Field Research

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SOIL SERIES #136
Field Research in Soil Science

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DISCLAIMERS

Some of the results reported in this publication are from 1992 experiments and should be regarded on this basis. Since most of the data is from 1992 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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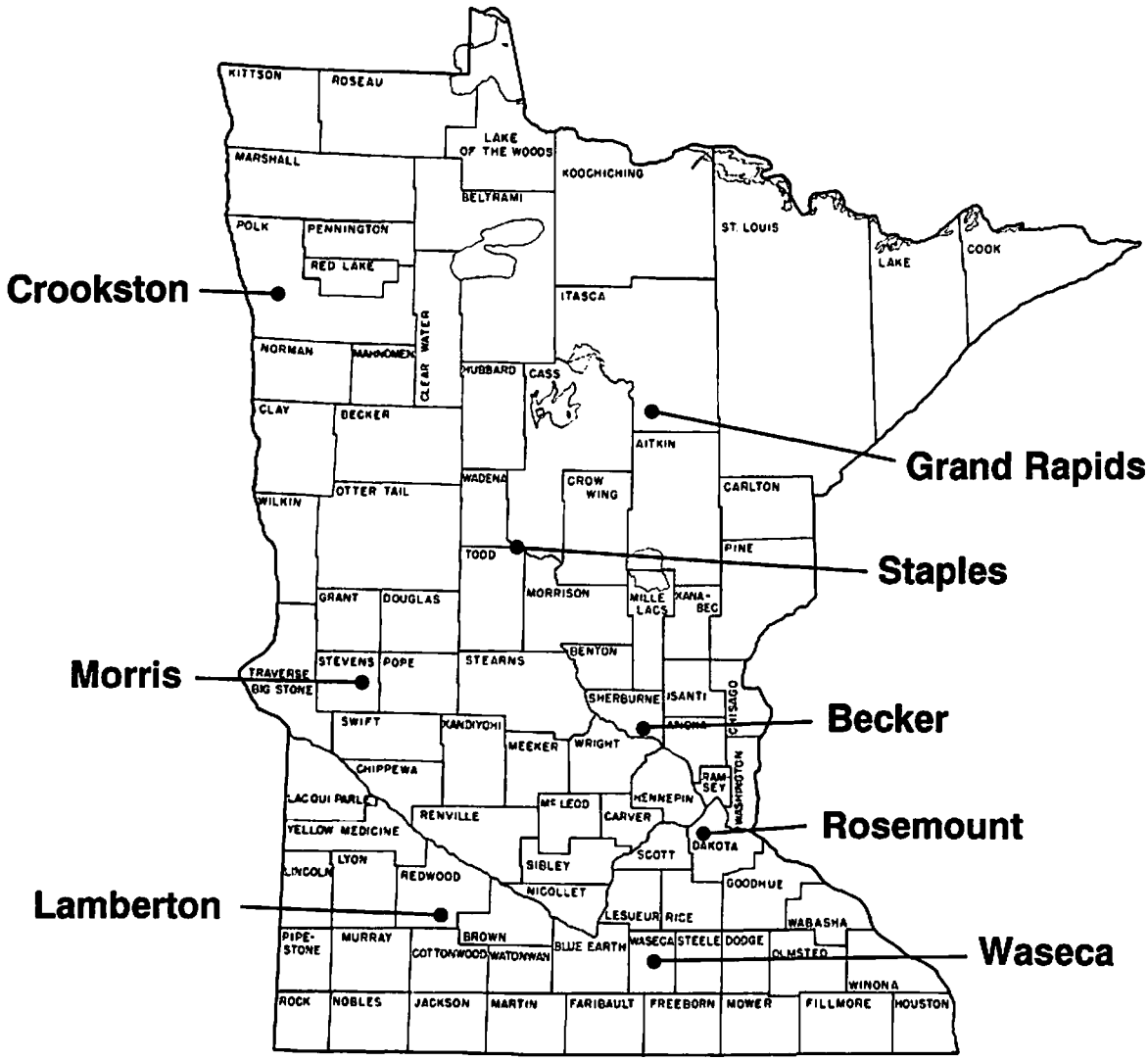

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AGRICULTURAL CLIMATE SUMMARY FOR 1992[1]

M. W. Seeley, Greg J. Spoden, and D. G. Baker[2]

Planting Season: A cool wet April caused delays in small grain plantings this year, however, a very favorable first 10 days of May promoted timely planting of row crops across all parts of the state. Unfortunately, May was the only month of the 1992 growing season with significantly warmer than normal temperatures.

Frosts: Significant ground and air frosts occurred May 24-26 and most unusually during June 20-21 (summer solstice). There was some damage reported to corn fields, and an apparent interaction with soil cultivation in many places. For southern Minnesota, it was the first time since the late 19th century that a ground frost of this type had occurred so late in June. The growing season came to an end with the frosts of September 19-22 in southern counties.

Summer Conditions: The months of June through August averaged 4 to 6 degrees below normal, marking the coolest or second coolest (behind 1915) summer of this century. In fact, for the astronomical summer of June 20 (summer solstice) to September 22 (autumnal equinox) it was the coldest on record! This is evident in the near record negative departures of growing degree days which led to late crop maturation and high harvest moisture (see attached maps). The lost degree days translated to equivalent planting dates showed that a climatic analogy would be a normal growing season with corn planting dates of May 30th to June 7th (see attached table).

Water used in irrigation was down considerably from normal, as precipitation was generally adequate, and with the cool temperatures crop water needs were lower as well. Because cooler air is less able to hold water vapor than warmer air, the cool summer meant a reduction in the atmosphere's evaporative power. Estimates indicate that 1992 summertime evaporation was approximately 15 to 20 percent less than average, and 40 percent less than the summer of 1988. Lakes, wetlands, land surfaces, etc. gave up two to four inches less water to the atmosphere than during an average summer, and as much as eight inches less than the summer of 1988.

The most notable precipitation event of the late summer occurred September 15th and 16th when seven or more inches of rain fell in a narrow band stretching from Scott county, through Dakota county, and into Wisconsin. The heavy rain led to road closures, mudslides, and flooding in some small streams and rivers.

The 1992 Water Year precipitation map (attached) indicates a typical pattern of decreasing precipitation from southeast to northwest. Wet spots included extreme southeastern and northeastern Minnesota, and much of Scott County. Drier areas were found in west central and central sections of the state. Reduced summer evaporation, and the psychological impact of the summer's coolness may have created the impression of above normal precipitation. However, much of Minnesota received near normal Water Year precipitation, and for sections of central Minnesota, totals were well below the norm. Because the precipitation deficit in central Minnesota was counterbalanced by reduced evaporation, no serious hydrologic imbalance unfolded.

Fall Recharge and Winter Outlook: Precipitation during September through November of 1992 was generally less than normal in the north, considerably above normal in the south, and mixed across central Minnesota. Thus across southern Minnesota counties, greater than normal soil moisture has been stored for the winter. Near normal to moderately below normal levels of soil moisture exist elsewhere.

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[1] *This was supported by the Minnesota Extension Service and the Soil Science Dept.*

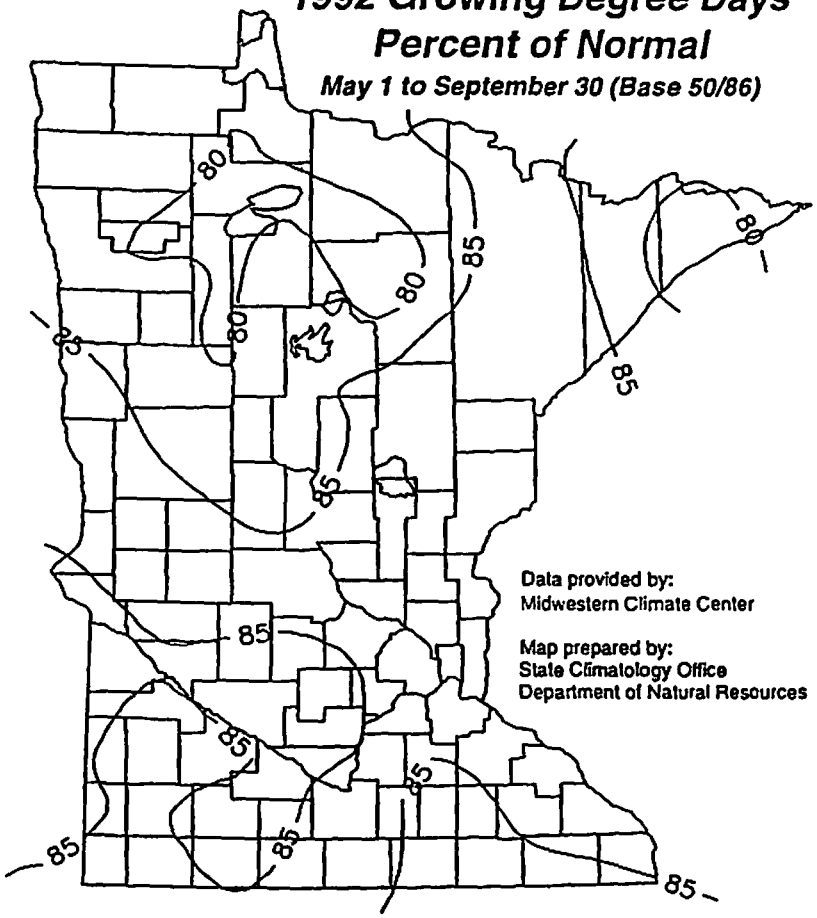
[2] *M. W. Seeley, Professor, Soil Science Dept.; G. J. Spoden, Assistant State Climatologist, Dept. of Natural Resources, and D. G. Baker, Professor, Soil Science Dept.*

PERCENTAGE OF NORMAL GROWING DEGREE DAYS (BASE 50/86) FOR MAY THROUGH SEPTEMBER AND THE EQUIVALENT PLANTING DATE (CALCULATED AS A DEPARTURE FROM MAY 1) FOR SELECTED MINNESOTA LOCATIONS IN 1992. THE DATA SERVE TO ILLUSTRATE WHY ADAPTED CORN HYBRIDS EITHER DID NOT MATURE OR WERE HIGH MOISTURE AT HARVEST.

LOCATION	PCT OF NORMAL GDD IN 1992	EQUIVALENT PLANTING DATE (DEPARTING FROM MAY 1)
ARGYLE	86	5/30
FOSSTON	82	6/7
HALLOCK	81	6/8
BROWNS VALLEY	83	6/6
CANBY	84	6/6
ALEXANDRIA	87	5/29
FERGUS FALLS	86	5/31
WADENA	82	6/4
GAYLORD	84	6/7
HUTCHINSON	83	6/8
ST CLOUD	88	5/30
WILLMAR	85	6/3
JORDAN	86	6/1
AITKIN	88	5/29
CAMBRIDGE	84	6/4
BRAINERD	86	6/1
MSP	86	6/1
MARSHALL	88	5/29
WORTHINGTON	88	5/30
PIPESTONE	85	6/2
REDWOOD FALLS	86	6/2
TRACY	86	6/1
LAMBERTON	87	5/31
ALBERT LEA	84	6/3
FARIBAULT	84	6/2
MANKATO	86	6/1
FAIRMONT	88	5/29
SPRINGFIELD	85	6/2
WINNEBAGO	88	5/30
GRAND MEADOW	84	6/4
ROCHESTER	86	6/2
WINONA	86	6/3
CALEDONIA	85	6/2

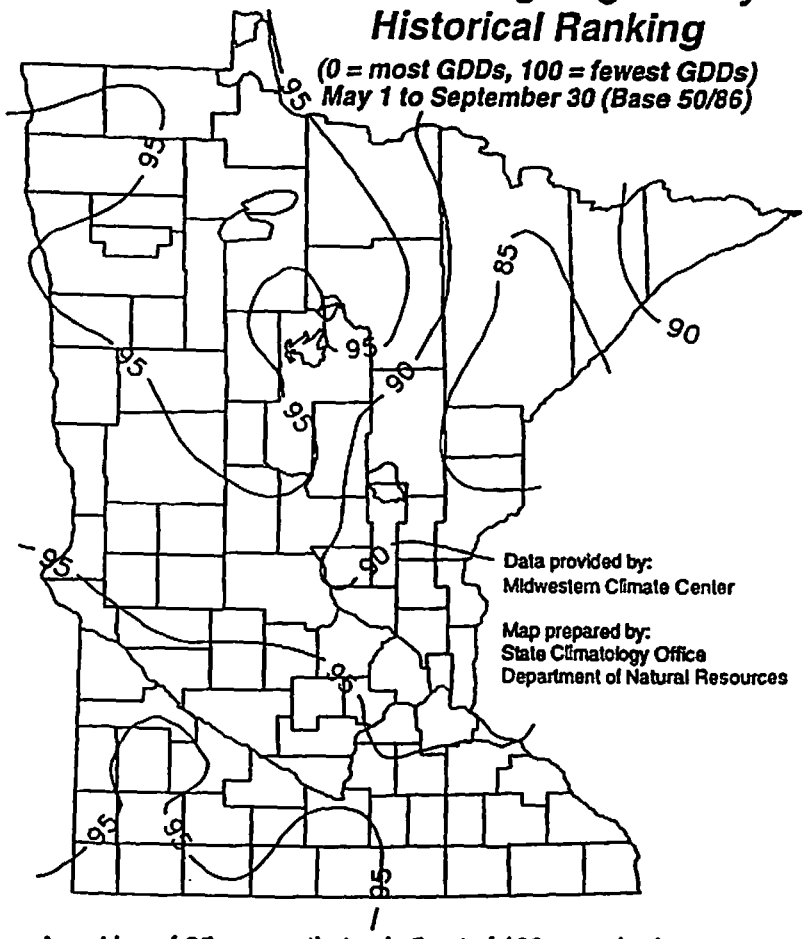
1992 Growing Degree Days
Percent of Normal

May 1 to September 30 (Base 50/86)

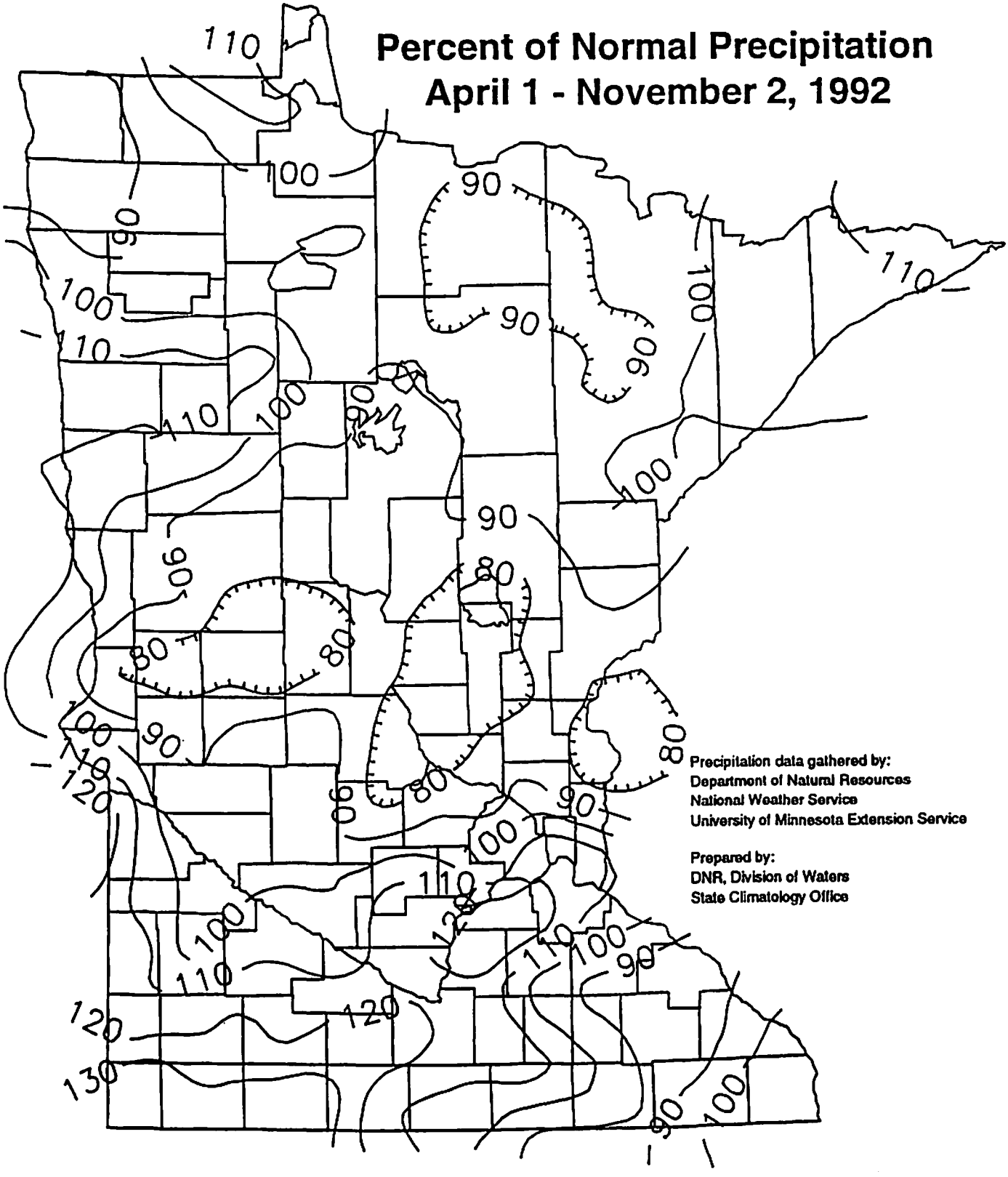


1992 Growing Degree Days
Historical Ranking

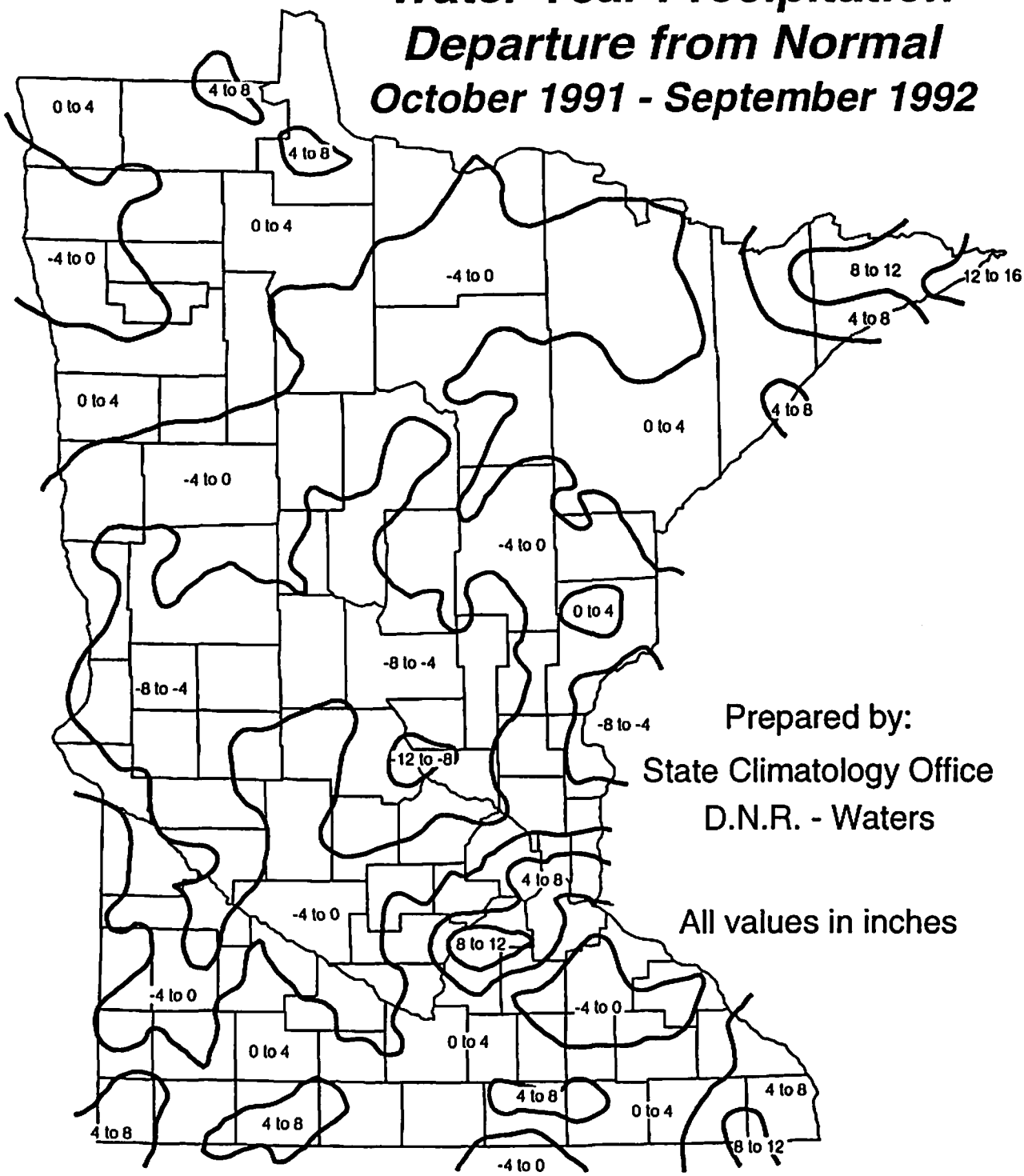
(0 = most GDDs, 100 = fewest GDDs)
May 1 to September 30 (Base 50/86)



A ranking of 95 means that only 5 out of 100 years had fewer growing degree days than 1992.


