08)	1.14(0.14)	0.99(0.10)ab
Anhydrous Ammonia	0.95(0.08)	1.00(0.09)	1.07(0.18)	0.98(0.10)ab
None	0.95(0.11)	0.90(0.03)	0.88(0.04)	0.93(0.09)b
Mean	0.96(0.08)a	1.00(0.09)a	1.01(0.15)a	

The p value of Nutrient Source (14-15) : 0.088
soil (n=12-48) : 0.359
Nutrient source x soil interactions (n=2-8) : 0.298

Tillage System	Soil			Mean
	Koronis	Marcellon	Cordova	
	----------%----------			
Moldboard Plow	0.95(0.09)	1.00(0.07)	1.10(0.16)	0.99(0.11)a
Chisel Plow	0.98(0.08)	1.00(0.11)	0.91(0.07)	0.98(0.09)b
Mean	0.96(0.08)a	1.00(0.09)a	1.01(0.15)a	

The p value of Tillage (n=42-43) : 0.072
soil (n=12-48) : 0.419
Tillage System x soil interactions (n=6-24) : 0.001

Table 12. Effect of tillage systems, soil type and nutrient sources on grain protein concentration at Meeker County (Ecker Farm) ,Oct. 10, 1991.

Nutrient Source	Tillage System		Mean
	Moldboard Plow	Chisel Plow	
	----------%----------		
Fall Hog	5.91(0.61)	6.10(0.38)	6.00(0.50)a
Spring Hog	6.30(0.52)	6.45(0.80)	6.38(0.66)a
Fall Dairy	6.18(0.78)	6.19(0.58)	6.18(0.66)a
Spring Dairy	6.29(0.89)	6.06(0.27)	6.18(0.62)a
Anhydrous Ammonia	6.20(0.72)	6.01(0.60)	6.10(0.64)a
None	5.86(0.80)	5.65(0.39)	5.75(0.60)a
Mean	6.13(0.69)a	6.08(0.56)a	

The p value of Tillage (n=42-43) : 0.975
Nutrient Source (n=14-15) : 0.184
Tillage x Nutrient Source interactions (n=7-8) : 0.871

Nutrient Source	Soil			Mean
	Koronis	Marcellon	Cordova	
	----------%----------			
Fall Hog	5.97(0.53)	6.30(0.37)	5.51(0.00)	6.00(0.50)ab
Spring Hog	6.34(0.55)	6.53(0.75)	6.13(1.22)	6.38(0.66)a
Fall Dairy	6.03(0.47)	6.23(0.71)	6.72(1.35)	6.18(0.66)ab
Spring Dairy	5.94(0.42)	6.18(0.51)	7.09(0.93)	6.18(0.62)ab
Anhydrous Ammonia	5.89(0.54)	6.24(0.58)	6.63(1.13)	6.10(0.64)ab
None	5.87(0.73)	5.62(0.20)	5.46(0.26)	5.75(0.60)b
Mean	6.01(0.54)a	6.82(0.57)a	6.26(0.96)a	

The p value of Nutrient Source (14-15) : 0.088
soil (n=12-48) : 0.359
Nutrient source x soil interactions (n=2-8) : 0.298

Tillage System	Soil			Mean
	Koronis	Marcellon	Cordova	
	----------%----------			
Moldboard Plow	5.92(0.59)	6.20(0.46)	6.84(1.01)	6.13(0.69)a
Chisel Plow	6.09(0.49)	6.24(0.68)	5.68(0.44)	6.08(0.56)b
Mean	6.01(0.54)a	6.22(0.58)a	6.26(0.96)a	

The p value of Tillage (n=42-43) : 0.072
soil (n=12-48) : 0.419
Tillage System x soil interactions (n=6-24) : 0.001

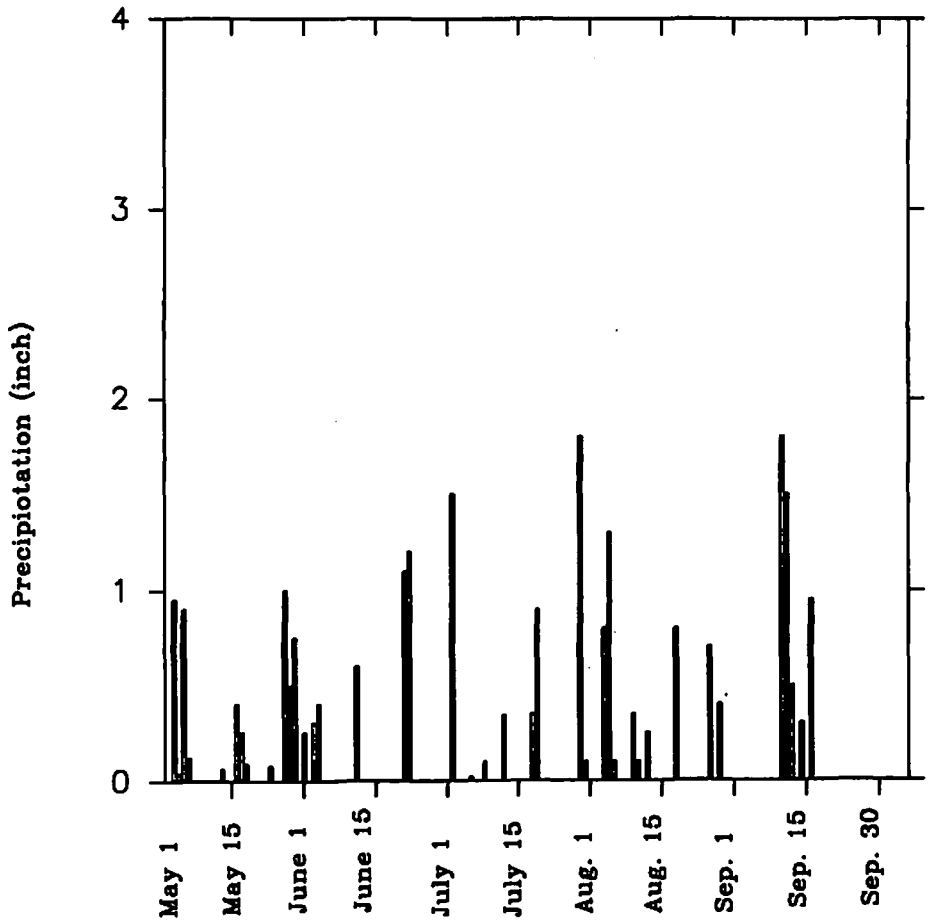

Fig. 6. Daily growing season precipitation at Kimball, Meeker County, MN. 1991 (Source:Minnesota Climatological Network).

TILLAGE EFFECTS ON CORN RESPONSE TO MANURE AT STEARNS COUNTY, MN[1]

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Abstract

Tillage, effects on two sources of plant nutrients (manure and anhydrous ammonia) on soil residue cover, plant responses and soil P, K distribution were evaluated. Soil type influences on grain yield components were also evaluated. Tillage significantly influenced surface residue. Amount of residue varied in or between rows. Lower plant population under field cultivating resulted from slippage of planter drive units. Differences in nutrient sources did not influence plant population, however soil phosphorus was increased significantly. Soil phosphorus varied significantly with row position and soil depth. Soil potassium was significantly influenced by barnyard manure application, row position and soil depth. Soil PH was not different among treatments. Ear leaf N and K were higher in moldboard plowing and field cultivating system compared to ridge tillage. Barnyard manure application significantly influence earleaf N and K. Earleaf P concentration was not influenced by manure application or tillage.

Tillage significantly influenced corn grain yield. The yield was the lowest under No-Till system which was mainly due to increased Russian Thistle. Yield were significantly effected by soil types which are different mainly in soil water holding capacity. Grain N and protein concentration of Hawick soil is significantly lower compared to deeper soil (Fairhaven and Esterville). Tillage and soil type did not influence corn population, number of ears or broken stalks above the ear. Difference in nutrient sources had no influences on grain yield. Broken corn stalks from corn borer damage was lower with barnyard manure application.

