A Report on Field Research in Soils

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SOIL SERIES 130
A Report on Field Research in Soil Science

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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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The numbering of this publication within the Miscellaneous Publication series changes with this edition of the soils "bluebook." To be consistent with other annual reports of ongoing research published by the Minnesota Agricultural Experiment Station, it will no longer be produced as an annually revised number "2" in the series. "Revised" implies that content, while updated and corrected, nevertheless parallels and otherwise covers the same territory found in earlier edition. By contrast, each of the last several editions of this publication has large amounts of new information and research. Each future edition will receive its own number current with the progress of titles in the series.

-- Series Editor

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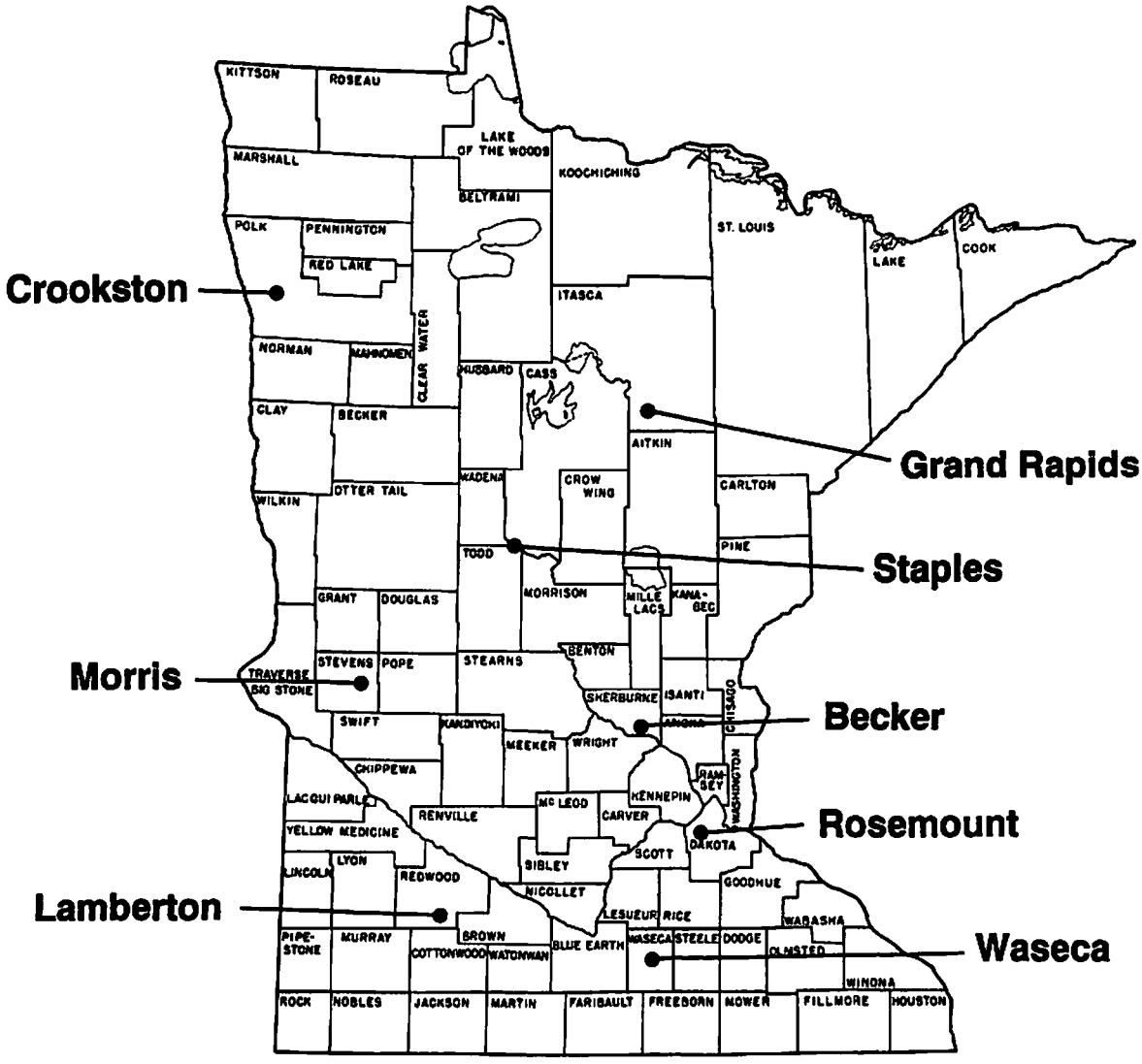