Percent of Normal Precipitation
April 1 - November 2, 1992
Precipitation data gathered by:
Department of Natural Resources
National Weather Service
University of Minnesota Extension Service
Prepared by:
DNR, Division of Waters
State Climatology Office

Water Year Precipitation Departure from Normal
October 1991 - September 1992



Prepared by:

State Climatology Office

D.N.R. - Waters

All values in inches

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

1992 SOIL MOISTURE RESULTS[1]

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

Results of the 1992 season are shown in the accompanying figure. Except for a brief period in late May, Waseca remained in good moisture condition, and it ended the year with nearly full profile. Lamberton's historic mid-June soil moisture maximum was not reached until about July 15. An unusual feature is that the precipitation was such that the soils did not experience the usual drawdown that has been so typical in the past. In other years the minimum of about 2.5-3.0 inches would be reached in late August or early September. The last sample at Lamberton indicates a better than average content with 6.3 inches in mid-October instead of the 4-inch average.

At Morris the typical mid-season drawdown of soil moisture supplies was delayed about two weeks. And, unlike the other two stations, the soil moisture supplies do not exhibit the typical end-of-the-season recharge.

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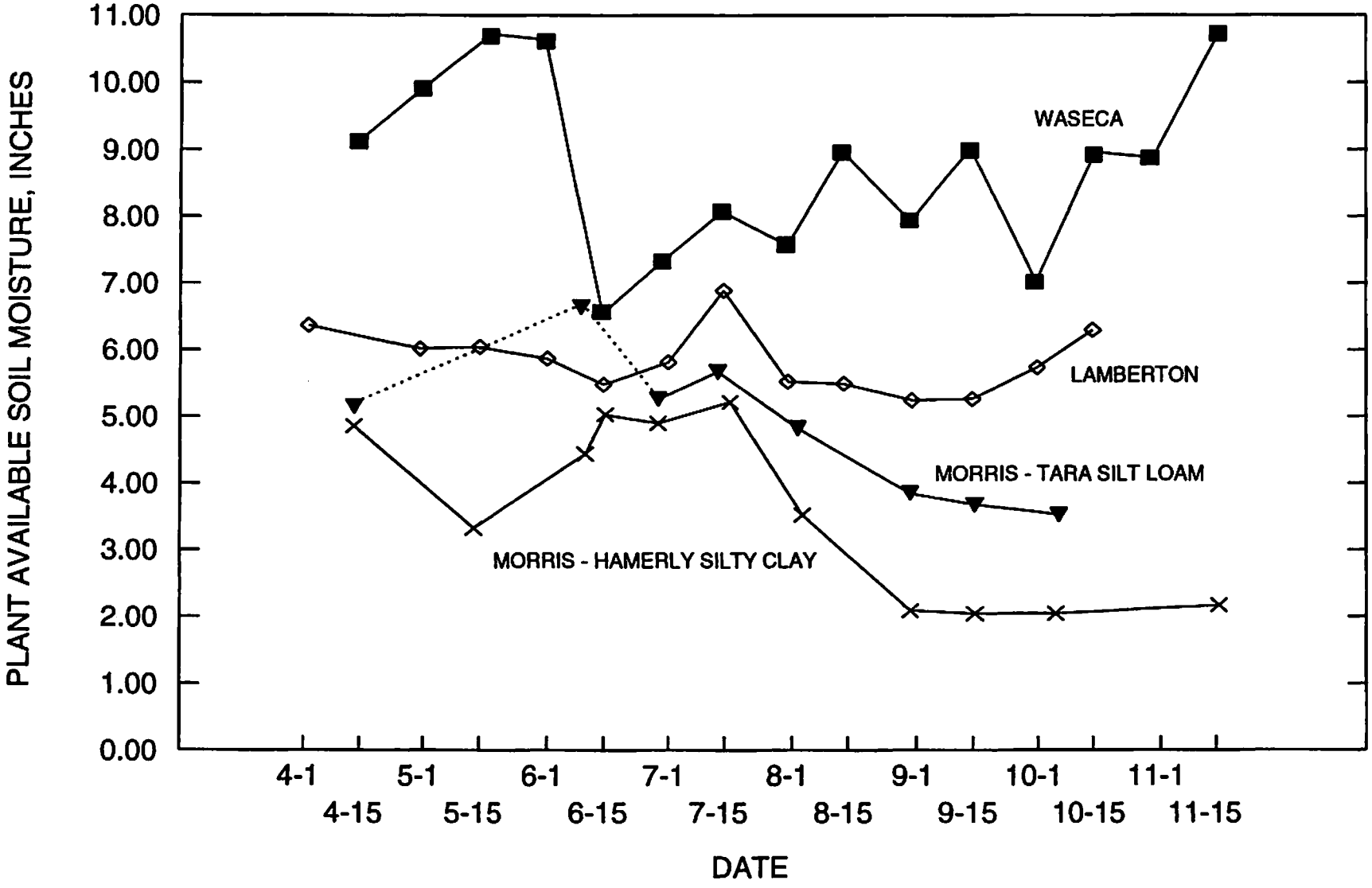
[1]*This project was supported by the Minn. Agric. Exp. Sta.*

[2]*Professor, West Central Experiment Station, Professor, Southern Experiment Station, Scientist, Southwest Experiment Station, Asst. Scientist, Soil Science Dept., and Professor, Soil Science Dept., respectively.*

1992 SOIL MOISTURE



PRECIPITATION NETWORK DENSITY REQUIREMENTS FOR SHORT TERM ANALYSIS[1]

Rodney R. Swerman, Donald G. Baker, and David L. Ruschy[2]

Precipitation not only is one of the most important climatological elements, but it is also the most highly variable in terms of amount and areal distribution. Thus, in order to arrive at an acceptable estimate of precipitation in a given area, the density of the gauges is important. The objective of this study was to determine the number of gauges to be recommended for areas of varying sizes. The results are based on the samplnig of different kinds of daily precipitation events with networks of varying density of gauges.

INTRODUCTION

Knowing the variability of rainfall from a single storm over a small area is of concern, for example, to drainage engineers and to those involved in small watershed runoff simulations. Accurate estimates of the amount and areal extent of a storm during a short period are of obvious importance to these and other related interests.

Within Minnesota, the National Weather Service (NWS) has a cooperative observer network of about 175 stations. With a land area of some 84,068 square miles each station in Minnesota represents an average of 480 square miles. An earlier study determined that this density was inadequate for total daily precipitation sampling for time periods of a single month to a season.

Study Area

The study area chosen measures 33 miles on a side or 1089 sq. miles, large enough to capture a single storm event, yet small enough to be comparable to certain watersheds. The test area selected is centered on the Twin Cities Metropolitan area, and includes all of Ramsey Co., the southern third of Anoka Co., the eastern two-thirds of Hennepin Co., the extreme eastern edge of Carver Co., the NE corner of Scott Co., the northern half of Dakota Co., and the western half of Washington Co. Within this 1089 sq. mile area there are as many as 150 rain gauge reports for an individual summertime rainfall event. This gives a density of 1 gauge per 7.3 miles, certainly sufficient for most analyses. Five storm events were selected to represent 5 different precipitation event types. All had good to excellent temporal isolation as determined from the weather records of the St. Paul Campus Observatory.

Networks were randomly selected with a specific number of rain gauges for the five storm events to determine the accuracy with which the reduced networks represent the rainfall pattern within the study area. Networks of 1, 3, 5, 9, 16, 25, 35, and 50 gauges were randomly selected from the complete network data set for each precipitation event. For sample networks of more than 50 gauges, the number of gauges was increased by increments of either 15 or 20 gauges, i.e., 50, 65, 80,..., or 50, 70, 90,..., up to the full density available for each event.

For each network density used in this study 10 sample networks were randomly selected from the full network. In effect the same storm was recorded by 10 different networks of 3 gauges, then 10 networks of 5 gauges, then 10 networks of 9 gauges, and son, up to the full density. A mean areal rainfall estimate was determined from each of these network densities. A sample size of about 10 was necessary in order to determine a reliable average and a standard deviation of the mean areal rainfall estimates at each network density.

The full density network for each precipitation event was analyzed and used as the "true" estimate of the mean areal rainfall. The reduced networks of 1, 3, 5, 9, 16,... gauges were tested against the "true" estimate to determine how accurately a network of a limited number of rain gauges can estimate the mean areal rainfall within the study area.

ANALYSIS

Once the series of reduced density networks were randomly selected, each network's rain gauge data were gridded onto the entire study area. The gridding method used was the kriging technique, as adapted by Golden Software, Inc. (1983).

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[1]*This project was supported by the Minn. Agr. Ext. Sta.*

[2]*Former graduate student Soil Science Dept., and Professor and Assistant Scientist, Soil Science Dept., St. Paul, respectively.*

For this study, the data were gridded to a 33 by 33 grid field, or 1089 gridpoints. This was done to give one gridpoint and rainfall estimate per square mile. For the mean areal rainfall estimate the average of these 1089 gridpoints was determined. And for each network density the 10 mean areal rainfall estimates were then averaged and the standard deviation calculated. From the standard deviation the 95% confidence interval was calculated for the mean areal rainfall estimate at each network density. An example is shown in Fig. 1.

RESULTS AND DISCUSSION

Fig. 1 depicts the average mean areal rainfall estimates (MARE) and a 95% confidence interval for each estimate as the network density was increased for each event. Several interesting features are found in Fig. 1. For the low network densities, networks of 1 to 9 guages, (> 100 sq. miles/gauge), MARE are very unreliable. As the number of gauges in the network for a 1089 sq. mile area is increased from a density of more than 100 sq. miles per gauge to about 20 sq. miles per gauge (a 9 to a 50 gauge network), the MARE stabilizes and the confidence interval surrounding the estimate narrows, as expected, for all event types.

Increasing the network from 50 to 70 gauges, (22 sq. miles per gauge to 15.5 sq. miles per gauge), produces the last noticeable increase in the accuracy of the MARE for almost all events. In general, increasing the number of gauges in the network above 70 gave little if any increase in accuracy of the MARE.

Results from the analysis of these five storm cases show that different storm types do require slightly differing rain gauge densities in order to adequately detect, sample, and determine an accurate mean areal estimate of the rainfall. The ideal or "true" network density required for cyclonic-type events is on the order of 1 gauge per 22 sq. miles, while for an intense localized event of the convective-type the ideal density is near 1 gauge per 22 sq. miles, while for an intense localized event of the convective-type the ideal density is near 1 gauge per 13 sq. miles.

RECOMMENDATIONS

Among the five event types studies there seems to be a relationship between the rainfall intensity, the rainfall totals, and the number of gauges required within a given area to adequately detect and determine an accurate MARE. In general, as the rainfall rate (inches/hr, intensity) increases, so too does the spatial variability of the precipitation pattern. Increasing the spatial variability of a short term event will increase the density of rain gauges required to maintain the same degree of accuracy in determination of a MARE.

It is essential to note that as the mean rainfall and the size of the target area increase, the density (sq. miles/gauge) requirement decreases, although the total number of gauges increases. In general, the smaller the target area and the greater the detail required, the higher is the network density requirement. Data from Beebe (1952), Causey (1953), Baker and Kuehnast (1973) and this study are plotted in Figure 2. They show the ideal density of a network that is suggested for a "true" sample of daily total rainfall for any area up to 100,000 sq. miles. Results can be expected to vary a bit from month to month, but Figure 2 provides a good first approximation.

Our recommendations can probably be applied to most areas of the state, since short term precipitation patterns and storm characteristics do not differ appreciably across most of Minnesota. Only in some portions of northern and northeastern Minnesota are we unsure of the applicability of our recommendations. This is because some of these areas are currently so very poorly represented by rain gauge reports that their true storm characteristics are yet to be determined.

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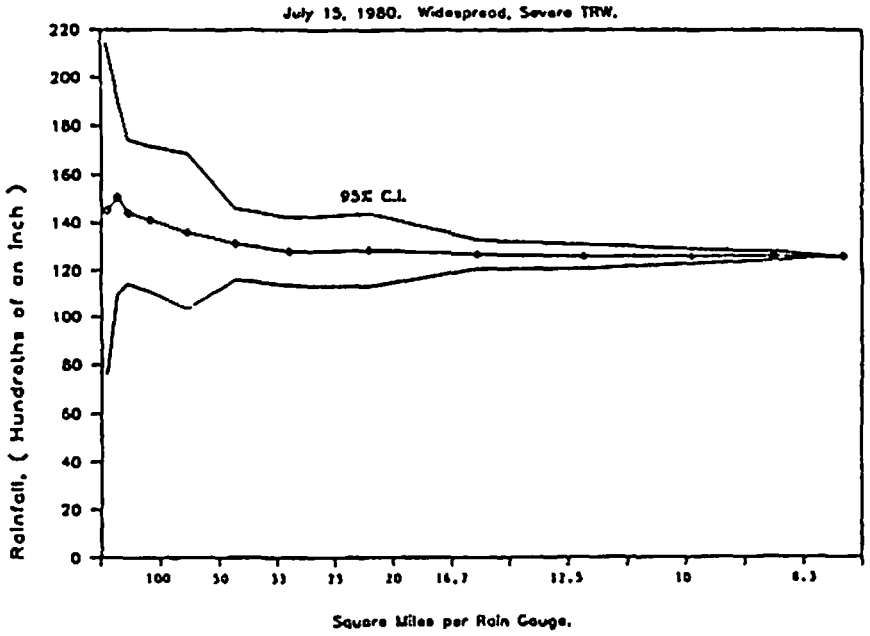

Fig. 1. Mean areal rainfall estimate. Each mean and standard derivation is calculated from 10 random samples at each density of rain gages. 95% C.I. is the 95% confidence interval.

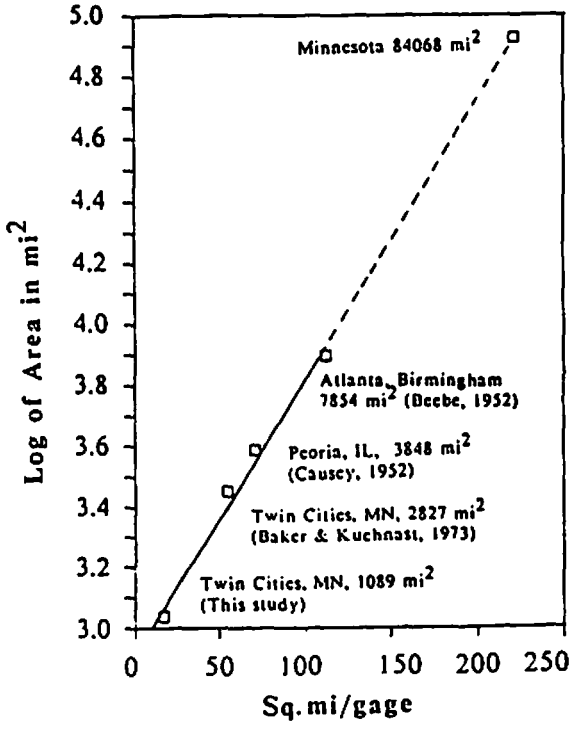

Fig. 2. Ideal sampling densities (square miles/rain gage) required for indicated areas. (A log of 3 = 1,000 mi^2, log 4 = 10,000 mi^2, and log 5 = 100,000 mi^2.)

CALCIUM NITRATE AS A SOURCE OF CALCIUM AND NITROGEN FOR POTATO PRODUCTION[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 calcium nitrate as a calcium and nitrogen source for potato production. The effects of potassium nitrate on potato production were also examined. Total and marketable Russet Burbank yields obtained when calcium nitrate was provided were similar to those when urea or potassium nitrate was used. Calcium nitrate increased calcium concentrations in leaf tissue at mid-season. Potassium nitrate increased leaf potassium. Calcium nitrate increased calcium concentrations in tuber skin, especially when post-hilling applications were made. None of the treatments tested significantly affected tuber flesh (medulla) calcium. Potassium nitrate did not affect tuber skin or flesh concentrations of potassium.

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

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 - 5.3; Organic Matter - 3%; Bray P1 - 34 ppm; NH_4OAc K, Ca, Mg - 79, 522, 80 ppm, respectively; 2N KCl nitrate-N (0-2ft) - 19 lb/A. The previous crop was rye. The cultivar 'Russet Burbank' was planted April 20, 1992. Prior to planting, 230 lbs 0-0-22/A were broadcast and incorporated over the entire field. At planting, all plots received 750 lb 8-10-30 as a band with urea as the N source. There were six treatments arranged in a randomized complete block design with four replications. The six treatments were:

	Time of application					
Treatment	Planting	Emergence	Hilling	3 weeks post-hilling	5 weeks post-hilling	Total N applied
	N rate (lb/A) and source					lb N/A
1.	60 Urea	75 Urea	75 Urea	0	0	210
2.	60 Urea	75 Urea	75 Ca Nit	0	0	210
3.	60 Urea	40 Urea	75 Ca Nit	35 Ca Nit	0	210
4.	60 Urea	40 Urea	35 K Nit	35 K Nit	35 K Nit	205
5.	60 Urea	40 Urea	35 Urea	35 Urea	35 Urea	205
6.	60 Urea	40 Urea	35 Ca Nit	35 Ca Nit	35 Ca Nit	205

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. Leaf samples were collected on July 1 and August 3 for nutrient analyses. Plots were harvested on September 9 and tubers were separated according to size. Subsamples of tubers were also collected for specific gravity determinations and nutrient analyses. Total leaf nitrogen was determined using Kjeldahl procedures (with nitrate reduction) and other elements in leaf and tuber tissue were determined on ashed samples using ICP techniques. Petiole nitrate was determined on water extracts.

RESULTS:

All treatments tested resulted in statistically similar potato yields (Table 1). However, treatments with posthilling applications, regardless of nitrogen source, tended to have lower total yields. Specific gravity was high, but not affected by treatment.

At the first sampling date, leaf nitrogen concentrations and petiole nitrate concentrations were highest when all the nitrogen was applied by the hilling stage (Table 2). This result is not surprising, since the posthilling nitrogen treatments had not yet been applied. By the second sampling date, the highest petiole nitrate levels were in the post-hilling treatments (Table 3). Leaf concentrations of phosphorus, iron, zinc,

[1] Partial support for this project was provided by WGM/Hydro and Cedar Chemical Corp.
[2] Extension Soil Scientist and Junior Scientist, Department of Soil Science

copper, and boron were not affected by treatment. Leaf calcium concentrations increased with calcium treatment at the first sampling date, but were not affected by treatment by the second sampling date. Leaf potassium increased with application of potassium nitrate at the second sampling date. Leaf magnesium was lowest when potassium nitrate was used. Leaf manganese tended to be lower when nitrogen was higher. In other words, high nitrogen tended to depress leaf manganese concentrations.

