A Report on Field Research in Soils

1991

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SOIL SERIES 132
A Report on Field Research in Soil Science

ACKNOWLEDGEMENTS

This 1990 edition of the soils "bluebook" compiles data collected and analyzed throughout Minnesota. Information is contributed by personnel of the University of Minnesota Department of Soil Science; by soil scientists at the Minnesota Agricultural Experiment Station branch stations at Crookston, Lamberton, Morris and Waseca, and at the Becker and Staples research farms; and by Soil and Crop area agents. Associated personnel from the Soil Conservation Service, and the Soil and Water Research group of the ARS-USDA, the Tennessee Valley Authority, and the Departments of Agriculture and Natural Resources also contribute.

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

DISCLAIMERS

Some of the results reported in this publication are from 1989 experiments and should be regarded on this basis. Since most of the data is from 1989 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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NOTE TO CATALOGERS AND LIBRARIANS

This is the second year of the soils "bluebook" being published as a newly numbered item within the Miscellaneous Publication series. Prior to the 1990 edition this publication was produced as number "2" annually revised. That was changed to gain consistency with numbering patterns for other annual reports of ongoing research published by the Minnesota Agricultural Experiment Station.

-- Series Editor

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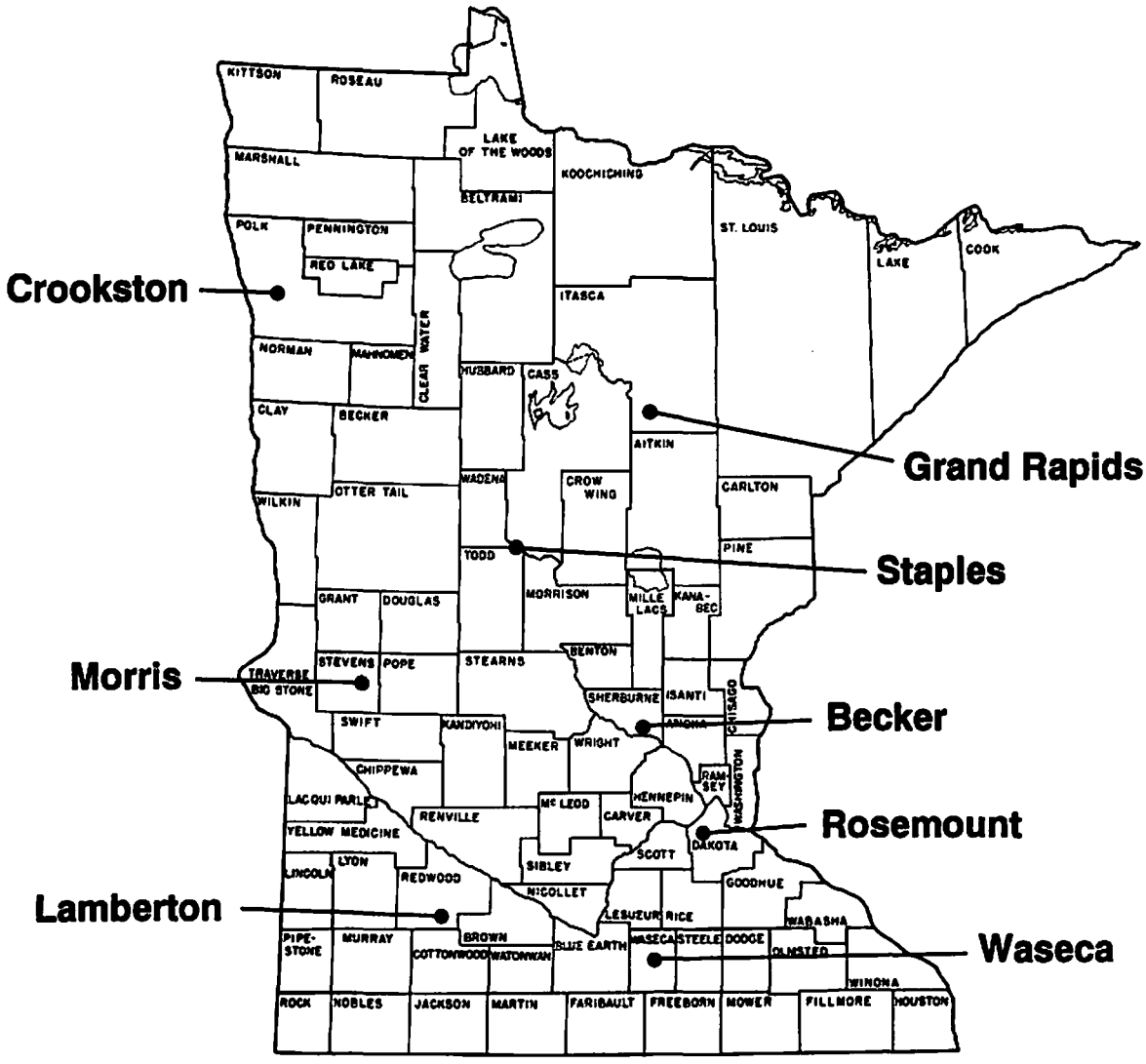

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FALL 1990 SOIL MOISTURE

W. W. Nelson, S. Evans, G. W. Randall, J. Lamb, D. L. Ruschy,
D. G. Baker, State Climatology Office and the S.C.S. Personnel
of Mille Lacs, Sibley, Todd and Wabasha Counties.

The autumn 1990 soil moisture picture for the state is good for that part of the state south and east of a line running from Ortonville to Hibbing. Because there is normally only very small additions to the soil moisture by the over-winter precipitation, the present condition represents quite well the expected early spring 1991 situation.

In the northwestern counties of the state, essentially Polk County northward and in smaller areas in the north central part of Minnesota soil water is very low. Where the soil was fallow or in small grains the situation is not quite as critical as where a full season crop such as sugarbeets was grown. The region south of this area, essentially the central and southern part of the Red River Valley is a bit better, but is also well below average.

The soil moisture values shown in Fig. 1 represent the total plant available water in a 5-foot column of soil. Although there are but nine sites there are several hundred stations where the November precipitation data are available. As a result a general but by no means detailed map of soil moisture can be made.

The map, Fig. 1, shows three important items:

1. Soil moisture
   a. The location of the 9 soil moisture sites.
   b. The total plant available water content in the 5-foot column of soil.
   c. The percent of the total plant available capacity that is occupied by water.
   d. The crop that was grown in 1990.

2. Precipitation
   a. Lines of equal amounts (isolines) of November precipitation that can be added to the indicated soil moisture values which were measured in October.

3. Soil moisture shortage
   a. The area of extreme northwestern Minnesota where moisture supplies are believed to be most critically short is indicated by the dashed line.

The biweekly soil moisture values at Crookston, Lamberton, Morris and Waseca are shown in Fig. 2-5. The final sample at Lamberton is about 1 inch above average and at Waseca it is about average. The Crookston and Morris values are low. The Crookston soil moisture value would be much lower if the crop had been sugarbeets rather than small grain. The Morris value is a reflection of a relatively dry streak that is oriented NE to SW through the Morris area. Immediately to the north and, particularly to the south, the moisture status is better.