Materials and Methods

Treatments. At this site spring applied solid dairy manure from a manure pack around a pole barn and side dress anhydrous ammonia were evaluated as nitrogen sources within moldboard, chisel, and ridge till tillage systems. This experiment is a continuation of the experiments in 1989 and 1990. In 1989 two dairy manure sources (barngutter and barnyard) were evaluated in terms of ability to provide nutrients for corn. The residual effects of manure application were evaluated for soybean in 1990. No nutrient were applied in 1990. In 1991, the experimental area was treated with fresh barnyard manure. Manure was applied in the last two week of April in 1989, whereas in 1991 manure was applied on May 15.

In addition to the barnyard manure, starter (9-18-9) was applied at planting time (5/23/91). Commercial N (75 lb/A) as anhydrous ammonia was applied in each tillage treatment (6/4/91). This resulted in tillage main plots split with manure and anhydrous ammonia. Agricultural activities conducted in the experimental area are shown in Table 1.

Tillage treatments evaluated were spring moldboard plowing or field cultivation followed by a light discing, ridge till and no till systems. Within every tillage system (except no-till) there were manure and anhydrous ammonia treatments.

Measurements. Soil cover was estimated by a line transect method at two sites in each plot. Soil cover was characterized relative to row position i.e. in row and between row. In row is defined as a 10 inch strip centered over the row and between row is the remainder.The residue measurements were made on two adjacent corn rows. Soil cover measurements were made over 10 foot of row with 25 points (6/6/91).

Corn stands were estimated by tallying the number of plants in 10-feet row from each treatment where four subsamples were measured for cover (6/6/91).

Soil sample were taken from each treatment. Individual soil samples were taken both in the row and between rows at 3 depth intervals (0-2, 2-4, and 4-6 inches). Soil P, K and pH were determined.

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Corn earleaf samples at 50% silk emergence were taken on July 26, 1991 for determination of N, P, K concentration.

Grain yield and moisture, corn stand, number of ears and number of broken stalks were measured at harvest (10/2/91). Corn grain yields were estimated for each of the three soil types found at this site. The soils vary in thickness and are underlain by coarse sand and gravel. The Fairhaven loam is the deepest with 22 to 48 inches of loam textured material, the Esterville sandy loam has 11 to 22 inches of sandy loam material, the Hawick sandy loam is the thinnest with less than 10 inches of sandy loam material.

Statistical Analysis . The experimental design is a split plot with tillage main plots and nutrient source (manure/fertilizer) subplots. The design was extended to split-split-split plot to adapt the analysis of the influence of row position and soil depth on soil measurements.

Results and Discussion

Residue Cover. Soil cover by soybean residue are shown in Table 2. There was not adequate soil cover effect for soil erosion control with all conservation tillage system in 1991. Average residue cover ranged from 0.75% with moldboard plowing to 14.5% under no-till conditions.

Tillage significantly affected surface residue. Moldboard plowing consistently resulted in less residue, either in the row or between row. Field cultivating and no-tillage, provide higher surface residue. In the ridge till system, soil residue cover was low in the row. This was mainly due to the removal of residue from the row to between row with mounted sweep.

Residue cover between the row was significantly higher than residue in the row. Although the residue amount is not adequate for soil erosion control, concentrating residue cover between the row is advantageous because runoff would likely occur on this area.

Corn Population. Corn stands are shown in Table 3. Tillage significantly influence stands. Corn stands were the lowest in plots field-cultivated. Corn was planted with different planter according to tillage treatments. No-till and ridge till were planted with a buffalo till planter. The molboard and chisel treatments were planted with conventional International Harvester planter. The application of barnyard manure in 1991 as a nutrient source did not influence corn stand establishment.

Soil Phosphorus . Soil P concentration is shown in Table 4. Average soil test phosphorus are not different with tillage systems evaluated. Barnyard manure application in the spring 1991 (Table 1) significantly increase soil phosphorus about 15 ppm compared to no application.

Row position influenced soil phosphorus significantly. Soil phosphorus was significantly higher between the row than in the row (Fig. 1).

The tillage and row position interaction was significant, especially with the ridge till system. Ridge tillage resulted in higher soil concentration at 0-2 inch deep located between the row. High soil phosphorus at the soil surface may be subject to soil erosion.

The tillage and soil depth interaction was significant. Ridge till resulted in a significantly higher soil P concentration gradient than other tillage methods in 4 inches deep (Fig. 1). Tillage, manure, and soil depth or tillage, soil depth, and row position interactions were also significant at P=0.1 in soil P concentration.

Soil Potassium . Soil K are shown in table 5. As in phosphorus, average soil K concentrations was similar among tillage methods.

The nutrient source influence soil K significantly. The application of 22.7 ton/a barnyard manure (Table 1) increase soil K concentration significantly, about 52 ppm compared to no application.

Row position influence soil K significantly. Soil K between the rows is higher than soil K in the row. This was mainly due tillage.

Soil depth influenced soil K significantly, which suggested that soil K decreased with depth. The soil K gradient was steep in the top 0-4 inch deep.

Tillage interacted significantly with row position, especially with ridge till. Soil K in ridge till between the row was higher than in the row where as there was not much difference in other tillage methods. Tillage, row position, and soil depth or nutrient source, row position, and soil depth interacted significantly at $P<0.10$ (Fig. 2).

Soil pH . Soil pH was shown in Table 6. Soil pH ranged from 6.3 to 6.9. Soil pH was similar over tillage methods, nutrient source and soil depth.

Earleaf N, P, K. Corn earleaf N, P, K as influenced by barnyard manure application and tillage are in Table 7. Corn earleaf N and K concentration was significantly influenced by tillage methods. Moldboard plowing and field cultivating provided significantly higher N concentration than ridge tillage. Earleaf P was not influenced by tillage.

Corn earleaf P was not influenced by nutrient source either. Barnyard manure application influenced corn earleaf N and K concentration significantly. Visual symptoms of what appeared to be K stress in unmanured plots in July was supported by the lower K concentration. Tillage and nutrient source did not interact in earleaf N, P or K.

Tillage influenced earleaf N concentration of plots treated with anhydrous ammonia. Compared to no-till or ridge till, moldboard plowing showed significantly higher earleaf N concentration (Table 8).

Grain yield. Tillage influenced corn grain yields (table 13). Ridge tillage, chisel and moldboard plowing statistically resulted in similar corn yields. Corn grown with a no-till system resulted in about a 20 bu/a lower yield then the other tillage methods. The lower yield with the no tillage system was due in part to a Russian Thistle problem. Tillage methods did not influence grain moisture, corn population, ear numbers and broken stalks at harvest (Table 12, 14, 15, and 16).

Yields, grain N (Table 17) and protein (Table 18) concentration were also affected by soil type. Hawick, shallow soils, resulted in lower N and protein concentration. Even in the wet year (Fig. 4), soil depth was correlated to yield (Fairhaven and Esterville soils produced a higher yield than the Hawick soil). Yield performance of soils is shown in Table 13 and Fig. 3. Soil types influenced grain moisture (Table 12). Soil types did not influence corn population, numbers of ears or broken corn stalks at harvest (Table 14,25 and 16).

Although on average there was no difference in nitrogen source (manure and anhydrous ammonia) effects were not consistent for all soil types found at the Stearns County site. The two deeper soils with more water holding capacity resulted in a 13 bu/a higher yield with the manure N source. There was an 8 bu/a advantage with the anhydrous ammonia N source on the Hawick soil (Fig. 3). Anhydrous ammonia has been a consistent performing nitrogen source on sandy, shallow soils. Difference in nutrient sources did not influence, corn population and numbers of ears. Barnyard manure, however resulted in significantly lower number of broken stalks at harvest compared to anhydrous ammonia (Table 16).

STEARNS COUNTY

Table 1. Cultural practices at Stearns County, MN. 1991.

Tillage

No Till
Ridge Till
Spring Field cultivation + discing
Spring Moldboard Plowing + discing

Cropping History

1981-red clover and oats, 1982-corn, 1983-soybeans, 1984-corn, 1985-corn, 1986-soybeans, 1987-corn, 1988-Soybeans 1989-corn, 1990-soybean
1991 Crop Corn-Johnson 882

Planting and Harvest Dates

Ridge till and notill plots were planted with a four row Buffalo Till planter equipped with 12" sweeps at a 36 inch row spacing. Moldboard and field cultivator plots were planted with a conventional International 55 harvester.