Tuber skin calcium concentrations were 4-5 times higher than calcium concentrations in tuber flesh (Table 4). Calcium nitrate tended to increase tuber calcium compared to urea or potassium nitrate, especially when the calcium nitrate was applied post-hilling. It is interesting to note, however, that post-hilling applications of nitrogen, regardless of nitrogen source, tended to increase tuber skin calcium compared to application of all the nitrogen by hilling. Calcium levels in tuber flesh were not significantly affected by treatment. Potassium concentrations in tuber skin and flesh were not affected by treatment.

Table 1. Comparative effects of calcium nitrate, potassium nitrate, and urea on 'Russet Burbank' potato yield and specific gravity. (Becker, 1992)

	Treatment											
	Time of application						Tuber size					Specific
Trt	Planting	Emergence	Hilling	3wk PH[1]	5wk PH	Knobs	<3 oz	3-7 oz	7-14 oz	<14 oz	Total	Gravity
-#-	N rate (lb N/A) and source[2]					cwt/A						
1	60 U	75 U	75 U	0	0	40.6	81.6	284.0	149.9	10.1	566.3	1.0921
2	60 U	75 U	75 C	0	0	25.8	91.2	310.5	124.6	4.3	556.4	1.0924
3	60 U	40 U	75 C	35 C	0	43.1	94.1	299.7	118.5	6.1	561.5	1.0930
4	60 U	40 U	35 K	35 K	35 K	23.2	77.5	275.5	130.7	16.3	523.2	1.0915
5	60 U	40 U	35 U	35 U	35 U	36.4	84.4	299.9	113.0	8.1	541.7	1.0921
6	60 U	40 U	35 C	35 C	35 C	33.5	89.7	277.9	109.4	6.2	516.7	1.0905
Significance						NS	NS	NS	NS	NS	NS	NS

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

Table 2. Comparative effects of calcium nitrate, potassium nitrate, and urea on nitrate nitrogen content of petioles, and elemental concentrations in leaves (petioles + leaflets), sampled July 1. (Becker, 1992)

		Elemental Concentration in Leaves									
Treatment[1]	dry weight petiole NO_3-N	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	ppm	%					ppm				
1. (60U, 75U, 75U, 0, 0)	15231	5.76	0.36	4.26	0.67	0.56	115	256	27	11	26
2. (60U, 75U, 75C, 0, 0)	18426	5.84	0.39	4.28	0.77	0.57	118	326	29	12	25
3. (60U, 40U, 75C, 35C, 0)	14242	5.54	0.37	4.44	0.85	0.61	119	315	28	11	27
4. (60U, 40U, 35K, 35K, 35K)	7900	5.19	0.36	4.62	0.68	0.55	107	258	28	11	27
5. (60U, 40U, 35U, 35U, 35U)	6690	4.94	0.32	4.40	0.67	0.53	108	265	28	10	27
6. (60U, 40U, 35C, 35C, 35C)	9227	5.15	0.36	4.34	0.82	0.58	118	264	27	11	26
Significance	**	**	NS	NS	*	NS	NS	*	NS	NS	NS
LSD (5% level)	2169	0.41	--	--	0.14	--	--	56	--	--	--

NS = not significant; *, ** = significant at 5% and 1%, respectively.
U = urea, C = calcium nitrate, K = potassium nitrate
[1]Respective timing of N applications are: (planting, emergence, hilling, 3 weeks post-hilling, 5 weeks post-hilling)

Table 3. Comparative effects of calcium nitrate, potassium nitrate, and urea on nitrate nitrogen content of petioles, and elemental concentrations in leaves (petioles + leaflets), sampled August 3. (Becker, 1992)

Treatment[1]	dry weight petiole NO_3-N	Elemental Concentration in Leaves									
		N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	ppm	%					ppm				
1. (60U, 75U, 75U, 0, 0)	1877	3.47	0.19	4.31	1.43	0.72	68	350	9	47	25
2. (60U, 75U, 75C, 0, 0)	581	3.54	0.20	4.42	1.51	0.73	71	321	9	52	25
3. (60U, 40U, 75C, 35C, 0)	1585	3.52	0.20	4.47	1.47	0.68	68	291	9	29	26
4. (60U, 40U, 35K, 35K, 35K)	5250	3.69	0.20	5.42	1.25	0.64	66	221	9	85	26
5. (60U, 40U, 35U, 35U, 35U)	7729	3.76	0.19	4.39	1.45	0.83	67	250	9	45	25
6. (60U, 40U, 35C, 35C, 35C)	5719	3.82	0.20	4.15	1.55	0.76	68	213	10	39	25
Significance	**	NS	NS	**	NS	**	NS	*	NS	NS	NS
LSD (5% level)	3258	--	--	0.43	--	0.09	--	88	--	--	--

NS = not significant; *, ** = significant at 5% and 1%, respectively.
U = urea, C = calcium nitrate, K = potassium nitrate.
[1]Respective timing of N applications are: (planting, emergence, hilling, 3 weeks post-hilling, 5 weeks post-hilling).

Table 4. Comparative effects of calcium nitrate, potassium nitrate, and urea on calcium and potassium concentrations in tuber skin and flesh at harvest. (Becker, 1992)

Treatment[1]	Calcium concentration		Potassium concentration	
	Skin	Flesh	Skin	Flesh
	ppm dry weight		ppm dry weight	
1. (60 U, 75 U, 75 U, 0, 0)	842	166	34492	17098
2. (60 U, 75 U, 75 C, 0, 0)	921	182	32815	17248
3. (60 U, 40 U, 75 C, 35 C, 0)	1021	189	35298	17111
4. (60 U, 40 U, 35 K, 35 K, 35 K)	944	180	35357	17628
5. (60 U, 40 U, 35 U, 35 U, 35 U)	1021	213	36141	17002
6. (60 U, 40 U, 35 C, 35 C, 35 C)	1097	198	35183	16744
Significance	*	NS	NS	NS
LSD (5% level)	175	--	--	--

NS = nonsignificant; * = significant at 5%.
U = urea, C = calcium nitrate, K = potassium nitrate
[1]Respective timing of N applications are: (planting, emergence, hilling, 3 weeks post-hilling, 5 weeks post-hilling).

NITROGEN FERTILIZATION STUDIES ON IRRIGATED POTATOES: NITROGEN USE, SOIL NITRATE MOVEMENT, AND PETIOLE SAP NITRATE ANALYSIS FOR PREDICTING NITROGEN NEEDS - 1992[1]

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ABSTRACT: The second 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 calibrate a quick petiole nitrate sap test for determining nitrogen status of the crop and predicting nitrogen needs. Increasing the rate of nitrogen in the starter fertilizer up to 120 lbs N/A at planting did not affect total or marketable yields, but did result in greater nitrate leaching. Delaying nitrogen application until emergence had no detrimental effect on yield, but did reduce nitrate leaching. At equivalent rates and times of application, use of urea as the nitrogen source resulted in less nitrate leaching than ammonium nitrate with similar effects on yield. Slow release fertilizer (Nutralene) resulted in the least nitrate movement, but yields tended to be lower when compared to equivalent rates of ammonium nitrate. Low rates of N fertilizer applied up to hilling, followed by two post-hilling applications of N resulted in lower yield than if all the N was applied by hilling. Nitrate leaching, however, was less when extended applications were used. In a low leaching year such as 1992, potatoes seem to benefit from higher applications of fertilizer N applied at emergence and hilling. Petiole sap nitrate concentrations were highly correlated with conventional petiole analysis, suggesting that quick tests can determine nitrogen status of the crop.

Potatoes grown on sandy soils under irrigation are usually provided with high rates of nitrogen (N) to promote growth and yield. Concern about ground water quality, however, has raised questions about the fate of N applied to potatoes on irrigated soils. In part, this concern is due to the fact that potatoes have a relatively shallow root system, yet require relatively high rates of N to maintain profitable production. Proper N management is critical to minimize losses of N from the root zone and maintain yields. The objectives of this study were to characterize the pattern of soil nitrate-N movement during irrigated potato production under defined management regimes and to develop diagnostic tools for quick and accurate prediction of the need for N by potato during the growing season. The results presented below are the second year of a two 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, 6.7; organic matter, 2.5%; phosphorus, 33 ppm; potassium, 106 ppm; sulfur, 4 ppm. Residual nitrate-N in the top 3 feet of soil was 20 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 27, 1992 at a spacing of 36" between rows and 10" within the row. Phosphate (0-46-0) and potash (0-0-60) fertilizer were applied in the band at planting at a rate of 80 lb P_2O_5/A and 200 lb K_2O/A to all plots. The fertilizer was banded 3" to each side and 2" below the tuber. Individual plot size consisted of six, 30 ft rows. The middle two rows (3 and 4) were harvest rows and rows 2 and 5 were sample rows. Ten treatments were tested to evaluate the effects of various N management practices on potato productivity, N use/uptake, soil nitrate movement, and petiole N status during the course of the season.

The 10 specific treatments were as follows:

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

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

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Nitrogen applied at planting was banded with the P and K fertilizer. Nitrogen applied at emergence (May 28) 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 treatment #9 were applied on June 25 and July 17. Applications were made by broadcasting ammonium nitrate over the plot by hand and then irrigating in. The June 25 application was based on a sap nitrate-N critical value of 1300 ppm. The July 16 application was based on a critical sap value of 900 ppm.

The experimental design was a randomized complete block with 4 replications. Rainfall was supplemented with overhead irrigation to supply water needs according to the checkbook method. Rainfall during the growing season totaled 21.5 inches and was supplemented with 8.6 inches of irrigation. The nitrate-N concentration in the irrigation water averaged 10 ppm. Given that 8.6 inches of irrigation were applied, approximately 20 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. NOTE: In contrast to the previous year, nitrate-N concentrations were accurately determined using nondiluted sap. The reason for inconsistent results using nondiluted sap in 1991 is believed to be due to a faulty membrane.

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 two days before harvest. Samples consisted of 3 cores from an individual plot taken to a depth of 3 feet at 1 foot increments. Two sets of samples at each depth were collected from each plot: one from between rows and the other within rows. All samples were brought back to the lab and air dried. Nitrate and ammonium were extracted with 2 N KCl using a 5 g to 25 ml soil:extractant ratio. 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. To calculate lbs nitrate-N/A, it was assumed that half the field was 'within row' and the other half 'between row'.

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

Three plants from the other sample row from each plot were harvested every two weeks starting one week before hilling. Samples were dried and weighed to determine dry weight accumulation through the season. Samples were ground and total N was determined using the salicylic Kjeldahl method. At harvest, vines were cut and weighed one week prior to harvest. Potatoes were mechanically harvested on September 15. Subsamples of vines and tubers were collected to determine dry matter and N accumulation using methods described above for the three plant samples.

RESULTS

Rainfall and Soil Nitrate Movement. Weekly precipitation over the course of the season is presented in Figure 1. Leaching events (> 2" irrigation + rainfall) only occurred once, at 68 days after planting. In contrast, five leaching events occurred in 1991, two of which occurred before hilling.

Seasonal nitrate-N concentrations in soil water extracted with the suction tubes at depths of 2.5' and 4.5' for each treatment are shown in Figures 2 to 11. Although nitrate-N in the soil water was measured, these numbers do not represent the concentration of nitrate in the ground water. Nor do they indicate the amount of nitrate lost to the ground water. The only way these data can be interpreted is in a more qualitative sense. That is, a higher peak for one treatment compared to another at a given time, indicates that losses of nitrate were relatively greater, but does not indicate how much greater. These data, therefore, can be used to determine which treatments minimized nitrate movement out of the root zone.

The control treatment, where no fertilizer N was applied, had higher than expected concentrations of nitrate-N (> 20 ppm) during the first 12 weeks of the growing season (Figure 2). Reasons for these high nitrate-N levels are unclear, but may have been due to some contamination of the samplers during installation.

Starter N fertilizer had dramatic effects on nitrate movement (Figures 3 to 6). The 80 and 120 lb N/A starter fertilizer rates had the highest concentrations of nitrate-N in the soil water between 12 and 18 weeks after planting compared to the other treatments. Delaying application of N to the emergence stage significantly reduced nitrate movement between 12 and 18 weeks after planting, even though the same total amount of N was applied. However, at the end of the season some nitrate-N was still moving downward regardless of starter N rate.

Slow release N fertilizer reduced nitrate movement compared to ammonium nitrate (Figures 7 vs. 8). The use of urea also reduced nitrate movement compared to ammonium nitrate (Figures 11 vs. 5). These results suggest that in terms of potential N losses, early applications of fertilizer N in the nitrate form should be avoided. Post-hilling applications of N resulted in slightly elevated nitrate-N levels at the end of the season (Figures 8 vs. 9). However, compared to treatments where higher rates of N applied up to hilling (240 lb N/A), N losses were less when post-hilling applications were used.
By the end of the season, nitrate-N was basically at background levels and differences among treatments were not detectable (Table 1).

Tuber Yield, Specific Gravity, and Vine Yield. The effects of the various N treatments on tuber yield, specific gravity, and vine yield are presented in Table 2. Total yield increased with N rate with most of the yield increase occurring between the control treatment and 120 lb N/A. The 7-14 oz tuber size increased significantly with N rate. Vine yield also increased with increasing N rate. Specific gravity of tubers from the control treatment was higher than in the those receiving N. Starter N had no significant effect on total tuber yield, but 7-14 oz tubers increased as starter rate decreased and the rate at emergence increased. Starter N had no effect on vine yield. Specific gravity increased with increasing starter N rates. At similar N rates and timing of application, there was little difference between urea and ammonium nitrate on vine and tuber yields. Specific gravity was similar for the urea and ammonium nitrate treatments when applied at equal rates. Total tuber yield with slow release N was lower than that obtained with an equivalent rate of ammonium nitrate. Specific gravity was higher with slow release, while vine yield was not affected. The post-hilling N application treatment resulted in 200 lb N/A (120 lb N/A before hilling and 80 lb N/A after hilling). This additional N after hilling increased tuber size (7-14 oz) and vine yield compared to the 120 lb N/A rate. However, tuber and vine yields were significantly lower in the post-hilling N treatment compared to those obtained in the 240 lb N/A rate applied in three equal applications up to hilling (treatment 4).

Tuber number per plant over the course of the season is presented in Table 3. Although some effects on tuber number per plant were detected during the season, no differences due to N management were detected by the time of harvest. Differences that were obtained were not consistent through the season. Because of small sample size (three plants per plot), variability was high and, therefore, these data should be interpreted with some caution.

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

Dry matter and N accumulation, as well as concentrations of N in vines and tubers at harvest, are presented in Table 4. As expected, dry weight and N accumulation increased with increasing N rate. The effect of starter N was not significant, indicating that losses of N due to early N application were minimal. Nitrogen accumulation tended to be greater in tubers when ammonium nitrate was used compared to urea or slow release nitrogen. Apparently, some immobilization of ammonium occurred during the season, since nitrate movement also tended to be lower in these treatments. The post-hilling treatment increased N accumulation in tubers, but had no effect on dry matter accumulation in vines or tubers. Reasons for lack of a response to post-hilling N are unclear, since higher rates of N applied up through hilling significantly increased N and dry matter accumulation. These results suggest that while efficiency of N use will be improved with post-hilling N applications, production may not necessarily be increased unless leaching rains occur early in the growing season.

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 the first sampling date, conventional analysis seemed to detect more subtle differences in nitrate status of the petiole compared to sap analysis. In all methods of analysis, differences due to N rate were apparent, particularly after the first sampling date. By the July 1 sampling date, differences due to starter N, N rate, N source and post-hilling N applications were apparent using all methods of analysis. Similar nitrate concentrations were obtained when the electrodes were used; however, the Wescan method gave slightly lower readings. At later sampling dates, the differences among the three methods for sap analysis were not as great.

Linear correlations between the sap nitrate analysis and conventional nitrate analysis are presented in Figures 22, 23, and 24. All R^2 values were above 0.890, indicating a strong relationship between sap analysis and conventional petiole analysis. Sap values can be inserted in the linear equation to determine whether nitrate-N levels are in an adequate range as predicted from conventional analysis. Both sap and conventional analysis predicted N applications when 120 lb N/A was applied up to hilling. An increase in 7-14 oz potatoes resulted from this application of N; however, yields were still not as great as when all the N was applied up to hilling. While the sap test does seem to be useful for determining N status of the plant, use of the technique to predict post-hilling N requirements still requires additional research.

SUMMARY

The 1992 season at Becker was one where leaching losses of N were minimal. Nitrogen source, rate, and management significantly affected nitrate losses under irrigated potatoes. Greatest losses were observed when N was applied early (before emergence), although some nitrate was still moving downward at the end of the season from the top 5 feet of soil. Use of urea and slow release N minimized N losses compared to ammonium nitrate. Post-hilling applications of N also reduced N losses compared to similar rates of N applied before hilling. Potato yield was primarily affected by N rate. The greatest yield increase was obtained between the 0 and 120 lb N/A increment. Petiole sap nitrate tests using portable nitrate electrodes appear to have promise for determining N status of the crop; however, using the N status to predict N needs will require additional 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. Assumes half the field was in-row and the other half was between-row. Becker, MN.

	Treatment		In-row	Between-row	Field total
	N source	N timing	Pounds per acre		
1.	Control	(0 N/A)	5.51 ± 1.23	6.32 ± 1.42	11.83 ± 2.41
2.	(34-0-0)	(0,120,120)[1]	9.81 ± 4.53	9.54 ± 3.76	19.35 ± 4.97
3.	(34-0-0)	(40,100,100)	14.03 ± 12.25	8.60 ± 1.27	22.62 ± 11.82
4.	(34-0-0)	(80,80,80)	10.97 ± 4.58	11.08 ± 3.07	22.05 ± 4.53
5.	(34-0-0)	(120,60,60)	8.67 ± 4.47	8.84 ± 2.89	17.51 ± 7.11
6.	(34-0-0)	(80,80,0)	9.53 ± 1.17	7.70 ± 1.40	17.22 ± 1.76
7.	SR[2]	(80,80,0)	7.66 ± 1.13	10.91 ± 4.85	18.57 ± 5.33
8.	(34-0-0)	(40,40,40)	9.44 ± 1.44	7.67 ± 0.46	17.10 ± 1.88
9.	(34-0-0)	(40,40,40,40+40)[3]	8.06 ± 1.48	7.31 ± 1.06	15.36 ± 2.33
10.	(46-0-0)	(80,80,80)	11.55 ± 3.71	7.84 ± 0.73	19.39 ± 3.29

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

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

Treatment			Fresh weight							Specific
	N source	N timing	Vines	Knobs	<3 oz	3-7 oz	7-14 oz	>14 oz	Total	Gravity
			Tons/A	cwt/A						
1.	Control	(0 N/A)	0.71	3.8	59.4	214.1	26.1	0.0	303.5	1.0967
2.	(34-0-0)	(0,120,120)[1]	5.65	30.4	33.9	231.3	270.1	36.1	601.8	1.0883
3.	(34-0-0)	(40,100,100)	4.46	16.9	46.5	249.5	221.3	33.8	568.0	1.0879
4.	(34-0-0)	(80,80,80)	5.11	30.7	53.1	281.8	222.9	12.1	600.5	1.0901
5.	(34-0-0)	(120,60,60)	4.93	29.0	49.1	268.0	199.0	13.7	558.8	1.0877
6.	(34-0-0)	(80,80,0)	2.97	19.8	53.9	294.0	156.1	5.4	529.2	1.0879
7.	SR[2]	(80,80,0)	1.74	24.9	46.0	286.7	132.9	0.8	491.3	1.0908
8.	(34-0-0)	(40,40,40)	1.83	32.0	57.9	266.8	158.4	2.8	517.9	1.0907
9.	(34-0-0)	(40,40,40,40+40)[3]	3.51	28.9	57.9	246.0	195.0	13.9	541.7	1.0893
10.	(46-0-0)	(80,80,80)	4.99	36.4	41.0	238.8	232.7	18.3	567.2	1.0877
Significance			**	**	**	**	**	++	**	**
BLSD (0.05)			1.80	15.1	11.9	30.8	40.6	33.0	33.9	0.0023
Contrasts										
Lin Starter N (2, 3, 4, 5)			NS	NS	**	**	**	*	NS	NS
Quad Starter N (2, 3, 4, 5)			NS	NS	*	NS	NS	NS	NS	NS
Lin Rate N (1, 8, 4)			**	**	NS	**	**	NS	**	**
Quad Rate N (1, 8, 4)			NS	*	NS	NS	++	NS	**	*
Treatment 4 vs 10			NS	NS	*	**	NS	NS	++	++
Treatment 6 vs 7			NS	NS	NS	NS	NS	NS	*	*
Treatment 8 vs 9			++	NS	NS	NS	++	NS	NS	NS
Treatment 4 vs 7			**	NS	NS	NS	**	NS	**	NS
Treatment 4 vs 9			++	NS	NS	*	NS	NS	**	NS

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

Table 3. Effect of nitrogen treatments on the number of tubers per plant. Becker, MN.