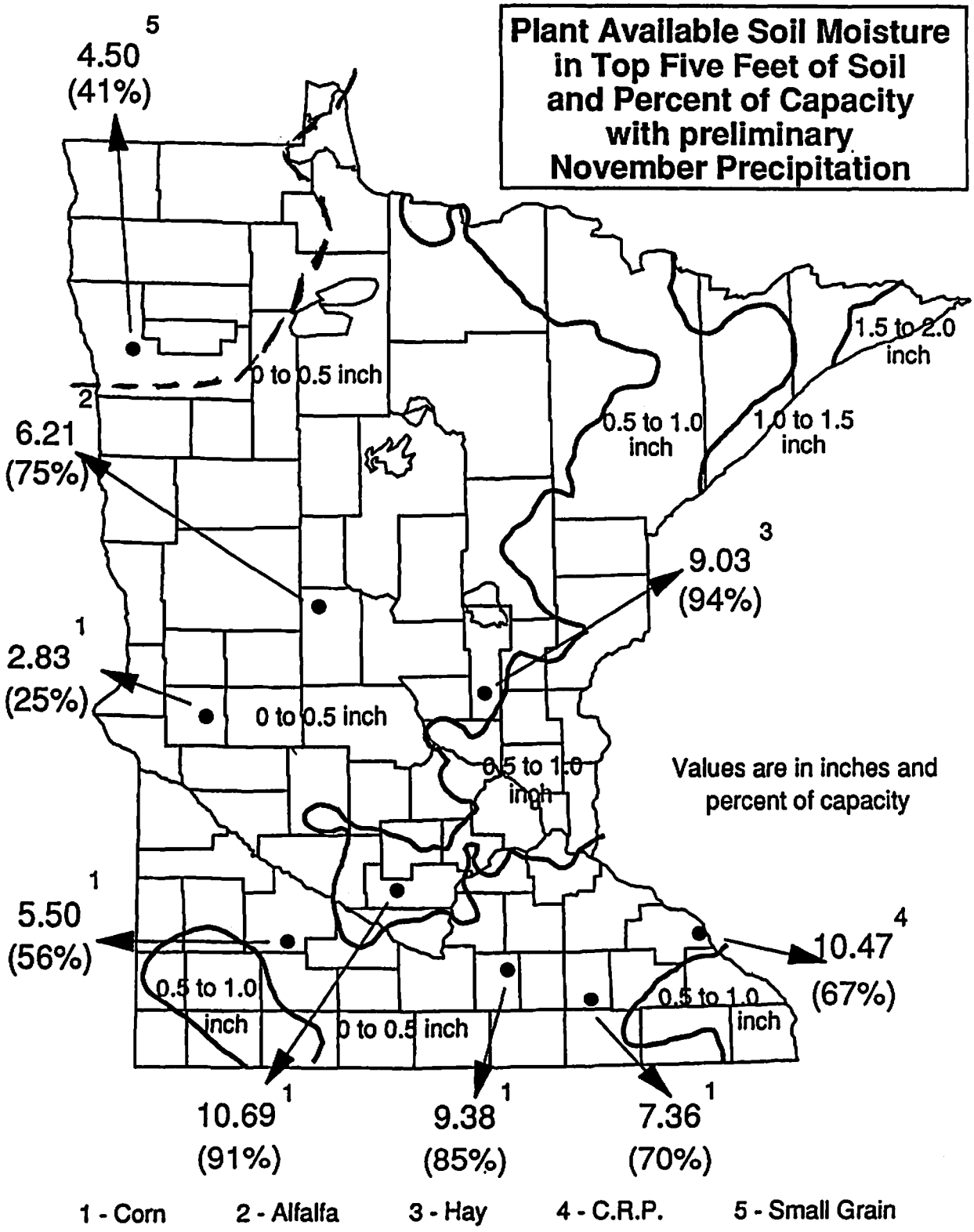


FIGURE 1. LATE AUTUMN 1990 SOIL MOISTURE

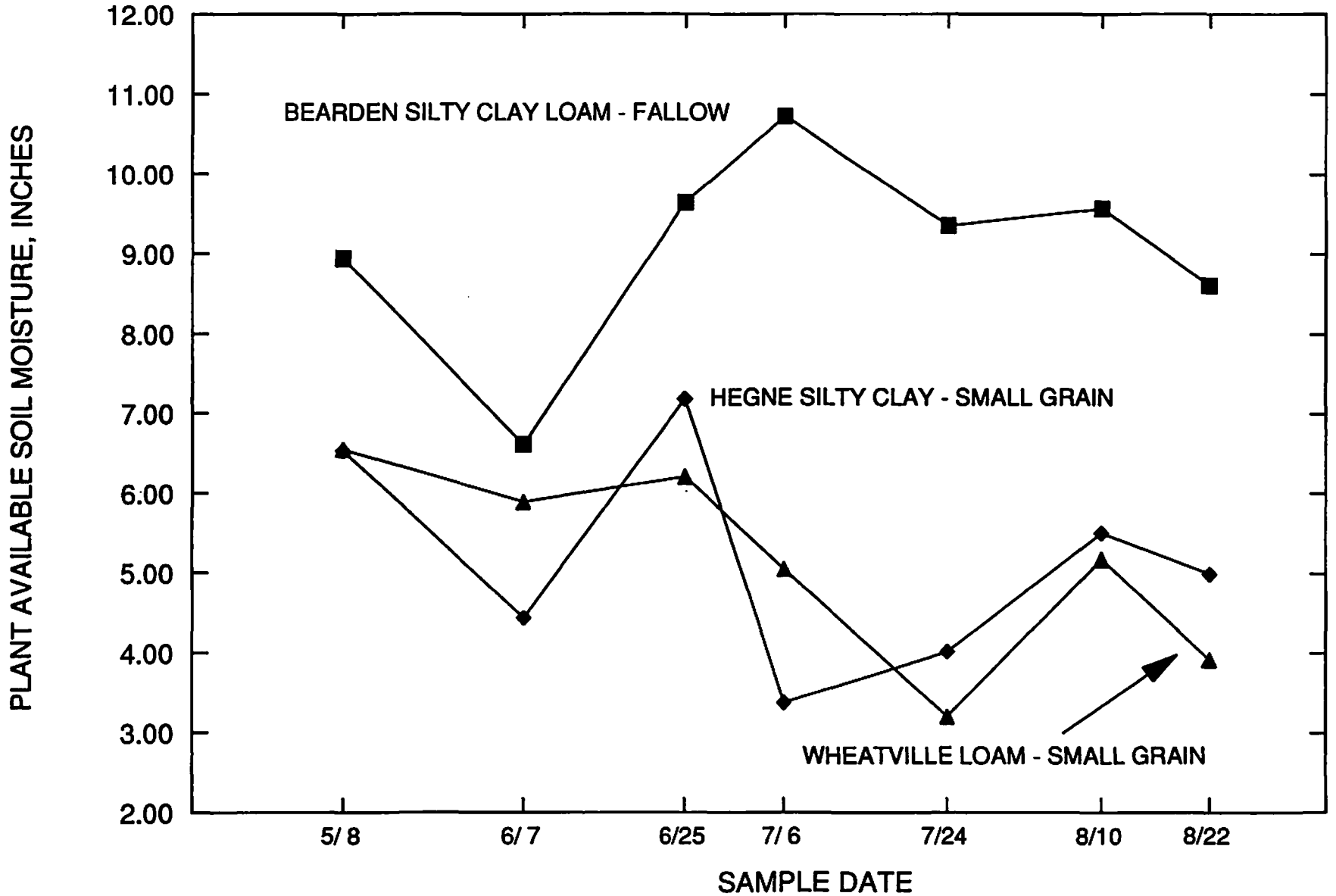


FIGURE 2. CROOKSTON 1990 SOIL MOISTURE DATA

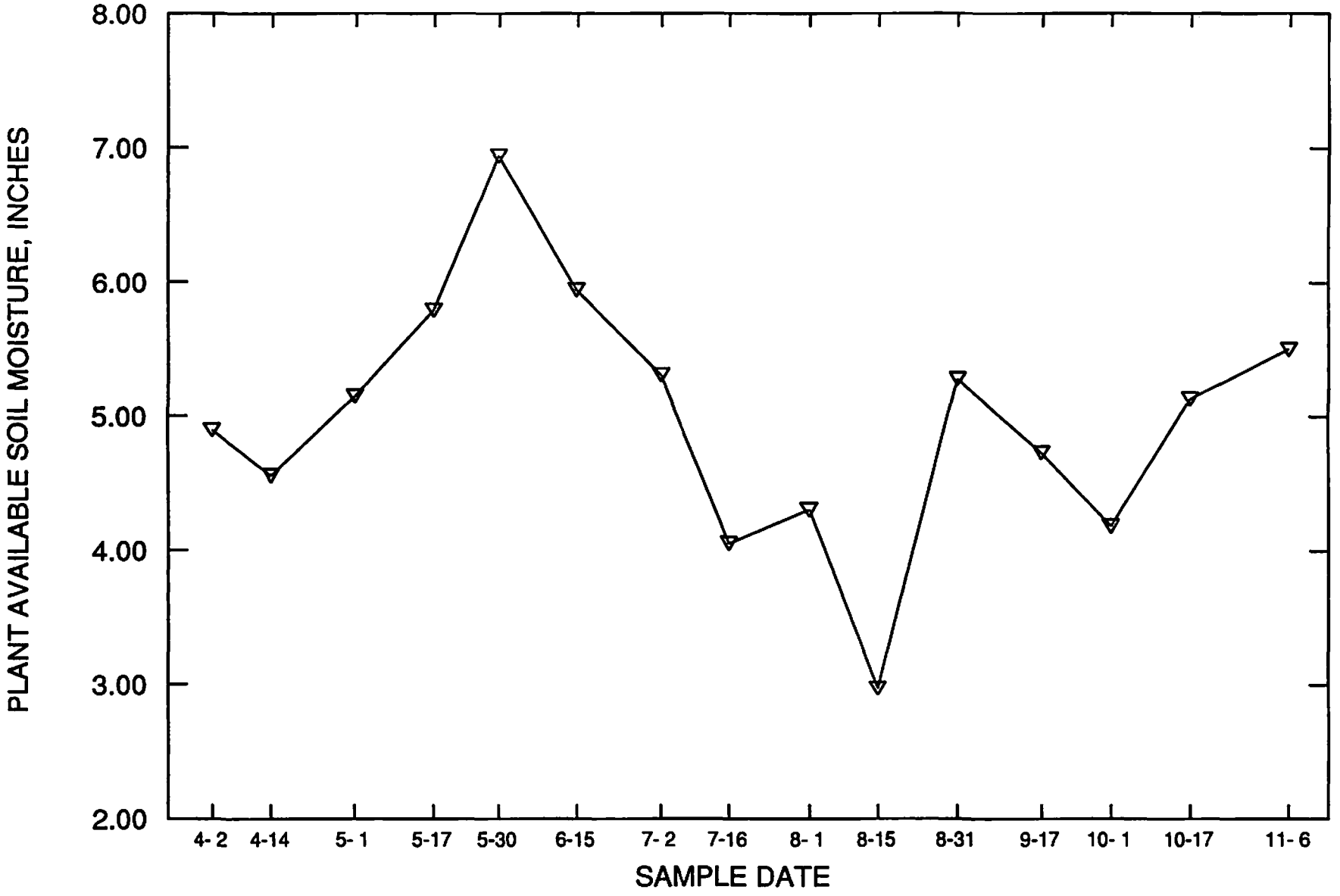


FIGURE 3. LAMBERTON 1990 SOIL MOISTURE DATA

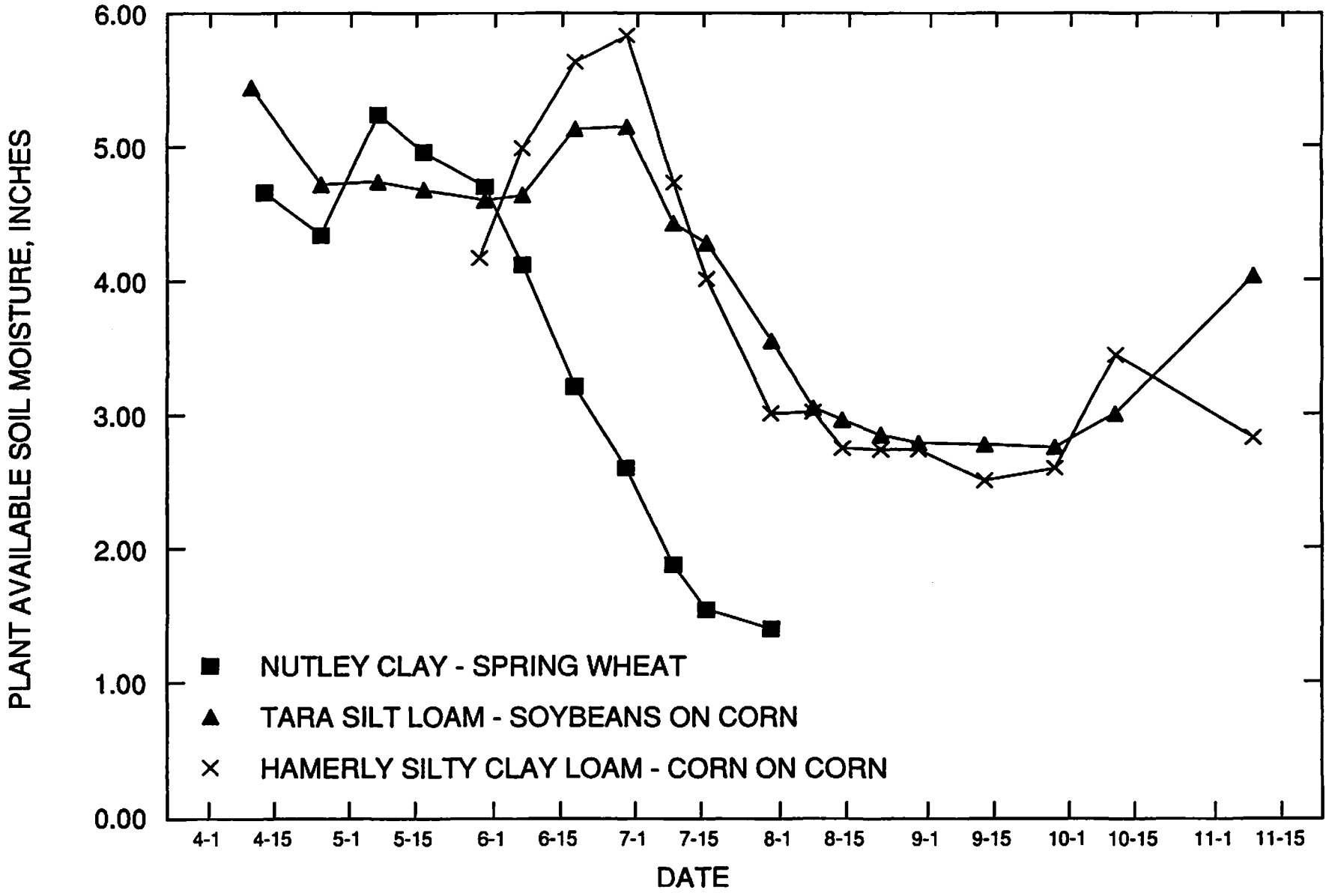


FIGURE 4. MORRIS 1990 SOIL MOISTURE DATA

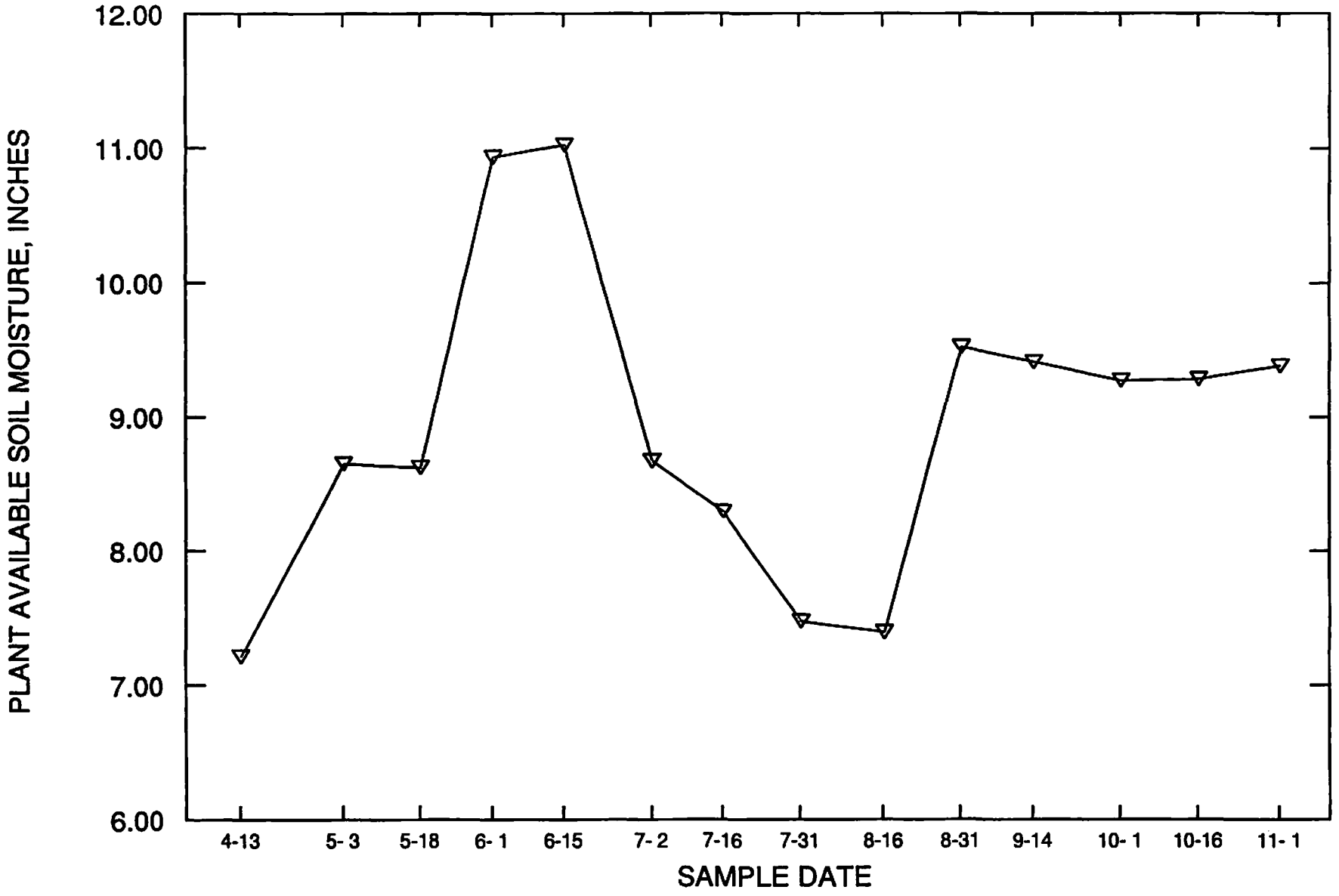


FIGURE 5. WASECA 1990 SOIL MOISTURE DATA

WATER YEAR CLIMATE SUMMARY
October 1989 - September 1990

Greg Spoden and James Zandlo, State Climatology Office,
and D. G. Baker

Despite the green lawns and the above average agricultural productivity observed in the 1989 growing season, the overall water picture at the onset of the 1989-1990 Water Year was grim. The relatively meager rainfall that fell during the growing season had been immediately swallowed up by thirsty vegetation. Very little surplus water was available to recharge lakes, rivers, wetlands, and shallow aquifers. Minnesota's drought was three years old with little improvement in sight. To aggravate matters, the Fall of 1989 provided less than normal precipitation during this critical recharge period. Not only were the large sinks of water such as lakes and wetlands in a deficient state, but soil moisture in the rooting zone was two to five inches below historical averages in many places. True recovery for most hydrologic systems can occur only after moisture in the soil is replenished.

The Winter of 1989-1990 began with a bitterly cold mid-December where temperatures consistently fell below -20 degrees Fahrenheit. Coupled with a lack of snow, the biting temperatures caused a thorough and deep freezing of the ground that prevented over-winter precipitation from entering the soil. Fortunately the temperature moderated for the remainder of the Winter, resulting in an exceptionally mild January and February. However, snowfall remained a rarity, with much of Minnesota displaying a brown landscape even in late January.

Late Winter and early Spring of 1990 began with a warm and soggy splash. For the first time in many months, heavier than normal precipitation doused the state. Many areas of Minnesota received double their normal March allotment of precipitation. The balmy breezes of March thawed soils two to three weeks ahead of schedule, allowing generous infiltration of the welcome rains. Warm temperatures also advanced lake ice-out by nearly 10 days.

The wet March was a harbinger of things to come. The Spring and early Summer continued at a pace that seemed destined to drown the drought. April and May finished at or above historical precipitation averages, and June produced a deluge of unusual magnitude. Several Minnesota communities waded through puddles resulting from eight to ten inch rainfall totals for the month of June. Excessive wetness was a problem for the first time in four years in southern Minnesota. Heavy rainfall continued into July in the southern half of the state, however areas of western, northwestern, and north central Minnesota were slighted by Mother Nature. By the second week of August, precipitation across the whole of Minnesota diminished abruptly, a pattern that continued to the end of the Water Year with one notable exception, the Cloquet Area flood. For the growing season of April through September, southern Minnesota, bolstered by a soggy June, finished much wetter than the historical average. By contrast, much of northwestern Minnesota once again came up short of normal.

Rainfall events of note included a large storm complex which drenched southeastern Minnesota in April; a succession of thunderstorms which dropped five to seven inches of rain on southwestern and central Minnesota in mid-June; a powerful storm that caused some flooding along a thin strip from the city of Faribault to Wabasha County in early July; and the grand finale, a group of heavy thunderstorms which pounded the Cloquet area in early September.

In summarizing the Water Year, Fig. 1 and 2, we find a contradictory pattern of above normal, even excessive, precipitation in southeastern section of the state, and below normal precipitation in the southwest, west, and north. A state of extreme drought persists in the northwest where no sustained relief has materialized for four years. Elsewhere in Minnesota, despite the wet early summer, the long term impacts of the three year (1987-1989) drought are still being felt. Soil moisture values are adequate to abundant in some areas, nonetheless the overall hydrologic situation is still in need of improvement.

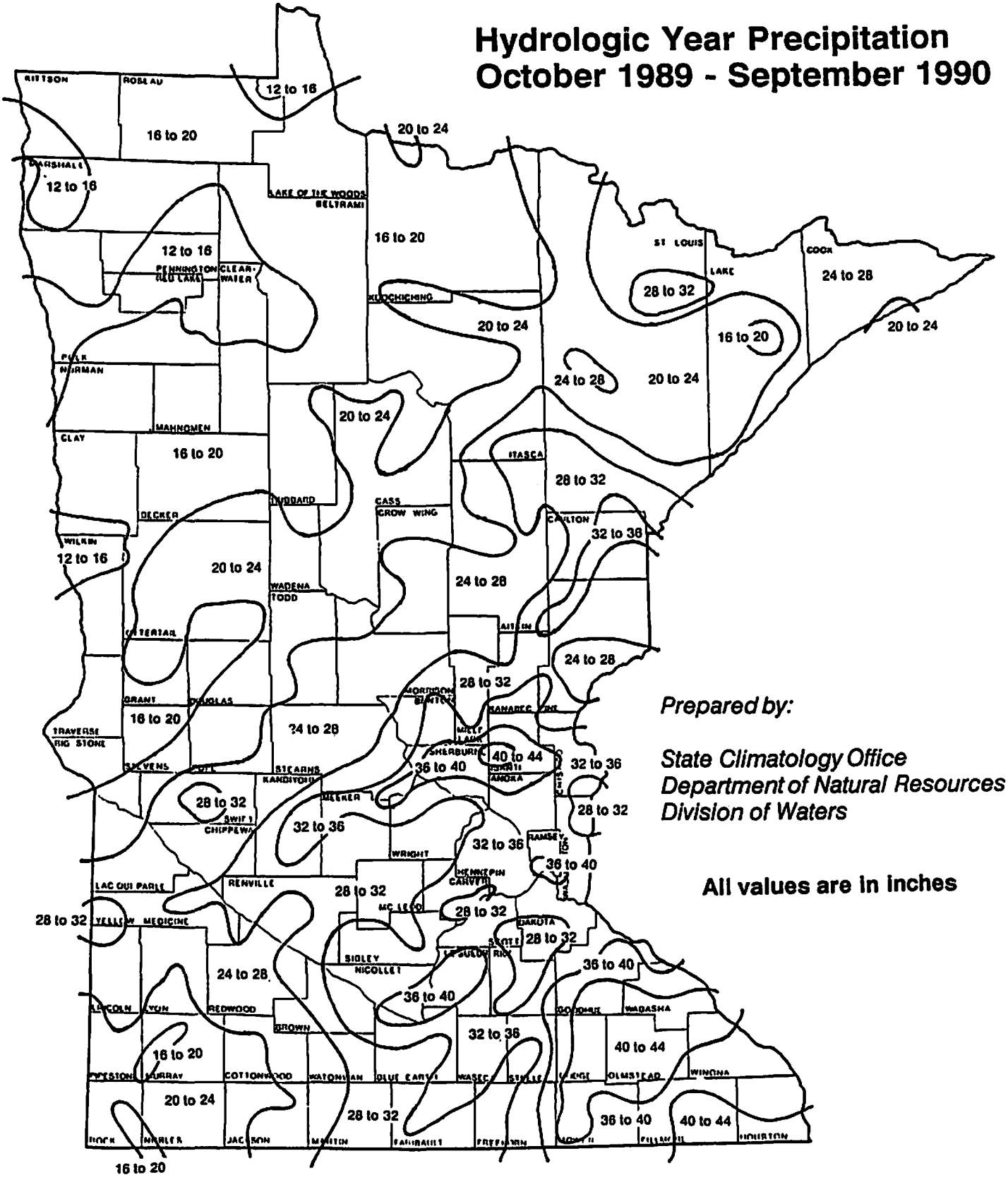


FIGURE 1. HYDROLOGIC YEAR PRECIPITATION

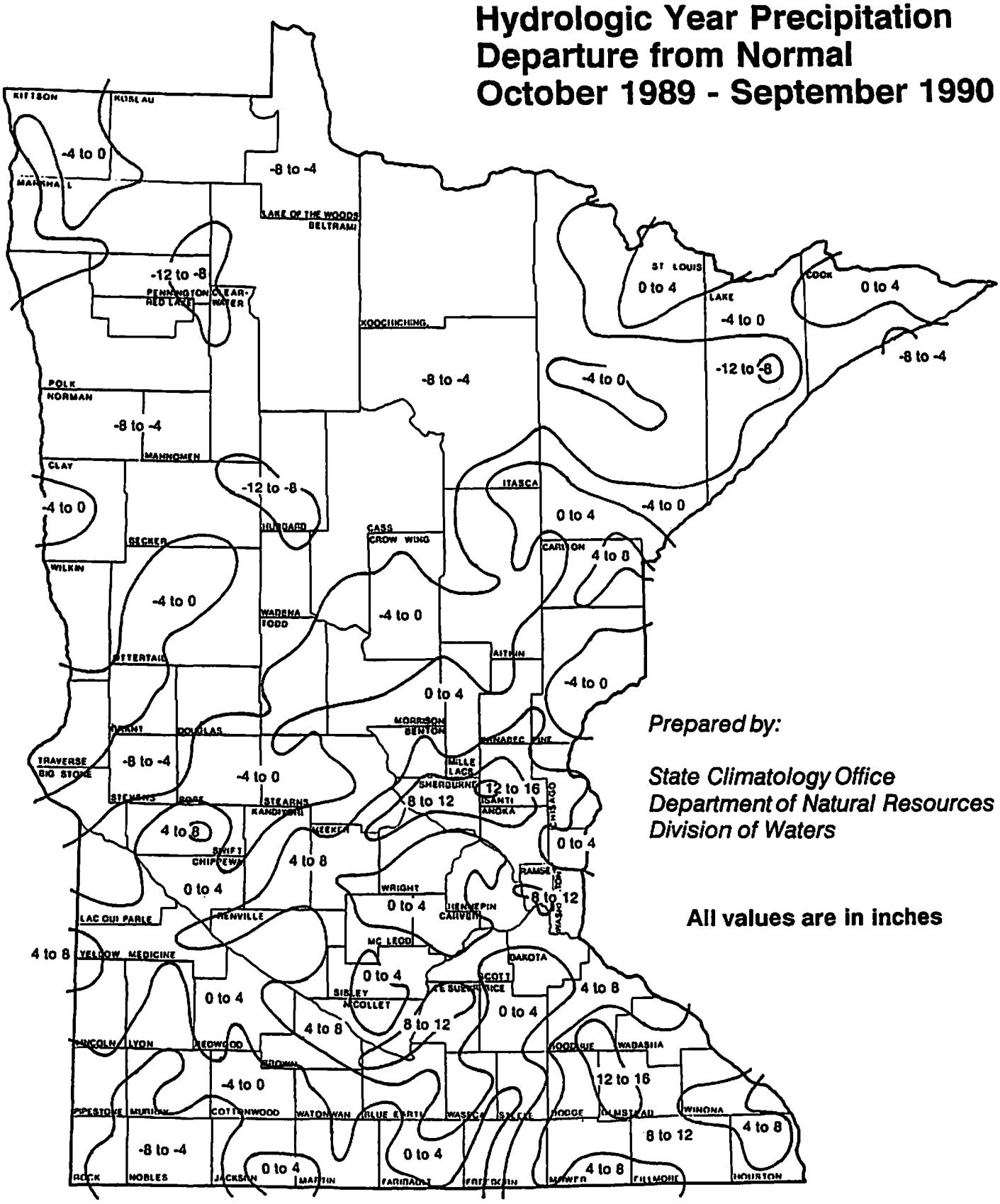


FIGURE 2. DEPARTURE FROM NORMAL

THE LOW TEMPERATURE EVENTS OF WINTER 1989-90

Donald G. Baker and David L. Ruschy

Several unusual meteorological events occurred during the 1989-90 winter that even now deserve our attention. The first was the outbreak of severe cold weather that lasted from 11 December, 1989, the first date when the minimum air temperature dropped below the long term average, until 25 December when the minimum was back to about average. The effects were much more severe than usual due to the lack of snow cover. A minimum air temperature of -26°F was observed at our climatological observatory on the St. Paul Campus on 21 December. This is not all that low for Minnesota, however, the resulting low soil temperatures, a minimum of 10°F at the 0.4 in and 18°F at the 8 in depth in the soil,point out the value of a good snow cover, which performs as a natural blanket or insulation for the soil.

A plot of the daily minimum soil temperatures under sod from 1 cm (0.4 in.) to 100 cm (40 in.) is shown in Fig. 1. It is evident that freezing temperatures in the soil reached a maximum depth of 97 cm (38 in.). The 60 cm (24 in) frozen layer is much deeper than usual for mid-December, although by late February or early March the mean depth of frozen soil at St. Paul over a 25-year period is about 100 cm (40 in.).

By late December, and for almost the remainder of the winter, the temperatures were unusually mild, except for two brief cold spells in mid-January and again in February (see Fig. 1). For example, a maximum air temperature of 59°F occurred on 12 February only to be followed by a minimum of 0°F on 14 February. This event may have been more serious than the December cold air outbreak, since the alfalfa dormancy probably was broken. What had started out as a record setting winter in terms of depth of soil freezing changed into a mild one. These wild temperature swings in both the air, and more particularly in the soil because of the lack of snow cover, exacted a toll upon the vegetation that is difficult to trace directly because the low temperature period occurred in the winter. The evidence was not apparent until spring. Forage specialists Don Barnes of the ARS, USDA, and Craig Sheaffer and Neal Martin, Agronomy Dept. U of M, estimated that these events damaged about 65% of the state's alfalfa acreage. These same specialists have stated that "most Minnesota alfalfa growers need greater levels of winterhardiness than growers in Wisconsin and Iowa". This is based on good climatology and we certainly agree; both states have milder winters in general and Wisconsin is more apt to have a better snow cover than Minnesota, particularly western Minnesota. The attached map of the state (Fig. 2) shows the areas of severe and moderate alfalfa damage (map courtesy of Barnes, Sheaffer, and Martin).

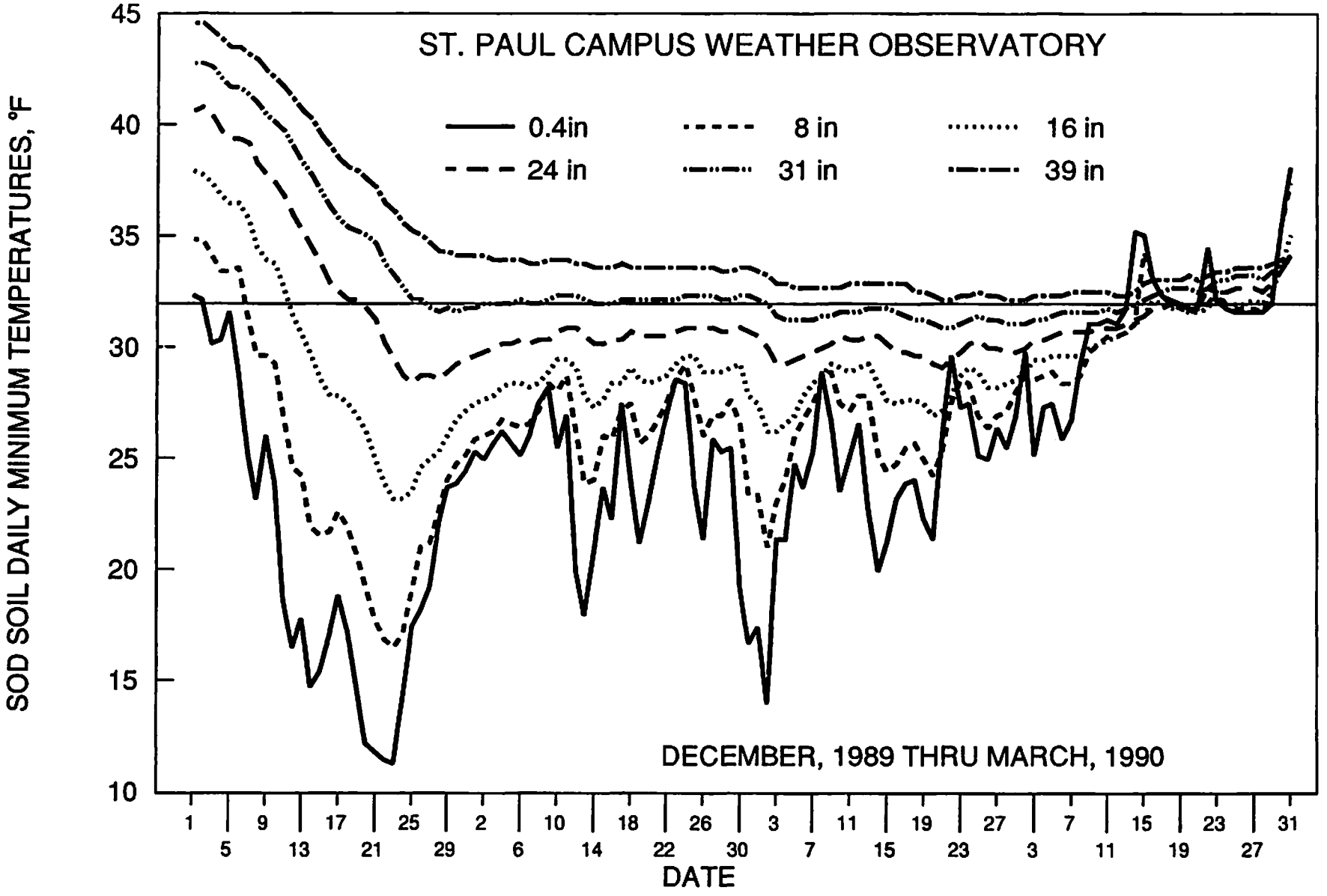
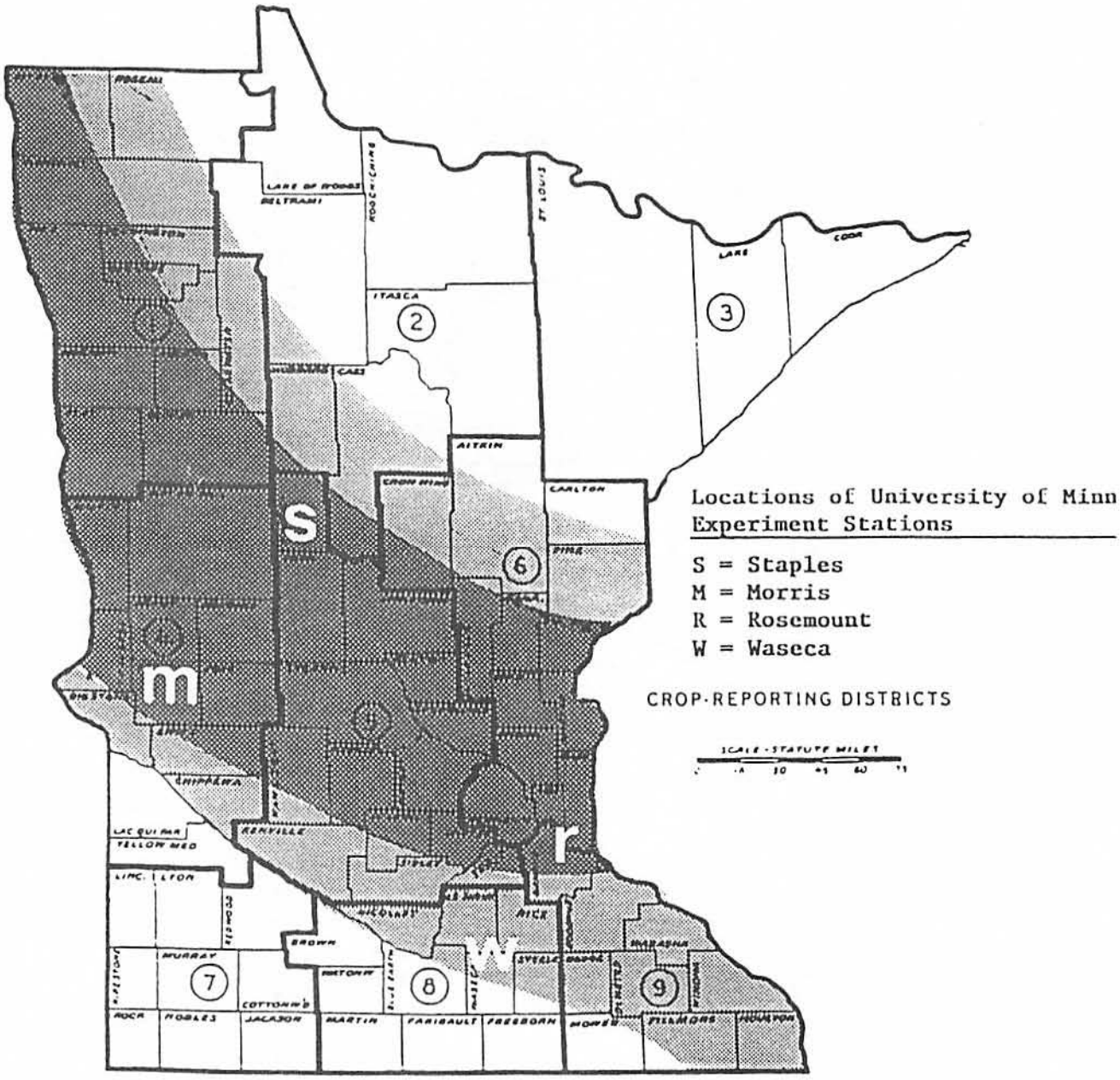


FIGURE 1. SOD SOIL DAILY MINIMUM TEMPERATURES.