Crop	Planting Date	Planting Rate	Harvested
Corn	May 23, 1991	23,000 seeds/A	Oct. 2 1991

Fertilization History 1981-1987

The fertilization history at this site is as follows: 1981-none, 1982-low rate of dry starter, 1983-low rate of starter and 0-0-60, 1984-4 gal/A of 9-18-9 only, 1985-60 lb/A of N and 4 gal/a of 9-18-9, 1986-all soybean plots were split with and without a row fertilizer treatment at planting, and in 1987-all corn plots were split with three rates of starter.

Crop	Material Analysis	Rate	Tillage	Actual N	Actual P_2O_5	Actual K_2O	Date Applied
				---- lb/A ----			
Soybeans	9-18-9[1]	4 gal/A	Ridge Till	4	8	4	May 16, 1986
	0-0-60[2]	90 lb/A	All Others	0	0	54	May 16, 1986
Corn	Starter Fertilizer Treatments						
	9-18-9[1]	0 gal/A	All	0	0	0	April 29, 1987
	9-18-9[1]	4.9 gal/A	All	4.7	10	4.7	April 29, 1987
	9-18-9[1]	9.7 gal/A	All	9.3	18.5	9.3	April 29, 1987
	Nitrogen Management						
	28-0-0	11 gal/A	No Till[3]	33	0	0	June 1, 1987
	28-0-0	11 gal/A	All Others[4]	33	0	0	June 1, 1987
	28-0-0	11 gal/A	No Till[3]	33	0	0	June 25, 1987
	28-0-0	11 gal/A	All Others[4]	33	0	0	June 25, 1987

1. Planter placement 1" below the seed. 2. Potash was surface banded ahead of and incorporated by the fluted coulters. 3. Nitrogen was surface banded. 4. Nitrogen was surface banded and incorporated by cultivation.

1989 Fertilizer and Manure Analysis

Crop	Material Analysis	Rate	Actual N	Actual P_2O_5	Actual K_2O	Date Applied
			---- lb/A ----			
Corn	9-18-9[1]	5 gal/A	5	10	5	May 11, 1989
	28-0-0[2]	11 gal/A	33	0	0	June 15, 1989
	28-0-0[3]	11 gal/A	33	0	0	June 30, 1989

1. Planter placement 1" below the seed. 2. Urea-ammonium nitrate (UAN) solution was surface banded and incorporated by cultivation on all non-manure plots. Solution was surface banded with no incorporation on no till plots. 3. Urea-ammonium nitrate (UAN) solution was surface banded and incorporated by cultivation on all plots manured and non-manured. Solution was surface banded with no incorporation on no till plots.

Analysis and rate of application of manure in 1989.

Manure Source	Date Applied	NH_4	NO_3	Mineral	Organic	Total N	Total P	Total K	Manure Density	Manure Rate	Solids Total	Solids Volatile	Solids Fixed
		%							lb/ft³	T/A	%		
Barn Gutter[1]	4/13/89	.260	.012	.272	.264	.536	.109	.424	64.8	16.4	27.66	45.96	54.04
Barnyard[2]	4/25/89	.050	.003	.053	.639	.692	.204	.377	33.8	15.0	16.50	64.62	35.38

1. Fresh daily manure collected every other day from barn gutters and applied the last two weeks of April.
2. A manure pack collected near a hay rack in the barnyard and applied April 25, 1989.

Rate of applied, available and value[1] of nitrogen[2], phosphorus, and potassium.

Source	Mineral	Organic	Total Nitrogen	$	Nitrogen Available 1989	1990	1991	P_2O_5	$	K_2O	$
	-- Applied N lb/acre ---				-- lb/A -			lb/A		lb/A	
Barn Gutter	89	87	176	17.60	111	11	6	82	16.40	167	16.70
Barnyard	16	192	208	20.80	64	24	12	140	28.00	136	13.60

1. It is assumed that fertilizer cost .10, .20, and .10 per pound of N, P_2O_5, and K_2O respectively.
2. It is assumed that all of the mineral N and 25% of the organic N will be available during the year of application.

1990 Treatment

No manure or anhydrous ammonia was applied.

1991 Fertilizer and Manure Analysis

Crop	Material Analysis	Rate	Actual N	P_2O_5	K_2O	Date Applied
			---- lb/A ----			
Corn	9-18-9	5 gal/A	5	10	5	May 23, 1991
	82-0-0	75 lb/A	62	0	0	June 4, 1991

1. Planter placement 1" below the seed.

Analysis and rate of application of manure on May 1991.

Manure Source	Date Applied	NH_4	NO_3	Mineral	Organic	Total N	Total P	Total K	Manure Density	Manure Rate	Solids Total	Solids Volatile	Solids Fixed
		----------			%	----------			lb/ft^3	T/A	--------	%	---------
Barnyard[2]	5/15/91	0.017	TR	0.017	0.559	0.576	0.02	0.08	33.8	22.7	21.03	71.54	28.46

2. A manure pack collected in and around a pole shed.
TR. Trace.

Rate of applied, available and value[1] of nitrogen[2], phosphorus, and potassium.

Source	Mineral	Organic	Total Nitrogen	$	Nitrogen Available 1989	1991	P_2O_5 1989	1991	K_2O 1989	1991
	-- Applied N lb/A ---				--lb/A--		-- lb/A--		---lb/A---	
Barnyard	8	254	262	26.20	64	72	140	21	136	44

1. It is assumed that fertilizer cost .10 $ per lb of N
2. It is assumed that all of the mineral N and 25% of the organic N will be available during the year of application.

Soil

The soils at the Stearns County site are Fairhaven loam (Typic Hapludolls) which is well drained on 54 percent of the plot. Estherville sandy loam (Typic Hapludolls) which is somewhat excessively drained on 36 percent of the plot, Hawick loamy sand (Entic Hapludolls), this soil is excessively drained on the remaining 10 percent of the plot. The slope average for all three soils is 2.5 percent with the highest being 4 percent.

Weed Control

0.75 lb a.i./A Prowl + 1.2 lb a.i./A Bladex 90 DF (June 4, 1991).

Table 2. Effect of tillage and row position on soybean residue (%) in corn at Stearns Co. MN (June 6, 1991).

Residue Location	Tillage				Mean
	No Till	Ridge Till	Field Cultivator	Moldboard Plow	
Between Row	14.5	11.0	14.0	1.0	10.1 a
In Row	5.0	1.5	13.0	0.8	5.1 b
Weighted Mean	13.5 ab	10.0 b	13.9 a	1.0 c	

The The p value for residue location, tillage and the tillage by location interaction are 0.013 (n=16), 0.004 (n=8) and 0.141 (n=4), respectively. Mean within the same row or column with the same letter are not significantly different (α=0.10).

Table 3. Effect of tillage and barnyard manure applied on corn population at Stearns Co. MN (June 6, 1991).

Manure Treatment	Tillage			Mean
	Ridge Till	Field Cultivator	Moldboard Plow	
	Plants/A x 10^{-3}			
Manure	20.5	16.0	19.2	18.6 a
Anhydrous ammonia	22.1	16.7	17.8	18.9 a
Mean	21.3 a	16.4 c	18.5 b	

The p value of manure, tillage and the manure x tillage interaction for corn population are 0.76 (n=24), 0.019 (n=16) and 0.474 (n=8) respectively.

Means within the same row and column with the same letter are not significantly different (α=0.10).

Table 4. Effects of tillage, manure application, row position, and soil depth on soil P (ppm) at Stearns Co. (June 1991).