Treatment			Date				
	N source	N timing	June 10	June 25	July 17	Aug. 5	Aug. 26
			Number of tubers per plant				
1.	Control	(0 N/A)	2.58	9.92	7.17	7.58	9.33
2.	(34-0-0)	(0,120,120)[1]	0.83	8.67	10.17	10.08	9.42
3.	(34-0-0)	(40,100,100)	2.08	10.92	13.50	11.67	8.50
4.	(34-0-0)	(80,80,80)	2.58	9.42	10.00	10.33	9.92
5.	(34-0-0)	(120,60,60)	1.58	8.83	13.08	9.50	10.75
6.	(34-0-0)	(80,80,0)	2.92	8.25	10.33	13.50	10.08
7.	SR[2]	(80,80,0)	3.33	12.00	10.17	10.08	9.33
8.	(34-0-0)	(40,40,40)	1.75	10.00	13.33	12.50	8.83
9.	(34-0-0)	(40,40,40,40+40)[3]	1.42	10.33	12.50	9.92	9.58
10.	(46-0-0)	(80,80,80)	0.75	10.42	9.75	9.75	10.17
Significance			NS	NS	NS	**	NS
BLSD (0.05)			--	--	--	2.74	--
Contrasts							
Lin Starter N (2, 3, 4, 5)			NS	NS	NS	NS	NS
Quad Starter N (2, 3, 4, 5)			NS	NS	NS	NS	NS
Lin Rate N (1, 8, 4)			NS	NS	NS	*	NS
Quad Rate N (1, 8, 4)			NS	NS	*	**	NS
Treatment 4 vs 10			NS	NS	NS	NS	NS
Treatment 6 vs 7			NS	*	NS	**	NS
Treatment 8 vs 9			NS	NS	NS	*	NS
Treatment 4 vs 7			NS	NS	NS	NS	NS
Treatment 4 vs 9			NS	NS	NS	NS	NS

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

Table 4. Effect of nitrogen on N content and dry matter production. Becker, MN

Treatment			Nitrogen content			N concentration		Dry matter		
	N source	N timing	Vines	Tubers	Total	Vine	Tubers	Vines	Tubers	Total
			lbs/A			% N		Tons/A		
1.	Control	(0 N/A)	9.0	64.8	75.3	1.63	0.92	0.24	3.54	3.78
2.	(34-0-0)	(0,120,120)[1]	22.6	183.9	209.1	1.65	1.40	0.69	6.58	7.27
3.	(34-0-0)	(40,100,100)	19.7	181.0	203.2	1.41	1.45	0.69	6.25	6.94
4.	(34-0-0)	(80,80,80)	24.0	195.8	223.2	1.58	1.53	0.72	6.42	7.14
5.	(34-0-0)	(120,60,60)	23.3	185.3	211.4	1.44	1.46	0.79	6.34	7.13
6.	(34-0-0)	(80,80,0)	12.8	157.1	172.2	1.10	1.37	0.58	5.76	6.34
7.	SR[2]	(80,80,0)	12.8	125.8	140.5	1.06	1.14	0.59	5.54	6.12
8.	(34-0-0)	(40,40,40)	11.8	148.3	162.0	1.11	1.30	0.52	5.72	6.24
9.	(34-0-0)	(40,40,40,40+40)[3]	16.1	179.6	198.0	1.64	1.51	0.50	5.97	6.47
10.	(46-0-0)	(80,80,80)	22.6	177.1	203.6	1.55	1.45	0.70	6.14	6.84
Significance			**	**	**	*	**	**	**	**
BLSD (0.05)			7.9	17.9	19.6	0.52	0.16	0.18	0.48	0.49
Contrasts										
Lin Starter N (2, 3, 4, 5)			NS	NS	NS	NS	NS	NS	NS	NS
Quad Starter N (2, 3, 4, 5)			NS	NS	NS	NS	NS	NS	NS	NS
Lin Rate N (1, 8, 4)			**	**	**	NS	**	**	**	**
Quad Rate N (1, 8, 4)			NS	*	NS	*	NS	NS	**	**
Treatment 4 vs 10			NS	++	++	NS	NS	NS	NS	NS
Treatment 6 vs 7			NS	**	**	NS	*	NS	NS	NS
Treatment 8 vs 9			NS	**	**	*	*	NS	NS	NS
Treatment 4 vs 7			**	**	**	*	**	NS	**	**
Treatment 4 vs 9			*	NS	*	NS	NS	*	++	*

[1] = Planting, emergence and hilling respectively. [2] = Slow release fertilizer. [3] = Two post-hilling applications, 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 9				June 23			
	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)	6559	463	402	454	261	89	60	45
2.	(34-0-0)	(0,120,120)[1]	17513	1005	918	981	18912	1438	1380	1294
3.	(34-0-0)	(40,100,100)	20534	1375	1265	1278	19565	1300	1267	1244
4.	(34-0-0)	(80,80,80)	22306	1375	1354	1349	18748	1275	1235	1164
5.	(34-0-0)	(120,60,60)	23290	1450	1380	1454	18817	1350	1230	1261
6.	(34-0-0)	(80,80,0)	22207	1338	1289	1308	18248	1200	1135	1105
7.	SR[2]	(80,80,0)	20474	1313	1219	1243	13571	944	834	834
8.	(34-0-0)	(40,40,40)	20405	1288	1191	1217	16651	1061	1130	1097
9.	(34-0-0)	(40,40,40,40+40)[3]	20599	1325	1209	1275	18162	1163	1171	1073
10.	(46-0-0)	(80,80,80)	20068	1275	1168	1250	20211	1375	1282	1281
Significance			**	**	**	**	**	**	**	**
BLSD (0.05)			1396	110	146	143	1281	109	116	95
Contrasts										
Lin Starter N (2, 3, 4, 5)			**	**	**	**	NS	NS	*	NS
Quad Starter N (2, 3, 4, 5)			++	**	**	++	NS	*	NS	++
Lin Rate N (1, 8, 4)			**	**	**	**	**	**	**	**
Quad Rate N (1, 8, 4)			**	**	**	**	**	**	**	**
Treatment 4 vs 10			**	NS	*	NS	*	NS	NS	*
Treatment 6 vs 7			*	NS	NS	NS	**	**	**	**
Treatment 8 vs 9			NS	NS	NS	NS	*	++	NS	NS
Treatment 4 vs 7			*	NS	++	NS	**	**	**	**
Treatment 4 vs 9			*	NS	++	NS	NS	++	NS	++

[1] = Planting, emergence and hilling respectively. [2] = Slow release fertilizer. [3] = Two post-hilling applications 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 7				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)	24	75	44	10	34	69	54	8
2.	(34-0-0)	(0,120,120)[1]	19482	1438	1433	1480	13782	1238	1210	1193
3.	(34-0-0)	(40,100,100)	17879	1388	1368	1452	10196	1073	1006	986
4.	(34-0-0)	(80,80,80)	15901	1225	1160	1198	9460	919	820	783
5.	(34-0-0)	(120,60,60)	16315	1275	1271	1269	8821	793	689	669
6.	(34-0-0)	(80,80,0)	10146	822	792	810	4468	444	377	354
7.	SR[2]	(80,80,0)	1505	221	187	178	373	93	75	26
8.	(34-0-0)	(40,40,40)	6130	628	596	601	1260	224	193	154
9.	(34-0-0)	(40,40,40,40+40)[3]	11520	949	968	950	7664	784	732	710
10.	(46-0-0)	(80,80,80)	16805	1350	1215	1345	11142	1040	929	920
Significance			**	**	**	**	**	**	**	**
BLSD (0.05)			2028	125	124	146	2222	161	151	155
Contrasts										
Lin Starter N (2, 3, 4, 5)			**	**	**	**	**	**	**	**
Quad Starter N (2, 3, 4, 5)			NS	NS	++	NS	++	NS	NS	NS
Lin Rate N (1, 8, 4)			**	**	**	**	**	**	**	**
Quad Rate N (1, 8, 4)			++	NS	NS	NS	**	**	**	**
Treatment 4 vs 10			NS	++	NS	++	NS	NS	NS	NS
Treatment 6 vs 7			**	**	**	**	**	**	**	**
Treatment 8 vs 9			**	**	**	**	**	**	**	**
Treatment 4 vs 7			**	**	**	**	**	**	**	**
Treatment 4 vs 9			**	**	**	**	NS	NS	NS	NS

[1] = Planting, emergence and hilling respectively. [2] = Slow release fertilizer. [3] = Two post-hilling applications, 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			
	N source	N timing	dry weight Petiole-N	sap Horiba	sap Hach	sap Wescan
			ppm NO_3-N			
1.	Control	(0 N/A)	30	103	49	5
2.	(34-0-0)	(0,120,120)[1]	8074	878	907	846
3.	(34-0-0)	(40,100,100)	4515	489	474	422
4.	(34-0-0)	(80,80,80)	3693	433	403	347
5.	(34-0-0)	(120,60,60)	3105	386	358	307
6.	(34-0-0)	(80,80,0)	966	189	140	91
7.	SR[2]	(80,80,0)	79	119	57	18
8.	(34-0-0)	(40,40,40)	445	163	125	74
9.	(34-0-0)	(40,40,40,40+40)[3]	11657	1040	1159	1094
10.	(46-0-0)	(80,80,80)	6207	583	597	538
Significance			**	**	**	**
BLSD (0.05)			1758	127	135	127
Contrasts						
Lin Starter N (2, 3, 4, 5)			**	**	**	**
Quad Starter N (2, 3, 4, 5)			*	**	**	**
Lin Rate N (1, 8, 4)			**	**	**	**
Quad Rate N (1, 8, 4)			++	++	NS	++
Treatment 4 vs 10			*	*	*	**
Treatment 6 vs 7			NS	NS	NS	NS
Treatment 8 vs 9			**	**	**	**
Treatment 4 vs 7			**	**	**	**
Treatment 4 vs 9			**	**	**	**

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

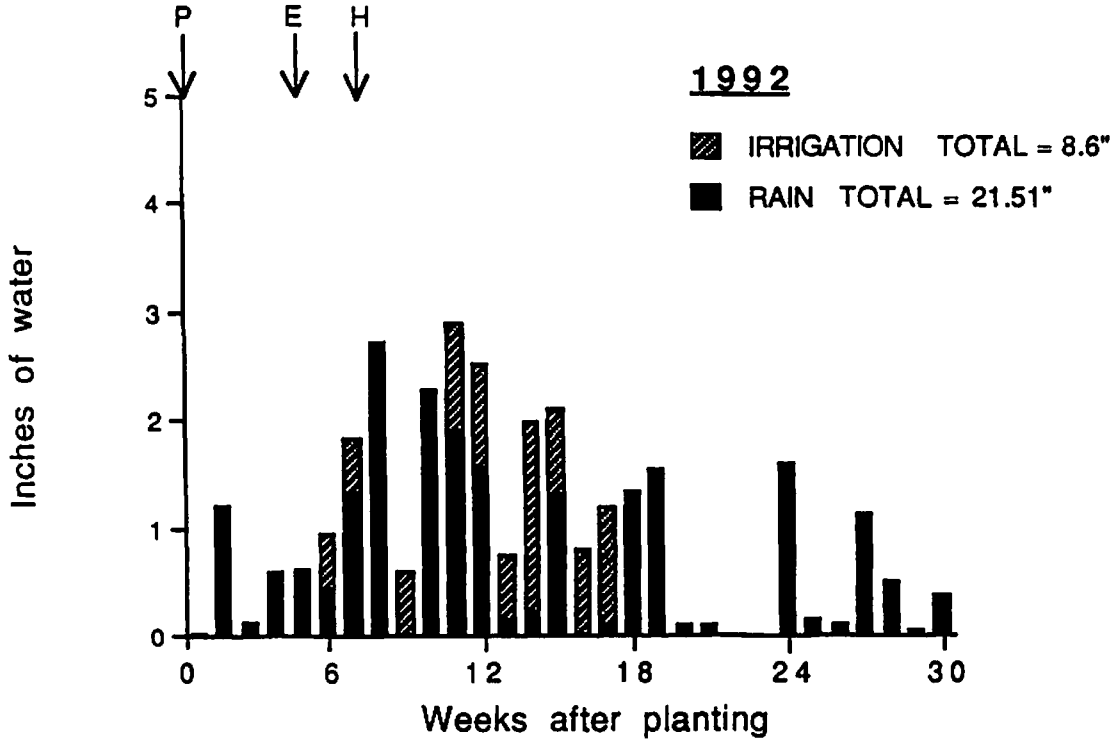

Figure 1. Rainfall and irrigation at Becker, MN during the 1992 growing season. P, E and H = planting, emergence and hilling, respectively.

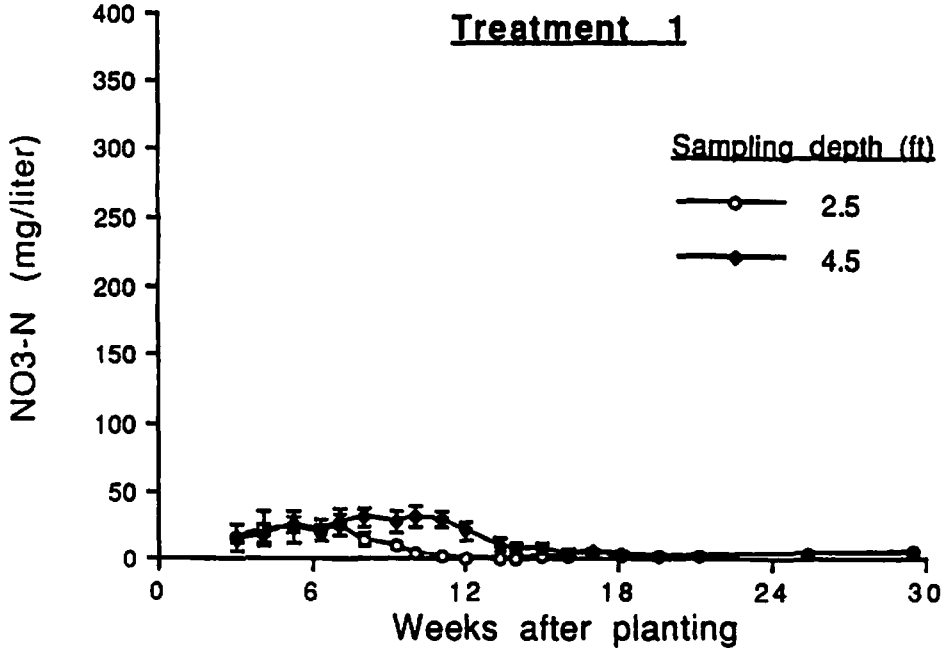

Figure 2. Nitrate - N concentration in soil water at two depths over the 1992 growing season. Nitrogen application rate: no nitrogen. Error bars represent SE of the mean.

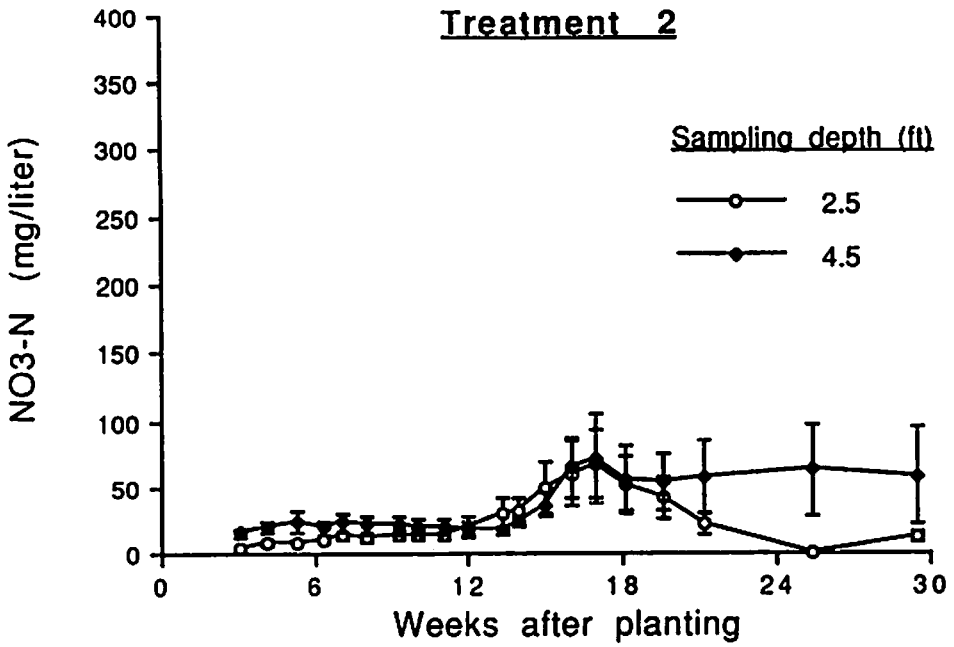

Figure 3. Nitrate - N concentration in soil water at two depths over the 1992 growing season. Nitrogen application rate: 120 lb N/A at emergence and hilling (34-0-0). Error bars represent SE of the mean.

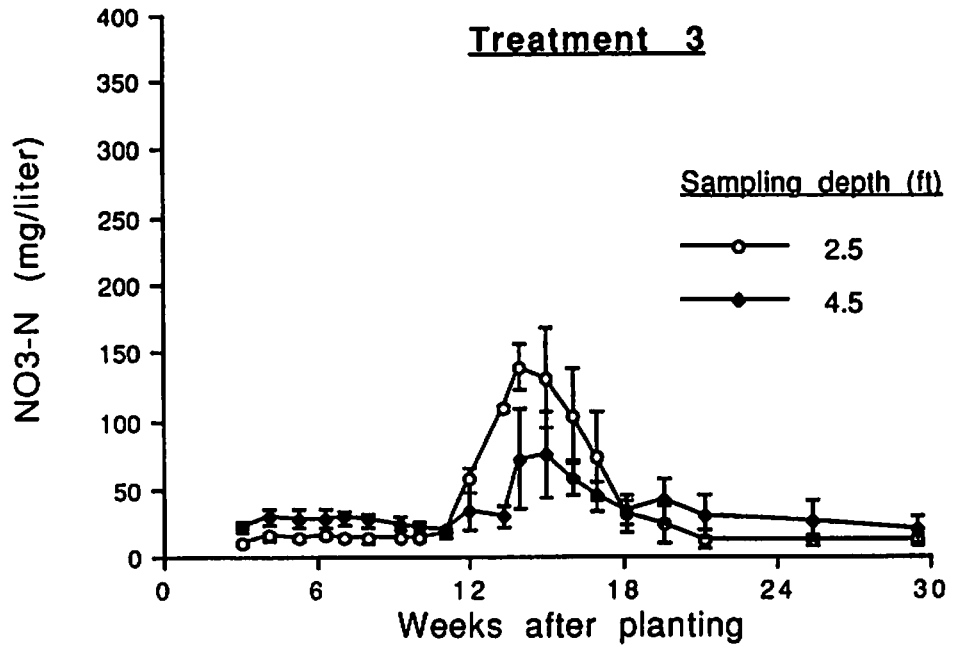

Figure 4. Nitrate - N concentration in soil water at two depths over the 1992 growing season. Nitrogen application rate: 40 lb N/A at planting, 100 lb at emergence and hilling (34-0-0). Error bars represent SE of the mean.

