Field Research
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SOIL SERIES #140
Field Research in Soil Science

ACKNOWLEDGEMENTS

This 1994 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.

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DISCLAIMERS

Some of the results reported in this publication are from 1993 experiments and should be regarded on this basis. Since most of the data is from 1993 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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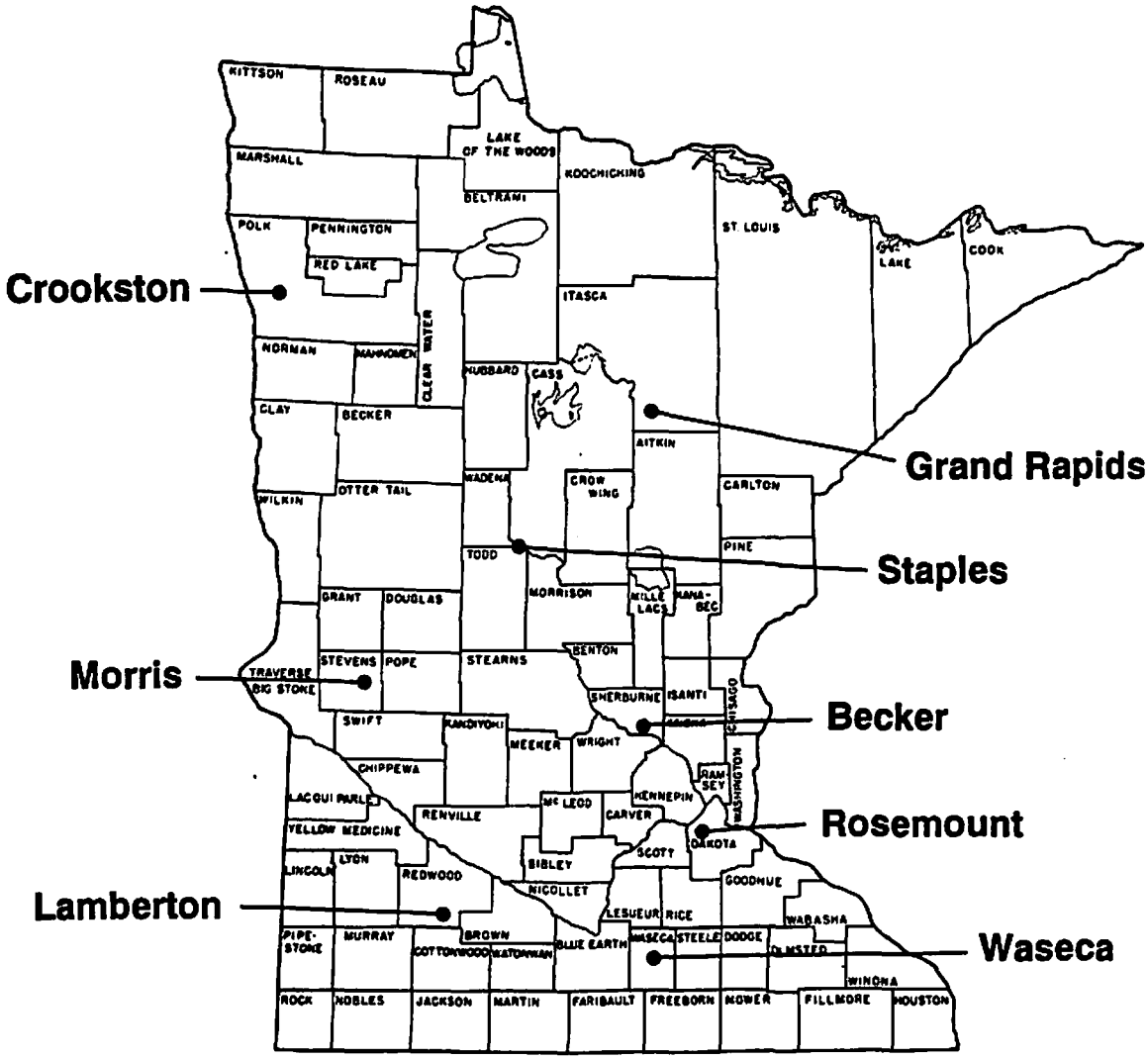

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CLIMATE UPDATE - FALL, 1993 AND WINTER, 1994

State Climatology Office[1]

The months of May through August of 1993 will be remembered as the wettest period in Minnesota's recorded climate history. The torrential rains that impacted nearly all of the Midwest left many locations in Minnesota with precipitation totals exceeding 200 percent of the mean, the equivalent of two summers worth of rain. Figure 1 shows that roughly one half of Minnesota ranked at, or above, the 99th percentile for May through August rainfall. A value above the 99th percentile means that those locations broke, or nearly broke, all-time May through August rainfall records. Four month totals exceeded 28 inches over much of southern Minnesota, the normal annual rainfall for many of those areas. Record breaking rainfall over such a broad area for such an extended period of time is unprecedented in Minnesota's 100-year climate record.

The same atmospheric conditions that led to the heavy rains also led to extraordinarily low evaporation rates. Cloudy and cool weather, in tandem with persistently high relative humidity, combined to dramatically reduce the atmosphere's ability to evaporate water from the surface. For the first time since such records have been kept, precipitation totals exceeded pan evaporation values for the May through August period. The lack of evaporation exaggerated an already serious hydrologic imbalance.

The most significant rainfall event of the late summer occurred on August 15th and 16th along a line that stretched from near New Ulm to south of Austin. A multi-county area received more than four inches of precipitation in this storm. Eight inches of rain or more fell in southern Freeborn and Mower counties. Falling upon already saturated ground, this storm caused wide-spread soil erosion and rural flooding, as well as serious urban flooding in Austin and elsewhere.

Fortunately, the rain slackened in the late summer and early fall. However, this dry weather was not accompanied by the warm temperatures needed to adequately dry crops and soils. September was one of the coolest on record, and with some exceptions, October was also quite cool.

At this time, soil moisture levels are very high for nearly all of Minnesota. As the soil freezes, the soil moisture status will remain generally unchanged through the winter season. Wetlands, lakes, rivers and streams are also at unusually high levels for this time of year. While it is too early to sound the alarm, it is important to recognize that the potential for significant spring flooding in 1994 does exist.

During Minnesota's winters the levels of our hydrologic systems remain relatively constant. The frozen soil allows little movement of water within the soil, and from the surface into the soil. Our winter precipitation most often falls as a solid, laying upon the ground as a latent supply of water, waiting to be released by the spring thaw. Minnesota's cold winter temperatures nearly eliminate evaporation (actually sublimation) from the surface to the atmosphere. Stream flows are driven almost entirely by base flow from the ground water. Therefore winter is a time to evaluate the previous seasons in an effort to anticipate the hydrologic conditions of the spring to come.

In soil measurements made this past fall, the data indicate that nearly all of Minnesota's soil are at or above their long term average soil moisture content. The fall soil moisture status is a good indicator of the amount of buffer space that the soil will offer after the spring thaw.

After a relatively dry fall, winter has brought a significant snow cover. As of February 1st, nearly all of Minnesota was covered with a snow depth that ranked at least in the 80th percentile (meaning that in 100 years, only 20 years would have more snow on the ground at this time of year). Early in January, Finland along the north shore, received over 4 feet of snow in a single storm. Preliminary estimates show that the snow pack across Minnesota contains from one to four inches of water.

Snow cover can act as an insulating blanket for the soil, inhibiting frost penetration. A shallower frost layer means fewer broken water pipes and less energy required to warm the ground in spring, opening the soils earlier to infiltration. Frost protection was critical during January when Minnesota experienced its coldest month in over a decade. Many minimum temperature records were broken as the thermometer dropped well below zero for extended periods of time.

Ground water base flow into surface water systems remains significant as the result of extraordinary rainfall that fell during the summer of 1993. All of the southern one third of Minnesota received over 36 inches of precipitation during the 1993 Water Year (October 1992 - September 1993). Some areas in Martin County received well over 50 inches of precipitation. Elsewhere across the state, Water Year precipitation ranged from 20 to 32 inches. Over two dozen counties in southern Minnesota reported precipitation departures of over one foot above the norm. With some exceptions in the northwest and the north, all of Minnesota received greater than normal precipitation for the period. The heavy precipitation fell upon a state already wet from the climate events of the early 1990s.

With soil moisture values high, surface water levels above average for this time of year, and a significant snow pack on the ground, Minnesotans must recognize that the potential exists for significant spring flooding, especially in the south.

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[1]The State Climatology, Division of Waters, Department of Natural Resources, U. of M., St Paul Campus.

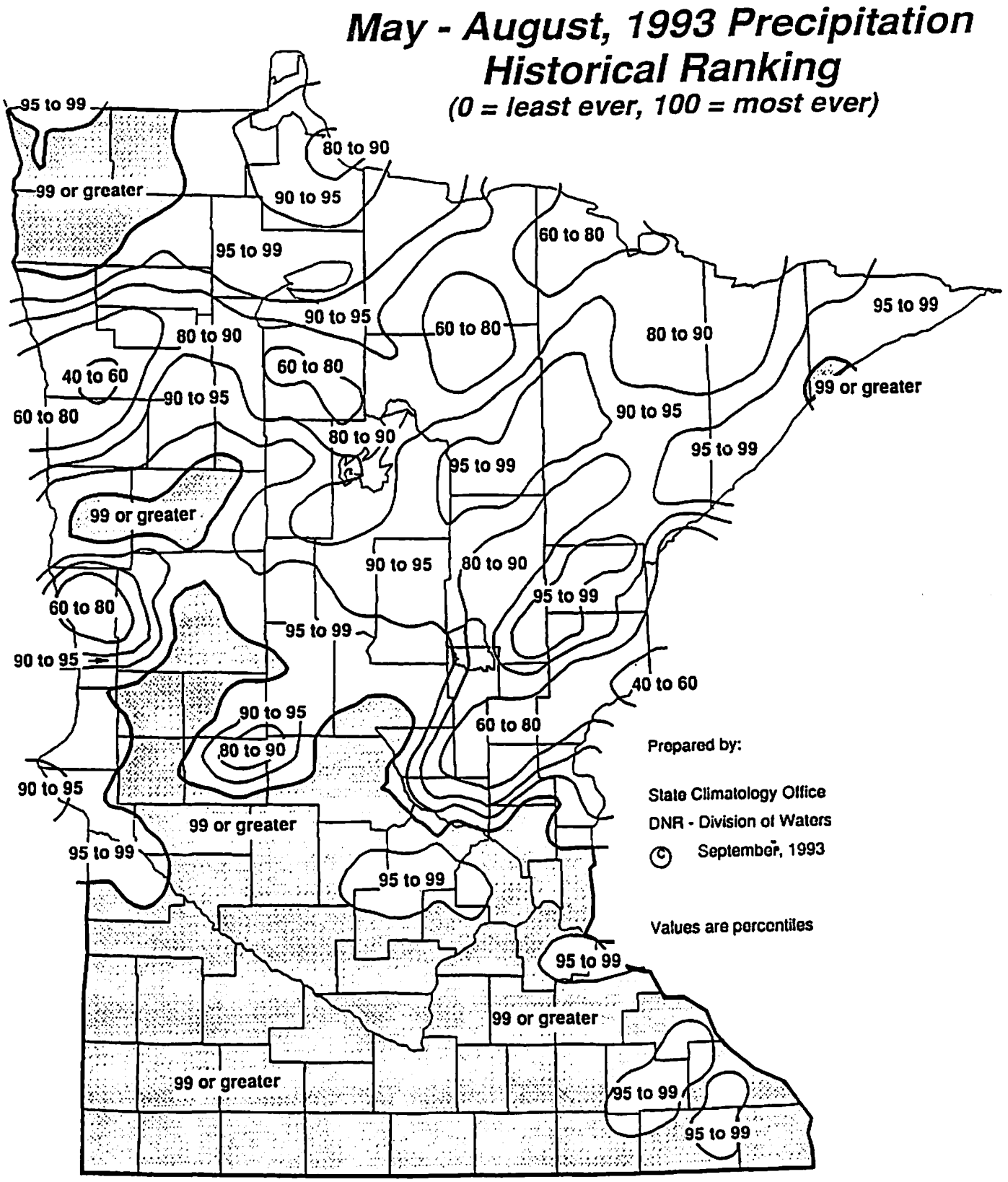

Fig. 1. This map depicts where the May to August 1993 precipitation totals fall in the context of history (100 years of climate data). A value of 99 or greater means the May to August all-time rainfall record was nearly matched or broken. A value of 90 means that greater amounts would only be expected one out of ten years.

SOIL MOISTURE, 1993[1]

G. Randall, D. Fuchs, D. Huggins, S. Evans J. Cameron, D. Ruschy and D. Baker[2]

The soil moisture monitoring program continues at the Crookston, Lamberton, Morris, and Waseca stations. The results for the year are shown in Fig. 2 and 3, and are a reflection of the annual precipitation amounts this past summer. As noted in the "Climate Update-Fall and Winter, 1993" article by the State Climatology Office the southern half of the state was inundated while the northern half received much less. At Morris, Fig. 2, there were several sampling times that had to be skipped due to the high water content of the soil. At Lamberton, Fig. 2, the familiar mid-season decrease in soil moisture was absent this year. This indicated that the precipitation essentially equalled the evapotranspiration and little or no soil water reserves remained about constant. The Lamberton soil profile ended the season containing about 2 inches more than average. At Waseca the profile contained only about one-half inch above average.

The above average amounts at the Lamberton, Morris and Waseca stations give an early indication that flooding could be a problem this spring. This is true particularly for the Minnesota valley where snow and soil moisture amounts are well above average.

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

[2]Gyles Randall, Southern AES; Dennis Fuchs and Dave Huggins, Southwest AES; Sam Evans, West Central AES; James Cameron, Northwest AES; and Dave Ruschy and Donald Baker at the St. Paul AES.

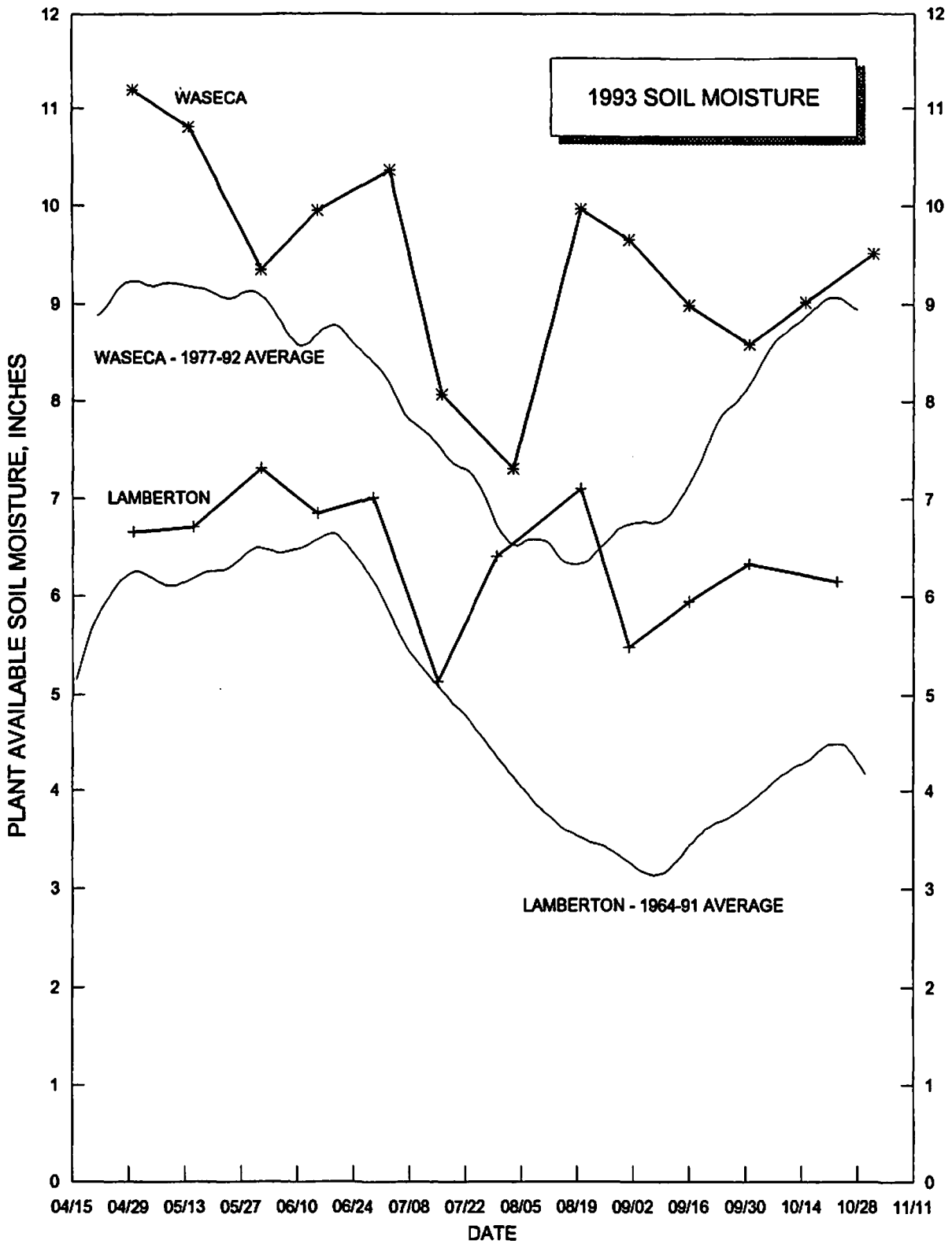

Fig. 2. Comparison of the total plant available soil moisture in a 5-foot column of soil under corn at the Lamberton and Waseca Agricultural Experiment Stations. The heavier lines are the 1993 totals and the lighter lines are the long-term averages.