Depth (inches)	Tillage			
	Ridge Till	Field Cultivator	Moldboard	Mean
		Manure		
0-2	65.7(52.5)	55.2 (8.1)	34.2 (9.3)	52.1(31.1)
2-4	17.0 (7.3)	31.7 (7.1)	55.7(11.9)	34.8(18.6)
4-6	12.3 (3.6)	19.8 (3.5)	42.5 (6.9)	37.1(24.5)
Mean	*31.7(37.4)*	*35.6(16.5)*	*44.1(12.6)*	*37.1(24.5)a*
		No Manure		
0-2	33.0(11.9)	32.6(6.2)	20.1 (3.8)	28.6(9.6)
2-4	20.6 (6.5)	20.3(5.4)	20.3 (7.5)	20.4(5.9)
4-6	14.3 (6.6)	15.2(4.4)	18.2 (6.5)	15.8(5.4)
Mean	*22.7(11.3)*	*22.7(9.0)*	*19.5 (5.6)*	*21.6(8.8)b*
Overall Mean	**27.2(27.3)a**	**29.1(14.6)a**	**31.8(15.8)a**	----

Depth (inches)	Tillage			
	Ridge Till	Field Cultivator	Moldboard	Mean
		In Row		
0-2	25.8 (7.7)	45.5(13.2)	28.1 (9.8)	33.1(13.2)
2-4	14.3 (5.9)	29.4 (9.2)	39.5(21.0)	27.7(16.4)
4-6	12.8 (5.3)	17.4 (4.7)	27.9(11.7)	19.4 (9.7)
Mean	*17.6 (8.4)*	*30.8(14.9)*	*31.8(14.7)*	*26.7(14.2)b*
		Between Row		
0-2	72.9(44.0)	42.2(16.2)	26.3(11.1)	47.1(32.7)
2-4	39.0 (3.8)	22.7(7.1)	36.5(24.3)	27.5(14.9)
4-6	13.8 (3.2)	17.7(4.8)	32.0(18.3)	21.3(13.2)
Mean	*36.6(36.0)*	*27.5(14.7)*	*31.8(17.6)*	*32.0(24.2)a*

- Numbers in parenthesis are standard deviations
- P>F value for main effect and significant interactions are:

- tillage	: 0.681 (n=24)	tillage x nutrient source	: 0.080 (n=12)
- nutrient source	: 0.003 (n=36)	tillage x row position	: 0.006 (n=06)
- row position	: 0.032 (n=36)	nutrient source x row position	: 0.070 (n=18)
- soil depth	:<0.001(n=24)	tillage x soil depth	: <0.001 (n=8)
- row position x soil depth	: 0.066 (n=18)	nutrient source x soil depth	: 0.092 (n=12)

- tillage x nutrient source x soil depth:0.010 (n=04) tillage x soil depth x row position : 0.010 (n=04)

* Means in the same row or column followed by the same letter are not significantly different.

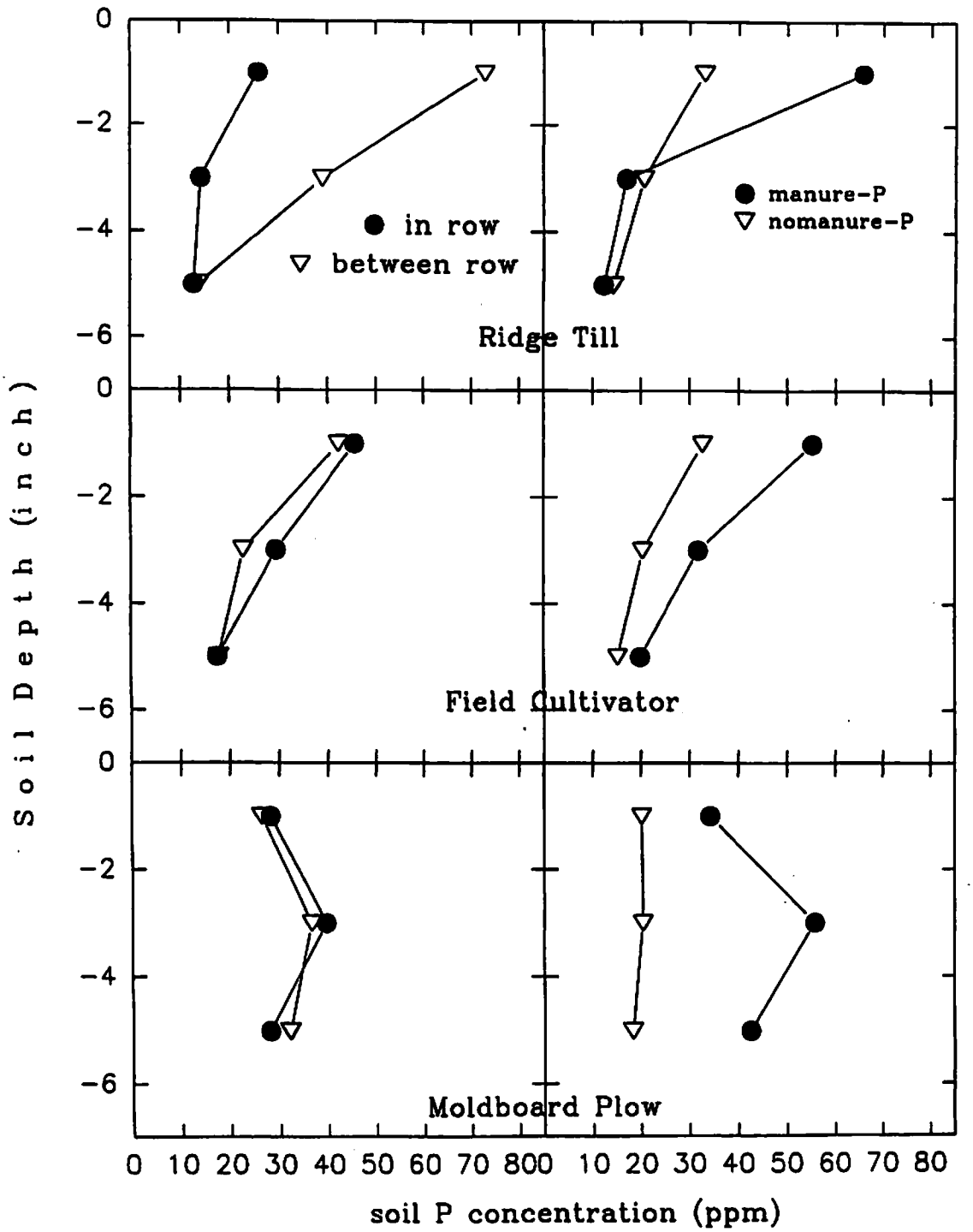

Fig. 1. The effects of (a) tillage methods*row position*soil depth interaction and (b) tillage methods*nutrient source* soil depth interaction on soil P at Stearns Co, MN (June 5, 1991).

Table 5. Effects of tillage, row position, manure application, and soil depth on soil K at Stearns Co. MN (June 6, 1991).

Depth (inches)	Tillage		
	Ridge Till	Field Cultivator	Moldboard
	ppm		
		IN ROW	
0-2	84.2(13.8)	125.3(82.2)	109.5(35.7)
2-4	42.8 (6.5)	91.7(28.7)	164.7(110.7)
4-6	40.7 (8.9)	70.5(17.3)	108.5 (43.5)
MEAN	*55.8(22.8)*	*95.9(51.9)*	*127.7 (70.5)*
		BETWEEN ROW	
0-2	292.4(164.0)	164.1(75.6)	98.7(31.2)
2-4	96.6 (45.8)	73.1(31.5)	125.4(38.7)
4-6	55.2 (07.4)	58.7(10.4)	111.3(41.7)
MEAN	*148.1(140.0)*	*98.6(65.0)*	*111.8(35.9)*
OVERALL MEAN	**102.0(108.8)a**	**97.2(57.6)a**	**119.7(55.2)a**

Depth (inches)	Nsource		
	Manure 1991	Anhydrous	Mean
	ppm		
		IN ROW	
0-2	102.5 (68.7)	92.1(20.6)	106.4(50.6)
2-4	131.0(104.6)	68.6(25.4)	99.8(79.5)
4-6	85.4 (45.5)	61.1(28.2)	73.2(38.1)
MEAN	*112.2 (75.0)*	*74.3(27.0)*	*93.0(58.8)* b
		BETWEEN ROW	
0-2	249.6(148.8)	120.5(59.4)	185.1(123.4)
2-4	122.3 (46.4)	74.6(18.3)	98.4 (41.9)
4-6	85.5(47.1)	64.7(15.8)	75.9 (35.3)
MEAN	*152.4(114.2)*	*86.6(42.8)*	*119.6 (91.4)*a
OVERALL MEAN	**132.3(97.4)a**	**80.3(39.9)a**	——

P value for main effects and significant interactions:
tillage : 0.3630 (n=24) tillage x row position: 0.0090 (n=12)
nutrient source : 0.0100 (n=36) till x soil depth : 0.0002 (n=08)
row position : 0.0370 (n=36) row position x soil depth : 0.0060 (n=12)
soil depth : 0.0001 (n=24) nutrient source x soil depth: 0.1000 (n=12)
tillage x row position x soil depth = 0.039 (n=4)
nutrient source x row position x soil depth = 0.067 (n=4)