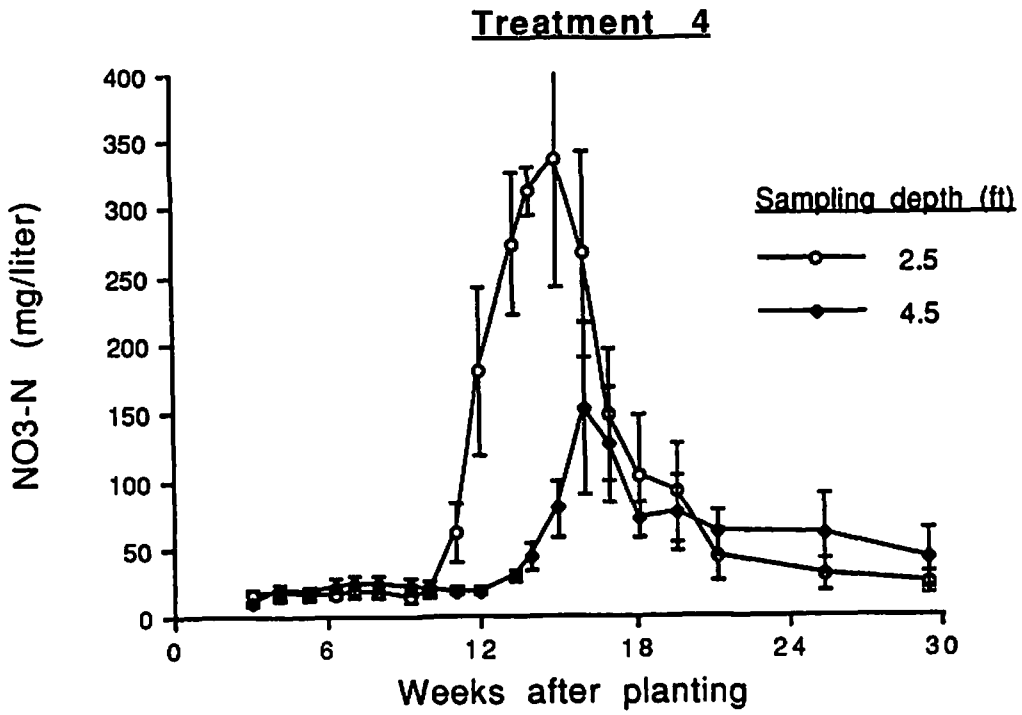

Figure 5. Nitrate - N concentration in soil water at two depths over the 1992 growing season. Nitrogen application rate: 80 lb N/A at planting, emergence and hilling (34-0-0). Error bars represent SE of the mean.

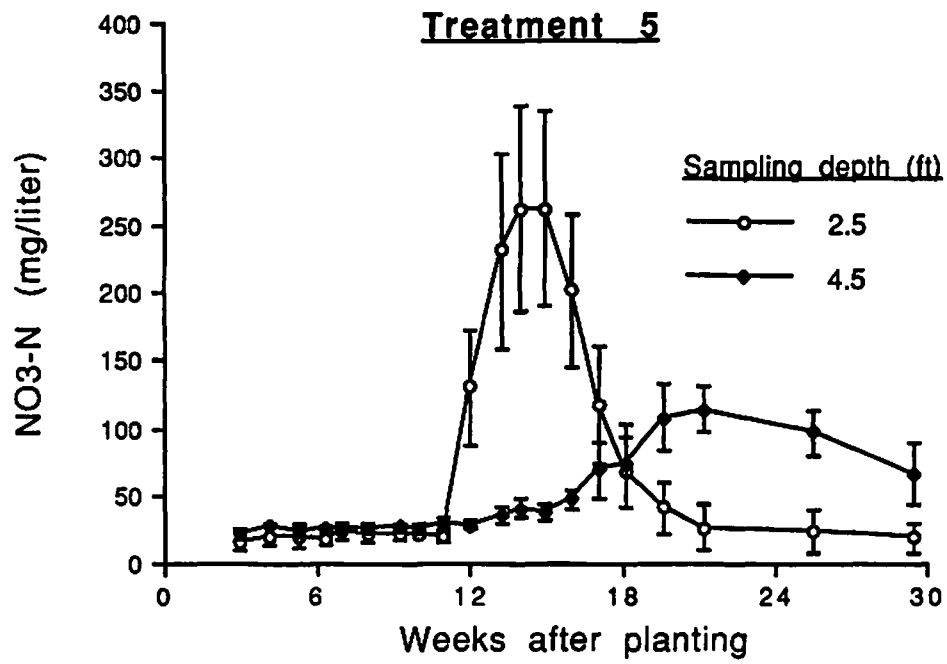

Figure 6. Nitrate - N concentration in soil water at two depths over the 1992 growing season. Nitrogen application rate: 120 lb N/A at planting, 60 lb at emergence and hilling (34-0-0). Error bars represent SE of the mean.

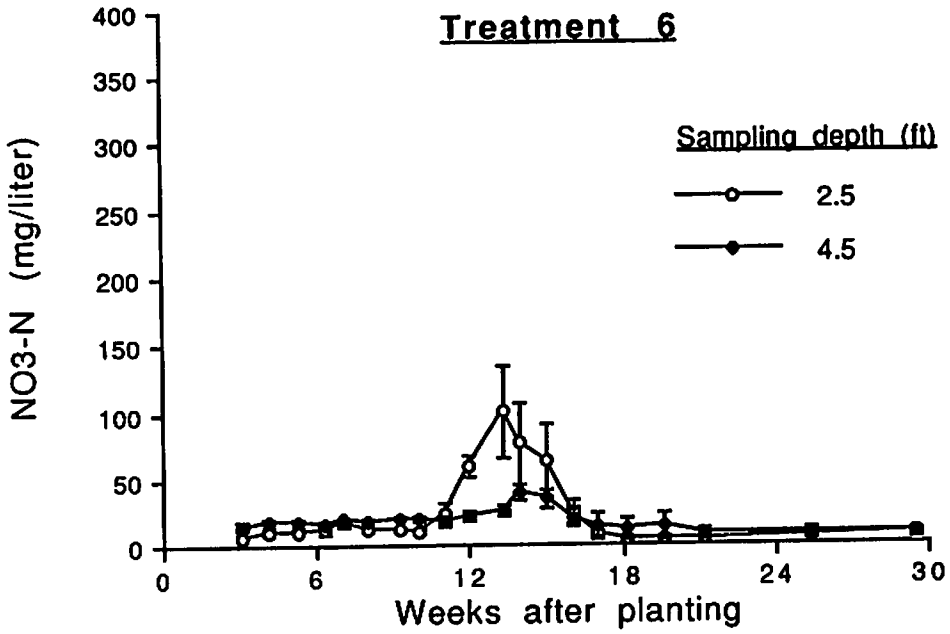

Figure 7. Nitrate - N concentration in soil water at two depths over the 1992 growing season. Nitrogen application rate: 80 lb N/A at planting and emergence (34-0-0). Error bars represent SE of the mean.

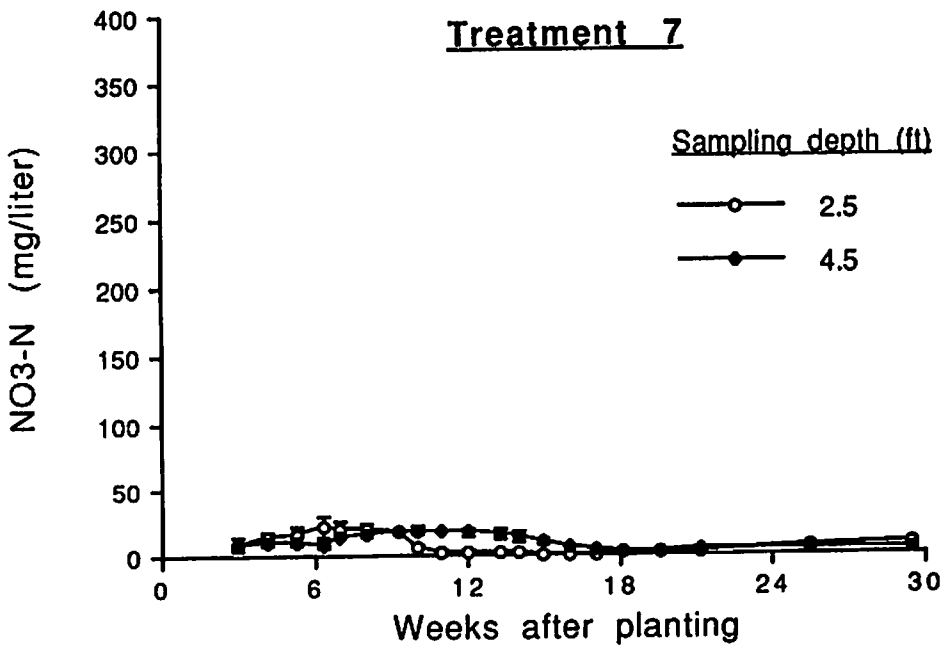

Figure 8. Nitrate - N concentration in soil water at two depths over the 1992 growing season. Nitrogen application rate: 80 lb N/A at planting and emergence (slow release). Error bars represent SE of the mean.

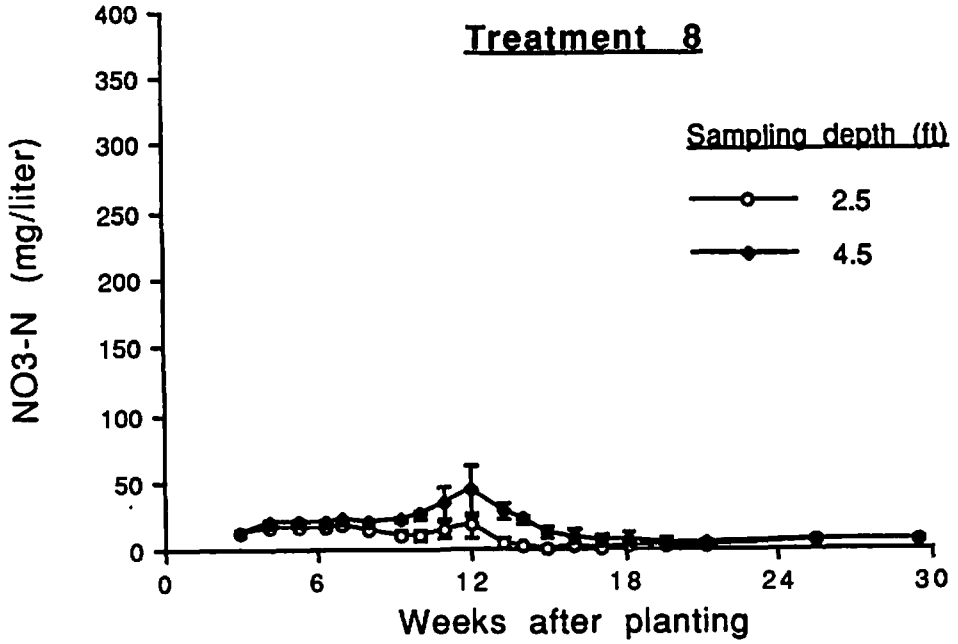

Figure 9. Nitrate - N concentration in soil water at two depths over the 1992 growing season. Nitrogen application rate: 40 lb N/A at planting, emergence and hilling (34-0-0). Error bars represent SE of the mean.

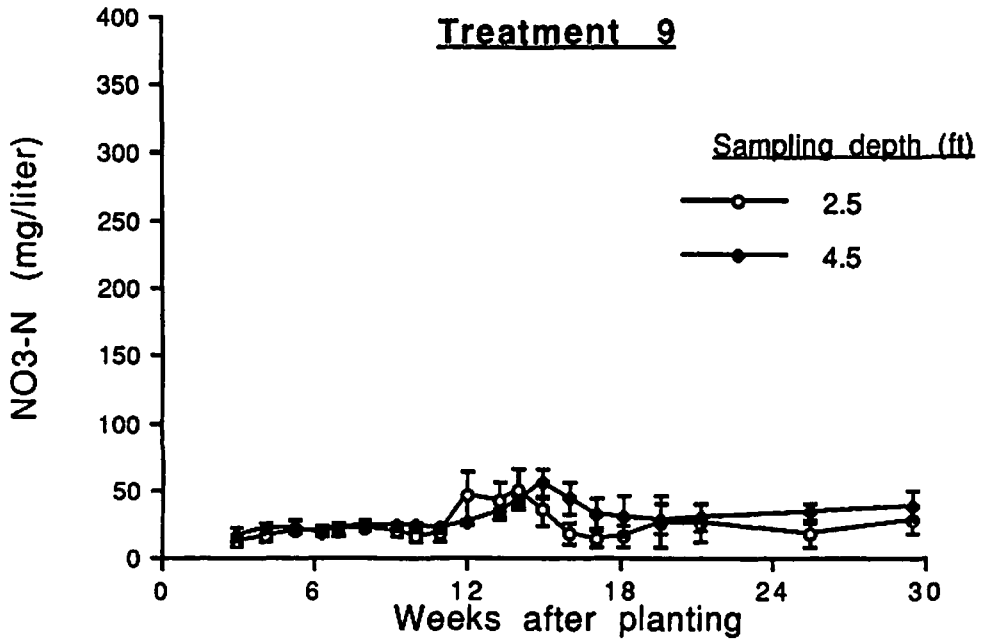

Figure 10. Nitrate - N concentration in soil water at two depths over the 1992 growing season. Nitrogen application rate: 40 lb N/A at planting,emergence, hilling and two post-hillings (34-0-0). Error bars represent SE of the mean.

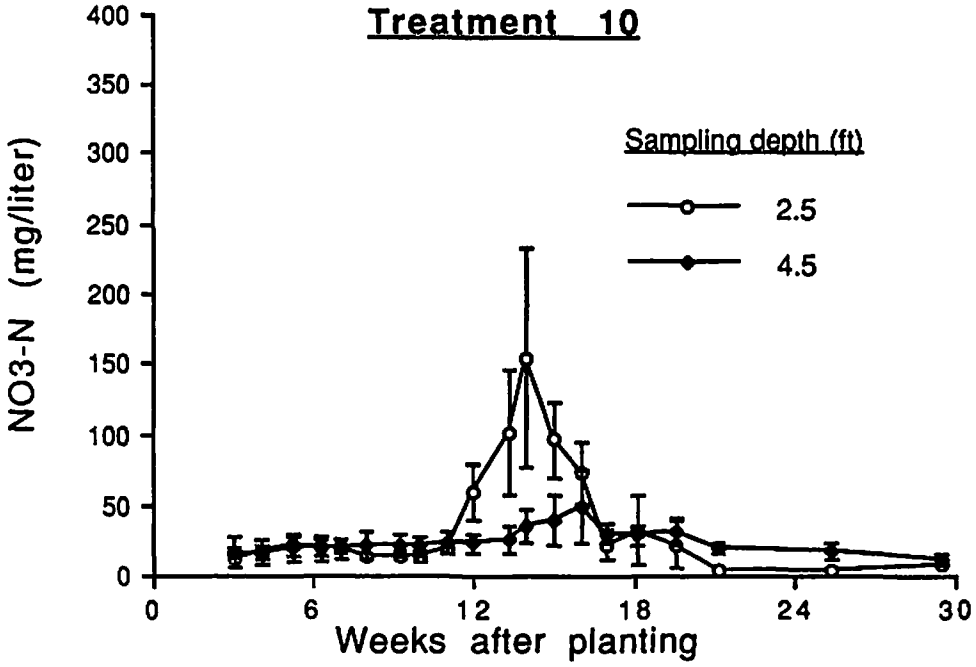

Figure 11. Nitrate - N concentration in soil water at two depths over the 1992 growing season. Nitrogen application rate: 80 lb N/A at planting, emergence and hilling (46-0-0). Error bars represent SE of the mean.

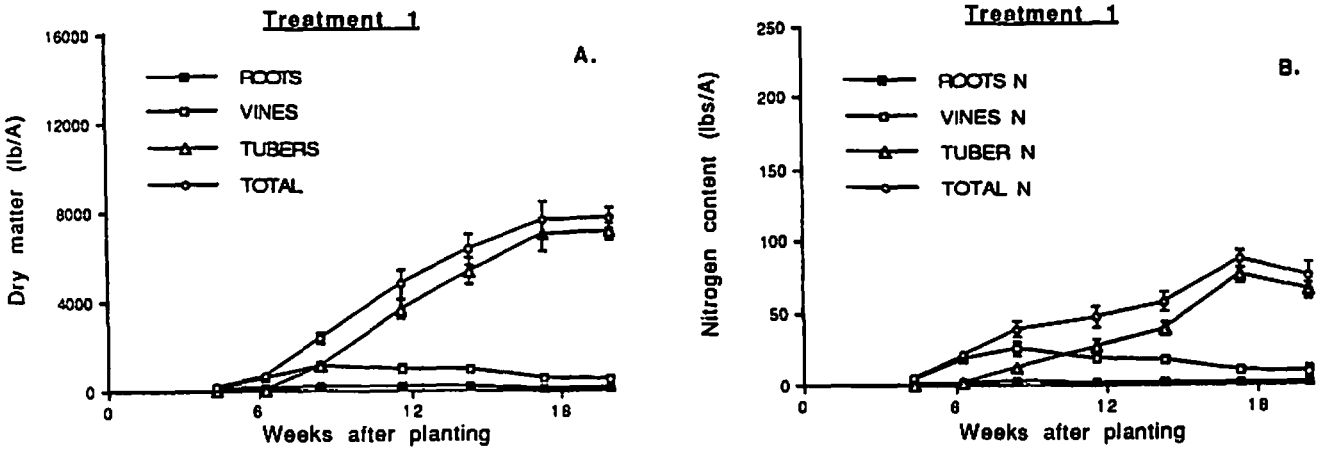

Figure 12. Dry matter (A) and nitrogen accumulation (B) in potato roots, vines and tubers during the 1992 growing season. Nitrogen application rate: no nitrogen.

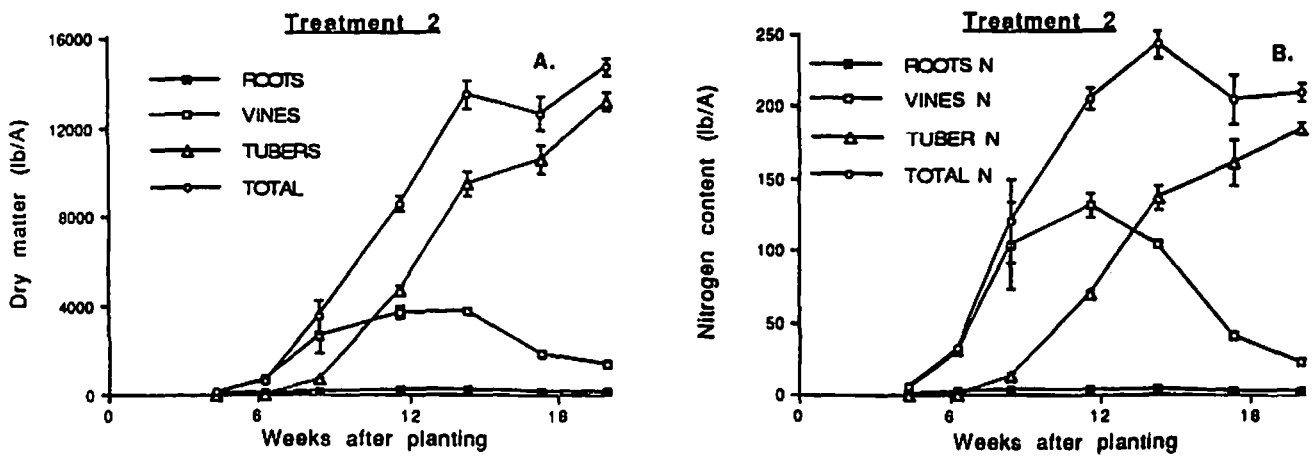

Figure 13. Dry matter (A) and nitrogen accumulation (B) in potato roots, vines and tubers during the 1992 growing season. Nitrogen application rate: 120 lb N/A at emergence and hilling (34-0-0).