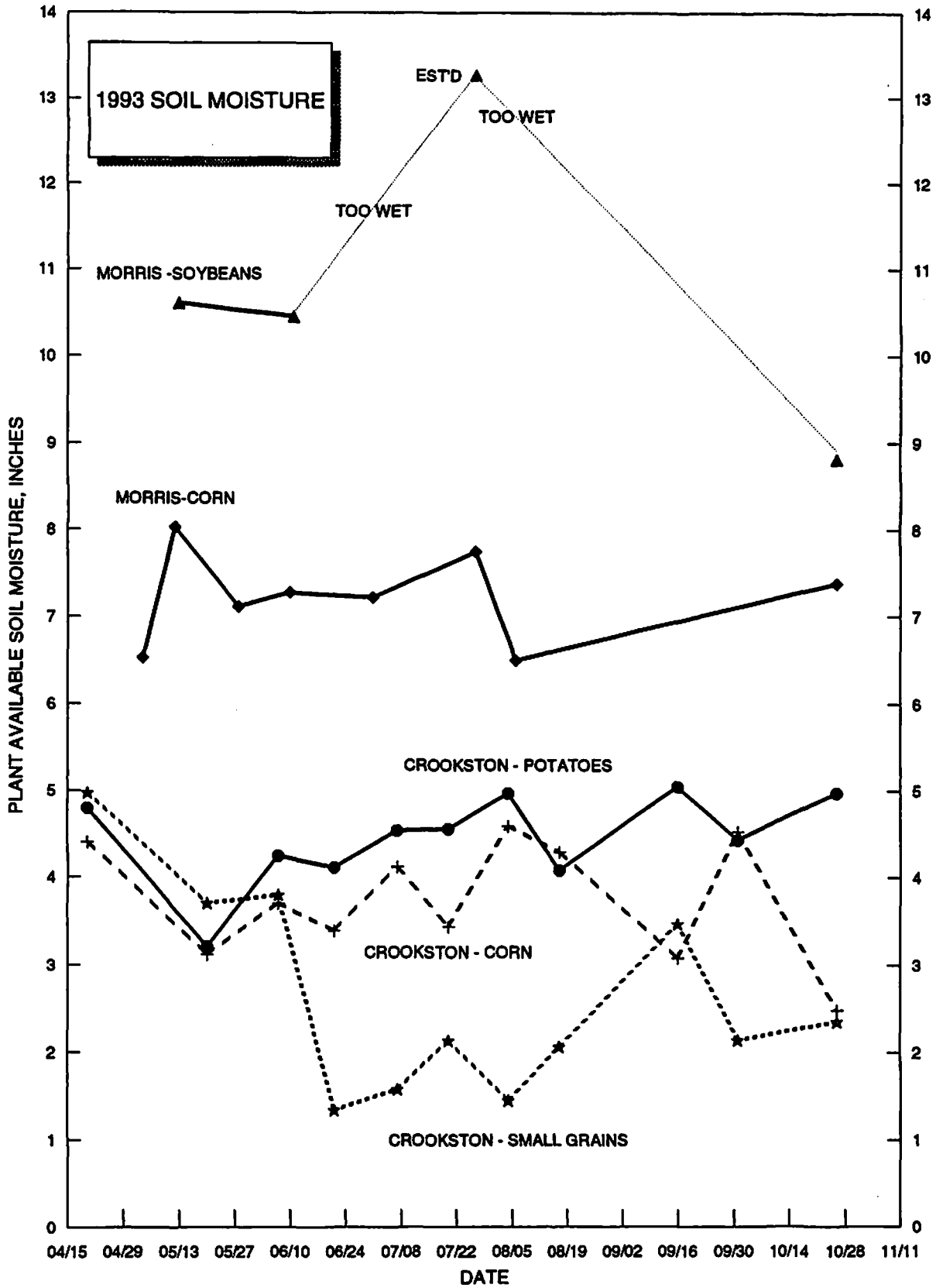

Fig. 3. Comparison of the total plant available soil moisture in a 5-foot column of soil under the indicated crops at the Crookston and Morris Agricultural Experiment Stations. At Morris, the soybean field was frequently too wet to obtain acceptable samples.

SOIL FREEZE-THAW OCCURRENCES[1]

D. G. Baker and D. L. Ruschy[2]

The fluctuation of temperature above, then below the freezing point and returning above the freezing level (or vice versa), constituting a freeze-thaw (or a thaw-freeze) occurrence, has long been considered an important measure of physical weathering. With the volume expansion of water upon freezing and the attendant relaxation of the pressure upon thawing, the freeze-thaw phenomenon is a natural physical force to be reckoned with. It is of importance to soil scientists as a result of its effect upon soil structure, to engineers for its effect upon highways and other structures resting in or on the soil, to geologists for its effect upon the weathering of rocks and minerals and the alteration of landscape features, and to agriculturists for its effect upon biological systems.

The statistics of the freeze-thaw phenomenon, essentially a surface feature, are difficult to determine from the usual climatological data for two reasons: a) the frequency of observation and the height of the standard air temperature measurement. Only at experimental sites and first order National Weather Service stations are observations made more frequently than the daily maximum and minimum measurements common to the cooperative network stations. And only at certain experimental sites are temperatures sometimes measured at heights other than the approximately 160-cm (63-in.) of the standard temperature shelter.

A comparison between air and soil temperature made at the St. Paul campus climatological observatory permit the determination of the best method to estimate the frequency of soil freeze-thaws when only daily maximum and minimum air temperatures are available. The estimated average monthly frequencies on a north to south transect from International Falls to Des Moines are shown in Fig. 5. All stations show the expected maximum frequency in the fall and spring maximums. At all stations except International Falls the maximums occur in November and March. Due to the lower temperatures and longer winter season at International Falls, the maximum occur in October and April. The January frequency of freeze-thaws increases north to south paralleling the increase in temperatures in the same direction.

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[1]Support for this project was provided by the Agricultural Experiment Station.

[2]Dr. Baker and D. Ruschy are professor and junior scientist, respectively, Soil Science Dept., University of Minnesota, St. Paul.

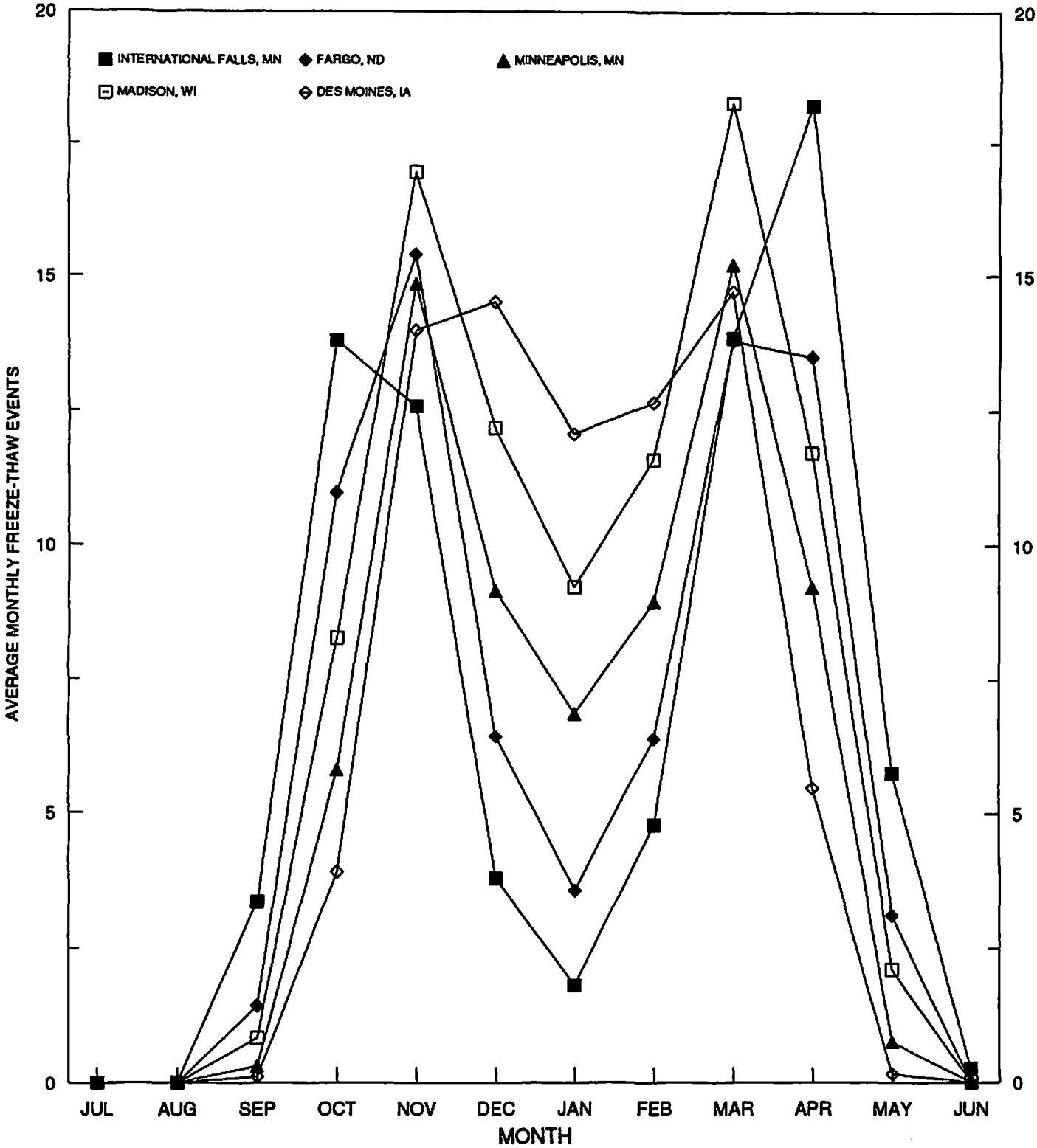

Fig. 5. Mean montly freeze-thaw cycles calculated from air temperatures in a north to south transect from International Falls to Des Moines. The method used to count the cycles most nearly represents the freeze-thaw cycles in soil bare of vegetation as determined at the St. Paul Campus Climatological Observatory using 7 years of data.

VARIABILITY OF CLIMATE[1]

D. G. Baker and D. L. Ruschy[2]

We are all aware of the vagaries of the weather from day to day and of the climate from year to year. And, anyone involved in agriculture is aware of the extremes, both good and bad, that can descend upon us. The bad events are rather well known to us and include the drought years of 1934, 1936 and 1976 and the heat wave and drought of 1988. Other years could be included. It is not as easy to name the good years since they don't seem to impress us as much - it is easier to remember catastrophes apparently.

There was a series of years that occurred from about 1956 to 1973 in which the climate from year to year was remarkably consistent and without major surprises. It was easy to forecast the next year's yield, since it seemed to increase in a regular fashion of 1-3 bu/A of corn per year, for example. Within a season the weather was such that the full effect of the applied technology (fertilizers and other chemicals, new and improved machinery, better seed, etc.) showed up in the nearly constantly improving yields. This time of an historically unique period of low climate variation was an important but little appreciated period that was termed the "benign climate".

In Fig. 4 is shown the remarkable decrease in interannual variability centered around 1952-1964 in the Eastern Minnesota record. It is even more apparent and over a more extended period when the average of 36 stations across the U.S. is calculated. Thus, it is confirmed as more than a chance occurrence at the single Minnesota station.

It is our contention that this agriculturally favorable period was in part responsible for the general euphoria that became a part of the general mood of the U.S. and of American agriculture in particular. The duration of this period was about a generation in length. It misled a number of the farmers who entered agriculture at that time into believing that the good weather and climate was the natural course of events; they hadn't experienced the bad times (climatic as well as economic) that their parents had experienced. As a result, farming looked extremely profitable and land prices began to rise.

However, by 1974 the precipitation totals began to decrease culminating in the drought of 1976. It was not realized by most that the variability of the climate had changed sharply, and from this point on equalled the variability experienced in earlier years; the variability common to most of the record. The recent and all too brief "benign climate" period was unique, and not the norm. Unfortunately, land prices and interest rates continued to increase while, in contrast to the "benign period", the yields were far more variable from year to year.

With the end of the benign period, yields became much more variable, and in consequence it became more difficult to carry the higher expenses that many had assumed in the benign period. The effect of the disappearance of this period was not realized immediately, but by about 1980 the end came with a rapid drop in land prices - a real deflation or depression in agriculture.

In summary, the "benign climate" was in part responsible for the good times agriculture experienced during about 1956-1973 that led less experienced farmers into assuming a debt burden that could be supported only with its continuation. The ending of this unique climatic period, which was largely unrecognized, was responsible in part for the sudden deflation and the agricultural depression that began in 1980. Thus, this series of events makes it very apparent that relatively minor climatic events - even very subtle events that are difficult to detect - can have far reaching consequences affecting the economic and social fabric of our nation.

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[1]Support for this project was provided by the Agricultural Experiment Station.

[2]D. Baker and D. Ruschy are professor and junior scientist, respectively, Soil Science Department at the University of Minnesota, St. Paul, MN 55108.

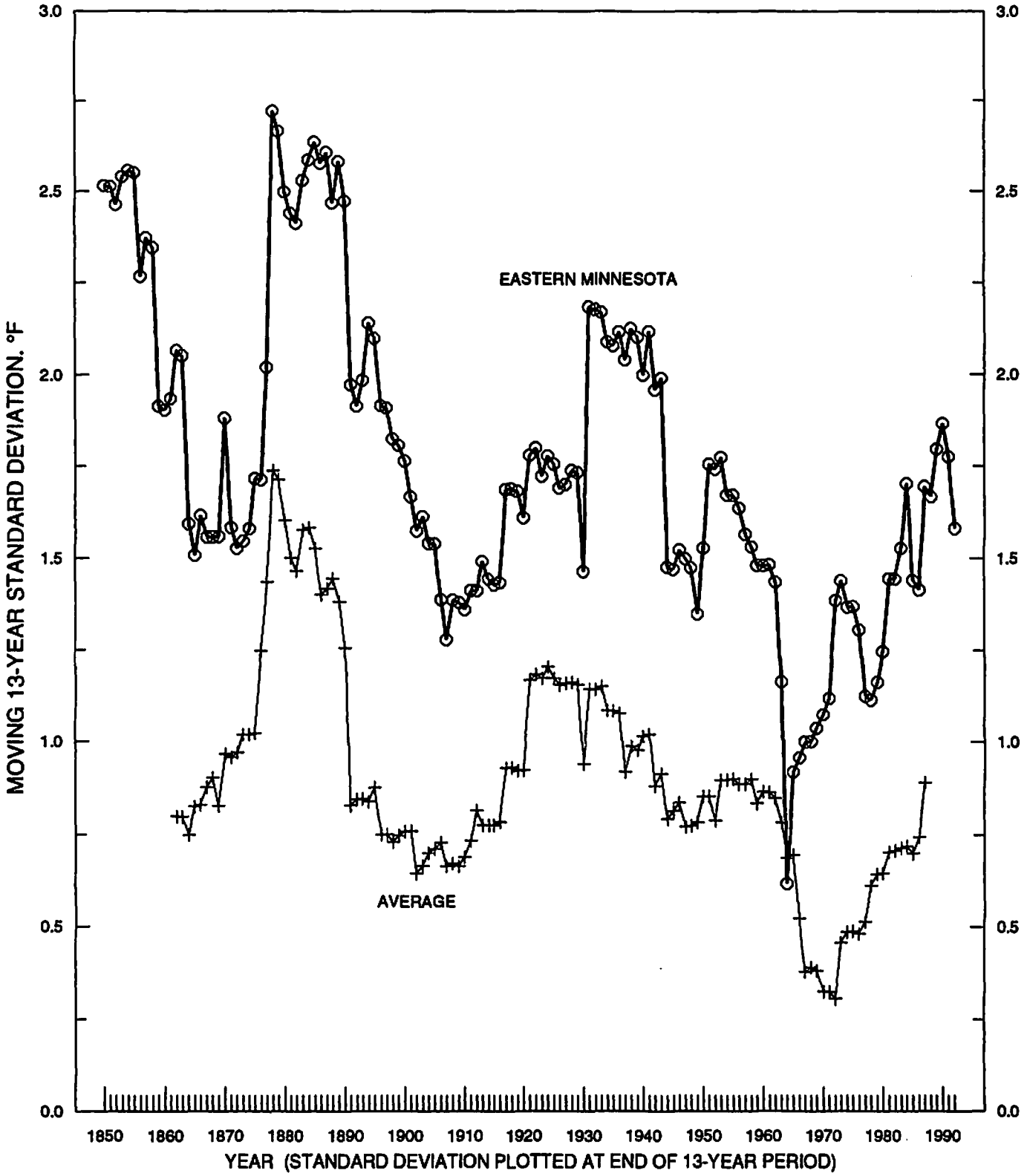

Fig. 4. Running standard deviations of 13-year periods of the average annual temperature at the Eastern Minnesota station and the average of 36 United States' stations. Note the minimum standard deviation in the mid-1960's and the early 1970's in the two records and the much higher variation both before and after the "benign climate" period.

NITROGEN MANAGEMENT FOR IRRIGATED POTATOES: EFFECTS OF NITROGEN TIMING AND SOURCE ON SOIL NITRATE MOVEMENT AND PETIOLE SAP NITRATE INTERPRETATION - 1993[1]

Carl Rosen, Mohamed Errebhi, John Moncrief, Satish Gupta, H. H. Cheng, and Dave Birong[2]

ABSTRACT: The third year of a four year study was conducted at the Sand Plain Research Farm in Becker, MN to evaluate the effects of various N management strategies on nitrogen use and nitrate movement under irrigated potatoes. A second objective was to continue with calibration of a quick petiole nitrate sap test for determining nitrogen status of the crop and predicting nitrogen needs. Tuber yield increased with increasing N rate up to 240 lb N/A, with the greatest increase occurring between the 0 and 120 lb N/A rate. At equivalent N rates, use of post-hilling N applications tended to result in larger tubers compared to applying all the N up to hilling. Hollow heart increased with increasing N rate, but was not affected by post-hilling N application. Higher concentrations of nitrate in soil water at the 4 ft depth were found in the row compared to between the row for most treatments. Leaching of N was related more to rate of N applied than timing of application. Final tuber yields with urea as the N source were similar to those with ammonium nitrate as the N source, although early plant growth with ammonium nitrate was greater than with urea. The early response to ammonium nitrate may have been due to cooler temperatures, which may have inhibited conversion of ammonium to nitrate when urea was used. Petiole nitrate increased with increasing N rate and with post-hilling N applications. For all treatments that did not involve post-hilling N, petiole nitrate decreased through the season. The quick tests used reflected the changes in petiole nitrate with N treatment. Sap nitrate concentrations determined with the Cardy meter tended to be 50 to 100 ppm higher than readings from the Hach or Wescan instruments.