Alfalfa winter injury observed during the spring of 1990 in Minnesota. Darkly shaded areas represent severe winter injury where most fields not planted to very winterhardy varieties were destroyed. Lightly shaded areas represent moderate winter injury. White areas had little or no injury.

FIGURE 2. ALFALFA WINTER INJURY.

DAILY PAN EVAPORATION ACROSS MINNESOTA

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

Evaporation pan measurements can serve as useful indicators of the water consumed by a crop when properly applied. The problem in the use of such data arises, of course, when the soil has been depleted of water and the plants transpire at a greatly restricted rate while the evaporation losses from the pan continues at a rapid rate. Therefore, the application of these data should be limited to those times when the soil water content is at least 50% of field capacity. Under such conditions an alfalfa crop will consume about 70-75% of the pan loss and an annual crop such as corn varies from about 40% of pan evaporation loss at the beginning of the season to nearly 85% at silking and tasseling time.

That the total daily evaporation from the pan is relatively constant across the state is shown in Fig. 1. Evaporation is known to be a conservative meteorological quantity, that is, it is a quantity which shows relatively little change. However, a greater difference than observed in Fig. 1 was our expectation.

The variation in the daily evaporation values as indicated by the standard deviation is shown in Fig. 2. A gradual decrease with the progression of the season from the peak was found in the long-term record, 1961-1990, at Lamberton. Comparison of the standard deviation change with time shown in Fig. 2 with the coefficient of variation in Fig. 3 indicates that the greatest relative variation actually occurs at the beginning and end of the season. The greater variation in mid-season, shown with the standard deviation in Fig. 2, is due to the larger evaporation values rather than actual variation in them.

The seasonal (April 21 - October 10) totals of evaporation at the four stations from 1961 to 1990 are shown in Fig. 4. The most obvious features are the very high evaporation amounts in 1976 and 1988. Both years represent drought periods that are still well remembered. The 1976 drought was more or less centered in southwestern Minnesota and eastern South Dakota while the one in 1988 was nearly nationwide. The excessive evaporation occurring in 1976 and 1988 was due, of course, to the very dry surroundings and the advection of dry air across the pans.

The average season (April 21 - October 10) totals and the individual maximums and minimums are listed in Table 1.

Table 1. Seasonal averages and extremes of evaporation pan losses, April 21 - October 10, 1972-1990.

Station	Average	Maximum,	Year	Minimum,	Year
Lamberton(1)	40.90 in.	56.95	1976	33.46	1972
Morris	41.10	58.22	1976	33.95	1985
St. Paul	39.31	51.41	1988	33.46	1972
Waseca (2)	41.35	53.33	1988	36.03	1972

(1) Average 1961-1990 equals 42.24 in.
(2) Average 1964-1990 equals 40.67 in.

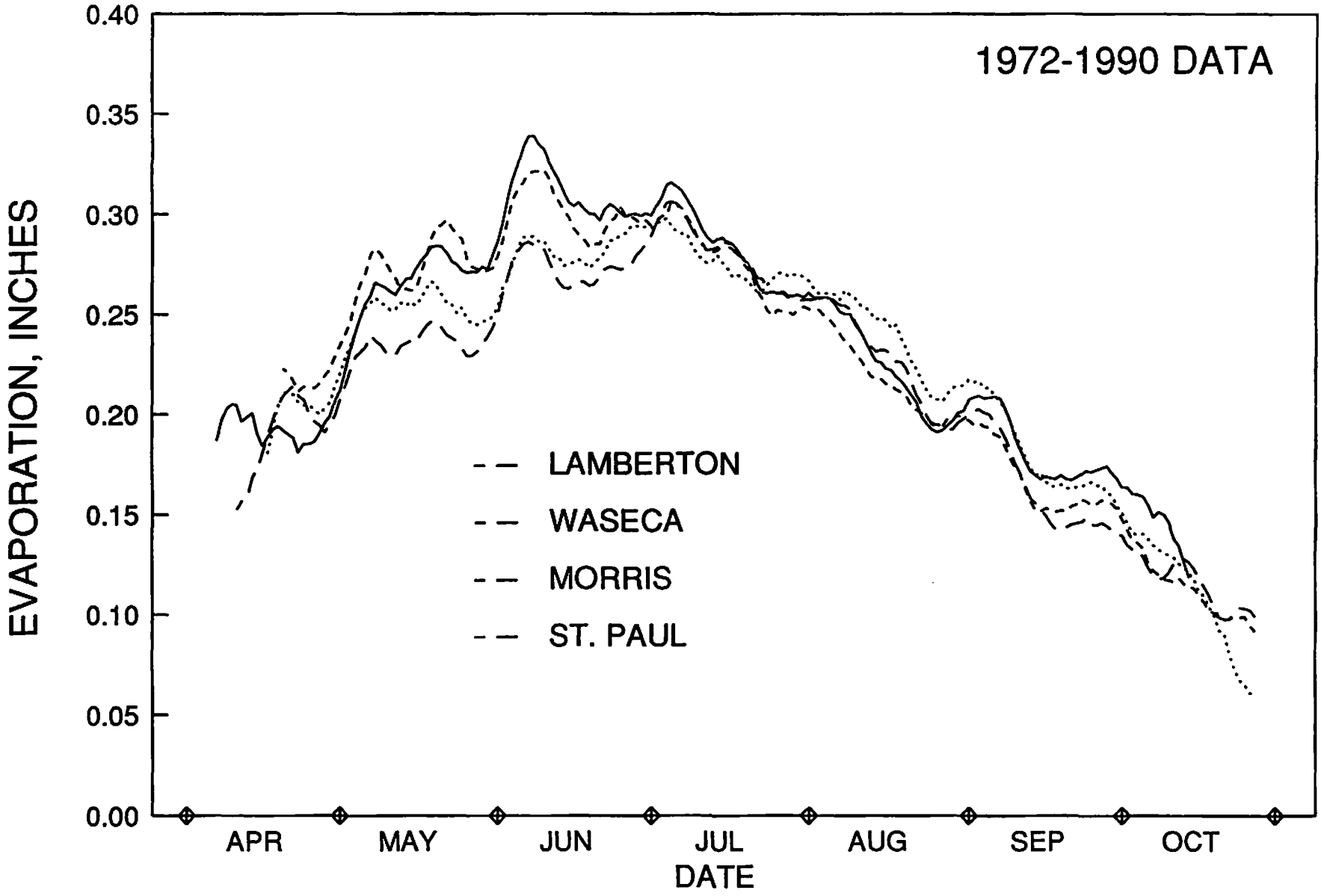


FIGURE 1. DAILY AVERAGE PAN EVAPORATION

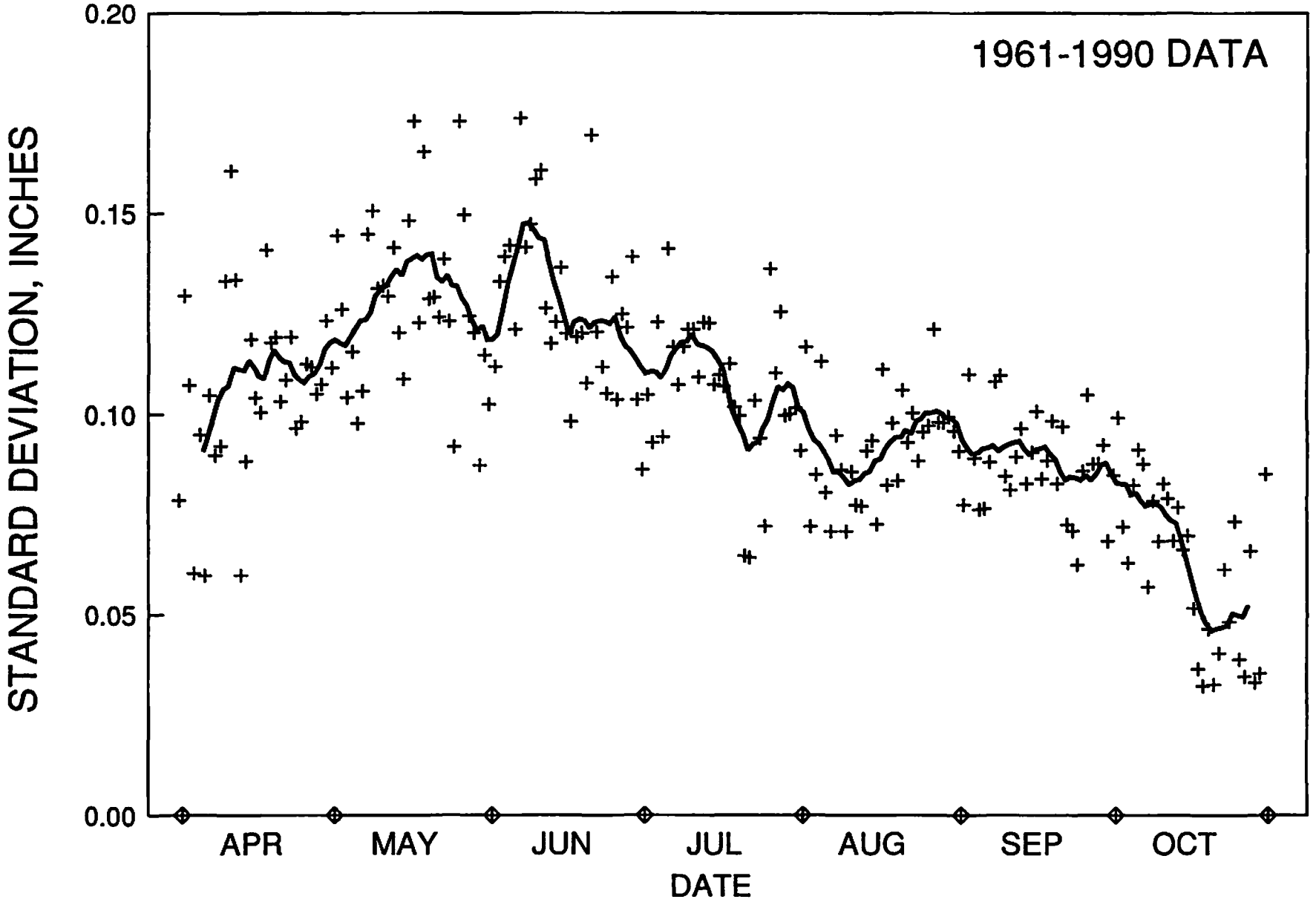


FIGURE 2. LAMBERTON DAILY PAN EVAPORATION

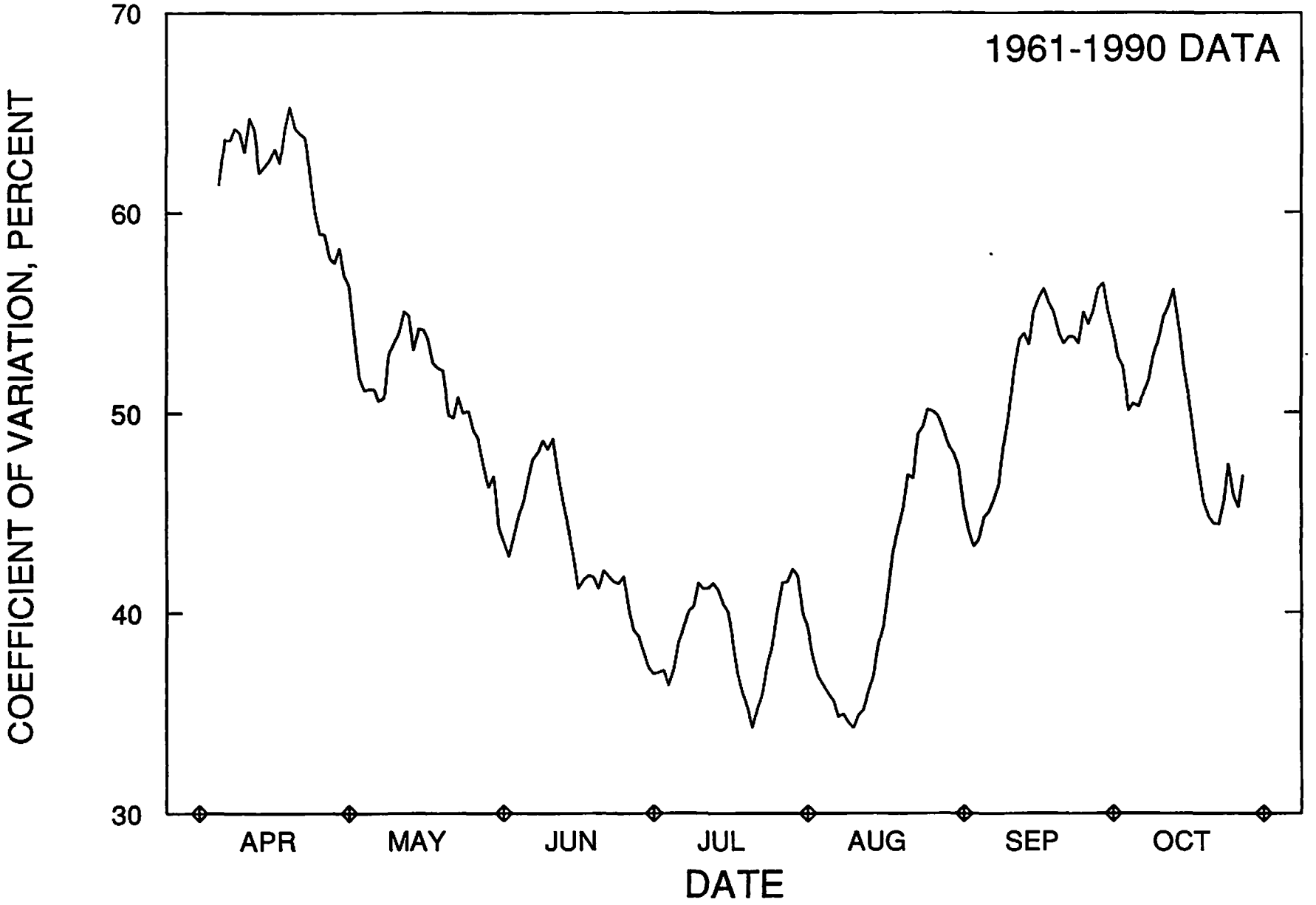


FIGURE 3. LAMBERTON DAILY PAN EVAPORATION

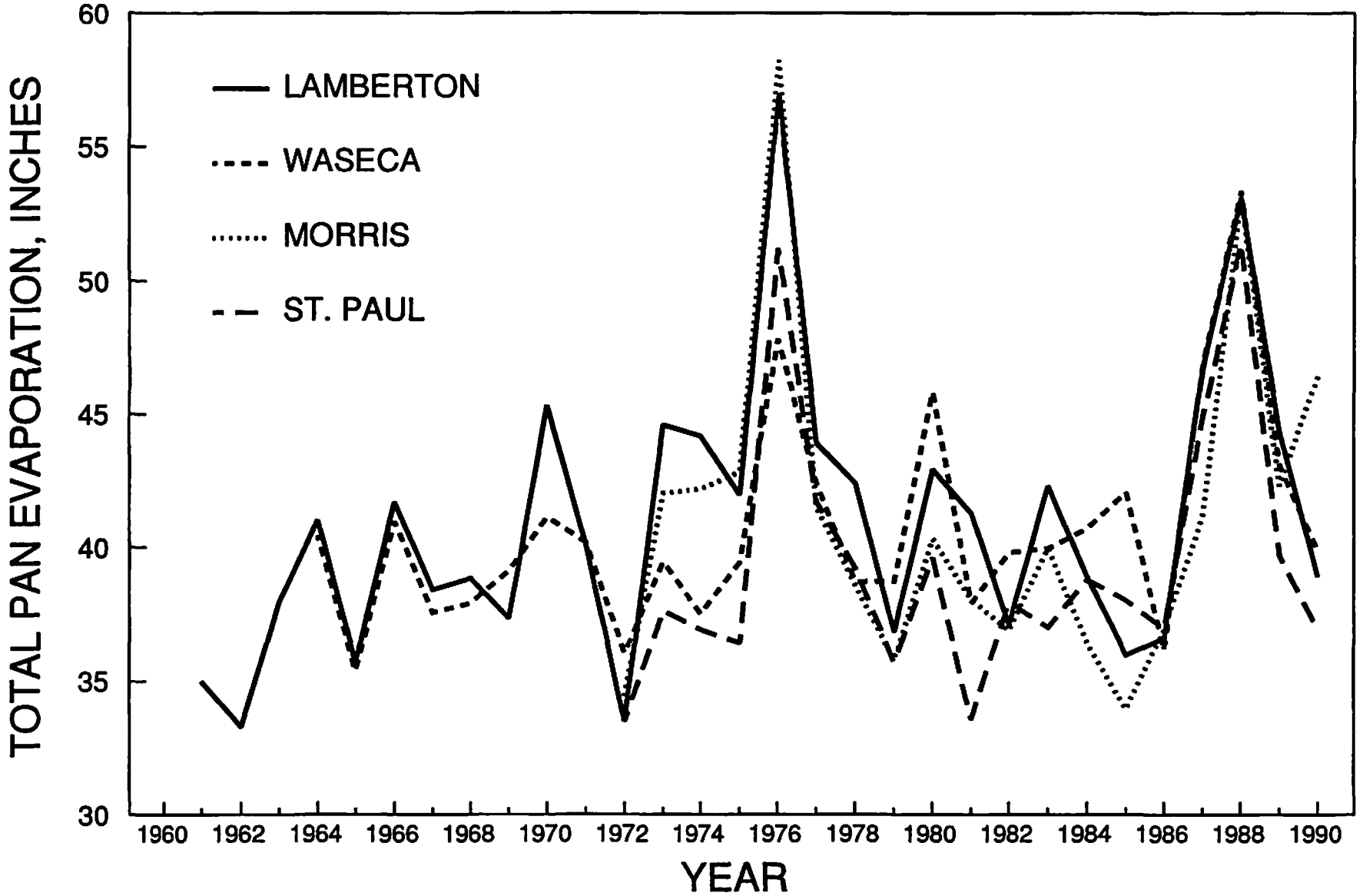


FIGURE 4. ANNUAL TOTAL PAN EVAPORATION

THE TEMPERATURE CHANGE ON DAYS FOLLOWING MEASURABLE PRECIPITATION

David L. Ruschy and Donald G. Baker

A question of some practical value for weather forecasters is this: following the passage of a front how many days is it before the really cold air arrives? For the horticulturist and gardener the question might be asked as: how much time in terms of covering sensitive vegetation do I have before covering the plants or otherwise protecting them. This is what we shall try to answer in this brief study.

In Minnesota the occurrence of precipitation is almost invariably associated with a frontal passage and a change in the air mass. Thus, a day with precipitation can also be taken to represent a day with a frontal passage. Of course, a front can pass without the occurrence of precipitation, but this is not frequent. It can also be argued that the great majority of the frontal passages counted this way are those of cold fronts. We chose this method of accounting for a frontal passage, that is, a day with precipitation, since a more suitable measure is not readily available to us.

The measure we used was the temperature of the days free of precipitation that followed a precipitation day. The precipitation day was defined as a day in which at least 0.01 inch was received. The number of days until the next precipitation day was counted and the maximum, minimum, and mean daily temperatures were recorded for each following day until the next precipitation day. The data used in this study are the 1891-1990 Minneapolis-St. Paul daily temperatures.

This 100 year record provides some extremely interesting results. For example, in Table 1 is listed both the total number of days on which measurable precipitation fell and the percent of possible days. The fewest precipitation days occurred in February and the greatest number in June. Spring, defined as March, April, and May, had the highest precent, 33.3%, with summer, June, July, and August, only fractionally lower. Winter had the lowest percentage of precipitation days, 27.1%.

The average decrease in temperature on the day following precipitation is shown in Table 2. It is interesting to note that the decrease was greater for the minimum temperature than for the maximum, and that it was much greater from November through March than the remainder of the year.