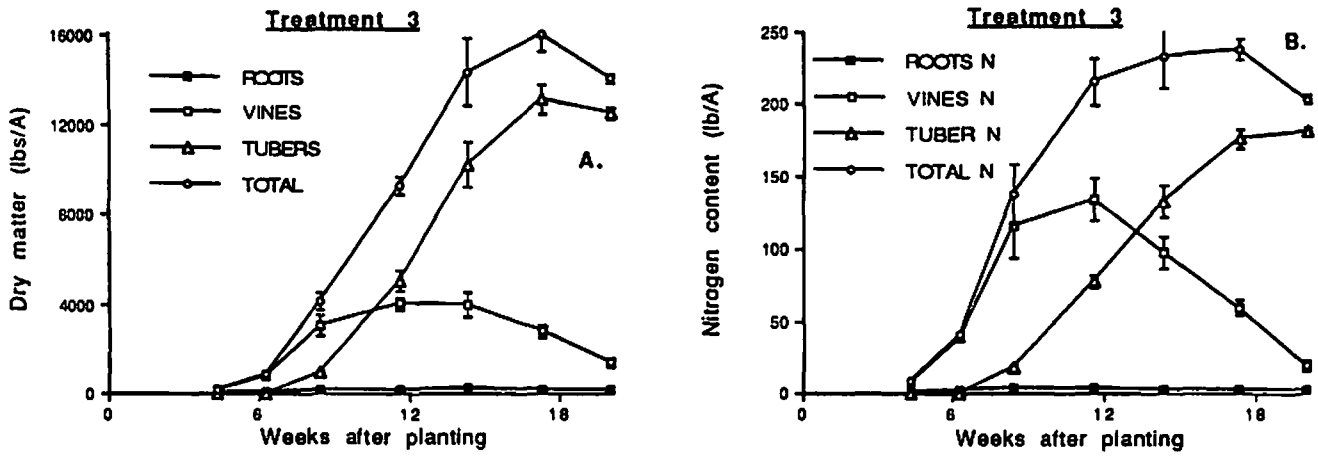

Figure 14. Dry matter (A) and nitrogen accumulation (B) in potato roots, vines and tubers during the 1992 growing season. Nitrogen application rate: 40 lb N/A at planting, 100 lb at emergence and hilling (34-0-0).

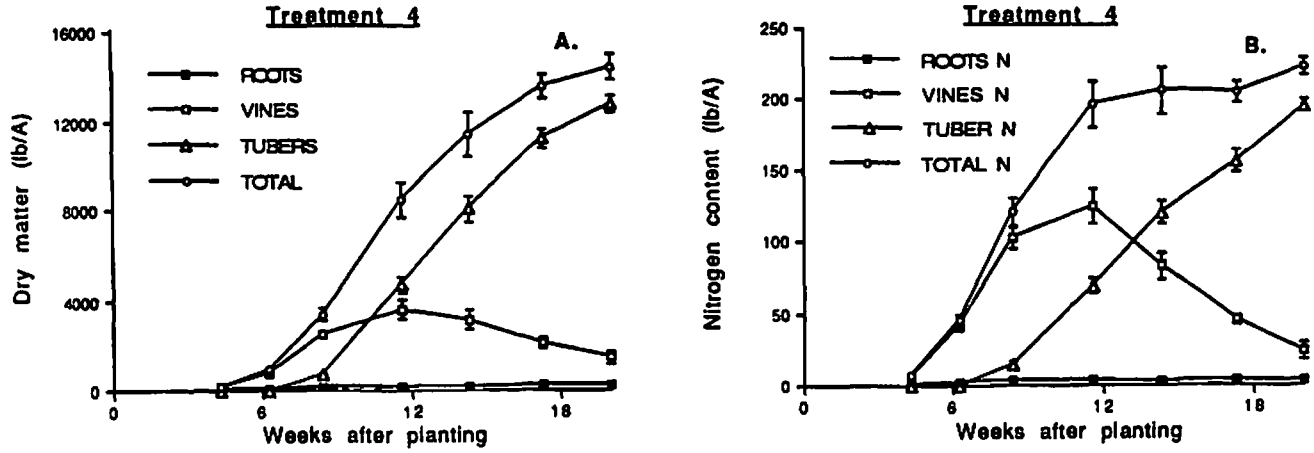

Figure 15. Dry matter (A) and nitrogen accumulation (B) in potato roots, vines and tubers during the 1992 growing season. Nitrogen application rate: 80 lb N/A at planting, emergence and hilling (34-0-0).

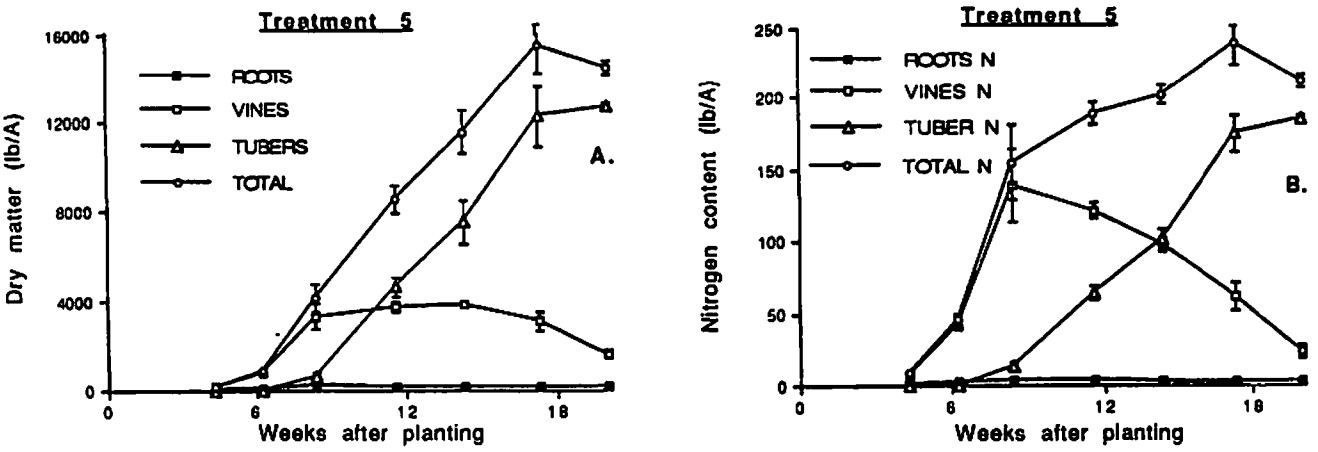

Figure 16. Dry matter (A) and nitrogen accumulation (B) in potato roots, vines and tubers during the 1992 growing season. Nitrogen application rate: 120 lb N/A at planting, 60 lb at emergence and hilling (34-0-0).

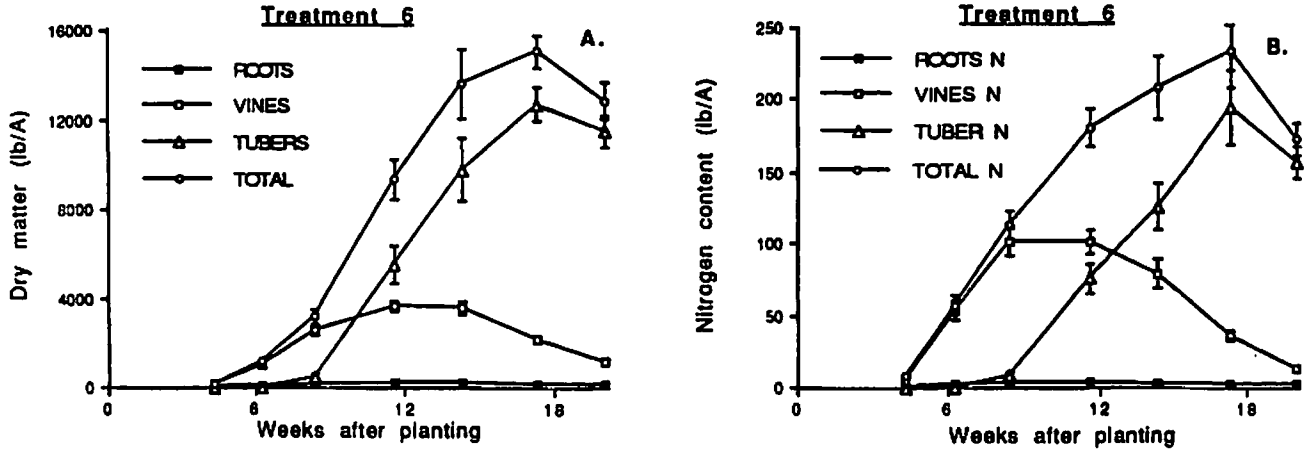

Figure 17. Dry matter (A) and nitrogen accumulation (B) in potato roots, vines and tubers during the 1992 growing season. Nitrogen application rate: 80 lb N/A at planting and emergence (34-0-0).

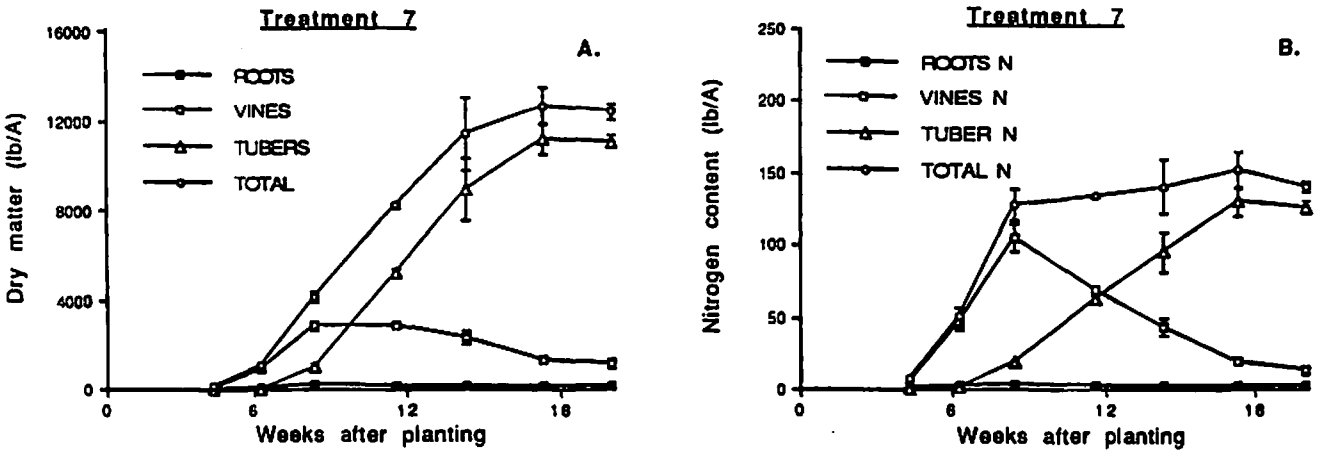

Figure 18. Dry matter (A) and nitrogen accumulation (B) in potato roots, vines and tubers during the 1992 growing season. Nitrogen application rate: 80 lb N/A at planting and emergence (slow release).

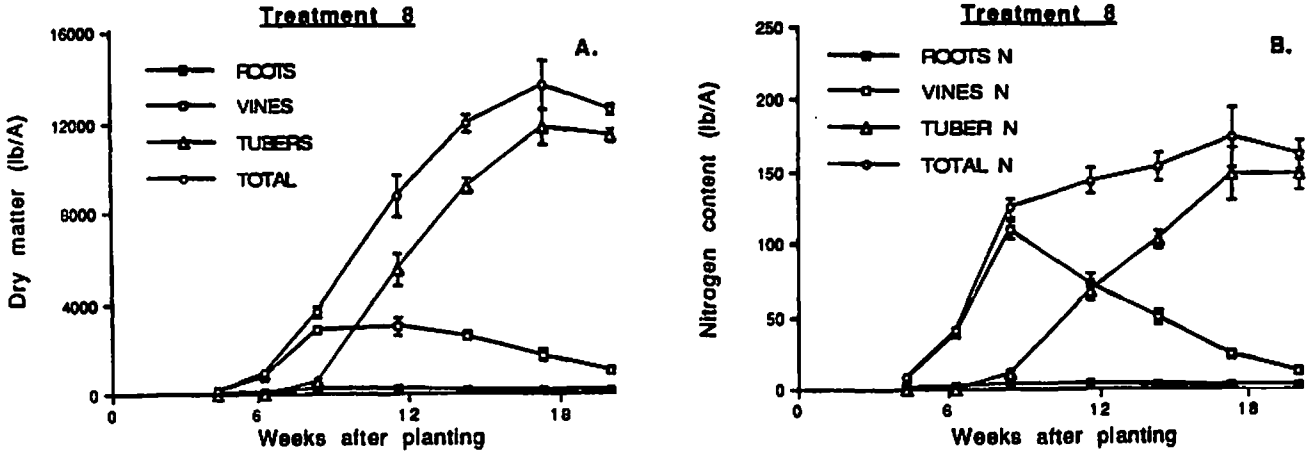

Figure 19. Dry matter (A) and nitrogen accumulation (B) in potato roots, vines and tubers during the 1992 growing season. Nitrogen application rate: 40 lb N/A at planting, emergence and hilling (34-0-0).

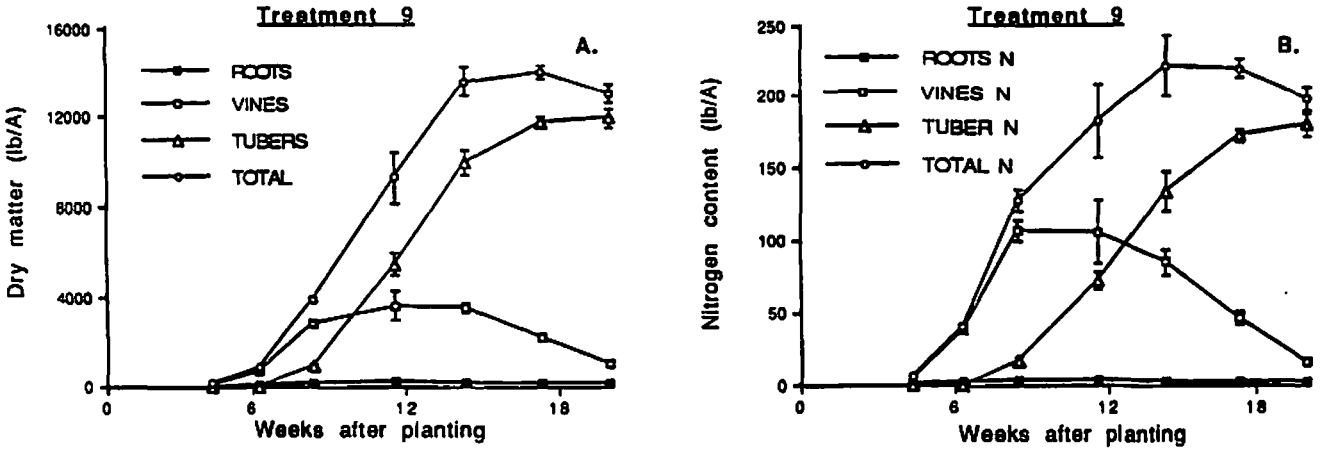

Figure 20. Dry matter (A) and nitrogen accumulation (B) in potato roots, vines and tubers during the 1992 growing season. Nitrogen application rate: 40 lb N/A at planting, emergence hilling and two post-hillings (34-0-0).

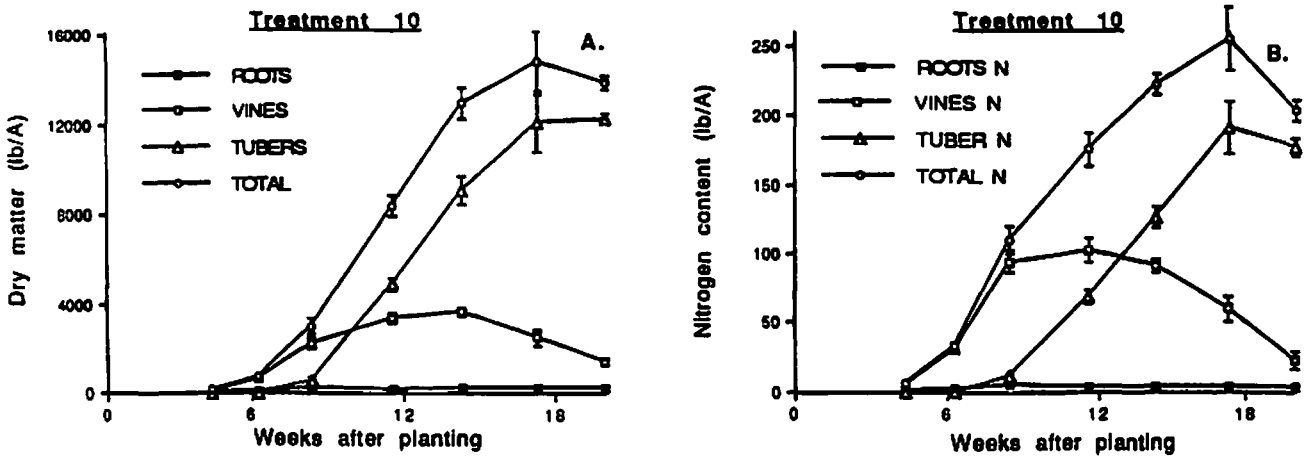

Figure 21. Dry matter (A) and nitrogen accumulation (B) in potato roots, vines and tubers during the 1992 growing season. Nitrogen application rate: 80 lb N/A at planting, emergence and hilling (46-0-0).

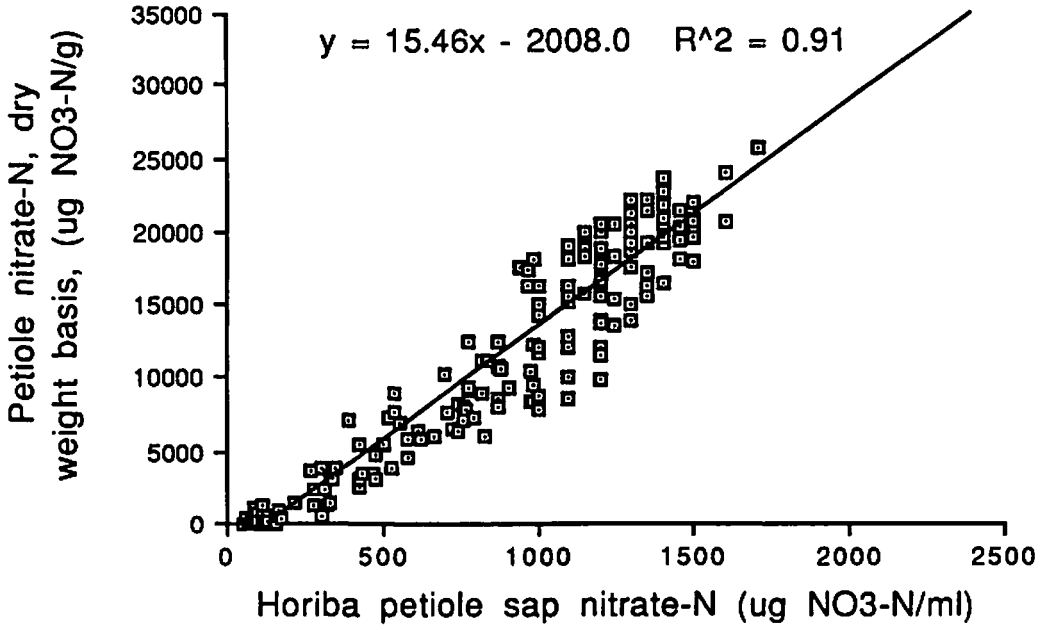

Figure 22. Correlation of petiole nitrate-N (dry weight basis) with petiole sap nitrate-N measured by Horiba electrode.