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 nitrogen management regimes and to develop diagnostic tools for quick and accurate prediction of the need for N by potato during the growing season. The results presented below are the third year of a four year study.

EXPERIMENTAL PROCEDURES

The experiment was conducted in Becker, MN at the Sand Plain Research Farm on a Hubbard loamy sand soil. The previous crop was rye. Selected soil chemical properties prior to planting were as follows (0-6"): pH, 6.8; organic matter, 2.5%; phosphorus, 31 ppm; potassium, 95 ppm; sulfur, 1 ppm. Residual nitrate-N in the top 3 feet of soil was 13 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 April 20, 1993 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	Post-Hilling	Post-Hilling	Post-Hilling
1) Control	0	0	0	0	0	0	0
2) Urea	40	100	100	0	0	0	0
3) Urea	20	70	70	20	20	20	20
4) Urea	20	70	70	0	0	0	0
5) Ammonium nitrate	40	100	100	0	0	0	0
6) Ammonium nitrate	20	70	70	20	20	20	20
7) Ammonium nitrate	20	70	70	0	0	0	0
8) Ammonium nitrate	40	40	40	0	0	0	0
9) Ammonium nitrate	40	40	40	0	20	20	20
10) Ammonium nitrate	40	40	40	20	20	20	20

[1]Funding for this project was provided by the Legislative Commission on Minnesota Resources. We thank Glenn Titrud for assistance in plot maintenance.

[2]Assoc. Prof., Grad. Res. Asst., Ext. Soil Sci., Prof., Prof., and Asst. Sci., respectively, Dept. Soil Sci.

Nitrogen applied at planting was banded with the P and K fertilizer. Nitrogen applied at emergence (May 26) was banded 1" deep and 8" from each side of the plant. At hilling (June 11), 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 treatments #3, 6, and 10 were applied on June 18, July 2, July 13 and July 19. Applications were made by broadcasting 50% ammonium nitrate and 50% urea over the plot by hand and then irrigating in. Post-hilling applications to treatment #9 were June 25, July 2, and July 13.

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 inches and was supplemented with 5.9 inches of irrigation. The nitrate-N concentration in the irrigation water averaged 8 to 10 ppm. Given that 5.9 inches of irrigation were applied, approximately 14 lbs of additional N was provided with the irrigation water. Figure 1 shows the weekly precipitation (rainfall + irrigation) through the growing season.

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 in 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, 34 and 450 ppm nitrate-N. A few drops of nondiluted sap were placed on the electrode membrane and a direct reading of nitrate-N was recorded.

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 one week after harvest. Samples consisted of 3 cores from an individual plot taken to a depth of 3 feet at 1 foot increments. 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. Results are expressed as pounds of nitrate-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.

Suction tubes, consisting of a porous ceramic cup and 1.5" diameter PVC tubes, were installed one week after planting in one of the sample rows and between the rows at the 4 ft depth. Nitrate-N in soil water was determined in samples collected every 1-2 weeks from the suction tubes.

Three plants from the other sample row from each plot were harvested on June 22 to determine the effects of the N treatments on initial growth. Samples were dried, weighed, and ground. Total N was determined using the salicylic Kjeldahl method. At harvest, vines were cut and weighed 5 days prior to harvest. Potatoes were mechanically harvested on September 15. Subsamples of vines and tubers were collected to determine dry matter and N accumulation. Tubers were evaluated for hollow heart and specific gravity was determined.

RESULTS

Rainfall and Soil Nitrate Movement. Weekly precipitation over the course of the season is presented in Figure 1. Leaching events (> 2" rainfall/day) only occurred three times, at 58, 111, and 130 days after planting. Seasonal nitrate-N concentrations in soil water extracted with the suction tubes at the 4 ft depth

in and between the row 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 nitrate-N concentrations that increased to 20 ppm during the first 12 weeks of the growing season (Figure 2). This nitrate originated from organic matter mineralization that occurs following tillage.

Differences in nitrate movement due to N sources (urea vs. ammonium nitrate) were not that apparent (Figs. 3, 4, 5 vs. 6, 7, 8) possibly due to the fact that leaching was not a problem until later in the growing season. Higher concentrations of nitrate were generally found in the row compared to between the row with little difference between nonpost-hilling and post-hilling applications at equivalent rates. Exceptions were post-hilling treatments 9 and 10, where high in row nitrate levels were found (Figs 10 and 11). Reasons for this higher level for these treatments are unclear. Higher rates of N generally resulted in higher nitrate concentrations in and between the row (Figs. 4, 7, 8 vs. 2, 3, 6, 7, 10) regardless of timing. By the end of the season after harvest, nitrate-N in soil water tended to increase for all treatments. Even though winter rye was planted, nitrate may have already moved beyond where the rye roots could take it up.

One week after harvest, extractable soil nitrate was higher in the N fertilized plots compared to the 0 N control, but there was little difference in soil nitrate concentrations among the N fertilized treatments (Table 1).

Tuber Yield, Specific Gravity, Hollow Heart, and Vine Yield. The effects of the various N treatments on tuber yield, specific gravity, hollow heart, and vine yield are presented in Table 3. Total yield increased with N rate with most of the yield increase occurring between the control treatment and 120 lb N/A (treatment 8). 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 generally higher than in those receiving N. Specific gravity decreased with increasing N rate. At similar N rates and timing of application, there was little difference between urea and ammonium nitrate on vine and tuber and vine yields. Specific gravity was similar for the urea and ammonium nitrate treatments when applied at equal rates. The post-hilling N application treatments 3 and 6 resulted in equal total yields compared to 240 lbs N/A applied through hilling (treatments 2 and 5). Post-hilling treatments resulted in greater yield of 7 - 14 oz potatoes compared to all the N applied up to hilling. Specific gravity was not affected by post-hilling N applications. Additional N after hilling resulted in larger tubers compared to the lower rates applied up to hilling; however, specific gravity was lower with the post-hilling N applications. Hollow heart tended to increase with increasing N rate but was not significantly affected by timing of N application.

Treatment Effects on Early Plant Growth. Increasing nitrogen rate resulted in more tubers per plant, greater dry matter accumulation, and higher N concentrations in plants sampled one week after hilling (Table 2). Ammonium nitrate did result in more tubers, and greater dry matter accumulation in vines and roots, and higher tissue N concentrations compared to urea. These results suggest that ammonium nitrate may be beneficial for early harvested potatoes. As expected all N applied up to hilling resulted in higher tissue N concentrations than post-hilling treatments since all the post-hilling N applications had not yet been applied.

Dry Matter and Nitrogen Accumulation. Dry matter and N accumulation, as well as concentrations of N in vines and tubers at harvest, are presented in Table 4. As expected, dry weight, N concentrations in vines and tubers, and N accumulation increased with increasing N rate. At equivalent N rates, post-hilling N applications increased N concentrations in vines and tubers compared to all N applied up to hilling, but did not significantly increase total N uptake. Dry matter accumulation was slightly lower with post-hilling N applications, which accounted for the lack of an effect on n uptake despite higher N concentrations with post-hilling applications. Nitrogen uptake and dry matter production were not affected by N source (urea vs. ammonium nitrate).

Nitrate-N Concentrations in Petiole Samples. The N status of the plant (sampled every 10-14 days starting one day before hilling), as measured by conventional petiole analysis and sap analysis, is presented in Table 5. On all sampling dates, nitrate on a dry weight or sap basis increased with increasing N rate. On the first sampling date, petiole nitrate concentrations were lower with the urea N source than with ammonium nitrate. After this date, petiole nitrate levels were not generally affected by N source. The lower level of petiole nitrate early may have been due to cooler weather inhibiting conversion of ammonium to nitrate for the urea N source. Differences in petiole nitrate due to post-hilling applications were not apparent until July 21. Sap Nitrate-N concentrations determined with the Cardy meter were 50 to 100 ppm higher than the those determined with the Hach or Wescan instruments.

SUMMARY

The 1993 season at Becker was a moderate year for nitrate leaching. Nitrogen rate significantly affected nitrate losses under irrigated potatoes. Greatest losses were observed as N rate increased. 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 N status of the crop; however, using the N status to predict N needs will require additional calibration research to evaluate timing and rates of post-hilling application to maximize yield.

Table 1. 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. Becker, MN.

Treatment					
N source	N timing	0 to 1 foot	1 to 2 foot	2 to 3 foot	Field total
		Pounds per acre			
1. Control	(0 N/A)	3.47 ± 2.06	3.28 ± 1.77	1.11 ± 0.41	7.86 ± 3.55
2. (46-0-0)	(40,100,100)[1]	9.98 ± 4.28	7.91 ± 6.21	1.68 ± 1.13	19.57 ± 10.49
3. (46-0-0)	(20,70,70)+80[2]	9.80 ± 4.01	8.33 ± 2.62	1.32 ± 0.63	21.95 ± 2.76
4. (46-0-0)	(20,70,70)	8.02 ± 5.02	8.17 ± 1.85	1.58 ± 0.30	17.77 ± 6.08
5. (34-0-0)	(40,100,100)	12.31 ± 5.25	6.77 ± 3.95	1.03 ± 0.68	20.11 ± 9.05
6. (34-0-0)	(20,70,70)+80[2]	9.82 ± 5.96	9.33 ± 4.35	1.74 ± 0.58	20.89 ± 10.21
7. (34-0-0)	(20,70,70)	10.27 ± 4.95	11.46 ± 3.48	2.07 ± 0.64	23.80 ± 6.92
8. (34-0-0)	(40,40,40)	7.50 ± 5.65	6.26 ± 3.34	1.89 ± 0.77	15.65 ± 9.31
9. (34-0-0)	(40,40,40)+60[3]	7.10 ± 4.08	5.81 ± 2.98	1.35 ± 0.76	14.26 ± 6.06
10. (34-0-0)	(40,40,40)+80[2]	12.21 ± 5.41	7.73 ± 3.52	2.26 ± 1.20	22.20 ± 9.41

[1] = Planting, emergence, and hilling respectively. [2] = Four post-hilling applications at 20 pounds N/A each, based on sap analysis. [3] = Three post-hilling applications at 20 pounds N/A each, based on sap analysis.

Table 2. Effect of nitrogen treatments on fresh weight of vines, tubers, and hollow heart. Becker, MN.

Treatment		Fresh weight							Specific	Hollow
		Vines	Knobs <3 oz	3-7 oz	7-14 oz	>14 oz	Total		Gravity	Heart-%
N source	N timing	Tons/A	cwt/A							incidence
1. Control	(0 N/A)	0.78	11.9	16.9	132.8	65.1	4.4	231.2	1.0874	2.0
2. (46-0-0)	(40,100,100)[1]	3.42	59.0	28.3	144.9	167.9	55.2	455.2	1.0825	10.0
3. (46-0-0)	(20,70,70)+80[2]	5.00	35.4	22.4	143.8	196.3	53.8	451.8	1.0831	14.7
4. (46-0-0)	(20,70,70)	1.91	63.3	28.0	156.5	160.6	28.0	436.5	1.0873	17.0
5. (34-0-0)	(40,100,100)	4.88	63.2	28.9	148.3	192.6	42.2	475.3	1.0828	12.0
6. (34-0-0)	(20,70,70)+80[2]	5.54	36.6	26.0	139.9	200.7	55.7	458.8	1.0812	10.0
7. (34-0-0)	(20,70,70)	1.51	66.3	31.6	153.1	169.6	21.8	442.5	1.0850	12.0
8. (34-0-0)	(40,40,40)	0.76	61.6	26.7	175.0	144.5	10.0	417.8	1.0885	6.0
9. (34-0-0)	(40,40,40)+60[3]	2.76	51.6	33.5	153.9	175.0	32.4	446.4	1.0843	15.0
10. (34-0-0)	(40,40,40)+80[2]	3.16	47.0	28.9	155.9	163.4	53.1	448.3	1.0810	5.0
Significance		**	**	NS	*	**	**	**	**	NS
BLSD (0.05)		1.44	20.1	--	27.1	28.6	16.8	24.0	0.0030	--
Contrasts										
Lin Rate N (1, 5, 7, 8)		**	**	*	NS	**	**	**	**	*
Quad Rate N (1, 5, 7, 8)		*	**	NS	*	**	NS	**	NS	NS
Post-hilling (2, 5) vs (3, 6)		*	**	NS	NS	++	NS	NS	NS	NS
(2, 3, 4) vs (5, 6, 7)		NS	NS	NS	NS	NS	NS	NS	NS	NS
Treatment 3 vs 4		**	**	NS	NS	*	**	NS	NS	NS
Treatment 6 vs 7		**	**	NS	NS	*	**	NS	*	NS
Treatment 9 vs 10		NS	**	NS	NS	NS	*	NS	*	++

[1] = Planting, emergence and hilling respectively. [2] = Four post-hilling applications at 20 pounds N/A each, based on sap analysis. [3] = Three post-hilling applications at 20 pounds N/A each, based on sap analysis. NS = Nonsignificant; ++, *, ** = significant at 10%, 5% and 1%, respectively.

Table 3. Effect of nitrogen treatments on root and vine dry matter, tuber number and dry matter; sampled June 22, 1993 - Becker, MN.

Treatment			----------dry matter----------				--- N concentration---		
	N source	N timing	Tubers	Tuber	Vine	Root	Total	Tuber	Vine	Root
			-#/plant-	----------g/plant----------				---------% N ---------		
1.	Control	(0 N/A)	3.83	2.2	8.3	1.8	12.3	1.48	3.01	1.49
2.	(46-0-0)	(40,100,100)[1]	5.25	7.0	31.5	2.8	41.3	1.98	4.88	2.41
3.	(46-0-0)	(20,70,70)+80[2]	5.55	5.8	32.4	2.8	41.0	2.17	5.22	2.58
4.	(46-0-0)	(20,70,70)	5.83	5.5	28.7	2.4	36.6	1.92	4.88	2.36
5.	(34-0-0)	(40,100,100)	6.33	5.2	41.7	3.2	50.0	2.00	5.25	2.40
6.	(34-0-0)	(20,70,70)+80[2]	7.08	6.3	35.4	3.3	45.1	2.29	5.67	2.70
7.	(34-0-0)	(20,70,70)	8.33	8.3	35.1	3.2	47.4	1.80	5.06	2.43
8.	(34-0-0)	(40,40,40)	5.66	5.7	38.4	3.2	47.3	1.94	4.63	2.43
9.	(34-0-0)	(40,40,40)+60[3]	6.25	7.3	35.1	3.0	45.3	1.87	4.58	2.19
10.	(34-0-0)	(40,40,40)+80[2]	8.33	9.7	38.9	3.3	51.8	2.17	5.26	2.34
Significance			NS	NS	**	**	**	**	**	**
BLSD (0.05)			--	--	5.4	0.6	7.5	0.25	0.20	0.22
Contrasts										
Lin Rate N (1, 5, 7, 8)			*	NS	**	**	**	**	**	**
Quad Rate N (1, 5, 7, 8)			NS	NS	**	*	**	**	**	**
Post-hilling (2, 5) vs (3, 6)			NS	NS	NS	NS	NS	**	**	*
(2, 3, 4) vs (5, 6, 7)			++	NS	**	**	**	NS	**	NS
Treatment 3 vs 4			NS	NS	NS	NS	NS	*	**	++
Treatment 6 vs 7			NS	NS	NS	NS	NS	**	**	*
Treatment 9 vs 10			NS	NS	NS	NS	NS	*	**	NS

[1] = Planting, emergence and hilling respectively. [2] = Four post-hilling applications at 20 pounds N/A each, based on sap analysis. [3] = Three post-hilling applications at 20 pounds N/A each, based on sap analysis. NS = Nonsignificant, ++, *, ** = significant at 10%, 5%, and 1%, respectively.

Table 4. Effect of nitrogen on N content, concentration, 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)	4.7	51.1	55.8	1.28	1.01	0.18	2.52	2.70
2.	(46-0-0)	(40,100,100)[1]	25.6	131.3	157.0	1.42	1.37	0.88	4.83	5.70
3.	(46-0-0)	(20,70,70)+80[2]	26.2	138.4	164.6	1.85	1.53	0.71	4.50	5.22
4.	(46-0-0)	(20,70,70)	13.7	112.4	126.2	1.03	1.16	0.67	4.84	5.51
5.	(34-0-0)	(40,100,100)	22.8	137.6	160.4	1.58	1.40	0.73	4.94	5.66
6.	(34-0-0)	(20,70,70)+80[2]	31.0	143.8	174.8	2.05	1.50	0.76	4.81	5.58
7.	(34-0-0)	(20,70,70)	16.6	119.5	136.2	1.18	1.24	0.71	4.78	5.49
8.	(34-0-0)	(40,40,40)	8.2	94.7	102.9	0.80	1.02	0.52	4.67	5.19
9.	(34-0-0)	(40,40,40)+60[3]	17.8	123.2	141.0	1.54	1.31	0.58	4.73	5.31
10.	(34-0-0)	(40,40,40)+80[2]	24.6	141.6	166.2	1.73	1.52	0.71	4.68	5.39
Significance			**	**	**	**	**	**	**	**
BLSD (0.05)			8.7	16.6	18.4	0.28	0.18	0.26	0.37	0.42
Contrasts										
Lin Rate N (1, 5, 7, 8)			**	**	**	++	**	**	**	**
Quad Rate N (1, 5, 7, 8)			NS	**	**	NS	NS	NS	**	**
Post-hilling (2, 5) vs (3, 6)			NS	NS	NS	**	*	NS	NS	++
(2, 3, 4) vs (5, 6, 7)			NS	NS	NS	++	NS	NS	NS	NS
Treatment 3 vs 4			**	**	**	**	**	NS	NS	NS
Treatment 6 vs 7			**	*	**	**	**	NS	NS	NS
Treatment 9 vs 10			NS	*	*	NS	*	NS	NS	NS

[1] = Planting, emergence and hilling respectively. [2] = Four post-hilling applications at 20 pounds N/A each, based on sap analysis. [3] = Three post-hilling applications at 20 pounds N/A each, based on sap analysis. NS = Nonsignificant, ++, *, ** = significant at 10%, 5%, and 1%, respectively.