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CLIMATE AND CLIMATOLOGY, 1989

D. Baker, D. Ruschy, S. Evans, W.W. Nelson, J. Lamb, G. Randall, G. Spoden, and J. Zandlo[1/]

ABSTRACT: At the time of writing, the drought that began in October, 1986 continues across much of the state. The drought is both hydrologic and agricultural in nature. The soil moisture remains low at many locations because of lack of the usual autumn recharge. Long-term Minnesota corn yields, from 1966-1989, are illustrated and discussed. Since about 1950, the mean increase has been 2.25 bushels per acre. As severe as 1988 was in terms of yield depression, it is shown that other years, particularly 1894, 1934, and 1936, were, relatively speaking, just as severe. Examples of the time change in the density of winter snowpacks is shown along with a density-time equation.

Our Ongoing Drought:

After public attention had been focused for nearly a decade on the abundance of precipitation, an abrupt reversal of the wet trend began in the fall of 1986 with rapid decline toward drought conditions. Drought is difficult to manage because it is a gradual phenomenon that has no well-defined beginning or end. While droughts are unpredictable, they are a normal feature of the North American climate. We're actually in the 40th consecutive month (as of February 1990) of drought conditions and this winter season, thus far, has done little to relieve apprehension for the coming growing season.

In 1989, Minnesota farmers harvested their best soybean crop and fifth largest corn crop. An indication of a return to "normal" weather? Unfortunately no. Minnesota's drought persists and it is now over three years old. Our agricultural good fortune can be attributed to well timed rainfalls and forgiving temperatures. However, as a whole, much of Minnesota received below normal precipitation for the past "hydrologic" year (October, 1988 - September, 1989). This comes on the heels of two extremely dry years, perpetuating the water deficit in Minnesota's overall hydrology. Many of Minnesota's wetlands, lakes, rivers, streams, and shallow aquifers require an abundant recharge to return to more desireable levels.

The climate Analysis Center of the National Weather Service quantifies the intensity of droughts by using a scheme called the Palmer Drought Severity Index. The Palmer index currently places northwestern and south central Minnesota in the "extreme" drought category, the worst case scenario. Most of the remaining agricultural regions fall in the moderate to severe category, whereas areas of north central Minnesota are near the neutral or "normal" class. While conditions in northwestern Minnesota are similar to last year at this time, there has been some improvement in the central tier of the state, with worsening conditions in the southern one-third of Minnesota.

Where do we stand as we enter 1990? Soil moisture in many areas is as short as it was entering the 1989 growing season. (See Fig. 1 which shows the cumulative departures of precipitation since 1987.). Extremely cold December temperatures and relatively little snow cover has caused a thorough and deep freezing of the ground. Over-winter precipitation will do little to add moisture to the rooting zone; therefore, growing season soil moisture levels will depend quite heavily on spring rain. Much of this winter's snowfall will likely run off along with frozen ground as it melts, causing an initial flush of water to the surface systems. This flush will be short lived however. True recovery of most of the hydrologic systems will occur only after moisture in the "unsaturated zone" (top few meters of the soil) is replenished.

Continuing precipitation shortages have reduced groundwater levels, reduced streamflows, and lowered lake levels. The length of time before these reduced water levels respond can vary greatly -- sometimes it is noticeable immediately, sometimes not until several months after the precipitation deficit occurs.