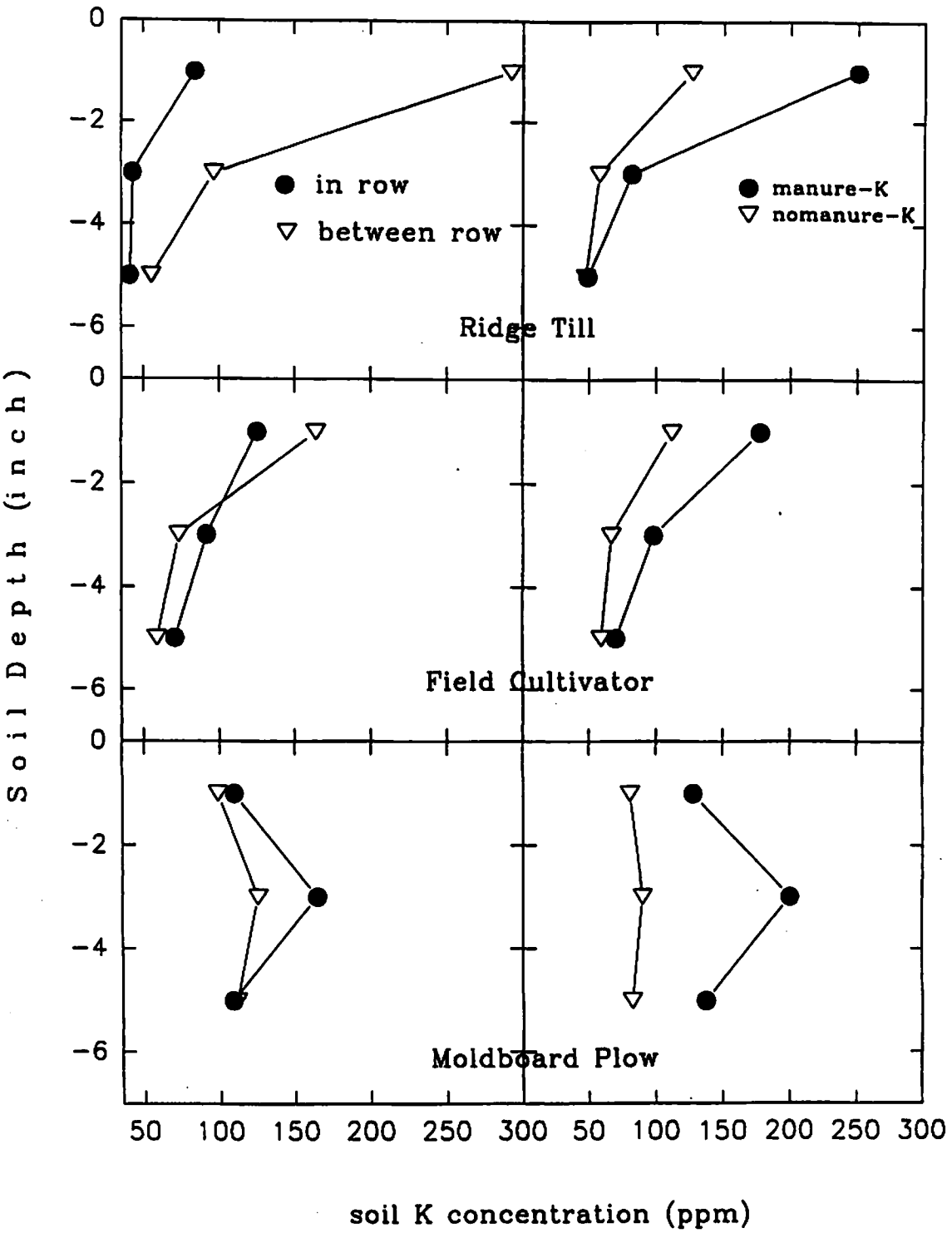

Fig. 2. The effects of (a) tillage methods*row position*soil depth interaction and (b) tillage methods*nutrient source* soil depth interaction on soil K at Stearns Co, MN (June 5, 1991).

Table 6. Effects of tillage, row position, nutrient source, and soil depth on soil pH at Stearns Co. MN (June 6, 1991).

Depth (inches)	Tillage			
	Ridge Till	Field Cultivator	Moldboard	Mean
		In Row		
0-2	6.5(0.2)	6.4(0.1)	6.4(0.2)	6.4(0.2)
2-4	6.5(0.1)	6.4(0.1)	6.4(0.2)	6.4(0.2)
4-6	6.6(0.2)	6.5(0.1)	6.5(0.2)	6.5(0.1)
Mean	*6.5(0.1)*	*6.4(0.1)*	*6.4(0.2)*	6.4(0.1)
		Between Row		
0-2	7.0(0.4)	6.4(0.1)	6.9(0.1)	6.6(0.3)
2-4	6.7(0.1)	6.4(0 .2)	6.5(0.2)	6.5(0.2)
4-6	6.6(0.1)	6.9(0.2)	6.4(0.1)	6.5(0.2)
Mean	*6.8(0.3)*	*6.4(0.2)*	*6.4(0.2)*	6.5(0.3)
Overall Mean	**6.6a(0.2)**	**6.4a(0.1)**	**6.4a(0.2)**	

Depth (inches)	Tillage			
	Ridge Till	Field Cultivator	Moldboard	Mean
		Manure		
0-2	6.9(0.5)	6.4(0.1)	6.5(0.2)	6.6(0.4)
2-4	6.6(0.2)	6.3(0.1)	6.6(0.2)	6.5(0.2)
4-6	6.7(0.3)	6.4(0.1)	6.5(0.1)	6.5(0.1)
Mean	*6.7(0.3)*	*6.4(0.1)*	*6.5(0.2)*	6.5(0.3)
		Anhydrous Ammonia		
0-2	6.6(0.2)	6.5(0.1)	6.4(0.1)	6.5(0.1)
2-4	6.6(0.1)	6.5(0.2)	6.3(0.2)	6.5(0.2)
4-6	6.6(0.1)	6.5(0.1)	6.3(0.2)	6.5(0.2)
Mean	*6.6(0.1)*	*6.5(0.1)*	*6.4(0.1)*	6.5(0.2)

- Numbers in parenthesis are standard deviations
- P>F value for main effect and significant interactions are:
- tillage : 0.301 (n=24)
- nutrient source : 0.309 (n=36)
- soil depth : 0.102 (n=24)
- row position x soil depth: 0.083 (n=12)
- nutrient source x soil depth: 0.089 (n=12)
- tillage x nutrient source x soil depth:0.045(n=6)
- tillage x nutrient source : 0.060 (n=18)
- tillage x row position x soil depth : 0.092(n=04)

Table 7. Effect of tillage and barnyard manure applied in 1991 on corn earleaf N , P and K concentration at Stearns Co. MN (July 26, 1991).

Manure Treatment	Tillage			Mean
	Ridge Till	Field Cultivator	Moldboard Plow	
		N (%)		
Manure	2.9	3.3	3.4	3.2 b
Anhydrous ammonia	3.1	3.4	3.4	3.3 a
mean	3.0 b	3.3 a	3.4 a	
		P (%)		
Manure	0.35	0.36	0.32	0.34 a
Anhydrous ammonia	0.42	0.36	0.35	0.38 a
mean	0.38 a	0.36 a	0.33 a	
		K (%)		
Manure	1.0	1.5	2.0	1.5 a
Anhydrous ammonia	0.6	0.9	1.3	0.9 b
mean	0.8 b	1.2 ab	1.6 a	

The p value of manure , tillage and manure x tillage interactions

1. for N are 0.062 (n=12) , 0.009 (n=8) and 0.855 (n=4) respectively .
2. for P are 0.119 (n=12) , 0.270 (n=8) and 0.262 (n=4) respectively .
3. for K are 0.005 (n=12) , 0.004 (n=8) and 0.927 (n=4) respectively .

Means within the row or column with the same letter are not significantly different.

Table 8. Effect of tillage on corn earleaf N , P and K concentration at Stearns Co. MN (July 26, 1991).