Table 5. 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 10				June 24			
	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 NO_3-N							
1.	Control	(0 N/A)	1676	211	159	122	1035	160	100	88
2.	(46-0-0)	(40,100,100)[1]	21779	1438	1260	1135	20688	1650	1288	1295
3.	(46-0-0)	(20,70,70)+80[2]	20844	1325	1209	1110	21662	1625	1308	1324
4.	(46-0-0)	(20,70,70)	22260	1538	1369	1187	20579	1600	1324	1241
5.	(34-0-0)	(40,100,100)	24332	1575	1425	1301	24584	1650	1261	1295
6.	(34-0-0)	(20,70,70)+80[2]	25143	1688	1469	1376	23198	1625	1346	1376
7.	(34-0-0)	(20,70,70)	24814	1625	1490	1380	21414	1600	1233	1249
8.	(34-0-0)	(40,40,40)	24106	1563	1376	1261	14265	1225	931	936
9.	(34-0-0)	(40,40,40)+60[3]	22730	1550	1303	1205	15054	1200	956	1089
10.	(34-0-0)	(40,40,40)+80[2]	24274	1538	1360	1255	19149	1525	1209	1204
Significance			**	**	**	**	**	**	**	**
BLSD (0.05)			1884	217	128	86	1817	156	124	126
Contrasts										
Lin Rate N (1, 5, 7, 8)			**	**	**	**	**	**	**	**
Quad Rate N (1, 5, 7, 8)			**	**	**	**	**	**	**	**
Post-hilling (2, 5) vs (3, 6)			NS	NS	NS	NS	NS	NS	NS	NS
(2, 3, 4) vs (5, 6, 7)			**	**	**	**	**	NS	NS	NS
Treatment 3 vs 4			NS	++	*	NS	NS	NS	NS	NS
Treatment 6 vs 7			NS	NS	NS	NS	++	NS	NS	++
Treatment 9 vs 10			NS	NS	NS	NS	**	**	**	NS

[1] = Planting, emergence and hilling respectively. [2] = Four post-hilling applications at 20 pounds N/A each, based on sap analysis. [3] = Three post-hilling applications at 20 pounds N/A each, based on sap analysis. NS = Nonsignificant, ++, *, ** = significant at 10%, 5%, and 1%, respectively.

Table 5 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 8				July 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 NO_3-N							
1.	Control	(0 N/A)	215	73	49	37	995	158	115	93
2.	(46-0-0)	(40,100,100)[1]	21451	1388	1295	1276	17670	1425	1356	1339
3.	(46-0-0)	(20,70,70)+80[2]	22951	1438	1385	1362	22257	1575	1475	1442
4.	(46-0-0)	(20,70,70)	17099	1200	1117	1099	4367	458	383	365
5.	(34-0-0)	(40,100,100)	22120	1488	1306	1342	17216	1375	1235	1217
6.	(34-0-0)	(20,70,70)+80[2]	21320	1375	1286	1235	18624	1375	1369	1359
7.	(34-0-0)	(20,70,70)	15678	1150	1067	1033	3853	503	431	401
8.	(34-0-0)	(40,40,40)	5986	550	458	434	384	136	67	44
9.	(34-0-0)	(40,40,40)+60[3]	15401	1275	1134	1099	15864	1350	1249	1223
10.	(34-0-0)	(40,40,40)+80[2]	16466	1175	1079	1032	13931	1300	1171	1128
Significance			**	**	**	**	**	**	**	**
BLSD (0.05)			1768	153	127	127	1867	164	121	120
Contrasts										
Lin Rate N (1, 5, 7, 8)			**	**	**	**	**	**	**	**
Quad Rate N (1, 5, 7, 8)			**	**	**	**	**	**	**	**
Post-hilling (2, 5) vs (3, 6)			NS	NS	NS	NS	**	NS	*	*
(2, 3, 4) vs (5, 6, 7)			NS	NS	NS	NS	*	NS	NS	NS
Treatment 3 vs 4			**	**	**	**	**	**	**	**
Treatment 6 vs 7			**	*	**	**	**	**	**	**
Treatment 9 vs 10			NS	NS	NS	NS	++	NS	NS	NS

[1] = Planting, emergence and hilling respectively. [2] = Four post-hilling applications at 20 pounds N/A each, based on sap analysis. [3] = Three post-hilling applications at 20 pounds N/A each, based on sap analysis.

Table 5. 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							
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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 NO_3-N							
1. Control	(0 N/A)	1676	211	159	122	1035	160	100	88
2. (46-0-0)	(40,100,100)[1]	21779	1438	1260	1135	20688	1650	1288	1295
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10. (34-0-0)	(40,40,40)+80[2]	24274	1538	1360	1255	19149	1525	1209	1204
Significance		**	**	**	**	**	**	**	**
BLSD (0.05)		1884	217	128	86	1817	156	124	126
Contrasts									
Lin Rate N (1, 5, 7, 8)		**	**	**	**	**	**	**	**
Quad Rate N (1, 5, 7, 8)		**	**	**	**	**	**	**	**
Post-hilling (2, 5) vs (3, 6)		NS	NS	NS	NS	NS	NS	NS	NS
(2, 3, 4) vs (5, 6, 7)		**	**	**	**	**	NS	NS	NS
Treatment 3 vs 4		NS	++	*	NS	NS	NS	NS	NS
Treatment 6 vs 7		NS	NS	NS	NS	++	NS	NS	++
Treatment 9 vs 10		NS	NS	NS	NS	**	**	**	NS

[1] = Planting, emergence and hilling respectively. [2] = Four post-hilling applications at 20 pounds N/A each, based on sap analysis. [3] = Three post-hilling applications at 20 pounds N/A each, based on sap analysis. NS = Nonsignificant, ++, *, ** = significant at 10%, 5%, and 1%, respectively.

Table 5 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 8				July 21			
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		ppm NO_3-N							
1. Control	(0 N/A)	215	73	49	37	995	158	115	93
2. (46-0-0)	(40,100,100)[1]	21451	1388	1295	1276	17670	1425	1356	1339
3. (46-0-0)	(20,70,70)+80[2]	22951	1438	1385	1362	22257	1575	1475	1442
4. (46-0-0)	(20,70,70)	17099	1200	1117	1099	4367	458	383	365
5. (34-0-0)	(40,100,100)	22120	1488	1306	1342	17216	1375	1235	1217
6. (34-0-0)	(20,70,70)+80[2]	21320	1375	1286	1235	18624	1375	1369	1359
7. (34-0-0)	(20,70,70)	15678	1150	1067	1033	3853	503	431	401
8. (34-0-0)	(40,40,40)	5986	550	458	434	384	136	67	44
9. (34-0-0)	(40,40,40)+60[3]	15401	1275	1134	1099	15864	1350	1249	1223
10. (34-0-0)	(40,40,40)+80[2]	16466	1175	1079	1032	13931	1300	1171	1128
Significance		**	**	**	**	**	**	**	**
BLSD (0.05)		1768	153	127	127	1867	164	121	120
Contrasts									
Lin Rate N (1, 5, 7, 8)		**	**	**	**	**	**	**	**
Quad Rate N (1, 5, 7, 8)		**	**	**	**	**	**	**	**
Post-hilling (2, 5) vs (3, 6)		NS	NS	NS	NS	**	NS	*	*
(2, 3, 4) vs (5, 6, 7)		NS	NS	NS	NS	*	NS	NS	NS
Treatment 3 vs 4		**	**	**	**	**	**	**	**
Treatment 6 vs 7		**	*	**	**	**	**	**	**
Treatment 9 vs 10		NS	NS	NS	NS	++	NS	NS	NS

[1] = Planting, emergence and hilling respectively. [2] = Four post-hilling applications at 20 pounds N/A each, based on sap analysis. [3] = Three post-hilling applications at 20 pounds N/A each, based on sap analysis. NS = Nonsignificant, ++, *, ** = significant at 10%, 5%, and 1%, respectively.

Table 5 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							
			August 4				August 18			
	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 NO_3-N							
1.	Control	(0 N/A)	67	94	44	12	20	58	37	3
2.	(46-0-0)	(40,100,100)[1]	9704	851	737	704	2486	250	202	182
3.	(46-0-0)	(20,70,70)+80[2]	15053	1263	1174	1120	5660	604	501	522
4.	(46-0-0)	(20,70,70)	1836	334	246	227	168	78	55	23
5.	(34-0-0)	(40,100,100)	8487	891	782	749	2587	245	196	182
6.	(34-0-0)	(20,70,70)+80[2]	15929	1188	1071	1046	5563	530	431	441
7.	(34-0-0)	(20,70,70)	1510	270	205	168	209	78	57	26
8.	(34-0-0)	(40,40,40)	161	101	55	18	151	66	40	10
9.	(34-0-0)	(40,40,40)+60[3]	9181	828	775	732	1474	205	171	154
10.	(34-0-0)	(40,40,40)+80[2]	16651	1150	1053	1033	3386	378	302	299
Significance			**	**	**	**	**	**	**	**
BLSD (0.05)			2080	106	96	98	1571	115	98	108
Contrasts										
Lin Rate N (1, 5, 7, 8)			**	**	**	**	**	**	**	**
Quad Rate N (1, 5, 7, 8)			**	**	**	**	++	++	NS	++
Post-hilling (2, 5) vs (3, 6)			**	**	**	**	**	**	**	**
(2, 3, 4) vs (5, 6, 7)			NS	NS	NS	NS	NS	NS	NS	NS
Treatment 3 vs 4			**	**	**	**	**	**	**	**
Treatment 6 vs 7			**	**	**	**	**	**	**	**
Treatment 9 vs 10			**	**	**	**	*	**	*	*

[1] = Planting, emergence and hilling respectively. [2] = Four post-hilling applications at 20 pounds N/A each, based on sap analysis. [3] = Three post-hilling applications at 20 pounds N/A each, based on sap analysis. NS = Nonsignificant, ++, *, ** = significant at 10%, 5%, and 1%, respectively.

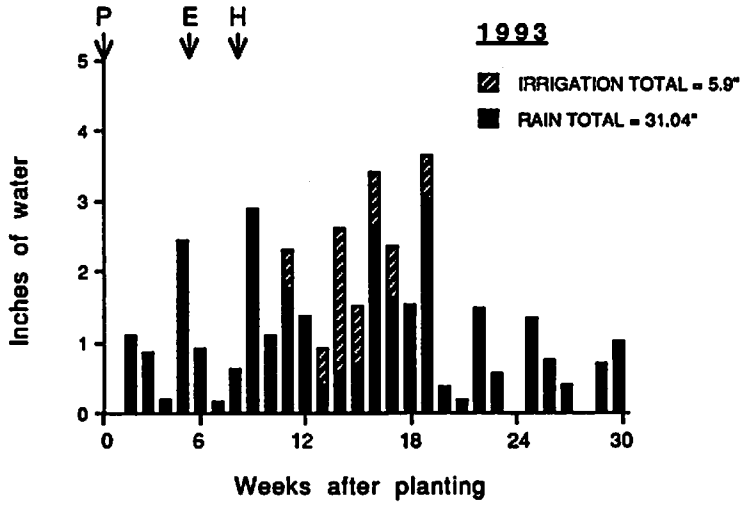

Figure 1. Rainfall and irrigation at Becker, MN during the 1993 growing season. P, H and E = planting, emergence and hilling, respectively.

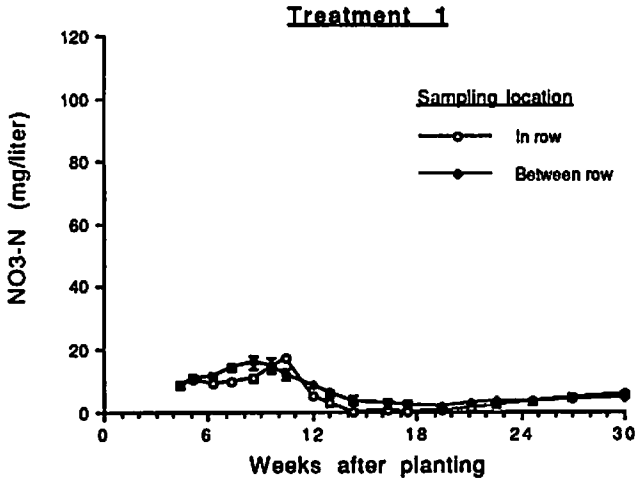

Figure 2. Nitrate - N concentration in soil water sampled in the row and between the row at the 4 ft. depth, over the 1993 growing season. Nitrogen application rate: no nitrogen. Error bar represents SE of the mean.

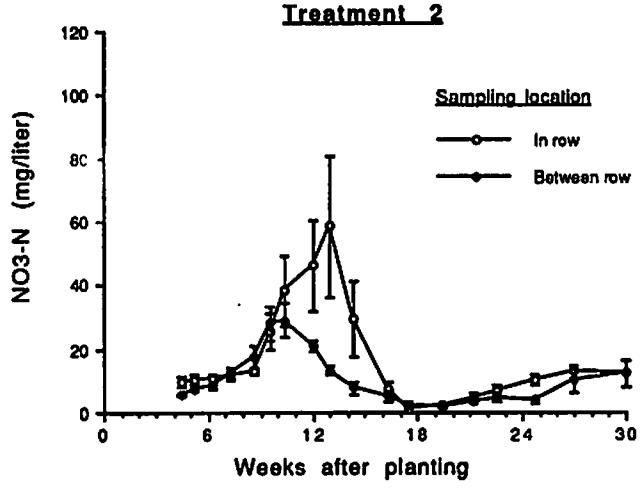

Figure 3. Nitrate - N concentration in soil water sampled in the row and between the row at the 4 ft. depth, over the 1993 growing season. Nitrogen application rate: 40 lb N/A at planting, 100 lb at emergence and hilling (46-0-0). Error bars represent SE of the mean.

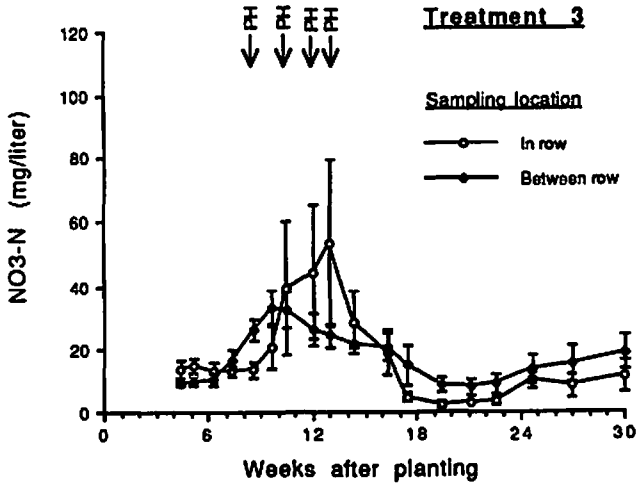

Figure 4. Nitrate - N concentration in soil water sampled in the row and between the row at the 4 ft. depth, over the 1993 growing season. Nitrogen application rate: 20 lb N/A at planting, 70 lb at emergence and hilling, plus 4 post-hilling applications at 20 lb N/A each (46-0-0). Error bars represent SE of the mean. PH = post-hilling application.

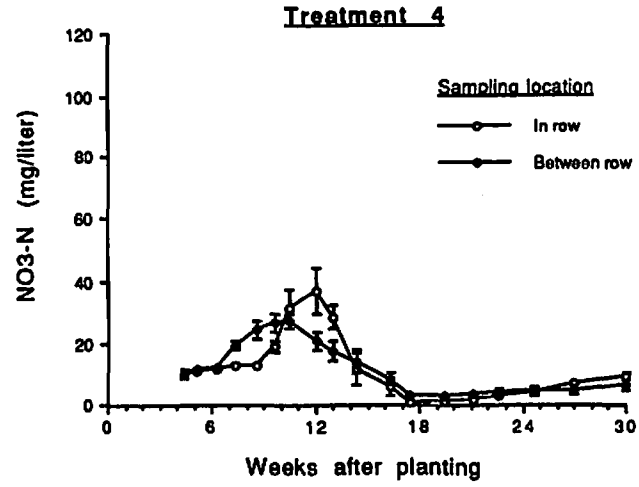

Figure 5. Nitrate - N concentration in soil water sampled in the row and between the row at the 4 ft. depth, over the 1993 growing season. Nitrogen application rate: 20 lb N/A at planting and 70 lb at emergence and hilling (46-0-0). Error bars represent SE of the mean.

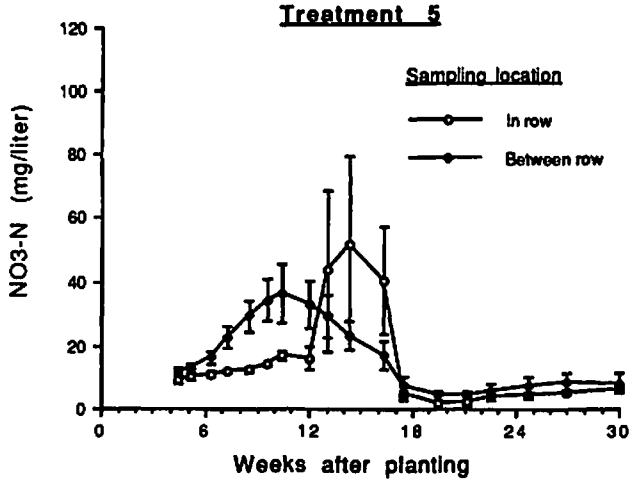

Figure 6. Nitrate - N concentration in soil water sampled in the row and between the row at the 4 ft. depth, over the 1993 growing season. Nitrogen application rate: 40 lb N/A at planting, 100 lb at emergence and hilling (34-0-0). Error bars represent SE of the mean.