The 1989 Hydrologic Year Precipitation:

The hydrologic year, which extends from October to September, is often considered a better indicator of general conditions than the calendar year. This is true because the low point in stream flow normally occurs in October. It also closely approximates the agricultural season since precipitation in October and November is stored in the soil for use by plants in the succeeding growing season.

[1/] Professor (Soil Sci. Dept.), Assist. Scientist (Soil Sci. Dept.), Professor (W.C. Ag. Exp. Sta.), Professor (S.W. Ag. Exp. Sta.), Professor (N.W. Ag. Exp. Sta.), Professor (S. Ag. Exp. Sta.), and Assist. State Climatologists, DNR, respectively.

The 1989 hydrologic year is shown in Figure 2. The total precipitation amounts received in the southern half of the state were generally below average and indicate why the 1989 crop was raised on "opportune" rains. In the extreme western part of the state, the amounts of some of the totals were quite marginal. This was accentuated in many soils, and not just in the extreme west, because there was little or no stored soil moisture from the previous season.

Soil Moisture:

Because soil moisture reserves in much of the state have not been recharged since September, 1986, the previous season's crop becomes very important when planning for the 1990 season. As a result, where small grains, for example, were grown in the 1989 season, the soil moisture is apt to be higher for the 1990 season than where sugarbeets or alfalfa, for example, were grown.

The change in the readily available soil moisture in the 1989 season is shown in Figure 3. It can be seen that at the end of the 1989 season the total water available in the 5-foot column of soil that was in corn was about 1.5 inches below the 1964-1988 average at the end of the season. The usual autumn recharge was missing in 1989, so the spring 1990 recharge becomes very important.

The 1989 growing season soil moisture changes at Crookston, Lamberton, Morris, and Waseca, are shown in Fig. 4. At all except Crookston, the crop was corn. The Crookston soil moisture is an average for three crops. The Morris data consist of two different soils -- the Hamerly silty clay loam, and the Tara silt loam.

Long-Term Corn Yields, 1866-1989:

It is a surprise for most of us to discover that statewide corn yields are available since 1866. They are shown in Fig. 5. The crosses represent the individual years and the solid lines the general trend for the indicated periods. It is apparent in Fig. 5 that although the yields varied from year to year due to the weather (and insects and diseases), there was no trend change between 1866 and 1938. That is, the overall yield for the 73 years between 1866 and 1938 was nearly constant at 30.1 bushels per acre with weather creating the difference between years. The severity of the drought and heat of 1934 and 1936 is made very evident by the low yields. The year 1894 was also a poor crop year.

Beginning with the year 1939, there appears to have been a marked change in corn yields. The 11-year period of 1939-1949 saw the mean state yield increase to 42.3 bushels per acre. This increase can probably be ascribed to the introduction of hybrid corn. The selection of the exact year to begin the next period is arbitrary, but beginning approximately in 1950, with the increasing adoption of new technology (such as commercial fertilizer, particularly nitrogen, denser plant populations, insecticides, herbicides, and improved machinery), the yield change was dramatic. The general trend for 1950-1987 was a phenomenal 2.24 bushels per acre increase. This includes the low yielding years of 1974, 1975, 1976, and 1983.

We all remember 1988 as such a devastating year, and indeed it was. However, when the departures of the mean annual yields from the general trends of the three periods are compared, Fig. 6, it is apparent that other years have been equally devastating. This figure shows the relative or percentage increase or decrease of each year's yield from the general trend line of that particular period. For example, the 1988 yield was nearly 40% below the expected yield. But, there have been other years in which the yield was as low or lower relative to the expectation for that period. In 1934 and 1936 the yields were even poorer, relatively speaking, than the 1988 yields. That is, the 1934 mean yield of 17 bushels per acre was a 43.5% departure from the expected yield of 30.1 bushels per acre. That size departure was obviously as serious in 1934 as the 1988 mean yield of 74 bushels per acre that was 39.9% below the expected yield.