The January and July maximum, minimum, and mean temperature decrease and recovery following the precipitation day (and presumably the passage of a front and the introduction of a different air mass) are shown in Fig. 1. It is to be noted that the coldest mean daily temperature was on the first day following the precipitation and the return to higher temperatures began on the second day. It is obvious that the temperature change was greater in January than in July.

On the average the lowest maximum was found to occur on the first day following the precipitation day as shown in Table 3. However, the lowest minimum occurred on the second day in every month but February, March, April, and June. That the lowest temperature frequently occurred on the second day can be explained as follows. First, the coldest and least modified air introduced into the area by the fresh air mass is located near the center of this air mass rather than at its margins. A second reason is that some time is required for the clouds associated with the precipitation to move out of the region. As a result it is the second day that is commonly associated with the lowest minimum. The February, March, and April exceptions are believed to be due to the faster moving weather systems, common to the winter and early spring. For example, April is the month with the highest average wind speed.

Table 1. The number and percent frequency of days with at least 0.01 inch precipitation per month, season, and year, Minneapolis-St. Paul, 1891-1990.

Period	Days With Precipitation	Percent of Possible	Period	Days With Precipitation	Percent of Possible
January	855	27.6	July	938	30.3
February	727	26.0	August	953	30.7
March	926	29.9	September	943	31.4
April	988	22.9	October	833	26.9
May	1145	36.9	November	784	25.3
June	1156	38.5	December	853	27.5
Spring	3059	33.3	Autumn	2560	28.1
Summer	3047	33.1	Winter	2435	27.1
Annual	11,101	30.4			

Table 2. The mean decrease in the maximum, minimum, and average daily temperature on the day following one with at least 0.01 inch precipitation at Minneapolis-St. Paul, 1891-1989.

Month	Maximum	Minimum	Average	Month	Maximum	Minimum	Average
January	4.8°F	5.7°F	5.2°F	July	0.7°F	1.9°F	1.3°F
February	4.0	6.1	5.1	August	0.7	2.6	1.6
March	1.4	5.0	3.2	September	1.0	3.9	2.5
April	0.2	4.4	2.3	October	2.0	4.6	3.3
May	0.1	3.2	1.6	November	4.2	5.4	4.8
June	0.2	2.1	1.2	December	5.1	5.8	5.5

Table 3. The number of days after a day with at least 0.01 inch precipitation when the lowest temperature was recorded, MSP-WSO, 1891-1990.

Month	Maximum	Mean	Minimum	Month	Maximum	Mean	Minimum
January	1	1	2	July	1	1	2
February	1	1	1	August	1	1	2
March	1	1	1	September	1	1	2
April	1	1	1	October	1	1	2
May	1	1	2	November	1	1	2
June	1	1	1	December	1	1	2

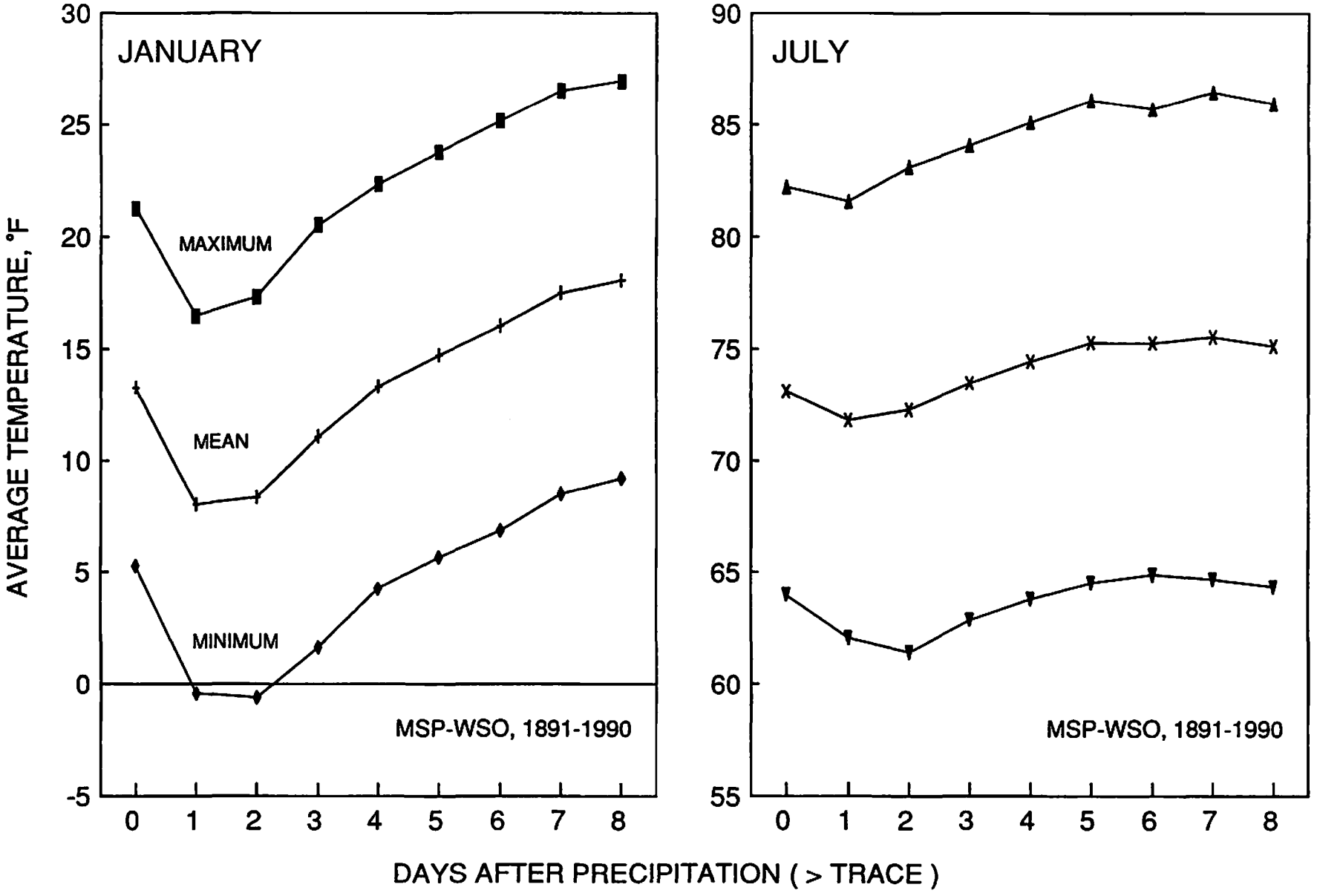


FIGURE 1. MEAN DAILY TEMPERATURES

THE CHANGE IN AIR AND DEEP (42 FEET) GROUND TEMPERATURES IN EASTERN MINNESOTA

Donald G. Baker and David L. Ruschy

In light of current concern over climate change high quality temperature records assume extra importance. As a result, the data from three Minnesota records are worthy of consideration. Although the duration of the records analyzed in this study are relatively short, their quality and source are such that they deserve our attention.

The data in this study were derived from two sources, all in or near St. Paul, Minnesota. The air temperatures are from the climatological observatory on the University of Minnesota St. Paul campus and from a National Weather Service Cooperative Network rural station (Farmington 3NW) 37 km south of the campus. This is termed the Eastern Minnesota record. At both stations the daily mean air temperatures were obtained from maximum and minimum thermometers housed in cotton region-type shelters. The deep ground temperatures (42 feet) were measured at the St. Paul campus and have been measured since 1963.

The mean annual temperatures of the three sets of data for the period 1963-1990 are shown in Fig. 1. The climatological observatory air temperature mean is 1.4°F warmer than the Eastern Minnesota mean, Table 1. This can be almost entirely ascribed to the 5 P.M. Central Standard Time observation time at the St. Paul observatory compared to the midnight observation at the Eastern Minnesota station. When the mean daily air temperatures are adjusted for the difference in the time of observation (midnight for the Eastern Minnesota record and 5 P.M. at St. Paul) the air temperature means for 1963-1990 period are nearly equal.

The difference between the deep ground and the Eastern Minnesota air temperatures, a nearly constant 3.0°F (Fig. 1 and Table 1), is a common difference between soil (ground) and air temperatures in continental climates. It is a demonstration of the fact that the atmosphere is warmed largely by the underlying (and warmer) surface rather than by the absorption of solar radiation.

Table 1. Means and linear trend slopes of the air and ground temperatures, 1963-1990

Temperature Source	Mean	Linear Trend Slope
Eastern Minnesota Air	43.9°F	0.063°F/year
Climatological Observatory Air	45.3	0.097
Climatological Observatory Ground	48.3	0.076

Temperature trends for the 1963-1990 period are in relatively close agreement as shown in Table 1. If continued over a century the increase for the Eastern Minnesota air temperatures would be 6.3°F while for the climatological observatory the air and the deep ground temperatures would be 9.7°F and 7.6°F, respectively. Of major interest is the appreciable rising trend in the deep ground temperatures, which are the least susceptible of the three to extraneous influences such as urban heating and industrialization.

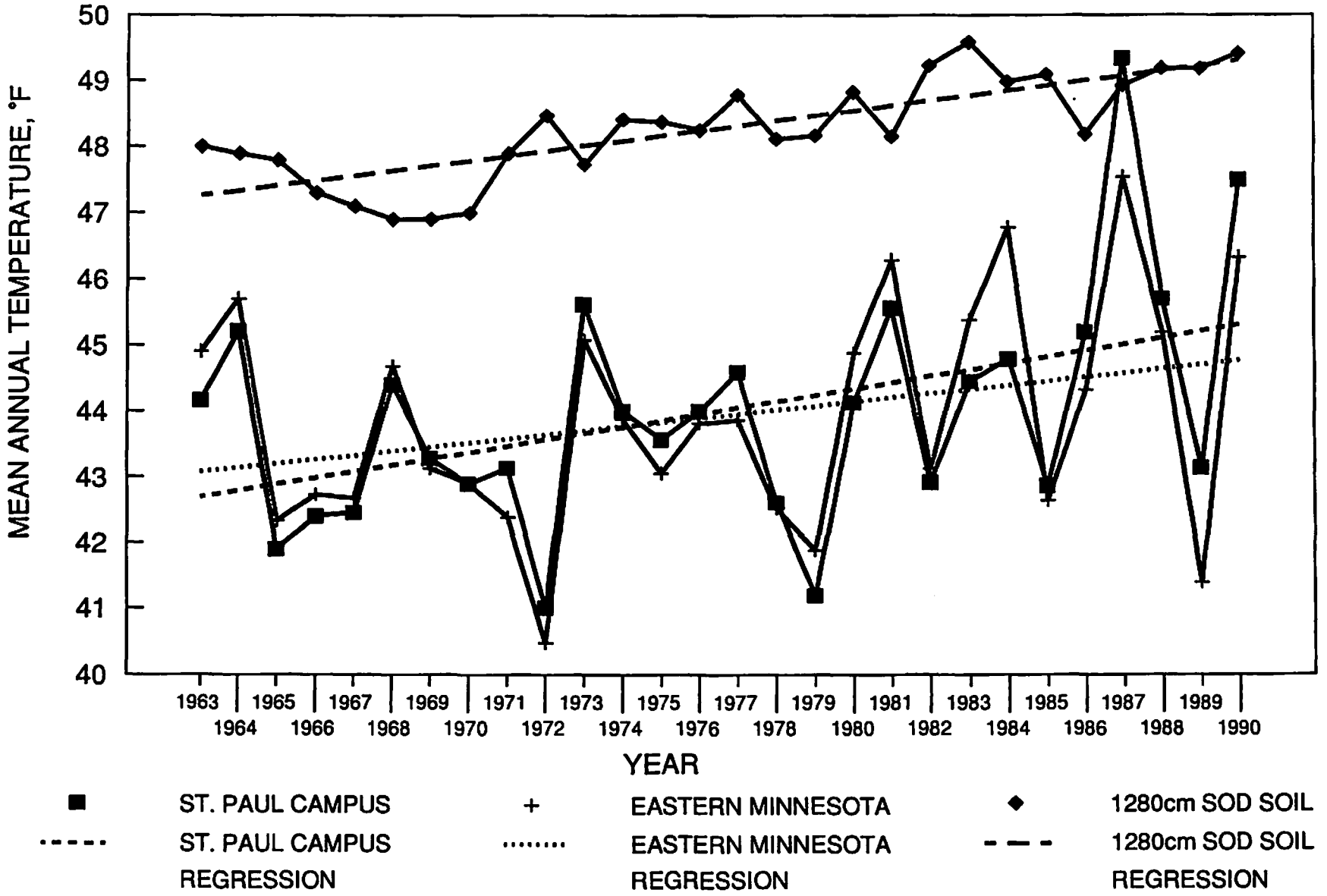


FIGURE 1. MEAN ANNUAL TEMPERATURE

NITROGEN AND BORON UTILIZATION BY POTATO: EFFECTS ON TUBER QUALITY AND IMPLICATIONS FOR GROUNDWATER QUALITY[1]

Carl Rosen, Florian Lauer, Dave Birong, and Louise America[2]

ABSTRACT: The third year of a three year field experiment was conducted at the Sand Plain Research Farm in Becker, MN to determine the effects of boron and nitrogen on yield and quality of Russet Burbank and Reddale potatoes. A secondary objective was to follow the movement of soil nitrate-N when different rates (70, 140, 280 lb N/A) of nitrogen fertilizer were applied. Boron applications (4 lb B/A) did not reduce the incidence of hollow heart or brown center. At the late harvest date (Aug. 2), boron applications increased yield of 7-14 oz tubers, but decreased the yield of tubers less than 7 oz. Vine and tuber yield increased linearly with increasing nitrogen rate at both harvest dates. In previous years tuber yield was generally lower at the early harvest date with increasing nitrogen fertilizer. The reason for the early response this year was due to lower nitrogen availability caused by leaching rains that occurred in June. Incidence of hollow heart or brown center was greatest in the largest size tubers. Nitrogen fertilizer increased hollow heart incidence in Russet Burbank tubers greater than 7 oz., but had no effect on internal quality of Reddale. Nitrogen uptake by the potato plant increased with increasing rates of nitrogen application. At the early harvest (vines killed July 25), levels in the vine ranged from 18 - 66 lb N/A while at the late harvest (vines killed September 5) levels ranged from 4 - 26 lb N/A. Levels in the tubers at the early harvest ranged from 30 - 75 lb N/A while at the late harvest levels ranged from 62 - 139 lb N/A. Nitrate levels in potato petiole sap monitored by quick tests generally correlated well ($r^2 = 0.86$) with petiole nitrates determined by conventional laboratory procedures. This correlation was not as high as in previous years. Significant soil nitrate movement was detected at all nitrogen application rates due to leaching rains that occurred in June and July.

The first aspect of this research dealt with nutritional factors affecting potato tuber quality. Preharvest internal tuber quality disorders such as brown center and hollow heart continue to be of great concern to potato growers. In some, but not all, cases brown center may precede hollow heart development. Susceptibility to these disorders has been related to interactions among environmental conditions, cultural practices, and potato cultivar, although the precise cause is still unknown. Cool soil temperatures and high soil moisture during tuber initiation tend to promote brown center. Conditions that promote large tubers such as wide plant spacing and high nitrogen fertilizer rates also appear to promote hollow heart. High potassium rates tend to decrease hollow heart incidence. In a year when hollow heart and/or brown center incidence were high in Russet Burbank and Reddale, there was virtually no sign of these disorders in Krantz. Reddale has a high degree of resistance to Verticillium wilt which would make this cultivar desirable to grow if the brown center problem could be alleviated. Because the sandy soils of central Minnesota usually test low in boron, the role of this element in brown center/hollow heart development was investigated. Nitrogen was also included in the study to determine whether tuber size could be regulated to improve internal tuber quality.

The second aspect of this research dealt with nitrogen utilization by potato. Potatoes grown on irrigated sandy soils are usually provided with high nitrogen rates to promote growth and yield. Recent concern about groundwater quality has raised questions about the fate of nitrogen 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 high levels of nutrition to maintain high yields. To obtain background information needed to assess whether significant nitrate leaching is occurring during potato production, we: 1) characterized nitrogen response by Russet Burbank and Reddale potato, and 2) monitored nitrogen in the soil and the plant over the growing season.

The overall objectives, therefore, were to: 1) determine the effects of boron and nitrogen nutrition on yield and preharvest tuber quality of Reddale and Russet Burbank potatoes 2) characterize nitrogen utilization by these cultivars over the growing season, and 3) monitor nitrate movement in the soil during the growing season. Reported here is the second year of a three year study.

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EXPERIMENTAL PROCEDURES

The experiment was conducted in Becker, MN at the Sand Plain Research Farm. The soil is a Hubbard loamy sand. The same site was used as in 1988. Selected soil chemical properties prior to planting in 1988 were as follows (0-6"): pH, 6.7; organic matter, 2.2%; phosphorus, 54 lb/A; potassium, 112 lb/A; boron, 0.2 ppm. Residual nitrate-N in the top 3 ft of soil was 7.0 lb/A. Prior to planting, 300 lbs/A 0-0-22 and 200 lbs/A 0-0-60 were broadcast and incorporated. Russet Burbank and Reddale "B" size potatoes were planted April 19, 1990 at a spacing of 36" between rows and 8" within the row for Reddale and 9" for Russet Burbank. At planting, all treatments received 875 lb/A 8-10-30 as a band application. Treatments included 2 cultivars, Russet Burbank and Reddale; 2 boron rates, 0 and 4 lb B/A; and three nitrogen rates, 70, 140, and 280 lb N/A. Boron was applied as Solubor in 2 split applications: 2 lb B/A as a broadcast application prior to emergence and 2 lb B/A as a sidedress one week after emergence. The low nitrogen treatment (70 lb N/A) was applied as a band at planting with no further N applied. The medium and high nitrogen treatments (140 and 280 lb N/A) were applied in three split applications: 70 lb N/A at planting, 35 or 105 lb N/A one week after emergence (May 22), and 35 or 105 lb N/A at hilling (June 7). Each plot consisted of four, 20 ft rows. The experimental design was a split plot with 4 replications. Nitrogen was the main plot and cultivar and boron were the subplots. Rainfall was supplemented with overhead irrigation to supply water needs. Monthly irrigation and rainfall through the season were as follows: April - 2.3" rainfall, no irrigation; May 3.9" rainfall, no irrigation; June - 9.2" rainfall, 0.8" irrigation; July - 6.9" rainfall, 3.9" irrigation; August - 7.0" rainfall, 3.2" irrigation. Figure 1 shows the daily precipitation through the growing season.

Leaf tissue (leaflets + petiole) and petiole (leaflets removed) samples were collected every two weeks starting one week after hilling for total nitrogen and nitrate-N determinations. Samples were analyzed using conventional laboratory methods. Nitrate-N was also determined in petiole samples in the field using EM Quant quick nitrate strips available from BME Lab Store, 2459 University Ave. St. Paul, MN 55114, 612-646-5339. The catalog number is CMS 158-659 and the price is $33.00 per 50 strips. For the quick nitrate test, 8 petioles from the most recently matured leaf from each plot were collected in the morning. Sap from the petiole was expressed into a small plastic dish using needle-nose pliers. The nitrate indicator strips were dipped into the sap and the time (in seconds) required to turn dark purple (based on a color chart provided with the kit) was recorded. The number of seconds to turn the strip dark purple was then converted to ug nitrate per ml of sap using a formula: nitrate (ug/ml) = $10^{(4.9-1.08\log t)}$ where t = seconds to reach dark purple. If the strip did not turn dark purple, a nitrate reading was recorded after two minutes using a color chart provided with the kit. All nitrate readings were converted to a nitrate-N basis.

Soil nitrate-N was determined in samples collected July 30 and September 6. Samples consisted of 3 cores from an individual plot taken to a depth of 3 ft. at 1 ft. increments. Two samples at each depth were collected from each plot: one from between rows and the other within rows. All samples were placed in plastic bags and kept moist at 40°F until analyzed. Nitrate and ammonium were extracted with 2 N KCl using a 5 g moist sample to 25 ml extractant ratio. Percent moisture was determined in each sample and ppm nitrate-N or ammonium-N were calculated on a dry weight basis. All results are expressed as pounds of nitrate-N or ammonium-N using the convention ppm X 2 = lb/A for a 6" furrow slice. Bulk density of each sampling depth was not determined, so lb/A values should be considered approximate. To calculate lbs nitrate-N/A, it was assumed that half the field was 'within row' and the other half 'between row'.

Nitrate-N in soil water was determined in samples collected weekly from suction tubes located in the row at depths of 2.5 ft. and 4.5 ft. This differed from last year when there were suction tubes only at the 2.5 ft. depth. Vines were cut and removed at two harvest dates: July 25 and September 5. Potatoes were mechanically harvested August 2 and September 14. Subsamples of vines and tubers were collected to determine nutrient uptake and to evaluate tuber quality.

RESULTS AND DISCUSSION

Tuber and Vine Yields. Boron applications had no effect on total tuber yield at either harvest date, but significantly increased tubers greater than 14 oz at the early harvest date and 7-14 oz tubers at the late harvest date (Table 1). Yield of tubers in the 4-7 oz at the late harvest date was lower with boron application. Boron may have reduced tuber initiation resulting in an increase in the larger tubers. Nitrogen rate had significant effects on tuber yield and size distribution. At both harvest dates yields of both cultivars increased linearly with nitrogen rate up to 280 lb N/A. These results are in contrast to previous years where early harvested potato yields decreased with nitrogen rate. Differences in N response between years are due to the high nitrate leaching

losses in 1990 compared to 1989 (see discussion below). Nitrogen fertilizer dramatically increased vine yield of both cultivars at both harvest dates Tables 2 and 3). Vines remained greener later in the season with the highest nitrogen rate, although dieback was noticeable in all treatments. Boron application had no effect on vine yield.

Tuber Quality. Effects of boron and nitrogen on tuber quality are presented in Table 4 for Reddale and Table 5 for Russet Burbank. Reddale had a higher incidence of tuber disorders than Russet Burbank. Regardless of fertilizer treatment or cultivar, greatest incidence of hollow heart and brown center occurred as tuber size increased. Boron applications had little effect on tuber quality in either cultivar or at either planting date. At the early harvest date there was actually an increase in brown center/hollow heart in Reddale when boron was applied. Under conditions of this experiment, boron does not appear to alleviate brown center or hollow heart disorders in potato. Nitrogen fertilizer did not affect incidence of hollow heart or brown center, within size categories for Reddale. However, since nitrogen increased the proportion of larger size tubers, there was actually a greater absolute number of tubers that exhibited the disorders as nitrogen rate increased. For Russet Burbank at the late harvest date, nitrogen fertilizer increased the incidence of hollow heart in tubers greater than 7 oz.