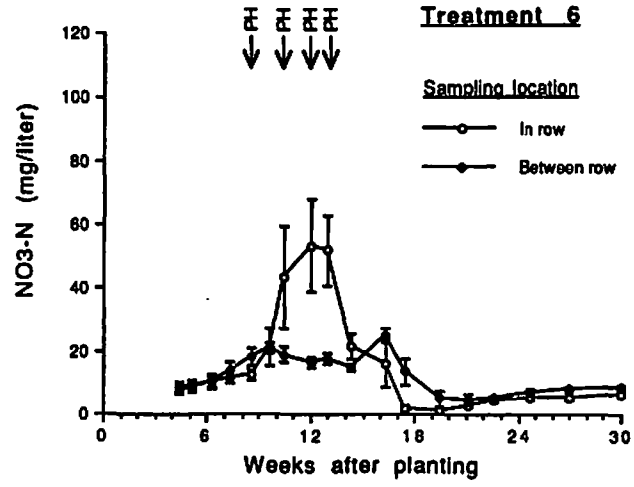

Figure 7. Nitrate - N concentration in soil water sampled in the row and between the row at the 4 ft. depth, over the 1993 growing season. Nitrogen application rate: 20 lb N/A at planting, 70 lb at emergence and hilling, plus 4 post-hilling applications at 20 lb N/A each (34-0-0). Error bars represent SE of the mean. PH = post-hilling application.

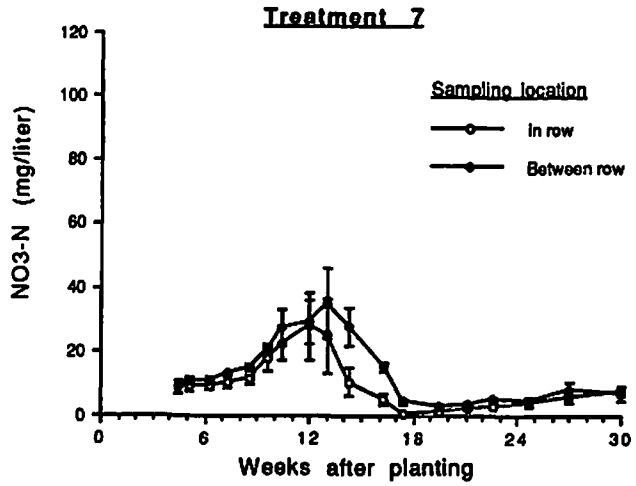

Figure 8. Nitrate - N concentration in soil water sampled in the row and between the row at the 4 ft. depth, over the 1993 growing season. Nitrogen application rate: 20 lb N/A at planting and 70 lb at emergence and hilling (34-0-0). Error bars represent SE of the mean.

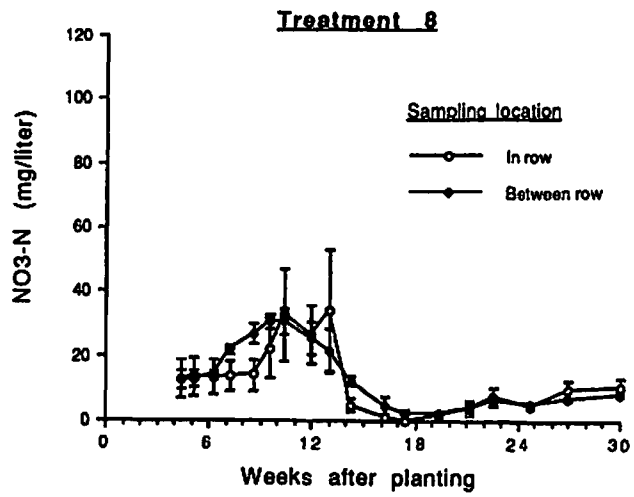

Figure 9. Nitrate - N concentration in soil water sampled in the row and between the row at the 4 ft. depth, over the 1993 growing season. Nitrogen application rate: 40 lb N/A at planting, emergence and hilling (34-0-0). Error bars represent SE of the mean.

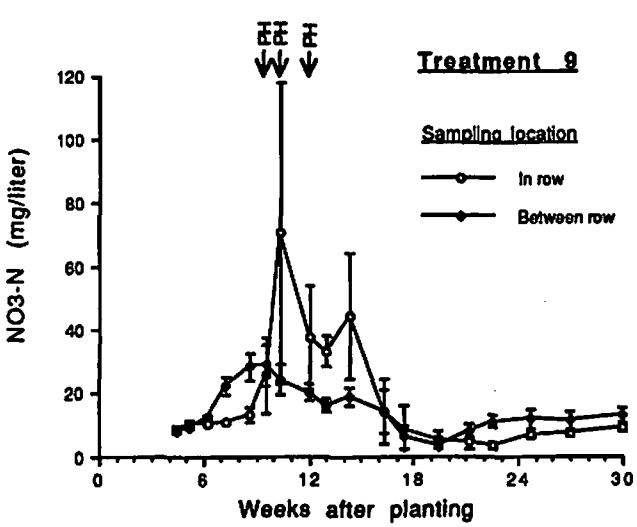

Figure 10. Nitrate - N concentration in soil water sampled in the row and between the row at the 4 ft. depth, over the 1993 growing season. Nitrogen application rate: 40 lb N/A at planting, emergence and hilling, plus three post hilling applications at 20 lb N/A each (34-0-0). Error bars represent SE of the mean. PH = post-hilling application.

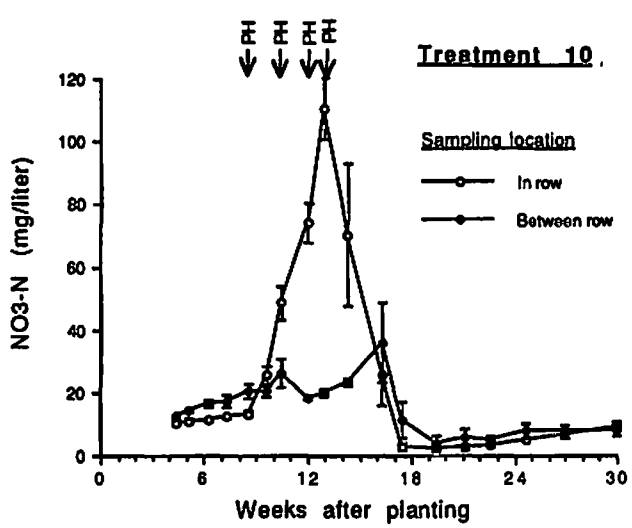

Figure 11. Nitrate - N concentration in soil water sampled in the row and between the row at the 4 ft. depth, over the 1993 growing season. Nitrogen application rate: 40 lb N/A at planting, emergence and hilling, plus four post-hilling applications at 20 lb N/A each (34-0-0). Error bars represent SE of the PH = post-hilling application.

PHOSPHORUS REQUIREMENTS FOR POTATOES ON SANDY SOILS - 1993

Carl Rosen, Dave Birong, and Glenn Titrud

ABSTRACT: Response of Russet Burbank and Norland potatoes to phosphate fertilizer on low and high P testing sites was evaluated. Phosphate fertilizer increased early tuber growth in both cultivars on low and high P testing soils. However, effects on final yield were not consistent. For Russet Burbank, P fertilizer had no effect on yields on high testing soils, but increased larger size tubers on low testing soils. For Norland, total tuber yield increased up to 150 lb P_2O_5/A in the low testing soil, with the greatest response to fertilizer occurring between the 0 to 50 lb P_2O_5. In the high testing soil, Norland tended to increase with phosphate fertilizer, up to 50 lb P_2O_5/A with an unusual increase when 250 lb P_2O_5/A was applied. Phosphate fertilizer increased phosphorus concentrations in petiole and leaf (leaflet plus petiole) tissue. However, phosphorus concentrations were 20-25% higher in leaf tissue compared to petiole tissue. Leaf tissue tended to be more sensitive than petiole tissue to phosphate fertilizer induced changes in micronutrient concentrations. In addition to increasing tissue P, phosphate fertilizer tended to increase tissue calcium, and decrease tissue copper.

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 even on soils testing above 25 ppm. The objective of this study, therefore, was to evaluate the response of early harvested Norland and late harvested Russet Burbank 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 soils 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/rye
Soil pH (1:1 - soil:water)	5.7	6.0
Bray P1	57 ppm	21 ppm
K - NH4OAc	177 ppm	95 ppm

The high P site had a history of potatoes from 1986 to 1988 prior to rye from 1989 to 1992. The low P site was planted to alfalfa in 1986 and was plowed under in 1991. In 1992 the low P site was planted to rye. Prior to planting, 250 lb sul-po-mag and 100 lb K_2O (as 0-0-60) were broadcast and incorporated at both sites. Norland and Russet Burbank "B" size potatoes were planted on April 16, 1993 at a spacing of 36" between rows and 10" within the row. Each plot consisted of four, 20' rows. At planting, all plots received 50 lb N/A and 200 lb K_2O. Phosphate fertilizer (triple superphosphate, 0-46-0) treatments were as follows: 0, 50, 100, 150, 200, 250 lb P_2O_5/A. Phosphate fertilizer (along with nitrogen and potash) was applied as a band 3 inches to each side and 2 inches below the row. Post-planting nitrogen was applied at the rate of 85 lb N/A at emergence for Norland (May 20). For Russet Burbank, post-planting N included 85 lb N/A emergence (May 20) and 100 lb N/A at hilling (June 8). Within each site, cultivars were planted in two strips. From a statistical standpoint, therefore, each cultivar will be analyzed separately. Within each cultivar, the experimental design was a randomized complete block with four replications. Each site was irrigated according to the checkbook method for potatoes. Recently matured leaves (leaflets plus petioles) were sampled on June 29. On half of the samples the leaflets were removed and only the petioles were saved. Both whole leaf samples and petiole samples were dried and ground through a 30 mesh screen for subsequent elemental analyses. Whole plant samples (two plants per plot) were collected on June 28 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 September 9 and tubers were graded according to weight classes: <3 oz, 3-7 oz, 7-14 oz, and >14 oz. A subsample of tubers was saved for specific gravity determination and hollow heart incidence.

[1]We thank the Area II potato growers for providing funds to support this project.

[2]Ext. Soil Scientist and Assistant Scientist, respectively, Dept. of Soil Sci.; Director, Sand Plain Research Farm.

RESULTS

Early plant growth: Dry weight of Russet Burbank vines, roots, and tubers sampled in June are presented in Tables 1 and 2. For the high P testing site, phosphate fertilizer increased dry weight of tubers, but not roots or vines. Tuber number was not affected by phosphate fertilizer application in the high testing site. For the low P testing site, phosphate fertilizer increased dry weight of vines, roots, and tubers. Tuber number was not affected by phosphate fertilizer. Dry weight of Norland vines, roots, and tubers sampled on June 28 are presented in Tables 3 and 4. For the high P testing site, phosphate fertilizer increased dry weight of tubers, but not roots or vines. Tuber number was not significantly affected by phosphate fertilizer application in the high testing site. For the low P testing site, phosphate fertilizer increased dry weight of vines and tubers. Tuber number was not affected by phosphate fertilizer.

Tuber yield: Tuber yield, size distribution, specific gravity, and hollow heart for Russet Burbank are presented in Tables 5 and 6. For the high P testing site, phosphate fertilizer had no effect on tuber yield or quality. In the low P testing site, significant yield increases were obtained in the greater than 14 oz size category. Knobby tubers also tended to increase with phosphate fertilizer. Tuber yield, size distribution, specific gravity, and hollow heart for Norland are presented in Tables 7 and 8. For the high P testing site, phosphate fertilizer increased tuber yield and decrease hollow heart incidence. The yield response up to 250 lb P_2O_5/A was unusual and not consistent with response up to 150 lb P_2O_5/A. In the low P testing site, phosphate fertilizer increased total yield up to 150 lb P_2O_5/A.

Leaf and petiole nutrient concentrations: Nutrient concentrations were determined in petiole and leaf (leaflets plus petioles) samples to determine how the type of tissue sampled affects diagnostic interpretations (Tables 9-16). Concentrations of phosphorus in both cultivars increased with increasing phosphate fertilizer rate in both petiole and leaf tissue in low and high P testing sites. Concentrations of P were approximately 25% higher in leaf tissue compared to petioles. Total N was not affected by phosphate fertilizer. In contrast, petiole nitrate-N tended to decrease with P treatment. Concentrations of nitrogen in leaves and nitrate in petioles were generally higher when alfalfa was the previous crop compared to rye even though the alfalfa had been plowed under two years before the experiment was initiated. Potassium concentrations in petioles were approximately twice as high as those in leaf tissue. Phosphate fertilizer did not consistently affect potassium concentrations in the tissues sampled. Calcium concentrations were similar in petiole and leaf tissue, while magnesium concentrations were lower in petiole tissue compared to leaf tissue. Calcium tended to increase with increasing phosphate fertilizer, probably due to the fact that 0-46-0 contains significant Ca. Iron concentrations were approximately twice as high in leaf tissue compared to petiole tissue. Phosphate fertilizer had no effect on leaf or petiole iron for either cultivar. Manganese concentrations were higher in leaf tissue than in petiole tissue. Phosphate fertilizer generally had no effect on manganese tissue concentrations. Petiole and leaf tissue had similar concentrations of zinc. Zinc concentrations were not consistently affected by phosphate fertilizer application. Copper concentrations were higher in leaf tissue than in petiole tissue. Phosphate fertilizer tended to decrease leaf and petiole copper concentrations in both low and high P sites. Petiole and leaf tissue had similar concentrations of boron. Increasing phosphate fertilizer had inconsistent effects on tissue boron. It is clear from these results that nutrient diagnostic criteria for petiole tissue will be different from the criteria used for leaf tissue.

Table 1. Effect of phosphate fertilizer on dry matter of Russet Burbank potato vines, roots, tubers, and number of tubers - sampled June 28, 1993. Previous crop - Rye; initial soil test P - 57 ppm.

Phosphate Treatment lb P_2O_5	Plant Part: vines	roots	tubers	number of tubers
	grams/plant			per plant
0	62.00	14.20	20.25	12.38
50	69.38	14.95	26.00	11.13
100	73.38	14.26	29.00	9.88
150	74.25	14.91	27.75	10.75
200	67.50	14.30	29.75	9.88
250	70.88	14.40	20.25	10.38
Pr>F	0.91	0.69	0.57	0.89
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 2. Effect of phosphate fertilizer on dry matter of Russet Burbank vines, roots, tubers, and number of tubers - sampled June 28, 1993. Previous crop - alfalfa/rye; initial soil test P - 21 ppm.

Phosphate Treatment lb P_2O_5	Plant Part vines	roots	tubers	number of tubers
	grams/plant			per plant
0	38.00	13.64	17.50	9.13
50	57.50	14.36	21.75	8.75
100	63.75	14.44	23.00	8.50
150	71.75	14.79	30.50	10.13
200	66.13	13.99	25.00	9.75
250	71.13	15.00	28.25	10.38
Pr>F	0.04	0.09	0.42	0.98
Lin P_2O_5	**	*	++	NS
Quad P_2O_5	++	NS	NS	NS
Cubic P_2O_5	NS	++	NS	NS

NS = nonsignificant; ++, *, ** = significant at 10%, 5% and 1%,respectively.

Table 3. Effect of phosphate fertilizer on dry matter of Norland potato vines, roots, tubers, and number of tubers - sampled June 28, 1993. Previous crop - Rye; initial soil test P - 57 ppm.

Phosphate Treatment lb $P2O_5$	Plant Part vines	roots	tubers	number of tubers
	grams/plant			per plant
0	43.25	14.42	47.00	9.00
50	46.50	14.68	59.00	14.50
100	62.13	15.61	73.00	13.00
150	58.63	15.31	66.75	13.63
200	54.25	14.99	64.25	12.50
250	56.75	15.40	61.75	14.63
Pr>F	0.26	0.63	0.33	0.45
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 4. Effect of phosphate fertilizer on dry matter of Norland vines, roots, tubers, and number of tubers - sampled June 28, 1993. Previous crop - alfalfa/rye; initial soil test P - 21 ppm.

Phosphate Treatment lb P_2O_5	Plant Part vines	roots	tubers	number of tubers
	grams/plant			per plant
0	46.63	14.36	36.75	10.75
50	61.00	15.74	56.00	13.38
100	57.38	14.86	49.50	11.63
150	59.00	15.74	54.00	12.00
200	74.13	15.49	63.75	14.38
250	65.00	14.86	60.50	12.88
Pr>F	0.03	0.48	0.29	0.73
Lin P_2O_5	**	NS	*	NS
Quad P_2O_5	NS	NS	NS	NS
Cubic P_2O_5	NS	NS	NS	NS

NS = nonsignificant; *, ** = significant at 5% and 1%, respectively.

Table 5. Effect of phosphate fertilizer on yield and specific gravity of Russet Burbank potatoes. Previous crop - Rye; initial soil test P - 57 ppm.

Phosphate Treatment lb P_2O_5	Tuber Yield: Knobs	Tuber Size: <3 oz	3-7 oz	7-14 oz	>14 oz	Total	Specific Gravity	Hollow Heart
	cwt/A							% incidence
0	58.6	30.8	179.1	133.3	6.7	408.6	1.0770	1.0
50	39.1	41.7	165.5	111.0	2.9	360.2	1.0794	2.0
100	54.6	34.7	148.7	157.0	8.0	403.0	1.0792	3.0
150	59.6	33.7	156.3	114.4	5.8	369.9	1.0755	0.0
200	50.0	36.9	176.1	130.9	7.9	401.8	1.0775	2.0
250	53.6	36.6	165.8	133.8	8.0	397.7	1.0774	6.0
Pr>F	0.81	0.57	0.53	0.19	0.90	0.23	0.33	0.63
Lin P_2O_5	NS	NS	NS	NS	NS	NS	NS	NS
Quad P_2O_5	NS	NS	NS	NS	NS	NS	NS	NS
Cubic P_2O_5	NS	NS	NS	NS	NS	NS	NS	NS

NS = nonsignificant.