N Source	Tillage			
Anhydrous Ammonia	No-Till	Ridge Till	Field Cultivator	Moldboard Plow
		N (%)		
	3.1bc	3.1c	3.4ab	3.4a
		P (%)		
	0.39a	0.42a	0.35a	0.35a
		K (%)		
	1.0a	0.6a	0.9 a	1.3 a

The p value of tillage

1. for N is 0.100 (n=4)
2. for P is 0.173 (n=4)
3. for K is 0.110 (n=4)

Means within the row with the same letter are not significantly different

Table 9. Effect of tillage and barnyard or barngutter manure applied in 1989 on blooming-soybean trifolia N , P and K concentration at Stearns Co. MN (July 25, 1990).

Manure (1989)	Tillage			Mean
	Ridge Till	Chisel Plow	Moldboard Plow	
		P (%)		
Barnyard	0.54	0.48	0.53	0.51 a
No Barnyard	0.51	0.49	0.50	0.50 a
mean	0.52 a	0.48 b	0.51 a	
		K (%)		
Barnyard	1.8	1.9	2.3	2.0 a
No Barnyard	1.4	1.5	2.3	1.8 b
mean	1.6 b	1.7 b	2.3 a	
		P (%)		
Barngutter	0.53	0.59	0.91	0.66 a
No Barngutter	0.54	0.45	0.77	0.58 a
mean	0.53 b	0.52 b	0.84 a	
		K (%)		
Barngutter	1.7	1.9	2.3	1.9 a
No Barngutter	1.4	1.5	1.6	1.5 b
mean	1.5 a	1.7 a	2.0 a	

The p value of barnyard manure, tillage and barnyard manure x tillage interactions

1. for P are 0.672 (n=6) , 0.084 (n=4) and 0.881 (n=2) respectively .
2. for K are 0.057 (n=6) , 0.052 (n=4) and 0.141 (n=2) respectively .

The p value of barngutter manure, tillage and barngutter manure x tillage interactions

1. for P are 0.703 (n=6) , 0.100 (n=4) and 0.952 (n=2) respectively .
2. for K are 0.029 (n=6) , 0.196 (n=4) and 0.472 (n=2) respectively .

Means within the row or column with the same letter are not significantly different.

Table 10. Effect of tillage and barnyard or barngutter manure applied in 1989 on soybean seed P and K concentration at Stearns Co. MN (October 11, 1990).

Manure (1989)	Tillage			Mean
	Ridge Till	Chisel Plow	Moldboard Plow	
		P (%)		
Barnyard	1.20	1.17	1.05	1.14 a
No Barnyard	1.17	1.16	1.22	1.18 a
mean	1.18 a	1.17 a	1.13 a	
		K (%)		
Barnyard	2.0	2.2	2.2	2.1 a
No Barnyard	2.0	2.1	2.4	2.2 a
mean	2.0 a	2.2 a	2.3 a	
		P (%)		
Barngutter	1.13	1.20	1.26	1.20 a
No Barngutter	1.24	1.08	1.17	1.16 a
mean	1.18 a	1.14 a	1.21 a	
		K (%)		
Barngutter	1.9	2.1	2.1	2.0 a
No Barngutter	1.9	2.0	1.9	1.9 b
mean	1.9 a	2.0 a	2.0 a	

The p value of barnyard manure, tillage and barnyard manure x tillage interactions

1. for P are 0.314 (n=6) , 0.169 (n=4) and 0.201 (n=2) respectively .
2. for K are 0.625 (n=6) , 0.324 (n=4) and 0.436 (n=2) respectively .

The p value of barngutter manure, tillage and barngutter manure x tillage interactions

1. for P are 0.649 (n=6) , 0.437 (n=4) and 0.456 (n=2) respectively .
2. for K are 0.091 (n=6) , 0.571 (n=4) and 0.420 (n=2) respectively .

Means within the row or column with the same letter are not significantly different.

Table 11. The influence of tillage on blooming-soybean trifolia and soybean seed P, K concentration as influenced on tillage of plots not treated with either barnyard or barngutter manure (July 25, 1990).

Material	Tillage			
	No-Till	Ridge Till	Chisel Plow	Moldboard Plow
Soybean Trifolia		P (%)		
	0.49a	0.52a	0.47a	0.63a
		K (%)		
	1.8ab	1.4b	1.5b	2.0a
Soybean Seed		P (%)		
	1.1a	1.2a	1.1a	1.2a
		K (%)		
	2.0a	2.0a	2.1a	2.1a

The p value of tillage for soybean trifolia

1. P is 0.424 (n=4)
2. K is 0.082 (n=4)

The p value of tillage for soybean seed

1. P is 0.318 (n=4)
2. K is 0.455 (n=4)

Means within the row with the same letter are not significantly different.

Table 12. Effect of tillage, soil and residual effect of manure applied in 1989 on corn grain moisture at Stearns Co., Oct. 2, 1991.

Nutrient Source	Tillage			Mean
	Ridge Till	Field Cultivator	Moldboard Plow	
	%			
Barnyard	21.8(1.5)	21.1(1.2)	21.9(1.4)	21.6(1.4)a
Anhydrous ammonia	21.1(1.9)	20.6(2.4)	23.1(5.8)	21.6(3.8)a
Mean	21.4(1.7)a	20.8(1.8)a	22.5(4.0)a	

The p value of manure (n=27-29) : 0.907
tillage (n=16-19) : 0.307
manure x tillage interactions (n=8-11) : 0.551

Nutrient Source	Soil			Mean
	Fair Haven	Esterville	Hawick	
	%			
Barnyard	22.1(1.0)	22.2(1.3)	20.8(1.6)	21.6(1.4)a
Anhydrous ammonia	21.7(1.9)	23.5(6.1)	19.9(1.2)	21.6(3.8)a
Mean	21.9(1.5)a	23.0(4.7)ab	20.4(1.4)b	

The p value of manure (n=27-29) : 0.970
soil (n=15-21) : 0.038
manure x soil interactions (n=6-11) : 0.436

Tillage System	Soil			Mean
	Fair Haven	Estherville	Hawick	
	%			
No Till	21.9(0.7)	20.9(0.8)	21.5(0.0)	21.4(0.9)a
Ridge Till	22.2(1.6)	21.7(1.7)	19.6(1.5)	21.1(1.9)a
Field Cultivator	21.2(2.9)	19.9(3.2)	20.0(1.4)	20.6(2.4)a
Moldboard	21.7(0.7)	28.4(9.2)	20.2(1.0)	23.1(5.8)a
Mean	21.7(1.6)a	22.7(5.2)a	20.1(1.2)a	

The p value of Tillage (n=8-11) : 0.294
soil (n=11-14) : 0.340
tillage x soil interactions (n=1-4) : 0.310

Means within the same row or column with the same letter are not significantly different .

Table 13. Effect of tillage, soil and residual effect of manure applied in 1989 on corn grain yield at Stearns Co.,Oct 2, 1991.

Nutrient Source	Tillage			Mean
	Ridge Till	Field Cultivator	Moldboard Plow	
	---------- bu/a ----------			
Barnyard	107(25)	109(22)	115(17)	111(21)a
Anhydrous ammonia	97(22)	105(9)	114(8)	105(16)a
Mean	101(23)b	107(16)ab	114(14)a	

The p value of manure (n=27-29) : 0.229
tillage (n=16-19) : 0.053
manure x tillage interactions (n=8-11) : 0.443

Nutrient Source	Soil			Mean
	Fair Haven	Estherville	Hawick	
	---------- bu/a ----------			
Barnyard	122(9)	118(8)	94(25)	111(21)a
Anhydrous ammonia	109(18)	105(21)	102(11)	105(17)a
Mean	116(16)a	110(17.6)a	98(19)b	

The p value of manure (n=27-29) : 0.330
soil (n=15-21) : 0.003
manure x soil interactions (n=6-11) : 0.052

Tillage System	Soil			Mean
	Fair Haven	Estherville	Hawick	
	----------bu/a ----------			
No Till	85(20)	71(4)	73(0)	77(15)b
Ridge Till	98(28)	99(31)	94(9)	97(22)a
Field Cultivator	107(12)	109(4)	98(4)	105(9)a
Moldboard	122(9)	110(8)	112(7)	114.3(9)a
Mean	102(21)a	94(23)b	99(14)a	

The p value of Tillage (n=8-11) : 0.024
soil (n=11-14) : 0.066
tillage x soil interactions (n=1-4) : 0.868

Means within the same row or column with the same letter are not significantly different .