Nutrient Concentrations and Uptake. Signs of nitrogen deficiency (general plant yellowing) were apparent at the 70 and 140 lb N/A rate toward the middle of July. Signs of nitrogen deficiency at the highest nitrogen rate were not apparent until early August. Concentrations of nitrogen, magnesium, and zinc in leaves sampled June 27 increased linearly with nitrogen application (Table 6). Concentrations of potassium and boron decreased with increasing nitrogen application rates. Boron treatment increased boron concentration in the leaf tissue, but had no effect on any of the other nutrients. Reddale leaves sampled June 27 had higher concentrations of phosphorus, iron, manganese, zinc, and boron, but lower concentrations of calcium and magnesium.

Concentrations of boron in tubers increased slightly with boron application at both harvest dates (Tables 7 and 8). Other nutrient concentrations in the tuber were not consistently affected by boron. Concentration of nitrogen in tubers sampled at both harvest dates increased with increasing nitrogen application. Tuber concentrations of copper, manganese, and zinc increased with nitrogen fertilizer at both harvests. Tuber calcium increased with increasing nitrogen at the early harvest date. Tuber phosphorus and potassium decreased with increasing nitrogen at the late harvest. Reddale tubers had higher concentrations of nitrogen, phosphorus, magnesium, zinc, copper, and boron, but lower concentrations of calcium and manganese at both harvest dates. Lower calcium levels in the Reddale tuber may be associated with the higher incidence of brown center in this cultivar.

Nutrient uptake by vines at each harvest is presented in Tables 2 and 3. Boron application increased boron uptake by vines, but had little effect on uptake of other nutrients. At the early harvest, Reddale vines accumulated more phosphorus, manganese, zinc, and boron, but less nitrogen and magnesium than Russet Burbank. At the later harvest, Reddale vines generally accumulated more nutrients than Russet Burbank. Due to the increase in vine growth with nitrogen fertilizer, uptake of nitrogen and most other nutrients increased with nitrogen application at both harvests. Boron application increased uptake of boron, but had no effect on the uptake of other nutrients.

Nutrient uptake by tubers is presented in Tables 9 and 10. Boron applications increased boron uptake at both the early and late harvest, but did not have any consistent effect on uptake of other nutrients. At both harvest dates, Reddale accumulated greater quantities of phosphorus, zinc, copper, and boron, but lower quantities of potassium, calcium, iron, and manganese compared to Russet Burbank. Uptake of all nutrients in the tuber increased with increasing nitrogen rate due to increases in dry matter accumulation. Boron applications increased the content of boron in the tuber, but had no effect on the uptake of other nutrients.

A summary of total nitrogen uptake by vines and tubers at both harvest dates (averaged over boron rates) is presented in Table 11. Total nitrogen uptake increased as nitrogen fertilizer increased. By the early harvest date (June 25), approximately 80% of the nitrogen had been taken up. During the month of August, the average uptake of nitrogen by Russet Burbank and Reddale was 12 lb N/A and 18 lb N/A, respectively. Most of the nitrogen within the plant was redistributed from vine to tuber during the month of August. At the early harvest date, there was still substantial amounts of N in the vine (62 lb N/A in the high nitrogen treatment). If the potato crop is killed early, there could be a significant contribution of nitrogen to the following crop.

Rainfall Distribution and Soil and Water Nitrate Levels Through the Growing Season. Several leaching events occurred during the 1990 growing season at Becker (Figure 1). Most notably was the rainfall occurring 60 days after planting. As expected, variability in the soil nitrate levels was high, particularly at the higher nitrogen rate (Table 12). There was little difference among soil nitrate levels due to nitrogen fertilizer treatments at either sampling date. Presumably, most of the nitrate had been leached by late July. The results of nitrate concentrations in soil water at the 2.5 and 4.5 foot depths also support the fact that most of the nitrate had leached by July (Figures 2, 3 and 4). Nitrate-N levels at the 2.5 foot depth peaked in June (about 60 days after planting) and then declined. This peak at the 2.5 foot depth was followed by a similar peak at the 4.5 foot depth and corresponded to the 4.5" inch rainfall occurring on June 18 and 19 (Figure 1). The only difference among the different nitrogen rates in nitrate movement was the time taken to achieve background concentrations. For the 70 and 140 lb N/A rates most nitrate had leached out or had been taken up by the potato plant at the 2.5' depth by 85 days after planting. In contrast, nitrate was still present at the 2.5' foot depth in the 280 lb N/A treatment for about 20 more days. At the 4.5' depth, nitrate-N concentrations correlated well with nitrogen rate. The higher the nitrogen rate the higher the nitrate-N concentration and the longer the peak lasted. By the end of the season, nitrate concentrations at all depths and nitrogen treatments were low indicating that significant movement of nitrate beyond the root zone had occurred.

Leaf and Petiole Total Nitrogen and Nitrate-N Concentrations. Nitrogen status of the plant every two weeks starting at hilling as measured by various procedures is presented in Table 13. All procedures used were able to detect differences in nitrogen status of the plant due to nitrogen fertilizer application. Total nitrogen in the leaf tissue was nearly twice as great as corresponding nitrogen in the petiole (leaflets removed). This difference became larger as the season progressed. In contrast, nitrate-N was 4-5 times higher in petiole tissue compared to leaf (leaflets + petiole) tissue. These results indicate that different sets of diagnostic values would need to be used depending upon the tissue that was analyzed. One of the problems with tissue analysis in general is that it often takes several days to a week before results can be obtained. A quick test for nitrate would be desirable so that decisions about fertilizer need could be made without waiting. Quick test indicator strips for nitrate have been on the market for many years; however, even a potato plant deficient in nitrate will have enough nitrate in the petiole to cause the reading to be off scale. One way to circumvent this problem is to time (in seconds) how long it takes for the petiole sap to turn the indicator strip to a particular color. Using a formula (see procedures section), nitrate in the petiole sap can be calculated from the number of seconds to turn color. There was a relatively good correlation ($r^2 = 0.86$) between the quick test and the conventional nitrate test. The equation relating the two tests is $y = 10.89x + 1035$, where x is the concentration of nitrate-N in the petiole sap (ug/ml) from the quick test and y is the predicted nitrate-N concentration (ug/g or ppm) based on the water extract from dried tissue. This correlation is not as good as those obtained in previous years, although the equation is similar (see 1990 and 1989 Bluebooks). One of the problems with the quick test is that when tissue nitrate concentrations are high, the amount of time it takes to turn the appropriate color may be only 10 seconds. In this range only a few seconds can make a big difference in the nitrate-N calculation. There is also some subjectivity in the reading - one person may see the end point differently than another. An additional problem is that nitrate-N can vary with time of day and with environmental conditions. Readings should be taken in the morning if possible. Despite these cautions, with some practice a grower or consultant could monitor nitrate in the sap to determine qualitative nitrogen status of the plant. This may help make a further decision related to submitting a sample to the laboratory for more extensive tests.

In summary, based on three years of research, boron had no effect on internal tuber quality and had inconsistent effects on tuber yield. Nitrogen tended to increase tuber size which in turn increased the number of tubers having hollow heart. In nonleaching years, virtually all the nitrogen applied at the 70 and 140 lb N/A rate was taken up by the potato plant while significant N remained in the soil at the 280 lb N/A rate. In a leaching year (such as 1990), nitrogen movement beyond the root zone was detected in all nitrogen treatments. Tuber yield response to nitrogen was dependent on cultivar and rainfall.

Table 1. Yield of Russet Burbank and Reddale potatoes at two harvest dates as affected by nitrogen and boron.

			Harvest Date									
			August 3					September 12				
			Tuber Size				Total yield	Tuber Size				Total yield
Cultivar	B rate	N rate										
	lb B/A	lb N/A	<4oz	4-7oz	7-14oz	>14oz	(Cwt/A)	<4oz	4-7oz	7-14oz	>14oz	(Cwt/A)
Russet B	0	70	30.9	241.4	34.0	0.0	306.4	39.5	258.3	101.2	12.8	411.8
	0	140	32.2	276.1	58.0	0.0	366.2	26.7	286.8	173.1	17.5	504.1
	0	280	34.0	297.8	55.4	0.0	387.3	21.4	238.0	297.1	39.7	596.3
	4	70	29.4	259.9	33.2	0.0	322.5	35.1	244.6	114.6	0.0	394.3
	4	140	33.4	275.9	47.6	0.0	356.8	22.0	214.9	248.0	20.9	505.8
	4	280	35.3	275.0	52.6	0.0	362.9	19.8	244.3	289.7	30.6	584.4
Reddale	0	70	5.9	125.6	131.5	9.6	272.7	6.6	153.4	189.7	39.1	381.6
	0	140	12.1	135.2	175.5	28.5	351.3	9.0	117.5	282.5	94.1	503.2
	0	280	17.6	172.6	198.6	2.9	391.7	13.5	146.4	270.9	173.1	603.9
	4	70	8.6	128.8	155.0	16.6	308.9	4.5	113.6	255.1	27.5	400.7
	4	140	14.9	142.4	194.8	33.6	385.7	8.9	127.7	287.9	83.5	508.0
	4	280	11.5	144.1	203.7	22.9	382.2	10.9	118.6	283.4	181.6	594.5
Analysis of Variance												
Cultivar (C)												
	Russet B		32.5	271.0	46.8	0.0	350.3	27.4	247.8	204.0	20.3	499.4
	Reddale		11.7	141.5	176.5	19.0	348.8	8.9	129.5	261.6	98.6	498.7
Signif.			**	**	**	**	NS	**	**	**	**	NS
B rate (B)												
	0		22.1	208.1	108.9	6.8	345.9	19.5	200.1	219.1	61.5	500.2
	4		22.2	204.3	114.5	12.2	353.2	16.9	177.3	246.5	57.4	497.9
Signif.			NS	NS	NS	*	NS	*	*	*	NS	NS
N rate (N)												
	70		18.7	188.9	88.4	6.5	302.6	21.4	192.5	165.2	18.0	397.1
	140		23.1	207.4	119.0	15.5	365.0	16.7	186.7	247.9	54.0	505.3
	280		24.6	222.4	127.6	6.5	381.0	16.4	186.8	285.3	106.3	594.8
Signif.			*	*	*	NS	**	**	NS	*	**	NS
Linear			**	*	*	NS	**	**	NS	**	**	**
Quad.			NS	NS	NS	*	**	**	NS	NS	NS	NS
Interactions												
C X B			NS	NS	NS	*	NS	NS	NS	NS	NS	NS
C X N			NS	NS	NS	**	NS	**	NS	**	**	NS
B X N			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C X B X N			NS	NS	NS	NS	NS	NS	*	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 2. Vine yield and nutrient uptake as affected by boron and nitrogen - early harvest (vines killed July 25).

Cultivar	B rate	N rate	F.W. Yield	Nutrient									
				N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	lb B/A	lb N/A	T/A	lb/A					oz/A				
Russet B	0	70	6.87	20.5	2.4	76.9	24.6	9.9	9.65	4.69	0.72	4.90	0.67
	0	140	10.44	34.9	3.6	108.3	36.9	20.2	17.80	5.37	0.71	4.05	0.99
	0	280	16.24	70.7	5.5	156.1	43.4	29.6	23.76	9.30	1.22	4.87	1.36
	4	70	7.50	24.2	2.5	81.8	25.7	11.4	12.48	4.58	0.80	4.97	1.07
	4	140	10.38	32.7	3.3	111.3	37.0	20.5	21.62	6.16	0.84	3.48	1.77
	4	280	16.44	66.1	5.2	158.9	42.2	28.1	21.45	9.17	1.15	4.59	1.84
Reddale	0	70	5.87	17.7	3.8	70.6	22.2	6.9	11.10	5.06	0.82	3.76	0.72
	0	140	10.05	27.3	4.4	103.9	31.1	11.4	11.03	6.05	0.73	3.36	1.02
	0	280	16.00	57.2	7.0	162.3	44.8	21.9	22.26	11.07	1.59	4.44	1.46
	4	70	7.43	21.9	4.2	85.9	24.8	8.3	16.61	6.28	1.07	4.58	1.32
	4	140	11.30	30.7	5.1	118.7	34.3	13.7	18.04	7.20	1.12	3.86	1.82
	4	280	15.52	56.2	6.8	158.7	47.4	23.2	21.38	11.49	1.24	5.59	2.26
Analysis of Variance													
Cultivar (C)													
Russet B			11.31	41.5	3.8	115.5	35.0	19.9	17.79	6.55	0.90	4.48	1.28
Reddale			11.03	35.2	5.2	116.7	34.1	14.2	16.74	7.86	1.09	4.27	1.43
Signif.			NS	**	**	NS	NS	**	NS	**	**	NS	**
B rate (B)													
0			10.91	38.1	4.5	113.0	33.8	16.6	15.93	6.92	0.96	4.23	1.04
4			11.43	38.6	4.5	119.2	35.2	17.5	18.60	7.48	1.03	4.51	1.68
Signif.			NS	NS	NS	NS	NS	NS	NS	*	NS	NS	**
N rate (N)													
70			6.92	21.1	3.2	78.8	24.3	9.1	12.46	5.15	0.85	4.55	0.95
140			10.54	31.4	4.1	110.5	34.8	16.4	17.12	6.19	0.85	3.68	1.40
280			16.05	62.5	6.1	159.0	44.5	25.7	22.21	10.26	1.30	4.87	1.73
Signif.			**	**	**	**	**	**	NS	*	NS	NS	**
Linear			**	**	**	**	**	**	**	**	**	NS	**
Quad.			NS	*	NS	NS	**	NS	NS	*	NS	**	**
Interactions													
C X B			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C X N			NS	*	NS	NS	**	NS	NS	NS	NS	NS	NS
B X N			NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
C X B X N			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 3. Vine yield and nutrient uptake as affected by boron and nitrogen - late harvest (vines killed September 5).

Cultivar	B rate	N rate	F.W. Yield	Nutrient									
				N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	lb B/A	lb N/A	T/A	lb/A					oz/A				
Russet B	0	70	0.88	3.5	0.4	9.9	10.3	3.9	6.39	1.18	0.32	0.16	0.26
	0	140	1.95	6.3	0.7	22.0	16.1	8.5	9.69	1.65	0.47	0.19	0.44
	0	280	4.96	13.2	1.0	36.6	17.2	12.0	8.72	2.14	0.45	0.17	0.55
	4	70	1.06	4.7	0.5	15.1	11.4	4.5	8.56	1.50	0.38	0.16	0.31
	4	140	1.81	6.8	0.7	18.9	19.7	9.4	12.85	2.50	0.43	0.33	0.58
	4	280	4.75	14.5	1.1	37.7	18.2	12.9	11.22	2.39	0.71	0.17	0.64
Reddale	0	70	1.04	6.7	1.2	18.2	13.3	4.4	10.07	2.80	0.98	0.40	0.32
	0	140	1.66	11.5	2.1	20.8	28.9	8.5	25.32	5.28	0.93	0.85	0.56
	0	280	2.73	18.1	2.4	31.2	26.6	11.1	25.30	6.53	1.00	0.57	0.63
	4	70	1.04	7.0	1.2	14.3	15.6	4.7	12.46	3.12	0.93	0.46	0.37
	4	140	1.70	11.5	2.0	24.7	27.3	8.5	24.17	5.45	1.24	0.85	0.62
	4	280	2.66	26.1	3.0	40.9	35.7	15.7	26.35	7.29	1.06	0.52	0.90
Analysis of Variance													
Cultivar (C)													
	Russet B		2.56	8.2	0.8	23.4	15.5	8.5	9.57	1.89	0.46	0.20	0.46
	Reddale		1.80	13.5	2.0	25.0	24.6	8.8	20.61	5.08	1.02	0.61	0.57
Signif.			**	**	**	NS	**	NS	**	**	**	**	*
B rate (B)													
	0		2.20	9.9	1.3	23.1	18.7	8.1	14.25	3.26	0.69	0.39	0.46
	4		2.17	11.8	1.4	25.3	21.3	9.3	15.93	3.71	0.79	0.41	0.57
Signif.			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
N rate (N)													
	70		1.00	5.5	0.9	14.4	12.7	4.4	9.37	2.15	0.65	0.29	0.32
	140		1.78	9.0	1.4	21.6	23.0	8.7	18.01	3.72	0.77	0.55	0.55
	280		3.78	18.0	1.9	36.6	24.5	12.9	17.90	2.77	0.80	0.36	0.68
Signif.			**	**	**	*	NS	**	*	*	NS	NS	**
Linear			**	**	**	**	**	**	**	**	NS	NS	**
Quad.			NS	NS	NS	NS	**	NS	**	NS	NS	**	*
Interactions													
C X B			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C X N			**	NS	**	NS	*	NS	**	**	NS	NS	NS
B X N			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C X B X N			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 4. Incidence of brown center and/or hollow heart in Reddale potatoes at early and late harvests as affected by nitrogen and boron.

		Harvest Date					
		August 3			September 12		
		Tuber Size					
		4-7 oz	7-14 oz	> 14 oz	4-7 oz	7-14 oz	> 14 oz
B rate	N rate						
lb B/A	lb N/A	% Incidence					
0	70	2.0	18.5	43.3	4.0	22.5	54.0
0	140	0.0	30.5	88.5	3.0	27.0	78.7
0	280	0.0	15.3	12.5	3.0	16.0	59.0
4	70	2.0	10.0	63.8	3.0	27.8	79.3
4	140	1.0	18.0	63.3	1.0	35.0	69.0
4	280	7.0	14.3	81.5	5.0	13.5	68.0
B rate (B)							
	0	0.7	21.4	48.1	3.3	21.8	63.9
	4	3.3	14.1	69.5	3.0	25.4	72.1
Signif.		**	NS	NS	NS	NS	NS
N rate (N)							
	70	2.0	14.3	53.5	3.5	25.1	66.6
	140	0.5	24.3	75.9	2.0	31.0	73.9
	280	3.5	14.8	47.0	4.0	14.8	63.5
Signif.		NS	NS	NS	NS	NS	NS
Linear		NS	NS	NS	NS	NS	NS
Quad.		NS	NS	NS	NS	NS	NS
Interaction							
B X N		**	NS	*	NS	NS	NS

NS= not significant, * = significant at 5%, ** = significant at 1%.

Table 5. Incidence of brown center and/or hollow heart in Russet Burbank potatoes at early and late harvests as affected by nitrogen and boron.

		Harvest Date					
		August 3			September 12		
		Tuber Size					
		4-7 oz	7-14 oz	> 14 oz	4-7 oz	7-14 oz	> 14 oz
B rate	N rate						
lb B/A	lb N/A	% Incidence					
0	70	0.0	4.0	0.0	0.0	4.0	0.0
0	140	0.0	6.8	0.0	0.0	10.0	36.0
0	280	1.0	0.0	0.0	1.0	13.0	67.0
4	70	0.0	5.0	0.0	0.0	5.0	0.0
4	140	0.0	3.8	0.0	0.0	8.0	39.5
4	280	0.0	3.0	0.0	1.0	8.0	71.0
B rate (B)							
	0	0.3	3.6	0.0	0.3	9.0	34.3
	4	0.0	3.9	0.0	0.3	7.0	36.8
Signif.		NS	NS	--	NS	NS	NS
N rate (N)							
	70	0.0	4.5	0.0	0.0	4.5	0.0
	140	0.0	5.3	0.0	0.0	9.0	37.8
	280	0.5	1.5	0.0	1.0	10.5	69.0
Signif.		NS	NS	--	NS	NS	**
Linear		NS	NS	--	NS	*	**
Quad.		NS	NS	--	NS	NS	NS
Interaction							
B X N		NS	NS	--	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 6. Effect of nitrogen and boron on nutrient concentration in recently matured leaves sampled June 27 (74 days after planting).

Cultivar	B rate	N rate	Nutrient									
			N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	lb B/A	lb N/A	%					ppm				
Russet B	0	70	4.27	0.30	4.80	0.91	0.62	104	58	16	252	33
	0	140	4.95	0.32	4.44	0.88	0.69	94	55	14	54	26
	0	280	5.45	0.32	4.24	0.93	0.78	96	69	17	45	28
	4	70	4.15	0.31	5.41	0.90	0.62	129	71	14	159	62
	4	140	4.83	0.40	5.38	1.05	0.80	117	71	19	80	58
	4	280	5.39	0.33	4.10	0.92	0.79	94	73	17	47	42
Reddale	0	70	4.15	0.43	5.11	0.72	0.44	125	82	18	81	44
	0	140	4.32	0.41	4.51	0.73	0.46	115	73	19	45	36
	0	280	5.20	0.41	4.26	0.83	0.52	120	105	22	49	34
	4	70	4.14	0.45	5.01	0.67	0.44	135	94	20	157	65
	4	140	4.72	0.42	4.50	0.77	0.51	124	84	21	48	54
	4	280	5.51	0.42	3.81	0.84	0.53	113	91	22	24	50
Analysis of Variance												
Cultivar (C)												
	Russet B		4.84	0.33	4.73	0.94	0.73	105	66	16	103	41
	Reddale		4.67	0.42	4.54	0.76	0.48	122	88	20	67	47
Signif.			NS	**	NS	**	**	**	**	**	*	*
B rate (B)												
	0		4.72	0.36	4.56	0.83	0.58	109	74	17	87	34
	4		4.79	0.39	4.71	0.87	0.62	118	81	19	83	55
Signif.			NS	NS	NS	NS	NS	NS	NS	NS	NS	**
N rate (N)												
	70		4.18	0.38	5.07	0.79	0.52	123	77	17	162	50
	140		4.70	0.39	4.75	0.87	0.63	113	71	18	58	44
	280		5.39	0.37	4.10	0.88	0.66	106	85	19	41	38
Signif.			**	NS	**	NS	**	NS	NS	*	**	**
Linear			**	NS	**	NS	**	*	NS	NS	**	**
Quad.			NS	NS	NS	NS	NS	NS	NS	NS	**	NS
Interactions												
C X B			NS	NS	**	NS	NS	NS	NS	NS	NS	NS
C X N			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B X N			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C X B X N			NS	NS	NS	NS	NS	NS	NS	NS	**	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 7. Nutrient concentrations in tubers as affected by N rate and boron - early harvest (Aug. 3).