Table 6. Effect of phosphate fertilizer on yield and specific gravity of Russet Burbank potatoes. Previous crop - Alfalfa/rye; initial soil test P - 21 ppm.

Phosphate Treatment lb P_2O_5	Tuber Yield: Knobs	Tuber Size: <3 oz	3-7 oz	7-14 oz	>14 oz	Total	Specific Gravity	Hollow Heart
	cwt/A							% incidence
0	33.1	30.9	185.6	138.9	8.7	397.2	1.0810	1.0
50	56.4	31.8	173.6	169.0	23.4	454.2	1.0799	0.0
100	66.7	26.9	202.2	148.8	23.6	468.2	1.0802	2.0
150	39.1	28.9	198.3	179.9	17.8	464.0	1.0794	0.0
200	46.4	32.6	175.0	164.5	13.1	431.7	1.0814	0.0
250	36.8	33.1	168.4	148.7	26.2	413.2	1.0802	4.0
Pr>F	0.08	0.46	0.74	0.68	0.08	0.73	0.90	0.24
Lin P_2O_5	NS	NS	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 10%, 5% and 1%, respectively.

Table 7. Effect of phosphate fertilizer on yield and specific gravity of Norland potatoes. Previous crop - Rye; initial soil test P - 57 ppm.

Phosphate Treatment lb P_2O_5	Tuber Yield: Culls	Tuber Size: <1.75"	1.75-2.5"	2.5-3.5"	>3.5"	Total	Specific Gravity	Hollow Heart
	cwt/A							% incidence
0	3.4	29.2	177.2	27.5	19.4	257.0	1.0695	10.0
50	5.8	27.4	195.1	28.9	22.0	279.3	1.0686	7.5
100	3.9	26.3	210.2	23.8	18.6	282.9	1.0672	5.0
150	5.3	28.8	202.2	26.0	24.6	287.0	1.0703	7.5
200	4.5	31.2	184.2	41.3	26.0	287.1	1.0697	2.5
250	3.0	31.6	215.3	25.1	29.9	305.0	1.0685	0.0
Pr>F	0.59	0.79	0.28	0.32	0.82	0.46	0.87	0.55
Lin P_2O_5	NS	NS	NS	NS	NS	++	NS	++
Quad P_2O_5	NS	NS	NS	NS	NS	NS	NS	NS
Cubic P_2O_5	NS	NS	++	NS	NS	NS	NS	NS

NS = nonsignificant; ++ = significant at 10%.

Table 8. Effect of phosphate fertilizer on yield and specific gravity of Norland potatoes. Previous crop - Alfalfa/rye; initial soil test P - 21 ppm.

Phosphate Treatment lb P_2O_5	Tuber Yield: Culls	Tuber Size: <1.75"	1.75-2.5"	2.5-3.5"	>3.5"	Total	Specific Gravity	Hollow Heart
	cwt/A							% incidence
0	4.1	20.6	158.6	48.4	0.0	231.8	1.0640	7.5
50	5.3	26.6	177.9	49.3	0.9	259.9	1.0651	2.5
100	3.0	30.5	187.6	40.2	0.0	261.2	1.0681	12.5
150	1.8	27.2	186.3	54.7	3.4	273.2	1.0651	7.5
200	4.8	30.7	183.4	53.0	0.0	271.9	1.0652	2.5
250	5.6	26.8	188.0	50.3	0.0	270.7	1.0660	2.5
Pr>F	0.08	0.53	0.54	0.84	0.52	0.25	0.23	0.27
Lin P_2O_5	NS	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	NS

NS = nonsignificant; * = significant at 5%.

Table 9. Effect of phosphate fertilizer on elemental composition of recently expanded Russet Burbank potato leaves, sampled June 29, 1993. Previous crop - rye; initial soil test P - 57 ppm.

Phosphate Treatment lb P_2O_5	Element: N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	%					ppm				
0	4.92	0.30	4.80	0.60	0.44	100	170	19	7.8	23
50	4.80	0.32	4.34	0.46	0.36	88	128	19	7.5	21
100	5.08	0.33	4.72	0.53	0.40	97	167	19	7.5	22
150	4.92	0.34	4.51	0.58	0.41	93	122	19	6.3	22
200	4.93	0.36	4.47	0.55	0.40	98	138	20	6.8	22
250	4.95	0.36	4.83	0.53	0.39	96	141	19	6.5	22
Pr>F	0.54	0.00	0.74	0.27	0.49	0.48	0.63	0.88	0.29	0.77
Lin P_2O_5	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 = nonsignificant; *, ** = significant at 5% and 1%, respectively.

Table 10. Effect of phosphate fertilizer on elemental composition of Russet Burbank petioles sampled June 29, 1993. Previous crop - rye; initial soil test P - 57 ppm.

Phosphate Treatment lb P_2O_5	dry wt. petiole NO_3-N	Element: P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	ppm	%				ppm				
0	18975	0.23	12.2	0.52	0.34	48	140	24	2.5	23
50	14753	0.26	11.2	0.48	0.30	44	101	23	2.4	22
100	16242	0.27	11.6	0.50	0.31	47	126	25	3.6	25
150	17498	0.30	12.1	0.56	0.35	46	93	24	2.3	23
200	16686	0.29	11.6	0.57	0.35	43	109	23	2.0	23
250	14269	0.30	12.1	0.53	0.28	44	123	23	1.6	24
Pr>F	0.02	0.02	0.70	0.52	0.39	0.52	0.51	0.91	0.63	0.23
Lin P_2O_5	*	**	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 = nonsignificant; *, ** = significant at 5% and 1%, respectively.

Table 11. Effect of phosphate fertilizer on elemental composition of recently expanded Russet Burbank potato leaves sampled June 29, 1993. Previous crop - alfalfa/rye; initial soil test P - 21 ppm.

Phosphate Treatment lb P_2O_5	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	Element									
	%					ppm				
0	5.13	0.28	4.42	0.62	0.52	93	100	18	9.3	24
50	5.11	0.29	4.32	0.65	0.53	95	96	17	8.1	23
100	5.11	0.33	4.14	0.60	0.51	94	82	19	8.5	21
150	5.21	0.34	4.06	0.64	0.53	96	96	19	7.3	21
200	5.08	0.35	4.08	0.63	0.51	95	81	19	7.4	20
250	4.91	0.34	3.91	0.60	0.49	90	93	18	6.9	20
Pr>F	0.58	0.00	0.14	0.94	0.78	0.48	0.48	0.08	0.00	0.00
Lin P_2O_5	NS	**	**	NS	NS	NS	NS	NS	**	**
Quad P_2O_5	NS	*	NS	NS	NS	NS	NS	*	NS	NS
Cubic P_2O_5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = nonsignificant; *, ** = significant at 5% and 1%, respectively.

Table 12. Effect of phosphate fertilizer on elemental composition of Russet Burbank petioles sampled June 29, 1993. Previous crop - alfalfa/rye; initial soil test P - 21 ppm.

Phosphate Treatment lb P_2O_5	dry wt. petiole NO_3-N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	Element									
	-ppm-	%				ppm				
0	19651	0.20	10.7	0.58	0.44	46	71	21	4.4	24
50	18512	0.22	10.9	0.61	0.48	54	70	25	4.8	27
100	18037	0.24	11.0	0.60	0.47	48	64	20	3.3	24
150	18752	0.27	10.7	0.64	0.49	52	63	23	4.2	25
200	18385	0.29	10.5	0.61	0.48	48	66	19	2.3	22
250	17090	0.30	10.3	0.65	0.52	49	60	21	3.2	24
Pr>F	0.26	0.00	0.03	0.58	0.45	0.24	0.23	0.25	0.41	0.20
Lin P_2O_5	++	**	**	NS	++	NS	*	NS	NS	NS
Quad P_2O_5	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
Cubic P_2O_5	NS	NS	NS	NS	NS	NS	NS	NS	NS	++

NS = nonsignificant; ++, *, ** = significant at 10%, 5% and 1%, respectively.

Table 13. Effect of phosphate fertilizer on elemental composition of recently expanded Norland potato leaves, sampled June 29, 1993. Previous crop - rye; initial soil test P - 57 ppm.

Phosphate Treatment lb P_2O_5	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	Element									
	%					ppm				
0	4.38	0.32	5.79	0.82	0.37	103	119	22	10.4	31
50	4.14	0.30	5.45	0.84	0.36	109	114	19	8.2	31
100	4.16	0.30	5.41	0.84	0.35	106	128	18	8.4	31
150	4.34	0.34	5.57	0.91	0.39	106	109	19	7.6	32
200	4.31	0.34	5.70	0.90	0.37	112	118	18	7.4	33
250	4.35	0.35	5.70	1.00	0.41	113	122	18	6.9	31
Pr>F	0.51	0.08	0.82	0.00	0.24	0.67	0.92	0.04	0.01	0.27
Lin P_2O_5	NS	*	NS	**	NS	NS	NS	*	**	NS
Quad P_2O_5	NS	NS	NS	NS	NS	NS	NS	++	NS	NS
Cubic P_2O_5	NS	++	NS	NS	NS	NS	NS	NS	NS	NS

NS = nonsignificant; ++, *, ** = significant at 10%, 5% and 1%, respectively.

Table 14. Effect of phosphate fertilizer on elemental composition of Norland petioles sampled June 29, 1993. Previous crop - rye; initial soil test P - 57 ppm.

Phosphate Treatment lb P_2O_5	dry wt. petiole NO_3-N	P	K	Ca	Mg	Element	Fe	Mn	Zn	Cu	B
	ppm	%					ppm				
0	4298	0.23	12.0	0.75	0.24		60	70	22	2.8	23
50	3191	0.23	11.6	0.76	0.23		59	64	18	2.2	23
100	2530	0.24	12.2	0.81	0.25		59	89	20	3.3	27
150	3582	0.29	11.1	0.82	0.27		59	66	18	2.3	24
200	2786	0.34	12.3	0.84	0.27		79	72	18	2.2	26
250	3584	0.32	11.7	0.87	0.27		63	65	20	3.2	27
Pr>F	0.63	0.00	0.65	0.62	0.99		0.51	0.68	0.31	0.02	0.03
Lin P_2O_5	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 = nonsignificant; ++, *, ** = significant at 10%, 5% and 1%, respectively.

Table 15. Effect of phosphate fertilizer on elemental composition of recently expanded Norland potato leaves sampled June 29, 1993. Previous crop - alfalfa/rye; initial soil test P - 21 ppm.

Phosphate Treatment lb P_2O_5	N	P	K	Ca	Mg	Element	Fe	Mn	Zn	Cu	B
	%						ppm				
0	5.24	0.35	4.86	1.00	0.54		104	83	24	12.8	28
50	5.04	0.35	5.22	1.10	0.57		100	92	22	11.5	30
100	4.71	0.35	5.42	1.04	0.51		105	94	21	10.8	31
150	5.10	0.38	5.18	1.20	0.66		109	94	23	10.7	31
200	4.79	0.38	5.25	1.11	0.56		105	88	26	10.4	31
250	4.91	0.39	5.06	1.09	0.55		104	87	22	9.8	31
Pr>F	0.44	0.24	0.55	0.31	0.44		0.77	0.78	0.74	0.03	0.31
Lin P_2O_5	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; ++, *, ** = significant at 10%, 5% and 1%, respectively.

Table 16. Effect of phosphate fertilizer on elemental composition of Norland petioles sampled June 29, 1993. Previous crop - alfalfa/rye; initial soil test P - 21 ppm.

Phosphate Treatment lb P_2O_5	dry wt. petiole NO_3-N	P	K	Ca	Mg	Element	Fe	Mn	Zn	Cu	B
	-ppm-	%					ppm				
0	11129	0.30	12.5	0.75	0.39		67	47	26	4.9	27
50	8736	0.28	12.0	0.86	0.47		60	52	27	5.3	28
100	5387	0.31	12.1	0.82	0.36		57	62	24	5.5	29
150	7254	0.31	10.9	0.83	0.44		57	49	23	4.8	27
200	6273	0.40	11.9	0.88	0.43		57	53	28	5.1	29
250	5844	0.39	11.6	0.87	0.42		59	49	24	4.4	28
Pr>F	0.16	0.00	0.17	0.26	0.84		0.43	0.71	0.61	0.91	0.19
Lin P_2O_5	*	**	++	++	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; ++, *, ** = significant at 10%, 5% and 1%, respectively.

EVALUATION OF POTASSIUM SOURCES FOR POTATO PRODUCTION ON SANDY SOILS[1]

Carl Rosen and Dave Birong[2]

ABSTRACT: A field experiment was conducted at the Sand Plain Research Farm in Becker, MN to evaluate the effects of potassium chloride, potassium sulfate, and potassium nitrate as a potassium source on potato yield, nutrient composition, petiole sap nutrient levels, and tuber quality under irrigated conditions. Potatoes at this site did not respond to potassium fertilizer or potassium fertilizer source. A reevaluation of potassium fertilizer recommendations for irrigated potatoes is warranted. The Horiba/Cardy potassium meter underestimated sap potassium concentrations compared to conventional laboratory methods.

Potatoes have a relatively high demand for potassium with up to 220 lb K/A removed in the tuber at harvest. Few studies have been conducted on sandy soils to determine potato response to potassium fertilizer sources. The objective of this study was to evaluate various potassium sources on potato yield and quality as well as to determine the effects of these sources on petiole nutrient composition on a sap and dry weight basis. The use of hand held nitrate and potassium electrodes were used to determine sap NO_3-N and K levels.

PROCEDURES:

The field experiment was conducted under irrigation at the Sand Plains Research Farm in 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 - 5.4; Bray P1 - 28 ppm; NH_4OAc K - 91 ppm. The previous crop was rye. The cultivar 'Russet Burbank' was planted April 21, 1993. There were five treatments arranged in a randomized complete block design with four replications. The five treatments were: 1) control 2) 250 lb K_2O/A as KCl - applied as a band at planting, 3) 250 lb K_2O/A as K_2SO_4 - applied as a band at planting, 4) 250 lb K_2O/A as KNO_3 - half applied at emergence and half applied at hilling, and 5) 250 lb K_2O/A as KNO_3 - 100 lbs applied at emergence, 75 lbs applied at hilling, and 75 lbs applied 3 weeks post-hilling. All plots received 80 lbs P_2O_5/A as triple superphosphate, 40 lbs N/A as urea and 300 lb/A Epsom salts as a band at planting. At emergence and hilling urea was applied at the rates of 80 and 100 lbs N/A for treatments 1, 2, and 3. Similar total rates of N were applied for treatments 4 and 5, except urea application was reduced to account for the N applied with potassium nitrate. The total N applied for all treatments was 220 lbs N/A. A breakdown of the five treatments are:

	K	Time of application								
Trmt	source	Planting		Emergence		Hilling		3 weeks post-hilling		Total N applied
		N rate	K rate	N rate	K rate	N rate	K rate	N rate	K rate	--- lb N/A ---
1.	--	40	0	80	0	100	0	0	0	220
2.	KCl	40	250	80	0	100	0	0	0	220
3.	K_2SO_4	40	250	80	0	100	0	0	0	220
4.	KNO_3	40	0	40	125	60	125	0	0	220
5.	KNO_3	40	0	48	100	52	75	0	75	220

Herbicides, linuron (1 lb/A ai) and Dual (1.5 lb/A ai), were applied on May 5. The N application at emergence was on May 27 and the hilling application was on June 11. Post-hilling N applications were made on July 1 and July 20. Irrigation was supplied according to the checkbook method for potato. Petiole samples were collected on June 10, July 8, and August 4 for nutrient analyses. Half the petioles were dried and the other half were crushed to express the sap. Nitrate-N in sap was determined using the Horiba/Cardy nitrate meter, the Hach electrode and the Wescan laboratory method. Potassium in sap was determined using the Horiba/Cardy potassium meter and with the ICP after dilution 1:100 (sap:water). Other elements in the sap were determined with the ICP. Nutrient concentrations (except nitrate) in petioles on dry weight basis were determined on ashed samples using ICP procedures. Nitrate on a dry weight basis was determined in water extracts using the Wescan N analyzer. Potassium source effects on early plant growth were evaluated by harvesting two plants per plot on June 29. Harvested plants were separated into roots, vines and tubers, dried and then weighed. Plots were harvested on September 9 and tubers were separated according to size. Subsamples of tubers were also collected for specific gravity determination and hollow heart incidence.

RESULTS:

Vine growth in June tended to be lower with potassium sulfate as the potash source compared to potassium chloride and potassium nitrate (Table 1). Root and tuber dry weight and number of tubers were not affected

[1] Partial support for this project was provided by Cedar Chemical Corp.

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by treatment. Potato yield and size distribution were not affected by treatment (Table 2). Lack of response to potash was most likely due to the relatively high soil test K. The recommendation for potash at this soil test level is 200 lb K_2O/A. Based on these results, this recommendation needs to be reevaluated. Tubers in the 0 potash control had the highest specific gravity, but also had the highest incidence of hollow heart.

Petiole nutrient concentrations on a dry weight and sap basis for three sampling dates are presented in Tables 3-8. Nitrate concentrations in petioles expressed on a dry weight or sap basis were lower when potassium chloride was applied compared to the other K sources and the control at all sampling dates. Nitrate concentrations in sap measured by the Horiba/Cardy meter tended to be higher than those measured by the Hach or Wescan methods. In contrast, potassium concentrations in sap measured by the Horiba potassium meter were lower than those measured by the ICP. The exact cause for these differences are not known and need to be further investigated. Potassium fertilizer increased petiole K on a sap and a dry weight basis. At the early sampling date, petiole K was higher in potassium chloride and potassium sulfate treatments compared to potassium nitrate. However, potassium nitrate was not applied until emergence, and by the last two sampling dates there was no difference in petiole K among potassium sources. These results indicate that potassium nitrate sidedressed after planting can still supply sufficient quantities of potassium for plant growth. Potassium fertilizer decreased petiole Ca and Mg, but not to levels where deficiency would be expected. Sap concentrations of P, Ca, Mg and S were low relative to K. Concentrations of micronutrients in sap were generally below detection limits. A much lower dilution rate than 1:100 would be needed to detect sap micronutrients. On a dry weight basis, petiole P was not affected by potassium source except at the first sampling date where the potassium sulfate treatment resulted in lower P concentrations. Fe, Cu, Zn, and B concentrations in petioles were generally not affect by treatment. Petiole Mn tended to be lower when potassium nitrate was the K source.