Snowpack Densities:

A typical feature of snowpacks is the sharp drop in the density that occurs following each new snowfall as lower density fresh snow is added to the total, Fig. 7. The winters of 1984-1985 and 1987-1988 provide an example of the frequent variations that occur in the pack's density. In two of the four years, the density of the snowpack increased within three days after a snowfall to about 200 kg m^{-3}. Fresh snows, however, repeatedly reduced the density so that there was a relatively gradual and approximately linear increase with time to over 300 kg m^{-3} in the four winters at St. Paul, It was our experience that at a density of about 250 kg m^{-3} the snow reached a physical state that one observer labeled "corn snow". That is, the snow had undergone sufficient metamorphosis that it resembled kernels of corn (maize). Such snow can be difficult to sample because once a side is cut, it flows like corn and has a similar angle of repose. This kind of snow has apparently undergone a process which results in rounded or irregular grains of uniform size. The winter of 1984-1985 was one of a rapidly increasing

density commencing at 97 kg m^{-3} with the first snow. The last sample, taken on March 8, was a very high density sample, with virtually no snow characteristics remaining. In the winter of 1985-1986, the density showed a far more gradual increase starting from a density of 110 kg m^{-3}, reaching a maximum of 396 kg m^{-3} in isolated drifts, but due to late season snowfalls, it ended at 301 kg m^{-3} with the last sample. In the third winter, 1987-1988, the density began at 90 kg m^{-3} and 72 days later reached a maximum of 326 kg m^{-3}.

In the winter of 1988-1989, the density started at a relatively high level but showed little overall increase until late February when warm temperatures and a lack of fresh snows resulted in just scattered snow drifts in which the density reached 480 kg m^{-3}. Then, more normal winter conditions returned with several snows and lower air temperatures. The resulting snowpack densities ranged from 188-324 kg m^{-3} until 11 March. The last three densities were of the remaining snow drifts, with the last sample measuring 460 kg m^{-3} on 13 March.

During the 1984-85 winter, the average daily rate of density change from 1 November was 3.4 kg m^{-3}. This daily increase usually rapid as a result of the shallow snow cover of relatively brief duration. In 1985-1986 and 1987-1988, the density change was less, amounting to a daily average increase of 1.5 and 1.8 kg m^{-3}, respectively. The 1988-1989 mean daily change was only .01 kg m^{-3} day^{-1}. The four-year mean density increase form 1 November equaled about 1.7 kg m^{-3} day^{-1}.

The U.S. Dept. of Agriculture Forest Service personnel near Grand Rapids, MN, have been measuring snow depth and density at various forested and non-forested sites since 1962. Their "open" site field condition approximated that at St. Paul, although the surrounding countryside is forested. The density data from their initial to final measurements, usually February or early March to the disappearance of the snow cover in early to mid-April, were added to the St. Paul data, Fig. 8. However, because the Grand Rapids site is about 265 km north of St. Paul, an appreciable lag occurs in the seasons. For example, the 50% probability date of the last occurrence of 0°C at St. Paul is 29 April compared to 29 May at Grand Rapids. Therefore, in combining the Grand Rapids and St. Paul data, in order to determine a density versus time equation, the Grand Rapids data were advanced 30 days. As a result, the two sets of data are quite homogeneous, Fig. 8.

In spite of the irregularity of the density changes with time, as shown in Fig. 7, each of the years showed an overall increase from either 1 November, or from the first snowfall, that could be approximated by a curvilinear equation: $Y=163.78 - 0.49X + 0.01x^2$ where X is days from 1 November and Y is density in kg m^{-3}.