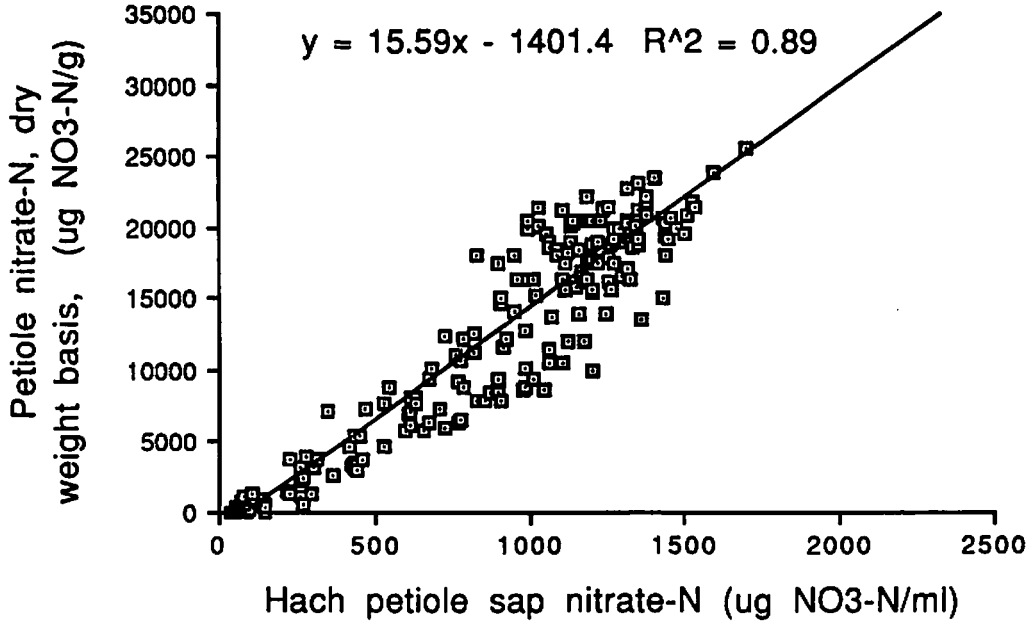

Figure 23. Correlation of petiole nitrate-N (dry weight basis) with petiole sap nitrate-N measured by Hach electrode.

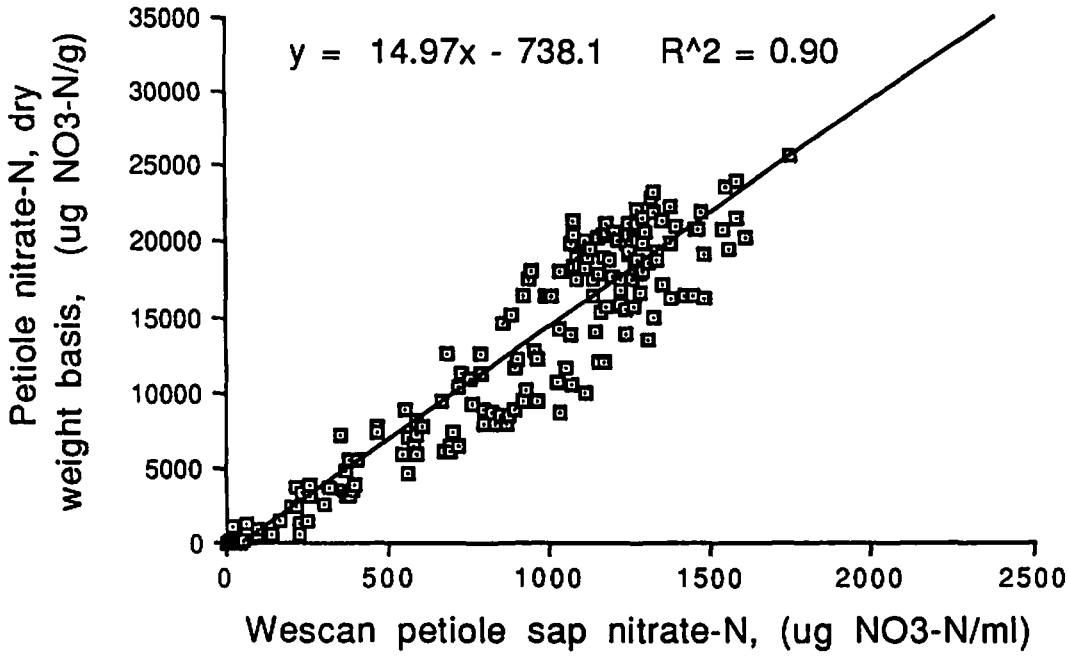

Figure 24. Correlation of petiole nitrate-N (dry weight basis) with petiole sap nitrate-N measured by Wescan electrode.

PHOSPHORUS REQUIREMENTS FOR IRRIGATED POTATOES - 1992

Carl Rosen, Dave Birong, and Glenn Titrud

ABSTRACT: Response of irrigated potatoes to phosphate fertilizer on low and high P testing sites was evaluated. Total and marketable yield increased with phosphate fertilizer application in both sites with most of the increase coming from increases in the 7-14 oz potatoes. The major response to phosphate fertilizer occurred between the 0 to 50 lb P_2O_5 application rate; however, economic increases were still recorded with applications of 150-250 lb P_2O_5/A. The cool season of 1992 may have played a role in these phosphate fertilizer responses. 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, magnesium, and zinc, but decrease tissue copper and boron.

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 irrigated potatoes to phosphate fertilizer on both high and low P testing soils. The results presented here are from the third year of a four year study.

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
Soil pH (1:1 - soil:water)	5.5	6.1
Bray P1	60 ppm	22 ppm
K - NH4OAc	200 ppm	168 ppm

Prior to planting, 250 lb sul-po-mag and 100 lb K_2O (as 0-0-60) were broadcast and incorporated at both sites. Russet Burbank "B" size potatoes were planted on April 23, 1992 at a spacing of 36" between rows and 10" within the row. Each plot consisted of six, 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 80 lb N/A at emergence (May 28) and 80 lb N/A at hilling (June 10). 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 July 1. 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 (five plants per plot) were also collected on June 26 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.

RESULTS

Dry weight of 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 vines, but not roots or tubers. 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. Dry weight of tubers and number of tubers also tended to increase with phosphate fertilizer, although some inconsistency occurred at the higher rates.

[1]We thank the Area II potato growers for providing funds to support this project.
[2]Ext. Soil Scientist and Jr. Scientist, respectively, Dept. of Soil Sci.; Director, Sand Plain Research Farm.

Tuber yield and size distribution are presented in Tables 3 and 4. For the low and high P testing sites, phosphate fertilizer tended to increase total tuber yield, primarily due to an increase in the 7-14 oz potatoes and to a lesser extent 3-7 oz potatoes. At rates higher than 150 lb P_2O_5/A, total yield tended to level off in the high P testing site. In the low P testing site highest total yields were recorded at 200 lb P_2O_5/A. For both low and high P testing sites, the greatest yield increase due to phosphate fertilizer occurred between the 0 and 50 lb/A rate. Assuming the price of potatoes is $5.00/cwt, economic increases due to phosphate fertilizer were realized up to 200 lb P_2O_5/A in the low testing site and 150 lb P_2O_5/A in the high testing site. For 7-14 oz potatoes, economic increases in yield were obtained when 50 lb P_2O_5/A were applied in the low testing site, and 250 lb P_2O_5/A were applied in the high testing site. This is the first year where yield increases at these high rates of phosphate fertilizer were recorded and may have been due to the abnormally cool growing season of 1992.

Elemental concentrations were determined in petiole and leaf (leaflets plus petioles) samples to ascertain whether the type of tissue sampled affected diagnostic interpretations (Tables 5-8). Concentrations of phosphorus 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. Based on this years data, a critical level of P in petioles would be about 0.3%, whereas in leaf tissue the critical level would be 0.4%. These critical levels are higher than those reported in previous years and therefore need further validation. Total N in leaf tissue tended to increase with increasing P rate in both high and low P sites. In contrast, petiole nitrate was not affected by P treatment. Concentrations of nitrogen in leaves and nitrate in petioles were generally higher when alfalfa was the previous crop compared to rye. Potassium concentrations in petioles were approximately twice as high as those in leaf tissue. Phosphate fertilizer had no effect on potassium concentrations in the tissues sampled. Calcium and magnesium concentrations were similar in petiole and leaf tissue. Both calcium and magnesium increased with increasing phosphate fertilizer in the low P site, but this trend was not apparent in the high P site. Iron concentrations were approximately twice as high in leaf tissue compared to petiole tissue. Phosphate fertilizer increased leaf iron in the low P site, but had no effect on iron concentrations in the petiole tissue or in any tissue sampled in the high P site. Manganese concentrations were higher in leaf tissue than in petiole tissue. Phosphate fertilizer had inconsistent effects on tissue manganese concentrations. Concentrations of zinc were higher in petiole tissue compared to leaf tissue. However, leaf zinc concentrations tended to increase with increasing phosphate fertilizer rate in both high and low P sites, while petiole 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. Boron concentrations were twice as high in petiole tissue compared to leaf tissue. Increasing phosphate fertilizer tended to decrease petiole and leaf 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 vines, roots, tubers, and number of tubers sampled June 26, 1992. Previous crop - Rye; initial soil test P - 60 ppm.

Phosphate Treatment lb P_2O_5	Plant Part: vines	roots	tubers	number of tubers
	grams/plant			per plant
0	48.50	5.97	19.42	8.40
50	62.20	6.88	26.89	12.15
100	65.46	6.46	20.65	10.45
150	60.16	6.14	21.60	10.55
200	62.43	6.52	19.81	10.85
250	56.84	6.07	22.96	10.35
Pr>F	0.13	0.13	0.67	0.28
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 5%.

Table 2. Effect of phosphate fertilizer on dry matter of vines, roots, tubers, and number of tubers sampled June 26, 1992. Previous crop - alfalfa; initial soil test P - 22 ppm.

Phosphate Treatment lb P_2O_5	Plant Part: vines	roots	tubers	number of tubers
	grams/plant			per plant
0	43.36	6.43	12.49	7.35
50	59.66	6.77	15.22	9.95
100	66.49	6.47	16.18	9.05
150	62.91	6.78	15.29	8.60
200	67.47	7.12	10.82	7.45
250	65.98	6.95	20.77	9.55
Pr>F	0.02	0.53	0.27	0.45
Lin P_2O_5	**	NS	NS	NS
Quad P_2O_5	*	NS	NS	NS
Cubic P_2O_5	NS	NS	++	++

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

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

Phosphate Treatment lb P_2O_5	Tuber Yield: Knobs	Tuber Size: <3 oz	3-7 oz	7-14 oz	>14 oz	Total	Specific Gravity
	cwt/A						
0	24.7	62.0	264.1	78.7	5.0	434.5	1.0840
50	29.9	71.4	314.8	110.0	6.9	533.0	1.0837
100	37.3	68.1	313.3	106.9	11.1	536.8	1.0843
150	39.9	65.1	293.5	150.3	10.2	559.0	1.0829
200	26.0	76.1	323.4	115.4	1.9	542.8	1.0843
250	36.0	63.9	278.6	173.8	11.2	563.5	1.0833
Pr>F	0.74	0.27	0.37	0.05	0.35	0.01	0.90
Lin P_2O_5	NS	NS	NS	**	NS	**	NS
Quad P_2O_5	NS	NS	++	NS	NS	*	NS
Cubic P_2O_5	NS	NS	NS	NS	NS	NS	NS

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

Table 4. Effect of phosphate fertilizer on yield and specific gravity of Russet Burbank potatoes. Previous crop - alfalfa; initial soil test P - 22 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
	cwt/A						
0	22.4	32.1	263.3	131.6	10.7	460.1	1.0861
50	39.9	34.5	277.8	194.5	23.0	569.6	1.0837
100	34.1	51.3	311.9	158.9	21.6	577.8	1.0817
150	23.2	44.4	317.8	173.1	31.0	589.5	1.0825
200	51.0	43.3	293.1	190.8	30.5	608.7	1.0848
250	34.6	41.6	288.5	177.1	23.8	565.7	1.0831
Pr>F	0.41	0.08	0.09	0.05	0.18	0.00	0.30
Lin P_2O_5	NS	++	NS	++	++	**	NS
Quad P_2O_5	NS	*	*	NS	++	**	NS
Cubic P_2O_5	NS	NS	NS	NS	NS	NS	NS

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

Table 5. Effect of phosphate fertilizer on elemental composition of recently expanded potato leaves (leaflets + petioles) sampled July 1, 1992. Previous crop - rye; initial soil test P - 60 ppm.

Phosphate Treatment lb P_2O_5	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	%					ppm				
0	5.26	0.29	4.98	0.59	0.48	119	162	19	9.9	29
50	5.13	0.31	4.83	0.54	0.45	118	175	18	7.9	29
100	5.35	0.36	4.59	0.59	0.48	167	165	21	9.0	27
150	5.64	0.41	4.74	0.55	0.46	162	195	23	8.6	27
200	5.52	0.44	4.79	0.60	0.48	119	175	23	7.9	25
250	5.51	0.43	4.66	0.57	0.47	112	147	22	7.4	26
Pr>F	0.02	0.00	0.30	0.74	0.87	0.59	0.81	0.00	0.00	0.01
Lin P_2O_5	**	**	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 = nonsignificant; ++,*,** = significant at 10%, 5% and 1%, respectively.

Table 6. Effect of phosphate fertilizer on elemental composition of petioles sampled July 1, 1992. Previous crop - rye; initial soil test P - 60 ppm.

Phosphate Treatment lb P_2O_5	dry wt. petiole NO_3-N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	-ppm-	%				ppm				
0	20048	0.22	1.03	0.52	0.39	62	141	28	6.4	56
50	17884	0.25	1.01	0.44	0.36	86	164	22	5.2	44
100	19634	0.25	1.02	0.54	0.42	66	143	23	5.0	46
150	20987	0.32	0.97	0.57	0.44	70	143	29	4.9	45
200	17243	0.33	0.99	0.53	0.44	66	134	26	4.2	43
250	18072	0.31	1.01	0.53	0.41	68	123	24	4.4	48
Pr>F	0.07	0.00	0.87	0.01	0.11	0.71	0.90	0.06	0.29	0.22
Lin P_2O_5	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 = nonsignificant; ++,*,** = significant at 10%, 5% and 1%, respectively.

Table 7. Effect of phosphate fertilizer on elemental composition of recently expanded potato leaves (leaflets + petioles) sampled July 1, 1992. Previous crop - alfalfa; initial soil test P - 22 ppm.

Phosphate Treatment lb P_2O_5	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	%					ppm				
0	5.47	0.31	4.61	0.62	0.53	98	95	22	8.5	29
50	5.40	0.33	4.62	0.68	0.54	103	100	21	7.4	26
100	5.74	0.38	4.81	0.71	0.58	107	99	22	7.0	26
150	5.78	0.40	4.52	0.76	0.61	109	92	23	7.1	26
200	5.80	0.43	4.51	0.73	0.59	107	94	23	6.6	26
250	6.00	0.47	4.42	0.73	0.61	107	109	26	7.2	26
Pr>F	0.02	0.00	0.38	0.06	0.01	0.02	0.33	0.02	0.01	0.10
Lin P_2O_5	**	**	NS	**	**	**	NS	**	**	++
Quad P_2O_5	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 8. Effect of phosphate fertilizer on elemental composition of petioles sampled July 1, 1992. Previous crop - alfalfa; initial soil test P - 22 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	21347	0.23	9.90	0.57	0.48	55	61	28	6.2	48
50	21209	0.28	10.01	0.63	0.57	56	72	29	5.1	40
100	21697	0.28	9.85	0.67	0.57	59	68	27	4.6	41
150	22255	0.31	9.70	0.69	0.61	60	58	29	4.8	40
200	20429	0.33	9.81	0.70	0.62	55	62	27	4.6	42
250	23404	0.39	9.55	0.72	0.64	54	68	31	5.0	42
Pr>F	0.33	0.00	0.77	0.11	0.01	0.88	0.05	0.48	0.09	0.22
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 = nonsignificant; ++,*,** = significant at 10%, 5% and 1%, respectively.

TILLAGE INDUCED MICRORELIEF IMPACTS ON NITRATE MOVEMENT IN SOILS BECKER MN. AND WESTPORT MN. CORN 1992[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 fertilizer use efficiency and movement through the soil profile. Grain yield were significantly increased at both Becker and Westport when 125 lbs N/A were applied. Tillage had relatively little impact on grain yield except for the chisel treatment at Becker which was adversely effected because the previous rye crop was not adequately controlled. Time of N application had minimal impact on grain yield at Becker while delayed applications were better at Westport. Placement of N at Westport had no impact on grain yield, but yields at Becker were increased with a placement close to the row at the late time of application.

Experimental Procedures

Two experimental locations were selected in 1992: 1. The Sand Plains Research Farm, Becker, MN. and 2. The Herman Rosholt Water Quality Research Farm at Westport, MN. Both experimental sites were irrigated.

Becker: A total of 39 treatments with four replications were established in a split plot design with tillage as the main plot. The 39 treatments consisted of three tillage (chisel, ridge till and plow), a control plot (zero N) plus three nitrogen rates (60, 120 and 180 lbs/A), two method of placement 7.5 or 15 inches from the row and two times of application early (3-leaf) or late (8-leaf). All fertilizer was applied as 28% N solution. The early N application was made on May 21 and the late application on June 22nd. 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 0-2 ft. depth in 6 inch increments from the control and the 180 lbs N/A rate. Soil samples were collected on May 26 (3-leaf), June 15 (8-leaf), June 25 (8-leaf), July 23 (silking) and Sept. 1 (dent). All soil samples were analyzed for nitrate and ammonium N.

Prior to planting 300 #/A 0-0-22 and 165 #/A 0-0-60 were broadcasted and incorporated by the different tillage systems. Corn (DeKalb 485 - 100 day R.M.) was planted on April 30th in 30 inch rows at a population of 30,700 seeds/A. Starter fertilizer was applied at the rate of 10 gal/A as 7-21-7 as a band below the seed. For weed control a tank mix of Dual (2 #/A) + Atrazine (1.5 #/A) was applied on May 1.

Plant samples were collected from the control and all N treated plots on June 15 (8-leaf), July 23 (silking) and October 1 (physiological maturity). Total dry matter production were determined on the first two sampling dates, N concentration and total N uptake. 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 June 26th and continued through August 11th with 8.25 inches of water being applied through irrigation. An additional 17.64 inches of water was obtained during the season as rainfall.

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2. Professor and Assistant Scientist respectively, Dept. of Soil Science, University of MN.

Westport: The experiment at Westport was identical to Becker except that the 180 lbs N/A was not included (27 treatments). Soil samples were collected to 18 inches in 6 inch increments on June 2nd (3-leaf), 25th (8-leaf), July 6th (8-leaf), August 4th (silking) and Sept. 2nd (denting). All soil samples were analyzed for nitrate and ammonium N.

Corn (Pioneer 3787 - 95 day R.M.) was planted on May 6th at a population of 30,700 seeds/A. Starter fertilizer was applied at the rate of 10 gal/A as 7-21-7 as a band below the seed and Counter 8 lbs/a was banded in the row at planting. A tank mix of Lasso (1.75 #/A) + Bladex (1.75 #/A) was applied May 23th for weed control. Nitrogen application took place on May 28th (3-leaf) and June 29th (8-leaf). Ridges were built on June 25th. Plant samples were taken June 25th (8-leaf), August 4th (silking), October 6th (physiological maturity). Plant samples were collected and analyzed simular to the Becker location.