Table 1. Comparative effects of potassium chloride, potassium sulfate, and potassium nitrate on potato dry matter of vines, roots, tubers, and number of tubers - sampled June 22,1993.

K source	Time of application: Planting	Emergence	Hilling	3wk PH[1]	Vines	Roots	Tubers	Number of tubers
	K rate (lb K/A)				g/plant			per plant
--	0	0	0	0	37.9	13.6	13.0	8.8
KCl	250	0	0	0	44.4	13.9	10.3	8.8
K_2SO_4	250	0	0	0	36.4	13.4	5.5	6.9
KNO_3	0	125	125	0	44.1	13.7	11.3	8.8
KNO_3	0	100	75	75	40.0	13.5	6.3	6.8
Significance					++	NS	NS	NS
LSD (5% level)					7.4	--	--	--

NS = nonsignificant; ++ = significant at 10%.
[1]wk PH = weeks post hilling.

Table 2. Comparative effects of potassium chloride, potassium sulfate, and potassium nitrate on potato yield, hollow heart, and specific gravity. (Becker, 1993)

K source	Time of application: Planting	Emergence	Hilling	3wk PH[1]	Tuber size: Knobs	<3 oz	3-7 oz	7-14 oz	<14 oz	Total	Specific Gravity	Hollow Heart
	K rate (lb K/A)				cwt/A							%
--	0	0	0	0	32.4	35.4	206.0	130.1	21.7	425.6	1.0888	6.0
KCl	250	0	0	0	37.7	31.8	193.4	156.1	18.9	437.9	1.0832	0.0
K_2SO_4	250	0	0	0	33.1	28.5	163.7	169.9	42.5	437.6	1.0842	0.0
KNO_3	0	125	125	0	38.7	29.8	186.4	168.0	19.3	422.1	1.0863	2.0
KNO_3	0	100	75	75	48.1	35.0	197.1	150.1	18.9	449.6	1.0849	2.0
Significance					NS	NS	NS	NS	NS	NS	**	++
LSD (5% level)					--	--	--	--	--	--	0.0026	4.9

NS = nonsignificant; **, ++ = significant at 1% and 10%, respectively.
[1]wk PH = weeks post hilling.

Table 3. Comparative effects of potassium chloride, potassium sulfate, and potassium nitrate on nitrate nitrogen content of petioles, and elemental concentrations in petioles, sampled June 10, 1993.

K source	Time of application: Planting	Emergence	Hilling	3wk PH[1]	dry weight petiole NO_3-N	Elemental Concentration in Petioles: P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	K rate (lb K/A)				ppm	%				ppm				
--	0	0	0	0	25,501	0.51	8.8	0.97	0.72	113	56	47	3.9	24
KCl	250	0	0	0	20,879	0.50	12.5	0.65	0.39	116	94	57	5.2	25
K_2SO_4	250	0	0	0	25,740	0.44	10.8	0.60	0.41	122	78	56	4.6	24
KNO_3	0	125	125	0	25,170	0.54	9.3	0.85	0.70	115	57	52	4.7	24
KNO_3	0	100	75	75	26,044	0.49	9.3	0.86	0.69	113	55	51	4.7	24
Significance					**	*	**	**	**	NS	**	NS	NS	NS
LSD (5% level)					2,127	0.05	0.6	0.05	0.07	--	15	--	--	--

NS = nonsignificant; **, * = significant at 1% and 5%, respectively.
[1]wk PH = weeks post hilling.

Table 4. Comparative effects of potassium chloride, potassium sulfate, and potassium nitrate on nitrate nitrogen and potassium concentration in petiole sap, as determined by various procedures, and elemental concentrations in petiole sap, sampled June 10, 1993.

K source	Time of application: Planting	Emergence	Hilling	3wk PH[1]	Horiba K	Horiba NO_3-N	Hach NO_3-N	Wescan NO_3-N	Elemental Concentration in Sap: P	K	Ca	Mg	S
	K rate (lb K/A)				ppm								
--	0	0	0	0	2925	1288	1289	1220	106	3734	211	252	46
KCl	250	0	0	0	3575	970	934	864	88	4333	36	106	38
K_2SO_4	250	0	0	0	3525	1575	1447	1345	99	4830	45	148	48
KNO_3	0	125	125	0	3275	1475	1474	1354	110	4195	176	250	40
KNO_3	0	100	75	75	3250	1450	1461	1367	104	4092	187	250	42
Significance					**	**	**	**	*	**	**	**	**
LSD (5% level)					83	85	58	52	13	273	38	34	4

NS = nonsignificant; **, * = significant at 1% and 5%, respectively.
[1]wk PH = weeks post hilling.

Table 5. Comparative effects of potassium chloride, potassium sulfate, and potassium nitrate on nitrate nitrogen content of petioles, and elemental concentrations in petioles, sampled July 8, 1993.

K source	Time of application: Planting	Emergence	Hilling	3wk PH[1]	dry weight petiole NO_3-N	Elemental Concentration in Petioles: P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	K rate (lb K/A)				ppm	%				ppm				
--	0	0	0	0	24,473	0.31	6.6	0.82	0.96	60	122	24	29.4	29
KCl	250	0	0	0	20,102	0.31	9.8	0.65	0.52	54	118	25	19.2	26
K_2SO_4	250	0	0	0	23,441	0.29	9.1	0.68	0.56	50	126	25	13.4	26
KNO_3	0	125	125	0	22,031	0.32	9.8	0.71	0.60	48	79	28	21.1	28
KNO_3	0	100	75	75	23,824	0.30	9.7	0.67	0.62	50	80	26	13.1	26
Significance					**	NS	**	*	**	NS	**	NS	NS	NS
LSD (5% level)					1,361	--	0.8	0.09	0.12	--	21	--	--	--

NS = nonsignificant; **, * = significant at 1% and 5%, respectively.
[1]wk PH = weeks post hilling.

Table 6. Comparative effects of potassium chloride, potassium sulfate, and potassium nitrate on nitrate nitrogen and potassium concentration in petiole sap, as determined by various procedures, and elemental concentrations in petiole sap, sampled July 8, 1993.

K source	Time of application: Planting	Emergence	Hilling	3wk PH[1]	Horiba K	Horiba NO_3-N	Hach NO_3-N	Wescan NO_3-N	Elemental Concentration in Sap: P	K	Ca	Mg	S
	K rate (lb K/A)				ppm								
--	0	0	0	0	2825	1488	1395	1490	61	3184	185	412	58
KCl	250	0	0	0	3325	1375	1120	1271	66	4473	39	220	51
K_2SO_4	250	0	0	0	3300	1588	1307	1413	60	4345	46	221	64
KNO_3	0	125	125	0	3275	1500	1164	1250	67	4273	18	195	50
KNO_3	0	100	75	75	3225	1563	1308	1394	61	4333	33	234	48
Significance					++	++	**	*	NS	**	**	**	++
LSD (5% level)					394	163	122	176	--	375	40	72	13

NS = nonsignificant; **, * = significant at 1% and 5%, respectively.
[1]wk PH = weeks post hilling.

Table 7. Comparative effects of potassium chloride, potassium sulfate, and potassium nitrate on nitrate nitrogen content of petioles, and elemental concentrations in petioles, sampled August 4, 1993.

K source	Time of application: Planting	Emergence	Hilling	3wk PH[1]	dry weight petiole NO_3-N	Elemental Concentration in Petioles: P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	K rate (lb K/A)				ppm	%				ppm				
--	0	0	0	0	17,540	0.25	4.8	0.99	1.38	44	160	13	10.9	30
KCl	250	0	0	0	10,488	0.23	8.6	0.76	0.68	37	176	14	9.2	29
K_2SO_4	250	0	0	0	12,910	0.20	8.5	0.78	0.69	35	166	13	4.6	29
KNO_3	0	125	125	0	7,636	0.18	8.5	0.84	0.68	32	98	10	8.2	30
KNO_3	0	100	75	75	7,853	0.18	8.3	0.85	0.67	38	85	12	6.4	30
Significance					**	**	**	**	**	++	*	++	NS	NS
LSD (5% level)					3,323	0.04	1.1	0.09	0.23	8	64	3	--	--

NS = nonsignificant; **, *, ++ = significant at 1%, 5%, and 10%, respectively.
[1]wk PH = weeks post hilling.

Table 8. Comparative effects of potassium chloride, potassium sulfate, and potassium nitrate on nitrate nitrogen and potassium concentration in petiole sap, as determined by various procedures, and elemental concentrations in petiole sap, sampled August 4, 1993.

K source	Time of application: Planting	Emergence	Hilling	3wk PH[1]	Horiba K	Horiba NO_3-N	Hach NO_3-N	Wescan NO_3-N	Elemental Concentration in Sap: P	K	Ca	Mg	S
	K rate (lb K/A)				ppm								
--	0	0	0	0	3025	1288	1383	1362	73	3296	313	670	67
KCl	250	0	0	0	4050	948	960	865	65	4997	25	284	54
K_2SO_4	250	0	0	0	3850	1218	1190	954	64	5081	43	287	63
KNO_3	0	125	125	0	4000	1025	914	825	60	5680	42	328	69
KNO_3	0	100	75	75	3800	1020	914	835	60	5346	28	291	70
Significance					**	*	**	**	NS	**	**	**	NS
LSD (5% level)					306	259	190	292	--	411	100	124	--

NS = nonsignificant; **, * = significant at 1% and 5%, respectively.
[1]wk PH = weeks post hilling.

TILLAGE INDUCED MICRORELIEF IMPACTS ON NITRATE MOVEMENT IN SOILS BECKER MN CORN 1993[1]

G.L. Malzer, T.J. Graff[2]

Abstract: Many nitrogen management practices such as rate, timing, source, placement and the use of additives can influence fertilizer use efficiency and potential groundwater contamination. The objectives of this experiment were to evaluate the impact of fertilizer placement within different tillage systems on grain yield, fertilizer N use efficiency and movement through the soil profile. Below average yields resulted from the unusually cool wet season. Spring plow treatments, in general, provided higher yields within a given treatment than either chisel or ridge tillage systems. Grain yield was increased with each increment of fertilizer N applied, although the rate of response was highest within the plow system. Placement of fertilizer N had no influence on grain yield in the plow and ridge-till system, but placement of N close to the row in the chisel system increased grain yield. Early sidedressed applications of N resulted in significant N loss and reduced yields in all tillage systems.

Experimental Procedures

A field site was located at the Sand Plains Research Farm at Becker MN in fall of 1991. During 1992 and 1993 the following experiment was conducted and treatments were applied to the same plot area. The experiment consisted of 39 treatments with four replications arranged in a split plot design with tillage as the main plot. The 39 treatments consisted of three tillage systems (chisel, ridge till, and plow), a control plot (zero N) plus three nitrogen rates (60, 120 and 180 lbs/A), two subsurface band placement methods (7.5 or 15 inches from the row) and two times of fertilizer N application (early=3-leaf or late=8-leaf).

All fertilizer was applied as 28% N solution. The early N application was made on May 20 and the late application on June 28. All N was injected 2-4 inches deep on 30" centers. Soil samples were collected from the knife bands five times during the year. Soil samples were obtained from a depth of 0-2' in 6 inch increments from the control and the 180 lbs N/A rate. Soil samples were collected on May 25 (3-leaf), June 22 (8-leaf, early N application), July 2 (8-leaf, late N application), July 28 (silking) and August 30 (dent). All soil samples were analyzed for nitrate and ammonium N.

Prior to tillage 300 lbs/A 0-0-22 and 165 lbs/A 0-0-60 were broadcasted and incorporated by the different tillage systems. Corn (DeKalb 485, 100 day R.M.) was planted on April 29 in 30 inch rows at a population of 30,700 seeds/A. Starter fertilizer (7-21-7) was applied at 10 gal/A as a band below the seed. Counter 15 G at 8 lbs/A was banded in the row at planting. For weed control a tank mix of Dual (2 lbs/A) + Atrazine (1.25 lbs/A) was applied on April 30.

Plant samples were collected from the control and all N treated plots on June 22 (8-leaf), July 29 (silking) and October 4 (physiological maturity). Total dry matter production, N concentration, and total N uptake were determined on the first two sampling dates. Plant samples obtained at physiological maturity were separated into grain and stover. Separate determinations were made for dry matter production and N concentrations. Grain yields were adjusted to 15.5% moisture.

The irrigation program was started on July 19 and continued through September 7 with 5.4 in. of water applied through irrigation. An additional 23.41 in. of water was obtained during the season as rainfall, with 6.75 in. received between 3 leaf and 8 leaf.

General Results

Results are summarized in Tables 1-4. Grain yields at Becker were below average in 1993 as a result of the cool wet growing season. The wet growing season also created conditions for significant N loss, especially with early season N applications. Grain yields were increased approximately 80 bu/A over the controls when 180 lbs N/A was applied. Overall grain yield and response to fertilizer N was highest within the plow treatment, while chisel and ridge systems provided similar but lower yield responses to applied N. Delayed application of fertilizer N reduced N loss and resulted in approximately a 20 bu/A increase in yield within each tillage system. The increased yields with delayed N applications reflects the N loss from leaching that occurred with early season N application. Placement position of N fertilizer had no influence on grain yield on the plow and ridge till systems, but the placement of N close to the row with the chisel treatment increased yields an average of 11 bu/A across all rate and time comparisons.

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1. Funding provided by Cooperative State Research Service (CSRS) and the Minnesota Agricultural Experiment Station. Appreciation is also expressed to DEKALB Plant Genetics for supplying seed.
2. Professor and Assistant Scientist respectively, Dept. of Soil Science, University of MN.

Table 1. Influence of N-rate, tillage, placement and time of application on grain yields and dry matter production at harvest. Becker, MN 10/4/1993.

Tillage	N-Rate	Placement	Time	Grain Yields	Dry Matter Production Stover	Grain	Total
	#/A			Bu/A	---------T/A----------		
Chisel	Control	---	-	61.8	2.37	1.46	3.83
	60	1	1	72.3	2.59	1.71	4.31
	60	1	2	114.8	3.12	2.72	5.84
	60	2	1	68.1	2.64	1.61	4.26
	60	2	2	104.9	3.13	2.48	5.61
	120	1	1	119.9	3.02	2.84	5.85
	120	1	2	137.4	3.07	3.25	6.32
	120	2	1	105.4	3.21	2.49	5.71
	120	2	2	104.7	2.87	2.48	5.34
	180	1	1	150.8	3.67	3.57	7.23
	180	1	2	125.5	2.84	2.97	5.81
	180	2	1	130.7	3.30	3.09	6.40
	180	2	2	142.3	3.29	3.37	6.65
Ridge	Control	---	-	60.6	2.20	1.43	3.64
	60	1	1	79.0	2.93	1.87	4.80
	60	1	2	106.8	2.95	2.53	5.48
	60	2	1	67.0	2.51	1.59	4.09
	60	2	2	104.2	2.79	2.47	5.26
	120	1	1	95.1	3.34	2.25	5.59
	120	1	2	132.0	2.97	3.12	6.09
	120	2	1	112.1	3.05	2.65	5.70
	120	2	2	137.4	2.99	3.25	6.24
	180	1	1	134.8	3.17	3.19	6.36
	180	1	2	141.9	3.24	3.36	6.60
	180	2	1	118.6	3.18	2.81	5.98
	180	2	2	151.9	3.37	3.59	6.96
Plow	Control	---	-	55.2	2.28	1.31	3.59
	60	1	1	80.7	3.12	1.91	5.03
	60	1	2	115.0	3.40	2.72	6.12
	60	2	1	81.7	2.79	1.93	4.73
	60	2	2	131.6	3.62	3.11	6.73
	120	1	1	129.2	4.08	3.06	7.13
	120	1	2	134.7	3.20	3.19	6.39
	120	2	1	112.2	3.81	2.66	6.47
	120	2	2	137.7	3.29	3.26	6.54
	180	1	1	141.7	3.70	3.35	7.05
	180	1	2	139.9	3.26	3.31	6.57
	180	2	1	142.1	3.57	3.36	6.93
	180	2	2	151.0	3.38	3.57	6.96

Placement 1 = 7.5 and 2 = 15 inches from the row.
Time 1 = 3-leaf and 2 = 8-leaf

Table 2. Influence of N-rate, tillage, placement and time of application on stover and grain N content and total N removal at harvest. Becker, MN 10/4/1993.