Cultivar	B rate	N rate	Nutrient									
			N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	lb B/A	lb N/A	%			ppm						
Russet B	0	70	0.52	0.22	1.85	268	869	90	10.7	6.9	2.9	4.9
	0	140	0.66	0.19	1.74	272	838	80	10.1	7.4	2.3	4.3
	0	280	0.86	0.20	1.91	388	940	88	11.7	10.2	3.6	5.4
	4	70	0.58	0.21	1.85	268	921	87	11.4	8.1	2.9	5.6
	4	140	0.63	0.19	1.75	283	845	93	10.7	7.8	2.3	5.4
	4	280	0.74	0.18	1.78	368	804	119	12.8	9.7	2.9	6.1
Reddale	0	70	0.62	0.29	2.08	153	937	74	7.7	9.3	4.0	6.7
	0	140	0.93	0.31	2.20	189	1180	75	9.0	11.6	4.3	7.8
	0	280	1.12	0.28	2.05	207	1007	88	9.7	14.0	4.9	6.8
	4	70	0.76	0.30	2.16	182	1009	76	8.7	10.7	4.2	7.6
	4	140	0.84	0.29	2.07	180	1044	78	8.6	11.4	4.2	7.2
	4	280	1.21	0.28	2.05	214	1049	87	9.8	13.3	4.5	7.7
Analysis of Variance												
Cultivar (C)												
	Russet B		0.66	0.20	1.81	308	870	93	11.2	8.3	2.8	5.3
	Reddale		0.92	0.29	2.10	188	1038	80	8.9	11.7	4.4	7.3
Signif.			**	**	**	**	**	**	**	**	**	**
B rate (B)												
	0		0.78	0.25	1.97	246	961	83	9.8	9.9	3.7	6.0
	4		0.80	0.24	1.94	249	946	90	10.3	10.2	0.9	6.6
Signif.			NS	NS	NS	NS	NS	*	NS	NS	NS	**
N rate (N)												
	70		0.62	0.25	1.98	218	934	82	9.6	8.8	3.5	6.2
	140		0.77	0.24	1.94	231	977	81	9.6	9.5	3.3	6.2
	280		0.98	0.24	1.95	294	950	96	11.0	11.8	4.0	6.5
Signif.			**	NS	NS	**	NS	NS	**	**	NS	NS
Linear			**	**	NS	**	NS	**	**	**	**	NS
Quad.			NS	NS	NS	NS	NS	NS	NS	NS	*	NS
Interactions												
C X B			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C X N			NS	NS	NS	**	*	NS	NS	NS	NS	NS
B X N			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C X B X N			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 8. Nutrient concentrations in tubers as affected by N rate and boron - late harvest (Sept 12).

Cultivar	B rate	N rate	Nutrient									
			N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
lb B/A	lb N/A		%			ppm						
Russet B	0	70	0.74	0.23	1.84	305	943	95	11.8	9.0	3.7	4.5
	0	140	0.87	0.22	1.80	301	1002	88	11.9	10.3	3.9	4.8
	0	280	0.90	0.20	1.63	294	876	87	11.9	11.0	4.2	4.2
	4	70	0.85	0.25	1.91	308	1005	99	12.7	10.0	3.7	5.0
	4	140	0.75	0.21	1.78	281	968	88	11.6	9.6	3.7	5.3
	4	280	1.13	0.20	1.71	309	995	95	13.1	12.4	4.8	5.4
Reddale	0	70	0.91	0.33	2.17	205	1141	66	9.6	13.3	5.9	7.1
	0	140	1.00	0.32	2.02	215	1121	71	9.5	13.5	5.3	6.3
	0	280	1.39	0.30	1.95	232	1171	86	11.9	17.4	7.1	7.2
	4	70	0.96	0.34	2.18	216	1175	80	10.5	13.8	5.8	7.7
	4	140	0.96	0.33	2.05	205	1204	73	9.9	14.5	6.5	7.5
	4	280	1.49	0.31	2.01	234	1236	92	12.3	17.1	6.8	7.8
Analysis of Variance												
Cultivar (C)												
	Russet B		0.87	0.22	1.78	300	965	92	12.2	10.4	4.0	4.9
	Reddale		1.12	0.32	2.06	218	1175	78	10.6	14.9	6.2	7.3
Signif.			**	**	**	**	**	**	**	**	**	**
B rate (B)												
	0		0.97	0.27	1.90	259	1042	82	11.1	12.4	5.0	5.7
	4		1.02	0.27	1.94	259	1097	88	11.7	12.9	5.2	6.4
Signif.			NS	NS	NS	NS	*	NS	NS	NS	NS	**
N rate (N)												
	70		0.87	0.29	2.00	259	1066	85	11.2	11.5	4.8	6.1
	140		0.90	0.27	1.90	251	1074	80	10.7	12.0	4.8	6.0
	280		1.23	0.25	1.80	267	1069	90	12.3	14.5	5.7	6.1
Signif.			**	**	**	NS	NS	NS	*	**	NS	NS
Linear			**	**	**	NS	NS	NS	*	**	**	NS
Quad.			*	NS	**	NS	NS	NS	NS	NS	NS	NS
Interactions												
C X B			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C X N			*	NS	NS	NS	NS	NS	NS	NS	NS	NS
B X N			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C X B X N			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 9. Nutrient uptake by tubers as affected by nitrogen and boron - early harvest (August 3).

Cultivar	B rate	N rate	Nutrient									
			N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	lb B/A	lb N/A	lbs/A					oz/A				
Russet B	0	70	33.3	14.2	118.8	1.7	5.6	9.3	1.10	0.71	0.30	0.51
	0	140	51.1	14.9	135.2	2.1	6.5	10.0	1.26	0.92	0.28	0.54
	0	280	64.5	14.8	142.7	2.9	7.0	10.6	1.41	1.22	0.43	0.65
	4	70	39.9	14.6	126.8	1.8	6.3	9.7	1.26	0.90	0.32	0.61
	4	140	47.2	14.0	131.3	2.1	6.3	11.2	1.29	0.94	0.28	0.64
	4	280	49.9	12.2	119.9	2.5	5.4	12.9	1.39	1.05	0.31	0.66
Reddale	0	70	29.5	13.5	97.8	0.7	4.4	5.6	0.59	0.70	0.30	0.50
	0	140	56.0	18.2	131.2	1.1	7.0	7.0	0.86	1.10	0.41	0.74
	0	280	68.1	16.9	124.5	1.3	6.1	8.6	0.95	1.36	0.47	0.66
	4	70	41.6	16.0	116.0	1.0	5.4	6.4	0.75	0.93	0.36	0.65
	4	140	52.8	18.1	130.0	1.1	6.6	7.8	0.86	1.15	0.43	0.72
	4	280	74.5	17.6	127.7	1.3	6.6	8.6	0.97	1.33	0.45	0.77
Analysis of Variance												
Cultivar (C)												
	Russet B		47.7	14.1	129.1	2.2	6.2	10.6	1.28	0.96	0.32	0.60
	Reddale		53.7	16.7	121.2	1.1	6.0	7.3	0.83	1.10	0.40	0.68
Signif.			NS	**	**	**	NS	**	**	**	**	**
B rate (B)												
	0		50.4	15.4	125.0	1.6	6.1	8.5	1.03	1.00	0.37	0.60
	4		51.0	15.4	125.3	1.6	6.1	9.4	1.09	1.05	0.36	0.68
Signif.			NS	NS	NS	NS	NS	*	NS	NS	NS	**
N rate (N)												
	70		36.1	14.5	114.8	1.3	5.4	7.8	0.93	0.81	0.32	0.57
	140		51.8	16.3	131.9	1.6	6.6	9.0	1.07	1.03	0.35	0.66
	280		64.2	15.4	128.7	2.0	6.3	10.2	1.18	1.24	0.42	0.69
Signif.			**	NS	*	**	NS	*	**	**	*	**
Linear			**	NS	**	**	*	**	**	**	**	**
Quad.			NS	**	**	NS	**	NS	NS	NS	NS	NS
Interactions												
C X B			NS	*	*	NS	NS	NS	NS	NS	NS	NS
C X N			NS	**	NS	**	*	NS	NS	NS	*	NS
B X N			NS	NS	**	*	*	NS	NS	*	NS	NS
C X B X N			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 10. Nutrient uptake by tubers as affected by nitrogen and boron - late harvest (September 12).

Cultivar	B rate lb B/A	N rate lb N/A	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
			Nutrient									
			lbs/A					oz/A				
Russet B	0	70	64.6	19.7	159.7	2.6	8.2	13.3	1.66	1.28	0.53	0.64
	0	140	93.1	23.2	193.0	3.2	10.8	15.0	2.05	1.78	0.67	0.83
	0	280	111.4	24.7	204.4	3.7	11.0	17.7	2.41	2.22	0.84	0.86
	4	70	69.3	20.0	156.4	2.5	8.2	13.3	1.70	1.33	0.50	0.66
	4	140	80.0	22.8	190.4	3.0	10.4	15.0	1.99	1.64	0.64	0.90
	4	280	139.2	25.2	211.0	3.8	12.2	18.7	2.58	2.46	0.96	1.06
Reddale	0	70	62.0	22.0	142.9	1.3	7.5	7.1	1.03	1.43	0.63	0.76
	0	140	85.5	27.2	172.1	1.8	9.5	9.6	1.29	1.84	0.72	0.86
	0	280	130.8	28.2	185.1	2.2	11.1	13.0	1.79	2.62	1.07	1.10
	4	70	63.5	22.3	145.1	1.4	7.8	8.6	1.13	1.49	0.63	0.82
	4	140	84.6	28.5	178.0	1.8	10.5	10.3	1.38	2.04	0.90	1.04
	4	280	138.6	29.2	187.2	2.2	11.5	13.9	1.85	2.56	1.03	1.16
Analysis of Variance												
Cultivar (C)												
	Russet B		92.9	22.6	185.8	3.1	10.1	15.5	2.07	1.78	0.69	0.82
	Reddale		94.1	26.3	168.4	1.8	9.7	10.4	1.41	2.00	0.83	0.96
Signif.			NS	**	**	**	NS	**	**	**	**	**
B rate (B)												
	0		91.2	24.2	176.2	2.5	9.7	12.6	1.71	1.86	0.74	0.84
	4		95.8	24.7	178.0	2.5	10.1	13.3	1.77	1.92	0.77	0.94
Signif.			NS	NS	NS	NS	NS	NS	NS	NS	NS	**
N rate (N)												
	70		16.7	21.0	151.0	2.0	7.9	10.6	1.38	1.38	0.57	0.72
	140		16.7	25.4	183.4	2.5	10.3	12.5	1.68	1.82	0.73	0.91
	280		23.0	27.0	196.9	3.0	11.5	15.8	2.16	2.47	0.97	1.04
Signif.			**	*	*	**	**	**	**	**	**	*
Linear			**	**	**	**	**	**	**	**	**	**
Quad.			NS	**	**	*	**	NS	NS	NS	NS	*
Interactions												
C X B			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C X N			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B X N			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C X B X N			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 11. Summary of nitrogen uptake by vines and tubers as affected by nitrogen fertilizer at early and late harvests.

Cultivar	N rate	Early Harvest			Late Harvest		
	lb N/A	Vines	Tubers	Total	Vines	Tubers	Total
		lb N/A					
Russet B	70	22.4	36.6	59.0	4.1	67.0	71.1
	140	33.8	49.2	83.0	6.6	86.5	93.1
	280	68.4	57.2	125.6	13.8	125.2	139.0
Reddale	70	19.8	35.5	55.3	6.8	62.7	69.5
	140	29.0	54.4	83.4	11.5	85.0	96.5
	280	56.7	71.3	128.0	22.1	134.7	156.8
Analysis of Variance							
Cultivar (C)							
	Russet B	41.5	47.7	89.2	8.2	92.9	101.1
	Reddale	35.2	53.7	88.9	13.5	94.1	107.6
Signif.		**	NS	NS	**	NS	NS
N rate (N)							
	70	21.1	36.1	57.2	5.5	64.8	70.3
	140	31.4	51.8	83.2	9.0	85.8	94.8
	280	62.5	64.2	126.7	18.0	130.0	148.0
Signif.		**	**	**	**	**	**
Linear		**	**	**	**	**	**
Quad.		*	NS	NS	NS	NS	NS
Interaction							
C X N		*	NS	NS	NS	NS	NS

NS = not significant, * = significant at 5%, ** = significant at 1%.

Table 12. Soil nitrate-N concentrations at the early (August 3) and late (Sept. 12) harvest.

N rate	Depth	Sampling Date			
		July 30		Sept. 6	
lb/A	Ft.	In Row	Betwn Row	In Row	Betwn Row
		lb NO_3-N/half acre[1]			
70	0-1	4.1 ± 1.3	3.2 ± 2.5	6.7 ± 2.1	5.1 ± 1.4
	1-2	2.1 ± 2.0	1.1 ± 0.9	2.2 ± 0.6	1.6 ± 0.6
	2-3	0.9 ± 0.5	2.1 ± 5.4	1.8 ± 1.3	2.0 ± 2.1
	Total	7.0 ± 2.9	6.3 ± 7.8	10.5 ± 3.3	8.4 ± 2.5
Total lbs NO_3-N/A in field[2]		13.3 ± 8.1		18.9 ± 4.6	
140	0-1	3.8 ± 1.3	2.7 ± 1.4	7.4 ± 2.1	6.0 ± 1.9
	1-2	1.3 ± 0.7	0.8 ± 0.2	2.6 ± 1.2	1.5 ± 0.4
	2-3	1.0 ± 0.5	1.2 ± 2.1	1.5 ± 0.9	1.1 ± 0.3
	Total	6.0 ± 1.3	4.6 ± 2.4	11.2 ± 3.7	8.4 ± 1.9
Total lbs NO_3-N/A in field		10.6 ± 2.2		19.6 ± 4.9	
280	0-1	8.2 ± 8.2	5.9 ± 10.0	8.0 ± 3.0	7.6 ± 3.2
	1-2	2.3 ± 1.3	1.1 ± 0.4	2.6 ± 1.4	1.7 ± 0.6
	2-3	1.4 ± 0.7	0.9 ± 1.0	1.4 ± 0.6	1.1 ± 0.4
	Total	11.8 ± 8.3	7.7 ± 10.9	11.7 ± 4.2	10.1 ± 3.6
Total lbs NO_3-N/A in field		19.5 + 19.0		21.8 + 7.6	

[1] Assumes half the field was row and the other half was between row.

[2] Total lbs NO_3-N/A in field = total in row plus total between row.

Table 13. Comparison of nitrogen and nitrate-N concentration in leaves (leaflet + petiole), petioles, and petiole sap at six sampling dates.

		Sampling Date														
		June 7 (49 DAP[1])					June 15 (57 DAP)					June 27 (69 DAP)				
				Water extractable NO_3-N		Quick test Sap NO_3-N			Water extractable NO_3-N		Quick test Sap NO_3-N			Water extractable NO_3-N		Quick test Sap NO_3-N
Cultivar	N rate	Kjeldahl N					Kjeldahl N					Kjeldahl N				
	lb N/A	Leaf	Petiole	Leaf	Petiole	Petiole	Leaf	Petiole	Leaf	Petiole	Petiole	Leaf	Petiole	Leaf	Petiole	Petiole
		---- % ----		--- ug/g ---		- ug/ml -	---- % ----		--- ug/g ---		- ug/ml -	---- % ----		--- ug/g ---		- ug/ml -
Russet B	70	4.79	3.33	2778	12270	1616	5.10	2.84	2145	10151	-	4.21	1.81	620	769	48
	140	5.02	3.45	3477	15182	1610	5.48	3.18	4106	16178	-	4.89	2.52	2008	10199	673
	280	5.54	3.74	4449	19843	1981	5.72	3.45	5358	22350	-	5.42	3.09	4375	18589	828
Reddale	70	4.89	3.34	3331	15513	1523	4.94	2.88	2116	11916	-	4.14	1.40	372	1597	91
	140	5.04	3.64	4183	18976	1464	5.76	3.76	3774	17923	-	4.52	2.11	2129	8988	680
	280	5.45	3.90	5315	21288	1798	6.14	4.02	4633	20007	-	5.36	2.89	4127	20362	993
Analysis of Variance																
Cultivar (C)																
Russet B		5.12	3.51	3568	15765	1736	5.43	3.16	3870	16227	-	4.84	2.47	2334	9852	516
Reddale		5.13	3.63	4276	18593	1595	5.61	3.53	3508	16615	-	4.67	2.13	2209	10315	588
Signif.		NS	*	**	**	*	*	**	NS	NS	-	NS	**	NS	NS	NS
N rate (N)	70	4.84	3.34	3054	13891	1569	5.02	2.86	2131	11033	-	4.18	1.60	496	1183	70
	140	5.03	3.55	3830	17079	1537	5.62	3.43	3940	17051	-	4.70	2.32	2068	9593	677
	280	5.50	3.82	4882	20565	1889	5.93	3.74	4996	21178	-	5.39	2.99	4251	19476	911
Signif.		**	**	**	**	NS	**	**	**	**	-	**	**	**	**	**
Linear		**	**	**	**	**	**	**	**	**	-	**	**	**	**	**
Quad.		NS	NS	NS	NS	*	**	**	**	**	-	NS	**	NS	**	**
Interaction																
C X N		NS	NS	NS	NS	NS	*	**	NS	*	-	NS	NS	NS	*	NS

NS = not significant, * = significant at 5%, ** = significant at 1%,
[1]DAP = Days after planting

Table 13. Con't.

Cultivar	N rate lb N/A	July 12 (84 DAP) Kjeldahl N Leaf (%)	July 12 Kjeldahl N Petiole (%)	July 12 Water extractable NO_3-N Leaf (ug/g)	July 12 Water extractable NO_3-N Petiole (ug/g)	July 12 Quick test Sap NO_3-N Petiole (ug/ml)	August 1 (104 DAP) Kjeldahl N Leaf (%)	August 1 Kjeldahl N Petiole (%)	August 1 Water extractable NO_3-N Leaf (ug/g)	August 1 Water extractable NO_3-N Petiole (ug/g)	August 1 Quick test Sap NO_3-N Petiole (ug/ml)	August 15 (118 DAP) Kjeldahl N Leaf (%)	August 15 Kjeldahl N Petiole (%)	August 15 Water extractable NO_3-N Leaf (ug/g)	August 15 Water extractable NO_3-N Petiole (ug/g)	August 15 Quick test Sap NO_3-N Petiole (ug/ml)
Russet B	70	3.24	1.21	6	256	6	2.74	1.02	42	27	2	2.90	1.18	37	30	1
	140	3.61	1.36	15	412	9	2.99	1.11	49	145	1	2.86	1.16	77	40	2
	280	4.66	2.48	2679	11791	658	3.97	1.70	343	1993	40	3.58	1.45	97	515	16
Reddale	70	3.63	1.08	8	55	3	2.97	1.02	57	434	2	2.94	1.07	61	181	3
	140	3.49	1.11	46	433	37	2.82	0.94	52	32	2	2.68	0.95	58	49	2
	280	4.45	2.21	1679	7692	366	3.46	1.17	96	741	41	3.25	1.11	62	529	1
Analysis of Variance																
Cultivar (C)																
Russet B		3.84	1.69	900	4153	224	3.23	1.28	144	722	14	3.12	1.26	70	195	6
Reddale		3.86	1.47	577	2727	135	3.08	1.04	69	402	15	2.96	1.05	60	253	2
Signif.		NS	**	*	**	*	*	**	**	**	NS	*	**	NS	NS	NS
N rate (N)																
	70	3.44	1.15	7	156	5	2.85	1.02	50	230	2	2.92	1.13	49	105	2
	140	3.55	1.23	31	423	23	2.91	1.02	51	89	2	2.77	1.05	68	44	2
	280	4.55	2.35	2179	9741	512	3.72	1.44	219	1367	40	3.42	1.28	79	522	9
Signif.		**	**	**	**	**	**	**	*	**	*	**	*	NS	**	NS
Linear		**	**	**	**	**	**	**	**	**	**	**	**	NS	**	*
Quad.		*	**	**	**	**	**	**	*	**	NS	**	**	NS	NS	NS
Interaction																
C X N		NS	NS	**	**	**	**	**	**	**	NS	NS	NS	NS	NS	**

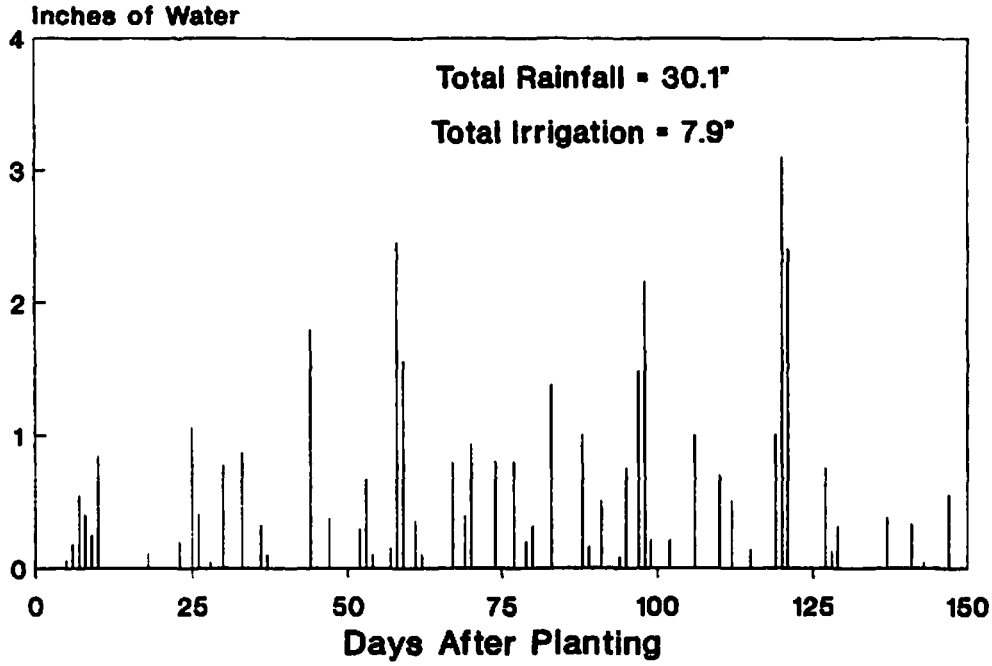

Figure 1. Rainfall and irrigation at Becker, MN during the 1990 growing season.