General Results

Grain yields at Becker were excellent in 1992 considering the cool growing season. Grain yields were increased approximately 70 bu/A at Becker and 50 bu/A at Westpotr with 125 lbs N/A. Tillage systems had relatively little influecec on grain yield except at Becker where the chisel treatments was inferior to both the plow and ridge systems. During the fall of 1991 a rye cover crop was planted into this area. The chisel plow system did not allow for adequet control of the rye the following spring, and additional chemical control was required. The delayed kill is belived to be responsible for the lower yields obtained. Time of N application had relativeily little influence at Becker while the yields at Westport were higher with delayed application. The magnituted of early season N loss due to leaching are usually reflected with decreased yields with early N applications. Placement of fertilizer N had relatively little influence on yield, although at Becker increased yields were optained when N was placed close to the row with the late applications.

The results from Becker location are presentd in tables 1-4,and a summary of the results from Westport are presented in tables 5-6.

Table 1. Influence of N-rate, tillage, placement and time of application on grain yields and dry matter production at harvest. Becker, MN 10/1/1992.

N-Rate	Placement	Time	Tillage	Grain Yields	Dry Matter Production Stover	Grain	Total
#/A				Bu/A	---------T/A----------		
Control	---	-	Chisel	85.6	2.95	2.03	4.98
60	1	1		143.4	4.03	3.39	7.42
60	1	2		146.4	3.79	3.46	7.25
60	2	1		144.6	3.84	3.42	7.26
60	2	2		138.2	3.81	3.27	7.08
120	1	1		165.9	4.30	3.92	8.22
120	1	2		169.7	4.08	4.02	8.10
120	2	1		169.4	4.29	4.01	8.30
120	2	2		150.5	3.65	3.56	7.21
180	1	1		166.9	4.45	3.95	8.40
180	1	2		157.4	3.89	3.72	7.61
180	2	1		177.5	4.31	4.20	8.51
180	2	2		157.5	3.88	3.73	7.61
Control	---	-	Ridge	115.5	3.70	2.73	6.43
60	1	1		170.2	4.39	4.03	8.42
60	1	2		158.8	3.58	3.76	7.34
60	2	1		148.0	3.98	3.50	7.48
60	2	2		166.8	3.77	3.95	7.72
120	1	1		161.7	3.82	3.83	7.65
120	1	2		178.9	3.95	4.23	8.18
120	2	1		178.6	4.18	4.23	8.41
120	2	2		196.3	4.06	4.65	8.71
180	1	1		167.6	3.88	3.97	7.85
180	1	2		172.4	3.87	4.08	7.95
180	2	1		180.0	4.43	4.42	8.85
180	2	2		170.8	3.77	4.04	7.81
Control	---	-	Plow	108.4	3.49	2.56	6.05
60	1	1		158.0	4.39	3.74	8.13
60	1	2		150.0	4.21	3.55	7.76
60	2	1		158.1	4.31	3.74	8.05
60	2	2		167.8	4.31	3.97	8.28
120	1	1		183.3	4.90	4.34	9.24
120	1	2		181.1	4.31	4.29	8.60
120	2	1		178.2	4.45	4.22	8.67
120	2	2		167.6	4.03	3.96	7.99
180	1	1		173.1	4.42	4.10	8.52
180	1	2		181.1	4.38	4.28	8.66
180	2	1		184.1	4.50	4.35	8.85
180	2	2		183.4	4.29	4.34	8.63

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 10/1/1992.

N-Rate	Placement	Time	Tillage	N-Concentration Stover	N-Concentration Grain	N-Removal Stover	N-Removal Grain	N-Removal Total
#/A				-------%------		---------#/A----------		
Control	---	-	Chisel	0.36	0.92	21.7	37.3	58.9
60	1	1		0.45	1.11	36.1	75.6	111.7
60	1	2		0.52	1.09	39.6	75.4	115.0
60	2	1		0.44	1.03	34.1	70.7	104.8
60	2	2		0.52	1.02	39.6	66.7	106.3
120	1	1		0.60	1.26	51.5	98.5	150.0
120	1	2		0.61	1.23	49.5	99.3	148.8
120	2	1		0.47	1.22	40.8	98.4	139.2
120	2	2		0.60	1.32	43.8	93.7	137.5
180	1	1		0.70	1.33	61.6	105.1	166.8
180	1	2		0.64	1.42	49.2	105.9	155.1
180	2	1		0.67	1.31	58.0	109.8	167.8
180	2	2		0.72	1.35	56.0	100.4	156.3
Control	---	-	Ridge	0.49	1.02	36.5	55.6	92.1
60	1	1		0.52	1.09	45.5	88.0	133.5
60	1	2		0.49	1.13	35.1	85.1	120.2
60	2	1		0.50	1.15	39.4	80.2	119.6
60	2	2		0.63	1.05	47.1	83.1	130.2
120	1	1		0.62	1.05	47.5	93.8	141.3
120	1	2		0.66	1.22	52.1	101.4	153.5
120	2	1		0.58	1.33	48.8	112.5	161.2
120	2	2		0.53	1.24	43.4	114.9	158.3
180	1	1		0.59	1.20	46.3	95.4	141.6
180	1	2		0.67	1.26	51.4	102.9	154.3
180	2	1		0.63	1.32	55.8	116.5	172.3
180	2	2		0.67	1.25	50.6	101.0	151.7
Control	---	-	Plow	0.43	0.97	29.9	49.8	79.6
60	1	1		0.41	1.00	35.8	75.4	111.2
60	1	2		0.46	0.98	39.2	70.4	109.6
60	2	1		0.45	1.01	39.2	75.8	114.9
60	2	2		0.53	1.01	46.5	80.7	127.2
120	1	1		0.68	1.24	66.6	107.5	174.1
120	1	2		0.58	1.23	50.7	105.5	156.1
120	2	1		0.76	1.30	67.3	109.5	176.8
120	2	2		0.63	1.30	51.5	102.9	154.4
180	1	1		0.73	1.30	64.6	106.2	170.8
180	1	2		0.64	1.32	55.8	113.5	169.3
180	2	1		0.71	1.42	64.0	123.7	180.7
180	2	2		0.76	1.36	65.9	117.9	183.8

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 Analalysis

N-Rate X Tillage X Placement	Grain Yields	Dry Matter Production Stover	Grain	Total
	Bu/A	---------T/A----------		
N-Rate #/A				
60	154.2	4.03	3.65	7.68
120	173.4	4.17	4.10	8.27
180	173.2	4.17	4.10	8.27
P-Value	99	90	99	99
BLSD (.05)	5.0		0.12	0.22
Tillage				
Chisel	157.2	4.02	3.72	7.74
Ridge Till	171.4	3.97	4.05	8.02
Plow	172.1	4.37	4.07	8.44
P-Value	99	94	99	96
BLSD (.05)	5.1		0.12	0.22
Placement				
1. 7.5 inches	165.8	4.14	3.92	8.07
2. 15 inches	168.0	4.10	3.97	8.07
P-Value	65	54	65	6
Tillage X Placement	66	84	66	81
N-Rate X Tillage	30	21	30	23
N-Rate X Placement	67	49	67	64
N-Rate X Tillage X Placement	96	64	96	91
N-Rate X Tillage X Placement X Time				
Time				
1. 3 leaf	167.5	4.27	3.96	8.23
2. 8 leaf	166.4	3.98	3.94	7.91
P-Value	38	99	38	99
Tillage X Time	93	27	93	71
Placement X Time	57	14	57	40
Tillage X Placement X Time	74	15	74	34
N-Rate X Time	60	15	60	38
N-Rate X Tillage X Time	84	95	84	95
N-Rate X Placement X Time	96	90	96	96
N-Rate X Tillage X Placement X Time	52	64	52	64

Table 4. Continued from table 2: Split Plot Statistical Analalysis

	N-Concentration		N-Removal		
N-Rate X Tillage X Placement	Stover	Grain	Stover	Grain	Total
	-------%------		---------#/A----------		
N-Rate #/A					
60	0.49	1.05	39.7	77.2	117.0
120	0.61	1.25	51.1	103.1	154.2
180	0.67	1.31	56.6	108.2	164.8
P-Value	99	99	99	99	99
BLSD (.05)	0.02	0.03	2.7	3.8	5.5
Tillage					
Chisel	0.57	1.22	46.6	91.6	138.2
Ridge Till	0.59	1.20	46.9	97.8	144.8
Plow	0.61	1.20	53.9	99.0	152.9
P-Value	85	90	99	99	99
BLSD (.05)			2.8	4.2	5.8
Placement					
1. 7.5 inches	0.58	1.20	48.7	94.7	143.4
2. 15 inches	0.60	1.22	49.5	97.6	147.2
P-Value	82	88	46	90	85
Tillage X Placement	98	99	87	96	97
N-Rate X Tillage	99	99	99	99	99
N-Rate X Placement	98	96	96	89	80
N-Rate X Tillage X Placement	84	81	4	84	39
N-Rate X Tillage X Placement X Time					
Time					
1. 3 leaf	0.58	1.21	50.1	96.8	146.9
2. 8 leaf	0.60	1.20	48.1	95.5	143.7
P-Value	92	30	89	51	79
Tillage X Time	97	80	67	23	33
Placement X Time	94	83	81	88	33
Tillage X Placement X Time	51	91	48	17	31
N-Rate X Time	99	53	98	13	66
N-Rate X Tillage X Time	97	37	99	23	79
N-Rate X Placement X Time	55	81	70	91	86
N-Rate X Tillage X Placement X Time	97	11	92	15	60

Table 5. Influence of N-rate, tillage, placement and time of application on grain yields and dry matter production at harvest. Westport, MN 10/6/1992.

N-Rate	Placement	Time	Tillage	Grain Yields	Dry Matter Production Stover	Grain	Total
#/A				Bu/A	----------T/A----------		
Control	---	-	Chisel	43.5	2.60	1.03	3.63
60	1	1		86.8	3.59	2.05	5.64
60	1	2		87.6	3.07	2.07	5.14
60	2	1		84.9	3.67	2.01	5.68
60	2	2		85.2	3.13	2.02	5.15
120	1	1		88.6	3.57	2.10	5.67
120	1	2		93.2	3.36	2.21	5.57
120	2	1		91.1	3.48	2.16	5.64
120	2	2		101.3	3.31	2.40	5.71
Control	---	-	Ridge	48.8	2.61	1.15	3.76
60	1	1		82.3	3.54	1.95	5.49
60	1	2		81.8	3.06	1.94	5.00
60	2	1		81.3	3.54	1.92	5.46
60	2	2		94.0	3.54	2.22	5.76
120	1	1		91.9	4.09	2.17	6.26
120	1	2		99.1	3.71	2.34	6.05
120	2	1		91.0	4.18	2.15	6.33
120	2	2		94.1	3.50	2.23	5.73
Control	---	-	Plow	54.8	2.76	1.30	4.06
60	1	1		79.0	3.68	1.87	5.55
60	1	2		103.4	3.59	2.45	6.04
60	2	1		92.8	3.74	2.20	5.94
60	2	2		92.2	3.42	2.18	5.60
120	1	1		93.0	3.85	2.20	6.05
120	1	2		104.1	3.23	2.46	5.69
120	2	1		102.3	3.97	2.42	6.39
120	2	2		109.8	3.51	2.60	6.11

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

Split Plot Statistical Analalysis

N-Rate X Tillage X Placement				
N-Rate #/A				
60	87.6	3.46	2.07	5.53
120	96.6	3.64	2.28	5.93
P-Value	99	99	99	99
Tillage				
Chisel	89.9	3.39	2.12	5.52
Ridge Till	89.4	3.64	2.11	5.76
Plow	97.0	3.62	2.29	5.92
P-Value	88	78	88	82
BLSD (.05)				
Placement				
1. 7.5 inches	90.8	3.52	2.15	5.67
2. 15 inches	93.3	3.58	2.20	5.79
P-Value	84	59	84	76
Tillage X Placement	28	18	28	18
N-Rate X Tillage	23	99	23	87
N-Rate X Placement	38	36	38	8
N-Rate X Tillage X Placement	89	79	89	84
N-Rate X Tillage X Placement X Time				
Time				
1. 3 leaf	88.7	3.74	2.09	5.84
2. 8 leaf	95.4	3.37	2.25	5.62
P-Value	99	99	99	98
Tillage X Time	74	2	74	20
Placement X Time	53	13	53	15
Tillage X Placement X Time	47	8	47	56
N-Rate X Time	26	54	26	29
N-Rate X Tillage X Time	51	94	51	89
N-Rate X Placement X Time	38	31	38	7
N-Rate X Tillage X Placement X Time	93	83	93	92

Table 6. Influence of N-rate, tillage, placement and time of application on stover and grain N content and total N removal at harvest. Westport, MN 10/6/1992.

N-Rate	Placement	Time	Tillage	N-Concentration Stover	N-Concentration Grain	N-Removal Stover	N-Removal Grain	N-Removal Total
#/A				-------%------		----------#/A----------		
Control	---	-	Chisel	0.50	1.17	26.0	24.1	50.1
60	1	1		0.55	1.31	39.3	53.6	92.9
60	1	2		0.58	1.36	35.7	56.1	91.8
60	2	1		0.57	1.16	41.6	46.5	88.1
60	2	2		0.55	1.29	34.0	52.1	86.1
120	1	1		0.60	1.36	42.6	57.1	99.7
120	1	2		0.81	1.49	54.6	65.6	120.2
120	2	1		0.73	1.48	50.6	63.4	114.0
120	2	2		0.73	1.62	48.0	77.6	125.6
Control	---	-	Ridge	0.48	1.05	25.2	24.2	49.4
60	1	1		0.58	1.22	41.5	47.6	89.1
60	1	2		0.56	1.31	34.5	50.8	85.3
60	2	1		0.57	1.33	40.2	51.2	91.4
60	2	2		0.62	1.39	43.9	61.9	105.7
120	1	1		0.74	1.53	60.2	66.4	126.6
120	1	2		0.77	1.48	57.6	69.4	127.0
120	2	1		0.74	1.60	61.9	68.9	130.8
120	2	2		0.77	1.54	54.1	68.7	122.8
Control	---	-	Plow	0.43	1.03	23.5	26.7	50.2
60	1	1		0.55	1.35	40.0	50.6	90.6
60	1	2		0.61	1.29	43.7	63.3	107.1
60	2	1		0.48	1.20	35.7	52.7	88.4
60	2	2		0.60	1.28	40.8	55.8	96.6
120	1	1		0.62	1.53	47.8	67.7	115.5
120	1	2		0.73	1.44	47.1	70.9	118.0
120	2	1		0.70	1.49	55.5	72.5	128.0
120	2	2		0.68	1.49	47.8	77.4	125.2

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

Split Plot Statistical Analalysis

N-Rate X Tillage X Placement				
N-Rate #/A				
60	0.56	1.29	39.2	53.5	92.7
120	0.71	1.50	52.3	68.8	121.1
P-Value	99	99	99	99	99
Tillage					
Chisel	0.63	1.38	43.2	59.0	102.2
Ridge Till	0.66	1.42	49.2	60.6	109.8
Plow	0.61	1.38	44.8	63.9	108.7
P-Value	67	91	76	86	81
BLSD (.05)					
Placement					
1. 7.5 inches	0.64	1.39	45.3	59.9	105.3
2. 15 inches	0.64	1.40	46.1	62.3	108.5
P-Value	21	61	48	93	89
Tillage X Placement	29	99	10	33	31
N-Rate X Tillage	66	8	99	29	84
N-Rate X Placement	65	99	35	96	90
N-Rate X Tillage X Placement	54	99	88	99	99
N-Rate X Tillage X Placement X Time					
Time					
1. 3 leaf	0.61	1.38	46.4	58.2	104.6
2. 8 leaf	0.66	1.41	45.1	64.1	109.2
P-Value	99	96	68	99	98
Tillage X Time	66	99	53	44	62
Placement X Time	93	85	79	26	43
Tillage X Placement X Time	96	72	84	58	54
N-Rate X Time	68	86	21	20	26
N-Rate X Tillage X Time	90	92	99	89	99
N-Rate X Placement X Time	99	35	98	17	80
N-Rate X Tillage X Placement X Time	33	27	18	76	67

LONG-TERM N MANAGEMENT EFFECTS ON CORN PRODUCTION AND NITRATE LEACHING POTENTIAL AT THE SOUTHWEST EXPERIMENT STATION, LAMBERTON, MN

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Improved N management can increase N use efficiency and minimize N leakage from production systems. A field study was initiated in 1960 to determine if continuous corn yields are affected by N form (urea or ammonium nitrate), amount (14 to 174 lbs N/ac), time of application (fall, spring or sidedressed), and placement (surface, moldboard plow incorporation or sidedress). In addition, crop and soil nitrate data collected in 1969 and 1989 were used with a computer model (NLEAP) to assess nitrate leaching potential. Long-term corn yields responded primarily to N rate, however, significantly greater yields were also obtained with spring and sidedress applied N as compared to treatments with fall applied N. Despite greater yields with sidedressed N, soil nitrate levels in the rooting zone (0 to 5 ft) after harvest in 1969 were significantly greater in treatments with sidedressed as compared to fall applied N. Similar results were obtained in 1989 but at only the greatest N rate. Nitrate levels below the root zone (5 to 10 ft) were significantly greater for fall and sidedressed applied N than for spring applied N. The N available for leaching calculated with the screening process of the NLEAP model indicated moderate to high values across all treatments in 1969 and 1989. However, despite high levels of N available for leaching, a low leaching index resulted in low leaching risk potentials for most treatments. The exceptions were treatments with high N rates (174 lbs N/ac) which had high annual leaching risk potentials. These results indicate that excessive N rates present the greatest risk for nitrate-N leaching under the environmental conditions of the this long-term study.

MATERIALS AND METHODS

The continuous corn study is a nitrogen fertilization experiment involving various rates (0, 40, 80, 160 lbs N/ac) and application times (fall, spring, sidedress) of ammonium nitrate and urea. The experiment has been conducted since 1960 on tiled Normania loam/Webster clay loam soils. The fertilizer treatments have been applied annually to the same plot area (20 x 77.5 ft) for 33 years. The experimental design is a randomized incomplete block with four replications. After ear corn removal and stalk cutting, plots with treatments of fall applied N receive either broadcast N followed by moldboard plowing or moldboard plowing followed by surface applied N. All other treatments are also fall moldboard plowed to a depth of 12 inches. Spring treatments of applied N are broadcast before seedbed preparations in late April or early May. The corn is planted in 30-inch rows, and 100 lbs/ac starter fertilizer (14-41-15) is banded in all treatments. Sidedress treatments of applied N are broadcast in June and incorporated during cultivation. Additional management information is provided in Table 1. In 1969 and 1989, soil samples were collected at one foot increments to a depth of 7 and 10 ft, respectively, and analysed for nitrate-N. These data were combined with N budget estimates in a screening procedure using the NLEAP model to assess potentially leachable nitrate-N below the root zone.

RESULTS AND DISCUSSION

Corn yield in 1992 responded significantly to increased N rate but showed no response to timing or N form (Table 2). Long-term corn yields (1960-1992) revealed a significant response to N rate and timing (Table 3). Yields with spring and sidedress applied N were up to 18% greater than yields with fall N applications (Table 3). Soil nitrate-N depth distributions were similar for the control and 80 lb N/ac rates across all N timings (Fig. 1). Over-application of N was indicated by increased levels of soil nitrate-N in treatments receiving 160 lb N/ac (Fig. 1). In 1989, accumulations of soil nitrate-N within the rooting zone (0-5 ft) were very high at the greatest N rate (Fig. 2). Nitrate-N levels below the rooting zone (5-10 ft) also increased with increasing N rate to a high of 100 lb N/ac for the sidedressed treatment (Fig. 3). In general, soil nitrate levels within and below the rooting zone were greater for sidedressed and fall applied N than for spring applied N.

The NLEAP model contains a screening procedure to assess the risk of nitrate-N leaching below the rooting zone. Inputs include: (1) precipitation data and soil hydrologic group to calculate a leaching index (LI); (2) estimates of the nitrate-N available for leaching (NAL) based on an estimated N balance; (3) estimates of the nitrate-N leached from the root zone (NLy) calculated from LI and NAL; and (4) the annual leaching risk potential (ALRP) based on NLy and qualitative aquifer data. Leaching indices (LI) during 1961-

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