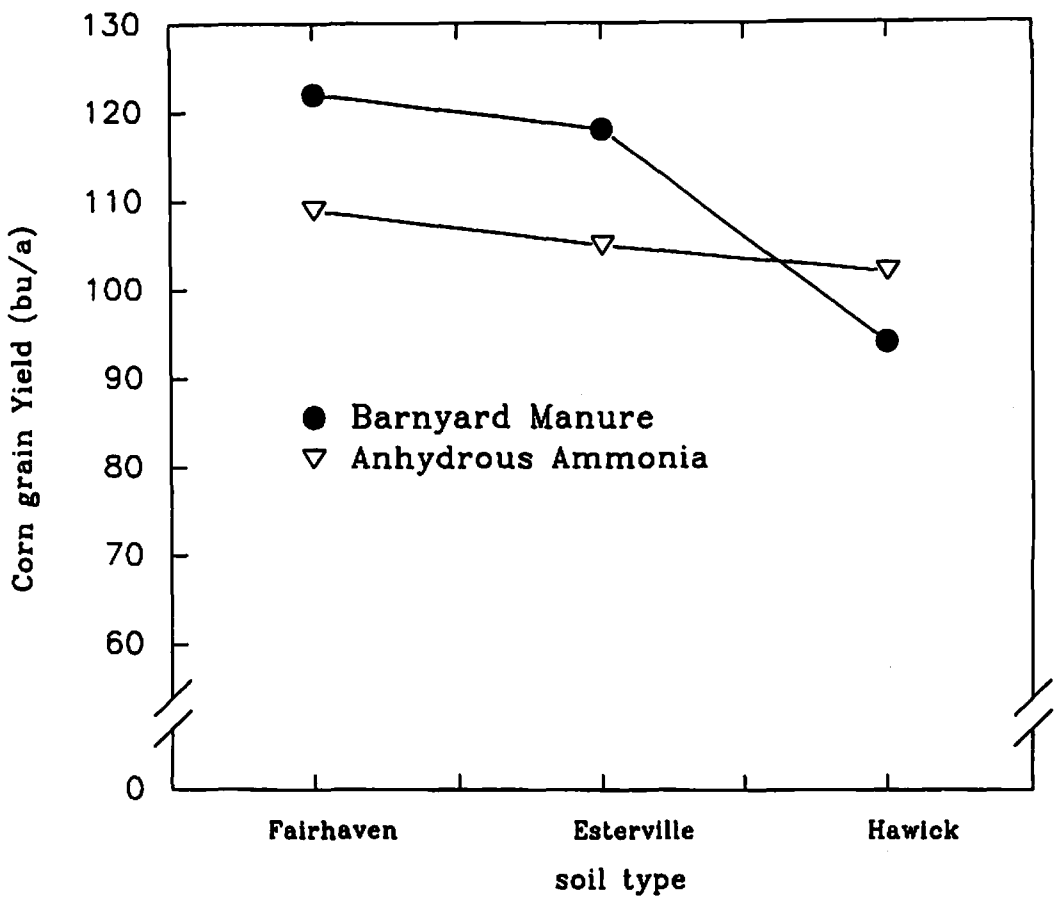

Fig. 3.. Nutrient source and soil type interaction on corn grain yield at Stearns Co., Oct. 2. 1991.

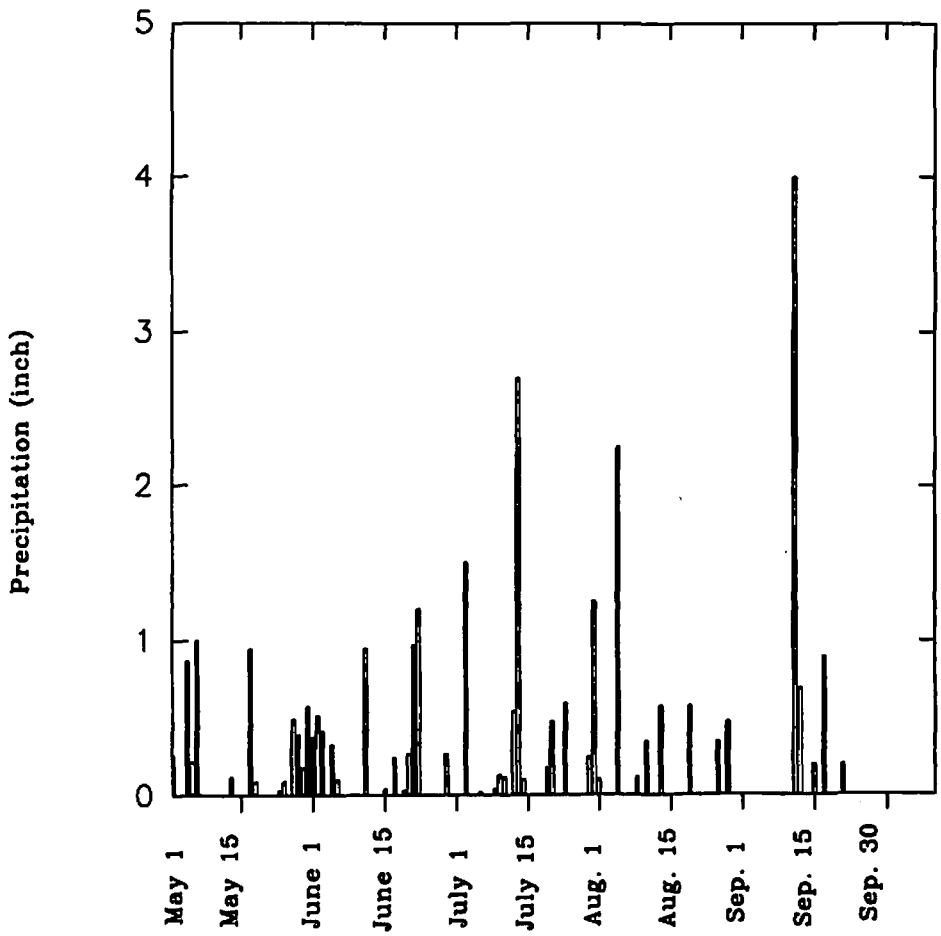

Fig. 4. Daily growing season precipitation at Kimball, Stearns County MN 1991 (Source: Minnesota Clomatological Network).

Table 14. Effect of tillage, soil and residual effect of manure applied in 1989 on corn population at harvest at Stearns Co., Oct 2, 1991.

Nutrient Source	Tillage			Mean
	Ridge Till	Field Cultivator	Moldboard Plow	
	1000 plants/a			
Barnyard	20.6(1.3)	17.5(0.9)	18.4(1.9)	18.8(1.9)a
Anhydrous ammonia	20.3(2.3)	17.7(1.2)	18.4(1.5)	18.9(2.1)a
Mean	20.4(1.9)a	17.6(1.1)b	18.4(1.7)b	

The p value of manure (n=27-29) : 0.684
tillage (n=16-19) : 0.009
manure x tillage interactions (n=8-11) : 0.955

Nutrient Source	Soil			Mean
	Fair Haven	Estherville	Hawick	
	1000 plants/a			
Barnyard	18.6(1.9)	19.2(1.7)	18.7(2.2)	18.8(1.9)a
Anhydrous ammonia	18.0(2.4)	18.8(1.4)	19.9(1.9)	18.9(2.0)a
Mean	18.3(2.1)a	19.0(1.5)a	19.3(2.1)a	

The p value of manure (n=27-29) : 0.857
soil (n=15-21) : 0.370
manure x soil interactions (n=6-11) : 0.382

Tillage System	Soil			Mean
	Fair Haven	Estherville	Hawick	
	1000 plants/a			
No Till	20.1(3.1)	20.1(2.8)	18.5(0.0)	19.9(2.6)a
Ridge Till	19.6(2.3)	19.7(1.6)	21.3(2.1)	20.2(2.3)a
Field Cultivator	17.2(1.6)	18.3(0.3)	18.0(0.8)	17.7(1.2)a
Moldboard	17.4(1.9)	18.0(1.4)	19.5(0.9)	18.4(1.5)a
Mean	18.6(2.7)a	19.2(1.9)a	19.8(1.8)a	

The p value of Tillage (n=8-11) : 0.373
soil (n=11-14) : 0.953
tillage x soil interactions (n=1-4) : 0.616

Means within the same row or column with the same letter are not significantly different .