Tillage	N-Rate	Placement	Time	N-Concentration Stover	N-Concentration Grain	N-Removal Stover	N-Removal Grain	N-Removal Total
	#/A			-------%------		---------#/A----------		
Chisel	Control	---	-	0.52	0.92	24.8	26.9	51.6
	60	1	1	0.54	0.91	27.7	31.3	58.9
	60	1	2	0.66	1.06	41.7	57.7	99.4
	60	2	1	0.52	0.85	27.6	27.5	55.1
	60	2	2	0.84	1.01	52.8	50.3	103.1
	120	1	1	0.64	0.99	38.3	56.2	94.5
	120	1	2	0.84	1.19	51.8	77.6	129.4
	120	2	1	0.63	0.98	40.6	49.2	89.8
	120	2	2	0.79	1.10	45.5	54.5	100.0
	180	1	1	0.81	1.24	61.0	89.0	150.0
	180	1	2	0.74	1.19	42.8	70.5	113.3
	180	2	1	0.67	1.09	44.5	67.6	112.1
	180	2	2	1.10	1.23	72.6	82.6	155.2
Ridge	Control	---	-	0.62	0.92	27.6	26.4	54.0
	60	1	1	0.50	0.94	29.2	35.4	64.6
	60	1	2	0.80	1.02	47.4	51.4	98.8
	60	2	1	0.56	0.95	28.4	30.3	58.7
	60	2	2	0.71	1.03	40.0	51.1	91.1
	120	1	1	0.55	1.01	36.8	45.8	82.6
	120	1	2	0.79	1.13	47.2	70.5	117.7
	120	2	1	0.77	1.05	47.2	55.4	102.6
	120	2	2	0.79	1.14	47.6	73.9	121.4
	180	1	1	0.73	1.16	46.1	74.1	120.1
	180	1	2	0.75	1.20	48.8	80.6	129.5
	180	2	1	0.63	1.02	39.5	57.4	96.9
	180	2	2	0.80	1.19	53.7	85.5	139.2
Plow	Control	---	-	0.59	0.87	27.0	22.9	49.9
	60	1	1	0.57	0.93	34.8	35.3	70.2
	60	1	2	0.72	0.95	48.6	51.5	100.1
	60	2	1	0.45	0.87	25.0	33.5	58.5
	60	2	2	0.76	0.97	55.1	60.8	115.9
	120	1	1	0.66	1.02	54.0	62.3	116.4
	120	1	2	0.75	1.16	47.5	74.4	121.9
	120	2	1	0.63	1.01	48.3	53.9	102.2
	120	2	2	0.93	1.15	61.0	75.1	136.1
	180	1	1	0.60	1.14	44.7	76.3	121.0
	180	1	2	0.86	1.23	56.2	81.6	137.7
	180	2	1	0.70	1.07	50.0	71.6	121.6
	180	2	2	0.84	1.24	57.4	88.6	146.1

Placement 1 = 7.5 and 2 = 15 inches from the row.
Time 1 = 3-leaf and 2 = 8-leaf

Table 3. Continued from table 1. Split Plot Statistical Analysis

N-Rate X Tillage X Placement X Time	Grain Yields	Dry Matter Production Stover	Grain	Total
	Bu/A	---------T/A----------		
Tillage				
Chisel	114.7	3.06	2.71	5.77
Ridge Till	115.0	3.04	2.72	5.76
Plow	124.7	3.43	2.85	6.38
P-Value	99	99	99	99
BLSD (.05)	3.5	0.09	0.08	0.14
N-Rate #/A				
60	93.8	2.96	2.22	5.18
120	121.4	3.24	2.87	6.11
180	139.2	3.33	3.29	6.25
P-Value	99	90	99	99
BLSD (.05)	3.4		0.08	0.14
N-Rate X Tillage	38	90	38	84
Placement				
1. 7.5 inches	119.5	3.20	2.82	6.03
2. 15 inches	116.8	3.15	2.76	5.91
P-Value	90	73	90	90
Tillage X Placement	99	57	99	65
N-Rate X Placement	79	61	79	75
N-Rate X Tillage X Placement	99	26	99	92
Time				
1. 3 leaf	107.8	3.20	2.55	5.75
2. 8 leaf	128.5	3.15	3.04	6.19
P-Value	99	74	99	99
Tillage X Time	99	76	99	96
N-Rate X Time	99	99	99	99
N-Rate X Tillage X Time	99	99	99	99
Placement X Time	99	99	99	99
Tillage X Placement X Time	65	49	65	71
N-Rate X Placement X Time	99	62	99	99
N-Rate X Tillage X Placement X Time	99	95	99	99

Table 4. continued from Table 2: Split Plot Statistical Analysis

N-Rate X Tillage X Placement X Time	N-Concentration Stover	N-Concentration Grain	N-Removal Stover	N-Removal Grain	N-Removal Total
	-------%------		---------#/A----------		
Tillage					
Chisel	0.73	1.07	45.5	59.4	105.6
Ridge Till	0.69	1.07	42.6	59.2	101.9
Plow	0.70	1.06	48.5	63.7	112.2
P-Value	48	30	87	97	94
BLSD (.05)				2.8	
N-Rate #/A					
60	0.63	0.95	38.1	43.0	81.2
120	0.73	1.07	47.1	62.3	109.5
180	0.77	1.16	51.4	77.1	128.5
P-Value	99	99	99	99	99
BLSD (.05)	0.04	0.02	3.2	2.5	4.5
N-Rate X Tillage	74	90	91	43	92
Placement					
1. 7.5 inches	0.69	1.08	44.7	62.2	106.9
2. 15 inches	0.73	1.05	46.4	59.3	105.8
P-Value	94	99	78	99	41
Tillage X Placement	20	64	33	99	62
N-Rate X Placement	32	77	35	34	94
N-Rate X Tillage X Placement	90	32	67	99	97
Time					
1. 3 leaf	0.62	1.01	40.2	52.8	93.0
2. 8 leaf	0.80	1.12	50.9	68.7	119.7
P-Value	99	99	99	99	99
Tillage X Time	52	33	15	94	47
Placement X Time	95	91	99	99	99
Tillage X Placement X Time	99	9	96	43	79
N-Rate X Time	70	75	99	99	99
N-Rate X Tillage X Time	8	90	36	99	91
N-Rate X Placement X Time	86	99	95	99	99
N-Rate X Tillage X Placement X Time	99	38	99	98	99

LONG-TERM NITROGEN MANAGEMENT EFFECTS ON CORN YIELD[1]

D.J. Fuchs and D.R Huggins[2]

ABSTRACT

Nitrogen management considerations for corn production include application rate, timing, form, and placement. A continuous corn study at the Southwest Experiment Station, Lamberton was initiated in 1960 on a Normania loam. The study was conducted to aid N management decisions regarding N rate (0 to 160 lb N/ac), form (urea or ammonium nitrate), application time (fall, spring or sidedressed), and placement (fall surface broadcast before and after moldboard plowing). Wet, cold weather conditions in the fall of 1992 and continuing in 1993 favored sidedressed applications of N as compared to fall applied N. Corn yields with urea applications of 80 lb N/ac were 40 bu/ac greater with sidedressed as compared to fall applied N. Maximum corn yields (100 bu/ac) were obtained with NH_4NO_3 applications of 160 lb N/ac, however, this was not significantly greater than yields obtained with 80 lb N/ac of urea. The 33 year yield average (no yields were taken in 1976) indicate that corn yields respond the greatest to N rate with a slight advantage to spring and sidedressed Aapplied N and little yield difference between N forms.

METHODS AND MATERIALS

The Corn N management study was initiated in 1960 and the same treatments were applied through 1993. The study is located at the Southwest Experiment Station on a tiled Normania loam. Each plot is 20 by 77.5 feet with the four replications arranged in a randomized block. After ear corn removal and stalk cutting, treatments with fall N are either surface broadcast before or after moldboard plowing to a depth of 12 inches. Spring N treatments are broadcast before seedbed preparations in late April or early May. Corn is planted in 30-inch rows, and starter fertilizer is banded at a rate of 14-41-15 lbs/ac (N-P_2O_5-K_2O). Sidedress N treatments are broadcast in June and incorporated during cultivation. Additional management information for 1993 is provided in Table 1. In the fall of 1993, the experiment was modified to include anhydrous ammonia, a 120 lb N/ac rate, a corn/soybean rotation, and a complete experimental design.

RESULTS

Cool, wet weather conditions during the fall of 1992 and the 1993 growing season favored spring and sidedressed applied N as compared to fall N applications (Table 2). Corn yields with urea applications of 80 lb N/ac were 40 bu/ac greater with sidedressed as compared to fall applied N. Maximum corn yields (100 bu/ac) were obtained with sidedressed NH_4NO_3 applications of 160 lb N/ac, however, this was not significantly greater than yields obtained with 80 lb N/ac of sidedressed urea. Corn yields with 160 lb N/ac of fall applied urea were statistically equal to yields with 40 lb N/ac of sidedressed NH_4NO_3 (Table 2). The 33 year yield average (no yields were taken in 1976) indicate that corn yields respond the greatest to N rate with a slight advantage to spring and sidedressed applied N and little yield difference between N forms (Table 3).

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[1] Funding provided by Agricultural Experiment Station

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

Table 1. Plot management information for 1993.

Item	Type	Rate	Date
Secondary Tillage	Disc Digger	1 pass 1 pass	5/5 5/6
Seed	Pioneer	29,000 seeds/ac	5/6
Fertilizer	Starter	14-36-13 lbs/ac (N-P_2O_5-K_2O)	5/6
Herbicides	Lasso Bladex	3.0 lbs/ac (ai) 2.0 lbs/ac (ai)	5/6
Insecticides	Counter	1.0 lbs/ac (ai)	5/6
Row Cultivation		2 passes	6/28, 7/21
Rotary Hoe		1 pass	5/14

Table 2. Corn yields in 1993.

Application Time	Nitrogen Form and Application Rate					
	NH_4NO_3 (lb N/ac)			UREA (lb N/ac)		
	40	80	160	40	80	160
	bu/ac					
Fall Incorp.	43	53	76	47	54	82
Fall Surface	51	nd†	nd	46	nd	nd
Spring preplt.	53	67	nd	52	66	nd
Sidedress	73	78	100	56	94	nd
Control: 42 bu/ac						

†nd=no data (treatments not in experiment).
LSD $_{0.05}$ = 14.5 bu/ac.

Table 3. Long-term corn yields (1960-1993).

Application Time	Nitrogen Form and Application Rate					
	NH_4NO_3 (lb N/ac)			UREA (lb N/ac)		
	40	80	160	40	80	160
	bu/ac					
Fall Incorp.	83	102	111	90	102	112
Fall Surface	87	nd†	nd	88	nd	nd
Spring preplt.	92	106	nd	92	108	nd
Sidedress	97	104	116	96	112	nd
Control: 63 bu/ac						

†nd=no data (treatments not in experiment).
LSD $_{0.05}$ = 3.8 bu/ac.

NITRATE LOSSES TO TILE DRAINAGE, RESIDUAL SOIL N, AND N UPTAKE AS AFFECTED BY CROPPING SYSTEMS[1]

Lamberton, 1993

G. W. Randall, D. R. Huggins, D. J. Fuchs,
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. Crop yields in this sixth year of the study were below average due to the very wet and cool conditions. Nitrogen uptake by the continuous corn, corn-Sb, soybean, and alfalfa crops totaled 96, 95, 167 and 243 lb/A, respectively. Residual soil NO_3-N remaining in the 0-5' profile in October totaled 62, 43, 53, 25 and 21 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 7.1 and 8.1 inches while the perennial crops had 6.8" (alfalfa) and 7.5" (CRP). Tile water drainage from the row-crop systems ranged from 17.4 to 19.2 acre-inches while 12.7 and 20.1 acre-inches drained from the alfalfa and CRP systems, respectively. Flow-weighted NO_3-N concentrations ranged from 13 to 20 mg/L for the 5-month drainage period with the corn and soybean systems but averaged <2 mg/L with the alfalfa and CRP systems. Nitrate-N losses ranged from only 1.5 lb/A with the CRP system and 3.2 lb/A with alfalfa to 81 lb/A with continuous corn.

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 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 indicated 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 (Table 3) were used to determine the N fertilizer rates needed for corn. The 140-lb N rate used for continuous corn and the 95-lb N rate for corn after soybeans was based on the NO_3 concentration in the 0 to 24" layer and a yield goal of 140 bu/A according to AG-FO-3790 (1993).

Results and Discussion

Weather

Climatic conditions during the 1993 growing season were cooler and wetter than normal (Table 2). Rainfall over the 7-month growing season was 10" above normal with greatest departure from normal in May and June. Monthly temperature averages were markedly below normal in August and September while the 7-month seasonal average was 5° F below normal. These conditions resulted in below normal corn and soybean yields and average alfalfa yield.

Spring Soil Nitrate

Residual NO_3 in the 0 to 5-foot soil profile in late-April was average to low for both the corn-soybean and soybean-corn systems and medium-high for the continuous corn system (Table 3). Nitrate-N distribution was relatively uniform in the top three feet of the continuous corn plots

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

but increased approximately two-fold in the 3 to 5' layer. This was similar to 1992. Residual NO_3-N following soybeans in 1992 was highest in the 0-1' and 4-5' layers and lowest between 2 and 3'. In the soybean-corn sequence (corn in 1992), very low NO_3-N levels occurred in the 1 to 3' layer with the highest concentration in the 4-5' layer. Residual soil NO_3 in the corn-soybean system (soybean in 1992) increased dramatically (74%) between the October '92 sampling and the April '93 sampling. Slight changes between the fall and spring NO_3-N data were seen in the continuous corn and soybean-corn systems. This suggests little over-winter loss of NO_3 in this year.

Crop Yields

Crop yields shown in Table 4 were below the yield goal for corn and below the expected yields for soybean and alfalfa. Although corn yields were about 8 bu/A higher following soybean compared to continuous corn, N uptake was not different between the two systems. Nitrogen uptake by soybean and alfalfa was 72 and 148 lb/A higher, respectively, compared to corn. The CRP plots continued to be completely dominated by grasses (primarily brome grass), similar to 1992 and N uptake in the above-ground dry matter was small.

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 > Sb-C> C-Sb>A=CRP. Nitrate-N concentrations were often highest in the 0-1' profile, usually lowest between 1 and 3' and were somewhat higher again below 3'. Distribution below 4' was very uniform for the CC and C-Sb systems but increased below 6' with the Sb-C system. The alfalfa and CRP systems exhibited very low NO_3-N concentrations between 1 and 9' with a slight increase in the 9-10' layer. Amounts of soil NO_3 in the top five feet in October were 44% lower than in April for the continuous corn and corn-soybean systems with no difference between sampling dates for the soybean-corn system. Absolute differences between the dates of sampling were -48 to -34, and -3 lb NO_3-N/A for the CC, C-Sb and Sb-C systems, respectively.

Soil Moisture

Soil moisture in the 0 to 5' profile in October was higher than in previous years and was affected by the cropping system (Table 6). Available soil water was lowest for the alfalfa and highest for continuous corn.

Tile Flow

Tile line discharge occurred from mid-March through early August with the alfalfa and CRP systems and from late March through early August (with minimal drainage from two plots again in November) from the corn and soybean systems. Drainage averaged 18.5" for the systems containing corn and soybean compared to 12.7" for alfalfa (Table 7). This was the first year where drainage from the CRP system was markedly higher than from alfalfa. Flow-weighted NO_3-N concentrations for the season were highest for the CC system and were approximately 20x higher than the alfalfa and CRP systems. Nitrate-N concentrations from the C-Sb and Sb-C systems averaged about 7 mg/L less than from the CC system. Temporal changes in NO_3-N concentrations did occur in 1993. Flow-weighted NO_3-N concentrations for each month show lowest concentrations for the year in the very first water samples collected (March) for the corn and soybean systems while concentrations in the first samples under alfalfa and CRP were highest for the year. Highest monthly F-W concentrations for the corn and soybean systems were found in April with a slight decline thereafter. Losses of NO_3-N in the tile drainage for the 1993 season ranged from 26 to 35 times higher for the corn-soybean sequences and CC systems compared to the two perennial crop systems. Losses averaged 80 lb/A for the two systems where corn was grown in 1993, 59 lb/A for soybean, and only 2.3 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 crops 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.

Conclusions

The wetter and colder than normal conditions in 1993 resulted in poor crop yields in this sixth year of the study. Nitrogen removal by soybean and alfalfa was 1.8x and 2.5x as high, respectively, as with continuous corn. After four moist years, the grass species again dominated the CRP system. Over winter, "loss" of soil NO_3 was very low. Residual soil NO_3 in the fall, although not as high as in some previous years, was approximately 2x higher with the row crop systems compared to the perennial crop systems. Tile flow occurred over a 5-month period for all crop systems. Drainage averaged 18.5 acre-inches from the row crop systems and totaled 20.1" for CRP and only 12.7" for alfalfa. Nitrate-N concentrations also were 16 to 25x higher with the row-crop systems. Nitrate-N losses to the drainage water totaled 81 lb/A from the continuous corn system and 78 lb/A from the corn-soybean rotation that received fertilizer N in 1992. Nitrate-N losses from the soybean-corn system were markedly lower (59 lb/A) due primarily to lower NO_3-N concentrations. Less than 4 lb NO_3-N/A were lost in the drainage water from the alfalfa and CRP systems.

Table 1. Experimental procedures used in 1993 for the nitrate-pesticide movement study at Lamberton.

Cropping System	Procedures
Cont. Corn and Corn-"Sb"	
Hybrid	Pioneer 3563
Planting rate and date	29000 ppA on 5/14
Insecticide	Counter (1 lb/A)
Herbicides	Lasso (4 lb/A) + Bladex (3 lb/A)
Date	Both applied on 5/14 after field cultivation and then incorporated with field cultivator.
N rate (Cont. corn only)	140 lb N/A as urea
Date	6/28 and cultivated in the same day
Cultivation date(s)	6/15 and 6/28
Harvest date	10/13
Fall tillage (kind and date)	Moldboard plow 11/11
Corn - "Sb"	
N rate	95 lb N/A as urea on 6/28
Soybeans	
Secondary tillage	Field cultivated 2X (5/14)
Variety	Hardin
Planting rate and date	150,000 seeds/A on 5/14
Row width	30"
Herbicides	
Lasso: Rate and date	4.0 lb/A on 5/14, incorporated with a field cultivator
Pursuit: Rate and date	0.063 lb/A plus surfactant + UAN on 7/12
Cultivation date(s)	6/15
Harvest date	10/5
Fall Tillage	None
Alfalfa	
K_2O date	6/29
Harvest date(s)	6/14, 7/26 and 9/2
Harvest area	3' x 20'
CRP	
Harvest date	9/24

Table 2. Growing season monthly air temperature averages and precipitation amounts during 1993 and the long-term normals for Lamberton.

	Avg. Temperature		Precipitation	
Month	1993	Normal	1993	Normal
	°F		inches	
April	41	46	2.55	2.69
May	56	59	7.09	3.28
June	64	68	8.14	3.76
July	69	72	5.23	3.84
Aug.	60	70	5.29	2.97
Sept.	54	60	2.55	3.24
Oct.	46	48	1.01	2.04
7-mo avg.	56	61		
Total	-	-	31.86	21.82