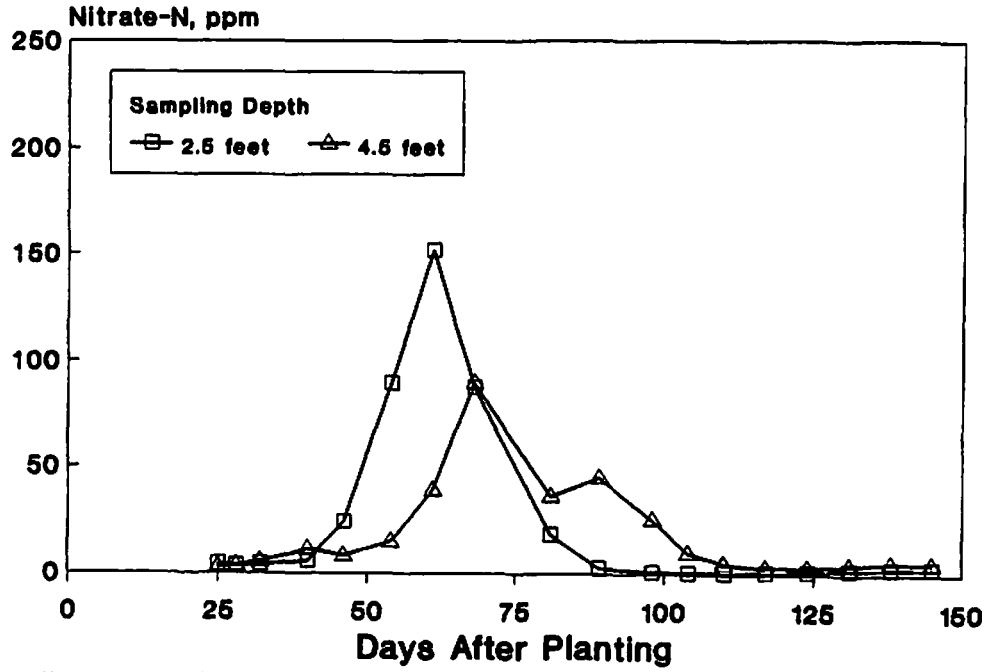

Figure 2. Nitrate-N concentrations in soil water at two depths during the 1990 growing season. Nitrogen application rate was 70 lb N/A.

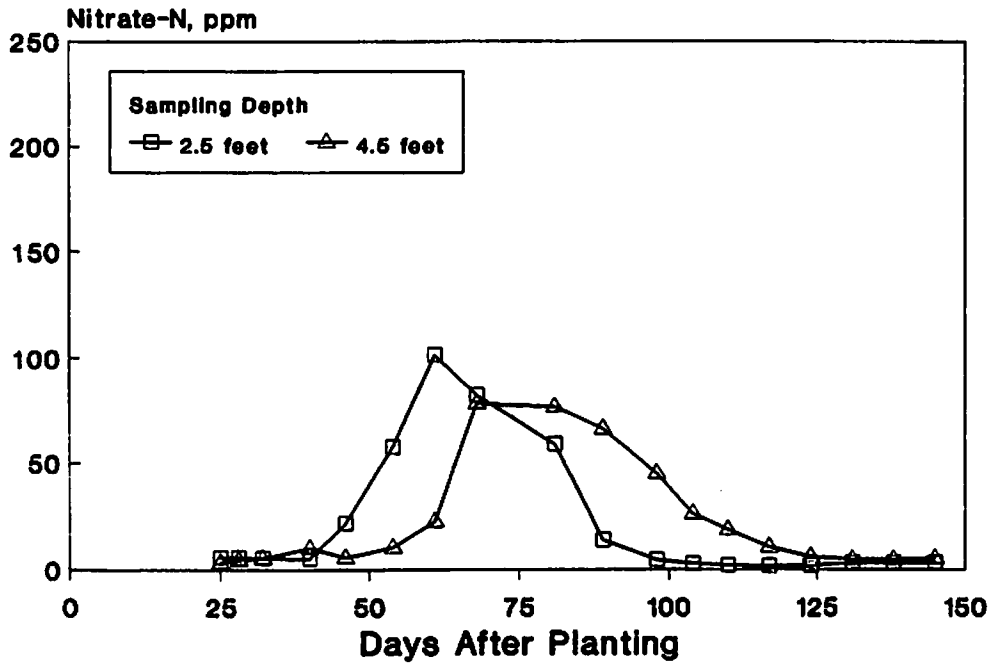

Figure 3. Nitrate-N concentrations in soil water at two depths during the 1990 growing season. Nitrogen application rate was 140 lb N/A.

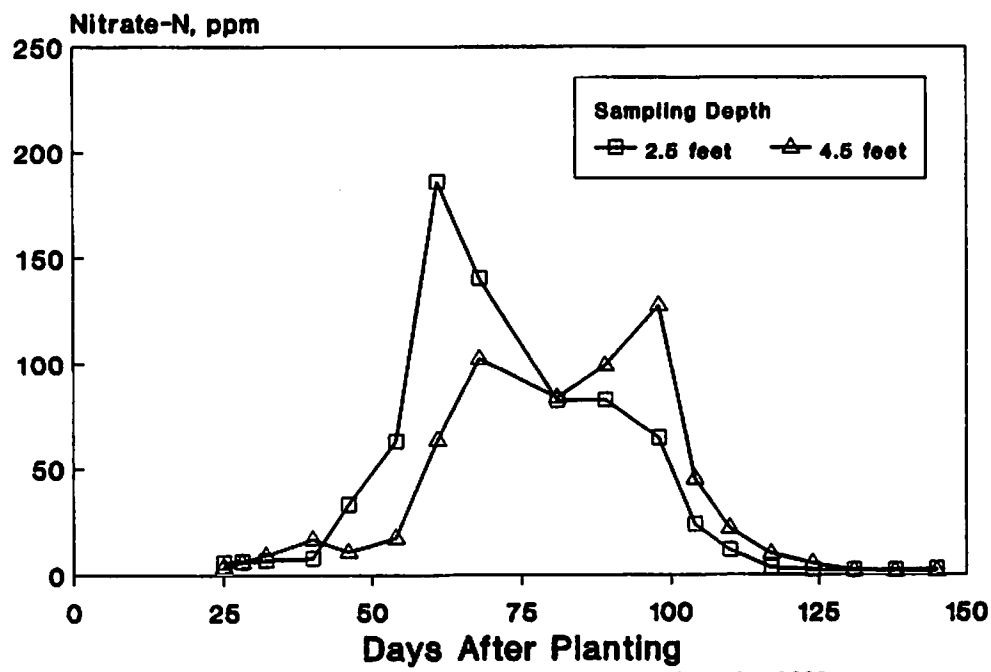

Figure 4. Nitrate-N concentrations in soil water at two depths during the 1990 growing season. Nitrogen application rate was 280 lb N/A.

PHOSPHORUS REQUIREMENTS FOR IRRIGATED POTATOES

Carl Rosen, Dave Birong, and Glenn Titrud

ABSTRACT: Response of irrigated potatoes to phosphate fertilizer on low and high P testing sites was evaluated. Phosphate fertilizer tended to increase tuber initiation and yield of 4-7 oz potatoes, but decrease the yield of 7-14 oz tubers. This effect was more pronounced on the low P site compared to the high P site. Total yield increased linearly with P fertilizer at the low P site, but was not affected by P fertilizer at the high P site.

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

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

	High P site	Low P site
Previous crop	Potato	Rye
Soil pH (1:1 - soil:water)	6.8	5.4
Bray P1	36 ppm	18 ppm
K - NH_4OAc	117 ppm	61 ppm

Prior to planting, 250 lb sul-po-mag in both sites, 100 lb K_2O in the high testing site and 200 lb K_2O in the low testing site were broadcast applied and incorporated. At planting, all plots received 70 lb N/A and 200 lb K_2O as a band application. Phosphate fertilizer (triple superphosphate, 0-46-0) treatments were as follows: 0, 50, 100, 150, 200, 250 lb P_2O_5/A. Phosphate fertilizer was applied as a band on either side of the row with a belt seed planter. Nitrogen was applied at the rate of 70 lb N/A at emergence (May 21), 70 lb N/A at hilling (June 6), and 30 lb N/A on July 25. Russet Burbank "A" size cut potatoes were planted on April 12, 1990 at a spacing of 36" between rows and 10" within the row. Each plot consisted of four 20' rows. 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 and dried for subsequent nutrient analysis. Whole plant samples (two plants per plot) were also collected on June 21 and separated into roots, vines, and tubers. Tubers were counted and plant parts were dried at 60C for two weeks and then weighed. The two middle rows of each plot were harvested on Sept. 18 and tubers were graded according to weight classes: <4 oz, 4-7 oz, 7-14 oz, and >14 oz.

RESULTS: Dry weight of vines, roots, and tubers sampled in June are presented in Tables 1 and 2. For the high P testing site, phosphate fertilizer did not significantly affect dry weight of the various plant parts although there was a trend toward increasing tuber weight with phosphate fertilizer application (Table 1). There was also a slight trend for increasing tuber number with phosphate fertilizer. For the low P testing site, phosphate fertilizer significantly increased vine and tuber dry weight as well as tuber number. From these early plant sample results, phosphate fertilizer appears to have some effect on tuber initiation. That is higher tuber numbers are correlated to an increase in phosphate fertilizer particularly when soil phosphorus is less than 20 ppm.

Elemental composition of the most recently matured leaf sampled in June is presented in Tables 3 and 4. Concentrations of leaf P generally increased with increasing phosphate fertilizer application. For the low testing P site, concentrations of leaf Ca and Mg also increased with phosphate fertilizer application which may be related to additions of these nutrients with the phosphate fertilizer. For the high P testing site leaf nutrient concentrations other than P were not affected by phosphate fertilizer.

Tuber yield and size distribution are presented in Tables 5 and 6. For the high P testing site, phosphate fertilizer did not affect total tuber yield, but did affect tuber size distribution. In general, phosphate fertilizer increased the yield of 4-7 oz tubers, but decreased the yield of 7-14 oz tubers. Similar results were also obtained in the low P testing site except that total yield also tended to increase with linearly with phosphate fertilizer. The increase in smaller sized tubers with P fertilization may be a reflection of the increase in tuber initiation observed in the June sampling. This study will be continued in future years to determine whether the trends observed are consistent over years.

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

Table 1. Effect of phosphate fertilizer on dry matter of vines, roots, tubers and number of tubers sampled June 21. High initial soil test P and high pH plot.

Phosphate Treatment	Plant Part			
	vines	roots	tubers	# of tubers[1]
lbs P_2O_5/A	-------g dry weight[1] -------			
0 lbs/A	84.5	14.0	47.0	22
50 lbs/A	83.5	16.0	64.5	20
100 lbs/A	105.0	22.5	57.0	24
150 lbs/A	89.0	21.0	65.0	22
200 lbs/A	83.0	17.5	50.0	26
250 lbs/A	115.0	25.0	74.0	29
Pr>F	0.13	0.33	0.16	0.45
Lin P_2O_5	NS	NS	NS	NS
Quad P_2O_5	NS	NS	NS	NS
Cubic P_2O_5	NS	NS	*	NS

NS = Nonsignificant, * = significant at 5%, ** = significant at 1%.
[1]Totals from two plants

Table 2. Effect of phosphate fertilizer on dry matter of vines, roots, tubers and number of tubers sampled June 21. Low initial soil test P and low pH plot.

Phosphate Treatment	Plant Part			
	vines	roots	tubers	# of tubers[1]
lbs P_2O_5/A	-------g dry weight[1] -------			
0 lbs/A	74.5	16.5	51.5	18
50 lbs/A	81.0	16.0	61.0	23
100 lbs/A	107.5	17.5	69.5	30
150 lbs/A	120.5	18.5	68.5	29
200 lbs/A	130.5	26.5	80.5	28
250 lbs/A	120.5	17.0	82.5	34
Pr>F	0.03	0.36	0.55	0.04
Lin P_2O_5	**	NS	++	**
Quad P_2O_5	NS	NS	NS	NS
Cubic P_2O_5	NS	NS	NS	NS

NS = Nonsignificant, ++ = significant at 10%, ** = significant at 1%.
[1]Totals from two plants

Table 3. Effects of phosphate fertilizer on nutrient concentration in leaf tissue (leaflets plus petioles). High initial soil test P and high pH. Leaves were sampled June 21, 1990.

Phosphate Treatment	Nutrient									
	NO3-N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
lbs P_2O_5/A	ppm	---------- %			----------	---------- ppm			----------	
0 lbs/A	2027	0.30	5.06	0.66	0.47	82	68	21	470	28
50 lbs/A	2314	0.32	5.15	0.65	0.49	89	67	21	512	28
100 lbs/A	2213	0.29	5.09	0.68	0.47	83	70	18	378	27
150 lbs/A	1666	0.33	4.72	0.66	0.48	84	61	21	546	28
200 lbs/A	1882	0.34	5.15	0.72	0.52	92	65	22	614	28
250 lbs/A	2214	0.36	5.18	0.72	0.48	87	68	20	468	27
Pr>F	0.44	0.18	0.23	0.90	0.60	0.21	0.83	0.23	0.26	0.94
Lin P_2O_5	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
Quad P_2O_5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cubic P_2O_5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 4. Effects of phosphate fertilizer on nutrient concentration in leaf tissue (leaflets plus petioles). Low initial soil test P and low pH. Leaves were sampled on June 21, 1990.

Phosphate Treatment	Nutrient									
	NO3-N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
lbs P_2O_5/A	ppm	%				ppm				
0 lbs/A	2012	0.26	4.82	0.52	0.34	97	113	17	175	20
50 lbs/A	2115	0.26	5.08	0.58	0.37	91	117	15	183	24
100 lbs/A	1706	0.24	4.64	0.54	0.35	78	128	15	144	22
150 lbs/A	1800	0.27	4.78	0.63	0.40	93	127	16	189	24
200 lbs/A	1866	0.26	4.88	0.61	0.39	93	115	14	148	24
250 lbs/A	1512	0.28	4.71	0.60	0.39	97	121	16	183	24
Pr>F	0.38	0.06	0.24	0.04	0.05	0.01	0.85	0.46	0.93	0.30
Lin P_2O_5	NS	NS	NS	**	**	NS	NS	NS	NS	NS
Quad P_2O_5	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
Cubic P_2O_5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = Nonsignificant, * = Significant at 5%, ** = Significant at 1%.

Table 5. Effect of phosphate fertilizer on yield of Russet Burbank potatoes grown on the high initial soil test P and high pH plot.

Phosphate Treatment	Tuber Size				
lbs P_2O_5/A	<4oz	4-7oz	7-14oz	>14oz	Total
	cwt/A				
0 lbs/A	16.3	217.7	377.5	74.6	686.1
50 lbs/A	17.9	251.1	366.3	62.4	697.6
100 lbs/A	26.4	241.6	344.4	65.8	678.1
150 lbs/A	19.4	255.4	349.0	76.3	700.1
200 lbs/A	17.6	304.1	310.1	72.3	704.0
250 lbs/A	21.9	229.5	363.3	72.9	687.5
Pr>F	0.28	0.04	0.55	0.99	0.91
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 = Nonsignificant, * = significant at 5%, ** = significant at 1%.

Table 6. Effect of phosphate fertilizer on yield of Russet Burbank potatos grown on the low initial soil test P and low pH plot.

Phosphate Treatment	Tuber Size				
lbs P_2O_5/A	<4oz	4-7oz	7-14oz	>14oz	Total
	cwt/A				
0 lbs/A	21.3	190.8	307.0	82.3	601.2
50 lbs/A	22.0	209.5	314.6	76.3	622.3
100 lbs/A	25.5	241.8	289.5	64.1	620.8
150 lbs/A	20.9	257.8	296.7	80.6	656.0
200 lbs/A	25.3	233.4	289.5	82.2	630.3
250 lbs/A	26.2	274.3	292.6	76.0	669.0
Pr>F	0.88	0.03	0.69	0.98	0.53
Lin P_2O_5	NS	**	NS	NS	++
Quad P_2O_5	NS	NS	NS	NS	NS
Cubic P_2O_5	NS	NS	NS	NS	NS

NS = Nonsignificant, ++ = significant at 10%, ** = significant at 1%.

INFLUENCE OF NITROGEN AND POTASSIUM FERTILIZATION ON THE YIELD AND NUTRIENT ACCUMULATION OF FOUR DIFFERENT CORN HYBRIDS-1990 [1]

G.L. Malzer, G.W. Randall and T.J. Graff [2]

ABSTRACT: How different corn hybrids utilize fertilizer and soil nutrients may impact the best fertilizer management that a producer should utilize. Previous research results would suggest that hybrids do vary in the total quantity and time period of nutrient absorption. The objectives of this experiment are to evaluate the N accumulation patterns of different corn hybrids and to determine the impact of N rate, K rate, and nitrification inhibitors on yield and N utilization. Results from both Becker and Waseca support the yields and N utilization differences between hybrids. Numerous interactions between hybrid with N and K and nitrification inhibitors treatments would suggest that management treatments can impact the utilization efficiency of a given corn hybrid.

Two experimental locations were selected in 1986 and two experiments established at each location. The two locations were: 1. The Sand Plains Research farm, Becker, MN (irrigated) and 2. Southern Experiment Station, Waseca, MN (dryland). In 1986 a corn and soybean experiment was started at each location to provide for a future corn-soybean sequence. In 1987 nitrogen (N) and potassium (K) treatments were established at each location.

The objectives of these experiments were to: 1. Determine the nutrient accumulation patterns of different corn hybrids grown in a high yield environment, and 2. Evaluate the impact of N, and K, and the use of nitrification inhibitors on the yields and nutrient utilization of different corn hybrids in a corn-soybean sequence.

Experimental Procedures

Becker: A total of 56 treatments with four replications were established on the corn experimental site. A split plot design was utilized with K as the main plot. Nitrogen and hybrid treatments were randomized within the main plots. A modified factorial arrangement consisting of four corn hybrids (Pioneer 3615, Pioneer 3737, LH74 x LH85, and DeKalb 485), three N rates (80, 160, and 240 lbs/A), two nitrification inhibitor treatments (w/wo N-Serve 0.5 lbs/A a.i.), and three K fertilizer rates (0, 100, and 200 lbs K/A) were utilized. To reduce the size of the experiment not all combinations of K were utilized with the 160 lbs/A N treatment.

Potassium treatments were broadcast before planting and incorporated by plowing. The four corn hybrids were planted on April 26th, at a population of 30,700 seeds/A in 30 inch rows. Starter fertilizer was applied as a side banded application of 160 lbs/A of 10-10-10. Weed control was accomplished by using Dual 8E (2.0 lbs/A a.i.) on April 27th and two cultivations May 30,and June 13th. Nitrogen treatments were applied as anhydrous ammonia on June 14th (4-5 leaf growth stage). The nitrification inhibitors were injected into the anhydrous ammonia flow stream and forced to passed through a bidirectional flow integrator prior to the manifold.

Plant and soil samples were taken four times during the growing season. Plant samples were taken on July 24th, August 14th, August 28th, and September 20th. These dates corresponded to the tasseling, milk stage R3, dent stage R5, and physiological maturity growth stages, respectively. Total plant material was removed from 20 ft^2 of plot area for each of the first three harvests and 100 ft^2 was sampled for the final sampling. For the first harvest total dry matter production was determined and subsamples collected for N concentration and determination of total N uptake. Plant samples obtained during the second, third and fourth harvest were separated into grain and stover samples. Separate determinations were made for dry matter production and N concentrations. Grain yields were adjusted to 15.5% moisture. Soil samples were collected from all N combinations at the high K rate for two hybrids (Pioneer 3615 and LH74 x LH85). Six to eight cores were taken from a depth of 0-1 ft through the anhydrous ammonia injection zone. All soil samples were analyzed for nitrate and ammonium N.

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2. Professors, and Asst.Scientist, respectively, Dept. of Soil Science, Southern Experiment Station, and Dept of Soil Science University of Minnesota.

The irrigation program began on June 27th and continued through September 5th with a total of 9.15 inches being applied through an overhead solid set irrigation system. An additional 29.31 inches of water was obtained during the growing season as rainfall.

Waseca: The corn experiment at Waseca was similar to that established at Becker except only 40 treatments were evaluated. The experimental design was a split plot with four replications. Treatments included a factorial combination of four hybrids (Pioneer 3615, Pioneer 3475, LH74 X LH51, AND LH74 X LH82), with two N rates (80 and 160 lbs N/A), two K rates (0 and 100 lbs K/A), and two nitrification inhibitor treatments (w/wo N-Serve 0.5 lbs/A). Two controls were included, both with no fertilizer N but one with K and one without.

Potassium treatments were applied in the fall of 1989. The four corn hybrids were planted on May 7th at a population of 32,000 seeds/A in 30 inch rows. Weed control was accomplished with a tank mix of Lasso (3.5 lbs/A a.i.) and Bladex (3 lbs/A a.i.) on May 8 and cultivation on June 21th. Nitrogen treatments were applied as anhydrous ammonia on July 2nd using procedures similar to that used at Becker. Rainfall accumulation over the growing season was 26.52 inches.

Plant and soil samples were taken four times (August 1st, August 29th, September 10th, and October 5th), during the growing season. (This coincides with the comparable growth stages at the Becker location.) The same plant sampling procedures were used at Waseca as was described for Becker. Soil samples were collected from the zero K rate (all N combinations) for two of the hybrids (Pioneer 3615 and LH74 x LH82) at each plant sampling.

General Results

The results from the Becker location are presented in tables 1-14, and a summary of the results from Waseca are presented in tables 15-28. The discussion presented here will not attempt to interpret all of the results. Major emphasis will be placed on the interpretations of the final yield and N utilization by the crop. A more thorough evaluation of the remaining data will be conducted at a later time.

Becker: Maximum grain yields obtained in 1990 were 185 bu/A. This yield level is approximately 35 bu/A less than comparable treatments in 1989. The four hybrids tested produced significantly different yields, with DeKalb 485 having the highest yield, P-3737 the lowest yield, and P-3615 and LH74 X LH85 intermediate in yield. Although there was more precipitation during the 1990 growing season than in 1989 there was no yield advantage associated with fertilizer nitrogen application in excess of 160 lbs N/A. Significant hybrid interactions suggested that DeKalb 485 and LH74 X LH85 were the highest yielding at the low N rate, but D-485 was more responsive to the highest rate of N fertilization. Pioneer 3615 was the only hybrid to exhibit a positive yield response to potassium fertilization. All hybrids tended to have reduced yields when 200 lbs/A of potassium was applied. Nitrification inhibitor application increased yields at the high rates of potassium fertilization, minimizing the negative effect of the highest rate of potassium fertilizer.