Table 15. Effect of tillage, soil and residual effect of manure applied in 1989 on number of corn ears at Stearns Co., Oct 2,1991.

Nutrient Source	Tillage			Mean
	Ridge Till	Field Cultivator	Moldboard Plow	
	1000 ears/a			
Barnyard	19.6(0.9)	17.2(1.3)	17.9(1.5)	18.2(1.6)a
Anhydrous ammonia	19.6(2.3)	17.4(1.0)	18.1(1.7)	18.4(2.0)a
Mean	19.6(1.8)a	17.3(1.1)b	18.0(1.6)b	

The p value of manure (n=27-29) : 0.986
tillage (n=16-19) : 0.034
manure x tillage interactions (n=8-11) : 0.881

Nutrient Source	Soil			Mean
	Fair Haven	Estherville	Hawick	
	1000 ears/a			
Barnyard	18.5(1.5)	18.3(1.4)	17.8(1.7)	18.2(1.6)a
Anhydrous ammonia	17.8(2.5)	18.6(1.9)	19.1(1.4)	18.5(2.0)a
Mean	18.2(2.0)a	18.5(1.6)a	19.4(1.7)a	

The p value of manure (n=27-29) : 0.822
soil (n=15-21) : 0.925
manure x soil interactions (n=6-11) : 0.299

Tillage System	Soil			Mean
	Fair Haven	Estherville	Hawick	
	1000 ears/a			
No Till	18.9(3.1)	18.2(2.4)	18.2(0.0)	18.5(2.5)a
Ridge Till	19.5(3.9)	19.4(2.3)	19.8(1.3)	19.6(2.3)a
Field Cultivator	17.1(1.2)	18.0(0.8)	17.4(0.5)	17.4(1.0)a
Moldboard	16.9(1.9)	18.0(1.7)	19.1(1.3)	18.2(1.7)a
Mean	18.1(2.6)a	18.5(2.0)a	18.9(1.4)a	

The p value of Tillage (n=8-11) : 0.674
soil (n=11-14) : 0.899
tillage x soil interactions (n=1-4) : 0.606

Means within the same row or column with the same letter are not significantly different .

Table 16. Effect of tillage, soil and residual effect of manure applied in 1989 on broken corn stalks at Stearns Co., Oct 2,1991.

Nutrient Source	Tillage			Mean
	Ridge Till	Field Cultivator	Moldboard Plow	
	1000 stems/a			
Barnyard	9.6(5.1)	8.3(4.0)	10.6(4.6)	9.6(4.5)b
Anhydrous ammonia	15.1(6.3)	12.3(4.6)	8.8(4.7)	12.2(6.0)a
Mean	12.8(6.6)a	10.3(4.7)ab	9.7(4.6)a	

The p value of manure (n=27-29) : 0.072
tillage (n=16-19) : 0.044
manure x tillage interactions (n=8-11) : 0.343

Nutrient Source	Soil			Mean
	Fair Haven	Estherville	Hawick	
	1000 stems/a			
Barnyard	8.8(3.5)	10.8(6.5)	9.7(4.5)	9.6(4.5)b
Anhydrous ammonia	10.2(6.2)	11.2(6.2)	15.1(4.9)	12.2(6.0)a
Mean	9.5(4.9)a	11.0(6.1)a	12.4(5.3)a	

The p value of manure (n=27-29) : 0.063
soil (n=15-21) : 0.284
manure x soil interactions (n=6-11) : 0.458

Tillage System	Soil			Mean
	Fair Haven	Estherville	Hawick	
	1000 stems/a			
No Till	16.2(4.2)	14.7(7.4)	17.1(0.0)	15.6(5.3)a
Ridge Till	14.5(8.2)	12.4(7.5)	18.4(4.6)	15.2(6.6)a
Field Cultivator	10.6(5.0)	12.5(6.4)	15.2(1.5)	12.3(4.6)a
Moldboard	5.3(1.1)	8.7(5.9)	11.6(4.3)	8.8(4.7)a
Mean	11.9(6.2)a	12.3(6.5)a	15.2(4.7)a	

The p value of Tillage (n=8-11) : 0.131
soil (n=11-14) : 0.594
tillage x soil interactions (n=1-4) : 0.825

Means within the same row or column with the same letter are not significantly different .

Table 17. Effect of tillage, soil and residual effect of manure applied in 1989 on corn grain N concentration at Stearns County (Eckman Farm), Oct 2,1991.

Nutrient Source	Tillage			Mean
	Ridge Till	Field Cultivator	Moldboard Plow	
	%			
Barnyard	1.25(0.12)	1.37(0.14)	1.35(0.12)	1.33(0.14)b
Anhydrous ammonia	1.38(0.07)	1.40(0.050	1.39(0.08)	1.39(0.07)a
Mean	1.33(0.12)b	1.38(0.11)a	1.37(0.11)a	

The p value of manure (n=27-29) : 0.020
tillage (n=16-19) : 0.034
manure x tillage interactions (n=8-11) : 0.412

Nutrient Source	Soil			Mean
	Fair Haven	Estherville	Hawick	
	%			
Barnyard	1.38(0.01)	1.37(0.11)	1.23(0.16)	1.32(0.14)a
Anhydrous ammonia	1.43(0.05)	1.41(0.06)	1.33(0.05)	1.39(0.07)a
Mean	1.41(0.07)a	1.39(0.08)a	1.28(0.13)b	

The p value of manure (n=27-29) : 0.195
soil (n=15-21) : 0.001
manure x soil interactions (n=6-11) : 0.458

Tillage System	Soil			Mean
	Fair Haven	Estherville	Hawick	
	%			
No Till	1.34(0.15)	1.43(0.01)	1.40(0.00)	1.38(0.10)a
Ridge Till	1.38(0.05)	1.43(0.07)	1.33(0.05)	1.38(0.07)a
Field Cultivator	1.44(0.01)	1.37(0.01)	1.34(0.02)	1.40(0.05)a
Moldboard	1.48(0.01)	1.40(0.03)	1.32(0.06)	1.39(0.08)a
Mean	1.41(0.09)a	1.42(0.04)a	1.34(0.05)a	

The p value of Tillage (n=8-11) : 0.802
soil (n=11-14) : 0.651
tillage x soil interactions (n=1-4) : 0.080

Means within the same row or column with the same letter are not significantly different .

Table 18. Effect of tillage, soil and residual effect of manure applied in 1989 on corn grain protein concentration at Stearns County (Eckman Farm), Oct 2,1991.

Nutrient Source	Tillage			Mean
	Ridge Till	Field Cultivator	Moldboard Plow	
	%			
Barnyard	7.74(0.75)	8.46(0.88)	8.40(0.81)	8.22(0.89)b
Anhydrous ammonia	8.58(0.45)	8.70(0.31)	8.65(0.49)	8.63(0.43)a
Mean	8.23(0.71)b	8.58(0.65)a	8.52(0.67)a	

The p value of manure (n=27-29) : 0.020
tillage (n=16-19) : 0.034
manure x tillage interactions (n=8-11) : 0.412

Nutrient Source	Soil			Mean
	Fair Haven	Estherville	Hawick	
	%			
Barnyard	8.57(0.47)	8.51(0.70)	7.67(1.0))	8.22(0.85)a
Anhydrous ammonia	8.92(0.32)	8.75(0.35)	8.26(0.30)	8.64(0.42)a
Mean	8.74(0.42)a	8.66(0.51)a	7.97(0.78)b	

The p value of manure (n=27-29) : 0.195
soil (n=15-21) : 0.001
manure x soil interactions (n=6-11) : 0.458

Tillage System	Soil			Mean
	Fair Haven	Estherville	Hawick	
	%			
No Till	8.34(0.94)	8.87(0.10)	8.68(0.00)	8.61(0.63)a
Ridge Till	8.56(0.34)	8.90(0.48)	8.27(0.35)	8.58(0.45)a
Field Cultivator	8.97(0.09)	8.52(0.04)	8.34(0.14)	8.70(0.31)a
Moldboard	9.19(0.08)	8.69(0.18)	8.20(0.36)	8.70(0.31)a
Mean	8.75(0.59)a	8.78(0.29)b	8.29(0.31)b	

The p value of Tillage (n=8-11) : 0.802
soil (n=11-14) : 0.651
tillage x soil interactions (n=1-4) : 0.080

Means within the same row or column with the same letter are not significantly different .