Waseca: When no fertilizer N or K was applied the final corn grain yield of Pioneer 3475 was more than 20 bu/A higher than any of the other hybrids tested. The yield of Pioneer 3475 was increased with 80 lbs N/A but did not increase further with 160 lbs N/A. All other hybrids tested required 160 lbs N/A to obtain top yield. When fertilized, all hybrids attained similar yield levels except LH74 X LH82 which was lower than Pioneer 3475. Potassium fertilization had relatively little influence on overall yield, but added potassium did allow for higher yields when the N rate was increased from 80 to 160 lbs/A. Nitrification inhibitor application reduced grain yields.

Table 1. Influence of N-rate, K-rate and nitrification inhibitors on stover N content, total N removal and dry matter production on four corn hybrids at **silking**. Becker, MN 1990.

N-Rate	Hybrid	Inh.	K-Rate	Whole Plant Silking Stover		
#/A			#/A	T/A	% N	#/A
80	Pioneer 3615	---	---	3.03	1.62	98.7
80		NS	---	2.81	1.67	94.3
80		---	100	2.88	1.23	71.9
80		NS	100	3.28	1.63	107.1
80		---	200	2.78	1.04	58.0
80		NS	200	2.97	1.11	65.6
160		---	200	3.18	1.90	120.6
160		NS	200	3.20	1.78	114.3
240		---	---	2.83	1.66	94.4
240		NS	---	2.77	2.11	116.2
240		---	100	3.05	2.09	127.5
240		NS	100	3.44	1.84	126.6
240		---	200	2.79	1.98	111.4
240		NS	200	2.94	1.84	108.4
80	Pioneer 3737	---	---	3.12	1.44	89.7
80		NS	---	2.93	1.97	114.6
80		---	100	2.97	1.63	96.5
80		NS	100	3.15	1.84	115.4
80		---	200	3.14	1.62	101.8
80		NS	200	3.20	1.22	77.8
160		---	200	3.31	1.77	116.8
160		NS	200	3.21	2.07	132.9
240		---	---	3.16	2.28	144.8
240		NS	---	3.43	2.17	147.6
240		---	100	3.45	1.95	134.7
240		NS	100	3.13	1.74	109.2
240		---	200	2.88	1.70	96.7
240		NS	200	3.07	1.95	120.3
80	LH74 X LH85	---	---	2.97	1.40	83.5
80		NS	---	3.13	1.93	120.7
80		---	100	2.94	1.50	87.6
80		NS	100	3.27	1.51	99.1
80		---	200	3.26	1.53	99.9
80		NS	200	3.21	1.66	106.8
160		---	200	2.98	1.93	115.1
160		NS	200	3.16	1.77	112.2
240		---	---	3.08	1.93	119.0
240		NS	---	3.17	2.03	128.7
240		---	100	2.99	2.03	119.7
240		NS	100	3.05	1.99	121.4
240		---	200	2.99	1.75	105.2
240		NS	200	3.19	2.02	127.9
80	DeKalb 485	---	---	3.31	1.82	121.1
80		NS	---	3.51	1.61	112.6
80		---	100	3.41	1.56	107.1
80		NS	100	3.22	1.48	95.7
80		---	200	3.17	1.36	85.9
80		NS	200	3.54	1.68	118.7
160		---	200	3.34	1.94	130.0
160		NS	200	3.23	1.89	121.8
240		---	---	3.42	1.81	123.8
240		NS	---	3.26	1.99	130.1
240		---	100	3.26	2.04	133.1
240		NS	100	3.31	1.80	119.3
240		---	200	2.99	2.07	123.4
240		NS	200	3.31	2.16	142.9

Table 2. Influence of N-rate, K-rate and nitrification inhibitors on grain yields and dry matter production on four corn hybrids at **milk stage R3**. Becker, MN 1990.

N-Rate	Hybrid	Inh.	K-Rate	Grain Yields	Dry Matter Production Grain	Stover	Cob	Total
#/A			#/A	Bu/A	T/A			
80	Pioneer 3615	---	---	39.0	0.92	3.86	0.72	5.50
80		NS	---	41.1	0.97	3.44	0.75	5.16
80		---	100	31.3	0.74	3.92	0.64	5.29
80		NS	100	40.4	0.96	3.88	0.69	5.53
80		---	200	42.5	1.01	3.55	0.64	5.20
80		NS	200	35.3	0.84	3.58	0.63	5.05
160		---	200	42.0	0.99	3.87	0.81	5.67
160		NS	200	44.4	1.05	3.84	0.67	5.56
240		---	---	44.4	1.05	3.91	0.80	5.75
240		NS	---	37.7	0.89	3.34	0.79	5.02
240		---	100	40.7	0.96	3.91	0.72	5.59
240		NS	100	42.0	0.99	3.82	0.75	5.56
240		---	200	40.8	0.97	3.44	0.61	5.02
240		NS	200	41.6	0.98	3.72	0.68	5.38
80	Pioneer 3737	---	---	54.5	1.29	3.64	0.68	5.61
80		NS	---	48.8	1.15	3.69	0.67	5.51
80		---	100	46.4	1.10	3.49	0.56	5.14
80		NS	100	46.0	1.09	3.86	0.56	5.51
80		---	200	48.2	1.14	3.31	0.51	4.96
80		NS	200	48.8	1.15	3.44	0.54	5.13
160		---	200	53.3	1.26	3.55	0.58	5.40
160		NS	200	52.7	1.25	3.77	0.65	5.67
240		---	---	46.6	1.10	3.77	0.68	5.54
240		NS	---	49.4	1.17	3.54	0.69	5.40
240		---	100	58.6	1.39	4.21	0.71	6.31
240		NS	100	51.3	1.21	3.64	0.65	5.51
240		---	200	56.9	1.35	3.72	0.65	5.73
240		NS	200	59.4	1.40	3.65	0.70	5.75
80	LH74 X LH85	---	---	54.9	1.30	3.74	0.65	5.69
80		NS	---	49.3	1.17	3.30	0.71	5.18
80		---	100	55.0	1.30	3.90	0.73	5.92
80		NS	100	48.3	1.14	3.69	0.68	5.51
80		---	200	55.1	1.30	3.86	0.69	5.85
80		NS	200	53.8	1.27	3.84	0.73	5.84
160		---	200	46.7	1.11	3.42	0.70	5.23
160		NS	200	57.4	1.36	3.87	0.78	6.01
240		---	---	49.7	1.18	3.48	0.73	5.38
240		NS	---	61.6	1.46	3.70	0.77	5.93
240		---	100	54.0	1.28	3.92	0.71	5.91
240		NS	100	41.9	0.99	3.44	0.74	5.17
240		---	200	53.3	1.26	3.66	0.77	5.70
240		NS	200	57.3	1.36	3.60	0.73	5.69
80	DeKalb 485	---	---	48.1	1.14	3.92	0.66	5.72
80		NS	---	50.6	1.20	4.34	0.73	6.27
80		---	100	42.2	1.00	3.64	0.60	5.23
80		NS	100	42.7	1.01	3.85	0.66	5.51
80		---	200	41.6	0.98	4.33	0.62	5.93
80		NS	200	46.4	1.10	3.96	0.66	5.72
160		---	200	41.5	0.98	3.90	0.65	5.53
160		NS	200	44.0	1.04	4.02	0.73	5.79
240		---	---	53.8	1.27	3.75	0.72	5.74
240		NS	---	51.3	1.21	3.81	0.73	5.75
240		---	100	48.0	1.13	4.19	0.68	6.01
240		NS	100	47.3	1.12	4.05	0.67	5.84
240		---	200	46.5	1.10	4.14	0.72	5.95
240		NS	200	40.9	0.97	4.07	0.71	5.74

Table 3. Influence of N-rate, K-rate and nitrification inhibitors on N content and total N removal on four corn hybrids at **milk stage R3**. Becker, MN 1990.

				N-Concentration			N-Removal			
N-Rate	Hybrid	Inh.	K-Rate	Stover	Grain	Cob	Stover	Grain	Cob	Total
#/A			#/A	----------%----------			----------#/A----------			
80	Pioneer 3615	---	---	0.73	1.83	1.01	56.2	33.7	14.6	104.4
80		NS	---	0.61	1.88	0.99	41.4	36.5	14.9	92.8
80		---	100	0.83	2.07	1.03	64.3	30.7	13.1	108.1
80		NS	100	0.93	1.88	1.06	72.2	35.8	14.7	122.7
80		---	200	0.74	1.76	0.85	52.8	35.3	11.1	99.2
80		NS	200	0.88	2.01	0.94	63.1	33.6	12.0	108.6
160		---	200	0.97	2.12	0.98	74.8	42.1	15.8	132.8
160		NS	200	0.88	1.99	0.88	67.6	41.8	12.1	121.5
240		---	---	0.91	1.98	1.02	71.3	41.5	16.2	129.0
240		NS	---	1.11	2.28	1.08	74.9	40.2	17.1	132.1
240		---	100	1.10	1.88	0.95	86.8	36.0	13.8	136.6
240		NS	100	0.91	2.11	0.88	70.2	42.0	13.1	125.2
240		---	200	1.07	1.69	1.01	73.6	32.6	12.4	118.6
240		NS	200	0.88	2.04	1.12	65.7	39.9	15.1	120.7
80	Pioneer 3737	---	---	0.68	1.88	0.83	49.3	48.1	11.3	108.6
80		NS	---	0.75	1.89	0.82	54.7	43.6	11.2	109.6
80		---	100	0.79	1.78	0.80	54.9	38.8	9.1	102.9
80		NS	100	0.78	1.86	0.83	59.9	40.6	9.3	109.8
80		---	200	0.57	1.64	0.75	37.4	37.6	7.7	82.7
80		NS	200	1.00	1.71	0.87	69.3	39.5	9.3	118.1
160		---	200	1.10	1.93	0.74	78.3	48.6	8.6	135.5
160		NS	200	0.92	1.98	0.79	69.2	49.4	10.2	128.7
240		---	---	1.15	2.14	0.82	85.9	46.9	11.1	144.0
240		NS	---	0.93	2.09	0.88	66.6	48.9	12.0	127.5
240		---	100	0.73	1.99	0.84	61.9	55.2	12.1	129.2
240		NS	100	0.93	1.80	0.84	67.8	43.1	10.9	121.7
240		---	200	0.98	1.94	0.96	72.6	52.2	12.6	137.4
240		NS	200	1.01	1.97	0.73	73.4	55.3	10.2	138.9
80	LH74 X LH85	---	---	0.83	1.60	0.79	62.3	41.5	10.3	114.1
80		NS	---	0.75	1.53	0.81	49.1	36.0	11.6	96.6
80		---	100	0.62	1.64	0.77	47.6	42.9	11.2	101.7
80		NS	100	0.74	1.64	0.87	54.9	37.6	11.8	104.3
80		---	200	0.80	1.52	0.74	61.7	39.5	10.3	111.5
80		NS	200	0.75	1.53	0.74	57.1	38.9	10.8	106.8
160		---	200	0.99	1.89	0.87	67.7	41.9	12.3	121.8
160		NS	200	0.92	1.82	0.82	71.2	49.3	12.8	133.3
240		---	---	1.01	1.86	0.90	70.0	43.7	13.0	126.7
240		NS	---	0.65	1.76	0.75	46.6	51.5	11.4	109.5
240		---	100	0.99	1.94	0.83	77.2	49.4	11.7	138.4
240		NS	100	1.08	1.69	0.81	74.5	34.0	11.8	120.4
240		---	200	1.00	1.89	0.78	73.6	47.6	12.0	133.2
240		NS	200	1.24	1.81	0.83	88.3	49.0	12.1	149.4
80	DeKalb 485	---	---	0.74	1.73	0.74	58.3	39.1	9.9	107.3
80		NS	---	0.90	1.76	0.79	78.0	41.3	11.5	130.9
80		---	100	0.91	1.64	0.80	66.2	32.6	9.6	108.3
80		NS	100	0.54	1.65	0.73	41.7	32.8	9.5	84.0
80		---	200	0.91	1.59	0.77	78.6	31.6	9.7	119.9
80		NS	200	0.95	1.78	0.74	74.0	38.9	9.9	122.8
160		---	200	1.00	2.07	0.75	77.9	40.6	9.7	128.3
160		NS	200	0.77	1.97	0.70	62.1	41.1	10.3	113.5
240		---	---	0.94	1.94	0.77	68.7	49.0	11.0	128.7
240		NS	---	0.85	1.90	0.77	63.8	45.9	11.3	120.9
240		---	100	0.93	1.85	0.77	77.5	41.8	10.4	129.7
240		NS	100	0.99	1.97	0.83	79.3	43.8	11.2	134.3
240		---	200	1.01	1.93	0.85	83.3	42.4	12.2	137.9
240		NS	200	1.00	2.05	0.83	81.3	39.6	11.7	132.6

Table 4. Influence of N-rate, K-rate and nitrification inhibitors on grain yields and dry matter production on four corn hybrids at **dent stage R5**. Becker, MN 1990.

N-Rate	Hybrid	Inh.	K-Rate	Grain Yields	Dry Matter Production Grain	Stover	Cob	Total
#/A			#/A	Bu/A	T/A			
80	Pioneer 3615	---	---	117.4	2.78	3.12	0.79	6.69
80		NS	---	104.2	2.47	2.96	0.82	6.25
80		---	100	104.1	2.46	3.11	0.83	6.41
80		NS	100	113.8	2.69	3.18	0.79	6.66
80		---	200	103.6	2.45	2.88	0.72	6.05
80		NS	200	99.6	2.36	2.89	0.68	5.93
160		---	200	118.3	2.80	3.14	0.82	6.76
160		NS	200	124.5	2.95	3.29	0.87	7.11
240		---	---	117.7	2.78	3.08	0.83	6.70
240		NS	---	123.6	2.92	3.30	0.94	7.17
240		---	100	116.8	2.76	3.24	0.86	6.86
240		NS	100	117.7	2.79	3.49	0.86	7.13
240		---	200	121.7	2.88	2.94	0.86	6.69
240		NS	200	115.6	2.73	3.26	0.90	6.90
80	Pioneer 3737	---	---	118.4	2.80	2.86	0.66	6.33
80		NS	---	107.6	2.55	3.12	0.68	6.35
80		---	100	124.0	2.93	2.88	0.73	6.54
80		NS	100	107.2	2.54	2.75	0.62	5.90
80		---	200	109.8	2.60	2.60	0.57	5.77
80		NS	200	113.1	2.68	2.94	0.61	6.22
160		---	200	144.7	3.42	3.25	0.79	7.47
160		NS	200	124.1	2.94	3.04	0.72	6.69
240		---	---	124.9	2.96	3.16	0.78	6.89
240		NS	---	127.2	3.01	3.11	0.83	6.95
240		---	100	140.4	3.32	3.29	0.80	7.41
240		NS	100	129.6	3.07	3.10	0.77	6.94
240		---	200	131.6	3.11	3.17	0.72	7.00
240		NS	200	130.5	3.09	3.12	0.74	6.94
80	LH74 X LH85	---	---	123.2	2.92	2.98	0.82	6.72
80		NS	---	127.0	3.01	2.93	0.85	6.79
80		---	100	116.6	2.76	3.01	0.78	6.55
80		NS	100	112.5	2.66	3.12	0.73	6.51
80		---	200	123.5	2.92	3.13	0.85	6.90
80		NS	200	129.1	3.05	3.25	0.80	7.10
160		---	200	120.8	2.86	2.91	0.79	6.56
160		NS	200	139.0	3.29	3.25	0.84	7.38
240		---	---	121.3	2.87	2.95	0.82	6.64
240		NS	---	149.2	3.53	3.11	0.95	7.58
240		---	100	124.1	2.94	2.93	0.86	6.72
240		NS	100	131.6	3.11	3.21	0.88	7.21
240		---	200	117.6	2.78	2.81	0.79	6.38
240		NS	200	129.2	3.06	3.26	0.88	7.19
80	DeKalb 485	---	---	121.7	2.88	3.55	0.83	7.25
80		NS	---	124.9	2.96	3.53	0.84	7.33
80		---	100	122.1	2.89	3.49	0.80	7.18
80		NS	100	129.0	3.05	3.65	0.84	7.54
80		---	200	114.2	2.70	3.35	0.73	6.78
80		NS	200	112.4	2.66	3.13	0.73	6.53
160		---	200	113.5	2.69	3.33	0.77	6.78
160		NS	200	122.7	2.90	3.36	0.80	7.07
240		---	---	127.3	3.01	3.47	0.80	7.28
240		NS	---	121.5	2.87	3.45	0.79	7.12
240		---	100	129.9	3.07	3.53	0.88	7.48
240		NS	100	125.3	2.97	3.39	0.82	7.17
240		---	200	136.3	3.23	3.71	0.92	7.86
240		NS	200	119.4	2.83	3.58	0.79	7.19

Table 5. Influence of N-rate, K-rate and nitrification inhibitors on N content and total N removal on four corn hybrids at **dent stage R5**. Becker, MN 1990.

				N-Concentration			N-Removal			
N-Rate	Hybrid	Inh.	K-Rate	Stover	Grain	Cob	Stover	Grain	Cob	Total
#/A			#/A	----------%----------			----------#/A----------			
80	Pioneer 3615	---	---	0.82	1.27	0.51	51.3	70.6	8.0	129.8
80		NS	---	1.08	1.36	0.58	64.0	67.2	9.5	140.7
80		---	100	1.04	1.37	0.63	64.8	67.4	10.7	142.9
80		NS	100	0.97	1.54	0.63	61.6	82.6	9.9	154.2
80		---	200	0.76	1.41	0.50	44.3	69.4	7.2	120.9
80		NS	200	0.97	1.39	0.72	56.0	65.3	9.9	131.2
160		---	200	1.27	1.66	0.57	79.9	93.3	9.1	182.4
160		NS	200	1.11	1.47	0.51	73.0	86.5	8.9	168.4
240		---	---	1.40	1.55	0.53	86.0	86.3	8.8	181.2
240		NS	---	1.16	1.48	0.51	76.0	86.8	9.6	172.4
240		---	100	1.26	1.53	0.54	82.3	84.7	9.2	176.2
240		NS	100	1.37	1.69	0.52	95.3	94.1	9.0	198.4
240		---	200	1.13	1.56	0.56	66.2	90.0	9.5	165.7
240		NS	200	1.26	1.43	0.54	82.1	78.8	9.7	170.7
80	Pioneer 3737	---	---	0.93	1.37	0.45	53.1	76.4	5.9	135.4
80		NS	---	1.06	1.52	0.42	65.4	77.5	5.9	148.8
80		---	100	0.97	1.37	0.45	56.1	80.4	6.6	143.1
80		NS	100	1.08	1.46	0.45	59.5	74.2	5.6	139.3
80		---	200	0.80	1.33	0.38	41.6	68.8	4.4	114.8
80		NS	200	0.85	1.39	0.49	49.3	74.3	5.9	129.6
160		---	200	1.04	1.63	0.44	68.2	111.5	7.1	186.8
160		NS	200	1.20	1.60	0.53	72.2	93.7	7.7	173.6
240		---	---	1.53	1.73	0.48	96.8	102.4	7.4	206.5
240		NS	---	1.37	1.74	0.52	85.3	104.8	8.6	198.6
240		---	100	1.23	1.66	0.45	80.8	110.6	7.2	198.5
240		NS	100	1.13	1.70	0.43	70.3	103.4	6.5	180.2
240		---	200	1.32	1.67	0.51	83.5	104.2	7.2	194.9
240		NS	200	1.32	1.69	0.48	82.2	104.5	7.1	193.8
80	LH74 X LH85	---	---	1.01	1.35	0.51	60.6	78.8	8.2	147.7
80		NS	---	1.09	1.40	0.64	64.2	83.9	11.0	159.0
80		---	100	1.17	1.30	0.68	70.7	71.6	10.6	152.9
80		NS	100	1.03	1.27	0.48	63.9	67.6	6.9	138.3
80		---	200	0.99	1.32	0.62	61.8	77.3	10.7	149.8
80		NS	200	0.91	1.33	0.53	59.3	81.3	8.5	149.0
160		---	200	1.08	1.48	0.52	62.3	85.0	8.2	155.5
160		NS	200	1.18	1.37	0.48	76.8	90.3	7.9	175.1
240		---	---	1.23	1.55	0.56	72.6	88.7	9.2	170.6
240		NS	---	1.23	1.53	0.52	76.0	108.0	10.0	194.
240		---	100	1.27	1.48	0.44	74.2	87.2	7.6	168.9
240		NS	100	1.19	1.52	0.55	76.3	94.5	9.6	180.4
240		---	200	1.13	1.56	0.48	63.2	86.7	7.6	157.4
240		NS	200	1.19	1.54	0.52	77.4	94.2	9.2	180.8
80	DeKalb 485	---	---	1.06	1.24	0.46	75.2	71.3	7.5	153.9
80		NS	---	1.03	1.21	0.58	73.2	71.6	9.7	154.4
80		---	100	1.07	1.19	0.45	74.4	68.7	7.1	150.2
80		NS	100	1.15	1.23	0.48	84.7	75.0	8.2	167.9
80		---	200	0.84	1.20	0.46	56.1	64.7	6.7	127.6
80		NS	200	1.24	1.29	0.49	77.2	69.4	7.2	153.8
160		---	200	1.22	1.45	0.51	81.0	78.3	7.8	167.0
160		NS	200	1.23	1.35	0.45	82.9	77.8	7.2	167.9
240		---	---	1.36	1.54	0.43	94.5	92.9	6.9	194.2
240		NS	---	1.60	1.55	0.53	110.3	89.0	8.4	207.7
240		---	100	1.36	1.51	0.53	96.4	92.6	9.3	198.3
240		NS	100	1.39	1.49	0.49	94.1	88.0	8.0	190.2
240		---	200	1.40	1.53	0.48	103.7	98.8	8.8	211.3
240		NS	200	1.47	1.49	0.49	105.1	84.2	7.7	197.0