1987 - 1989 CUMULATIVE PRECIPITATION DEPARTURE

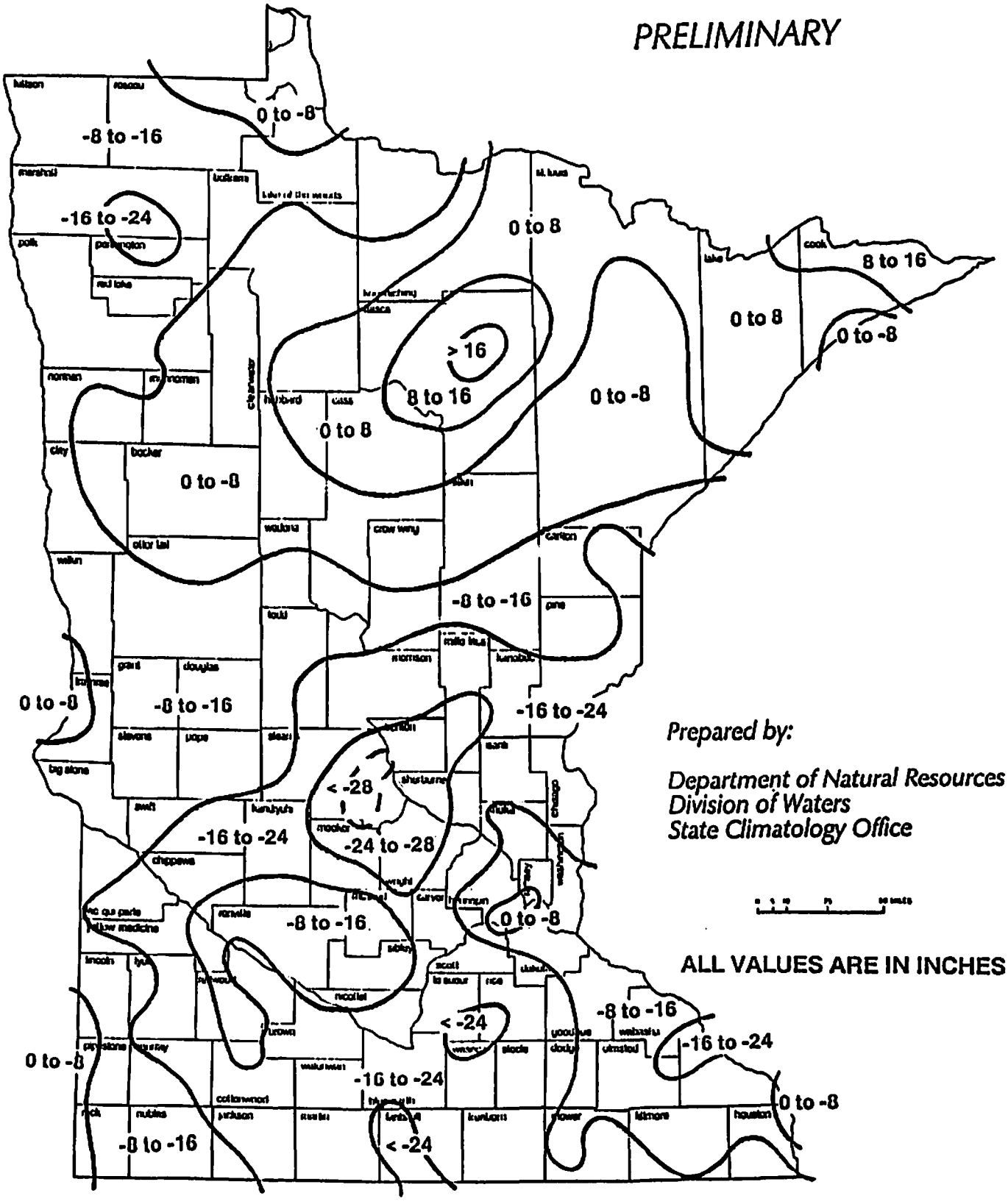

Fig. 1. The cumulative departure of precipitation between 1987-1989. All values are in inches.

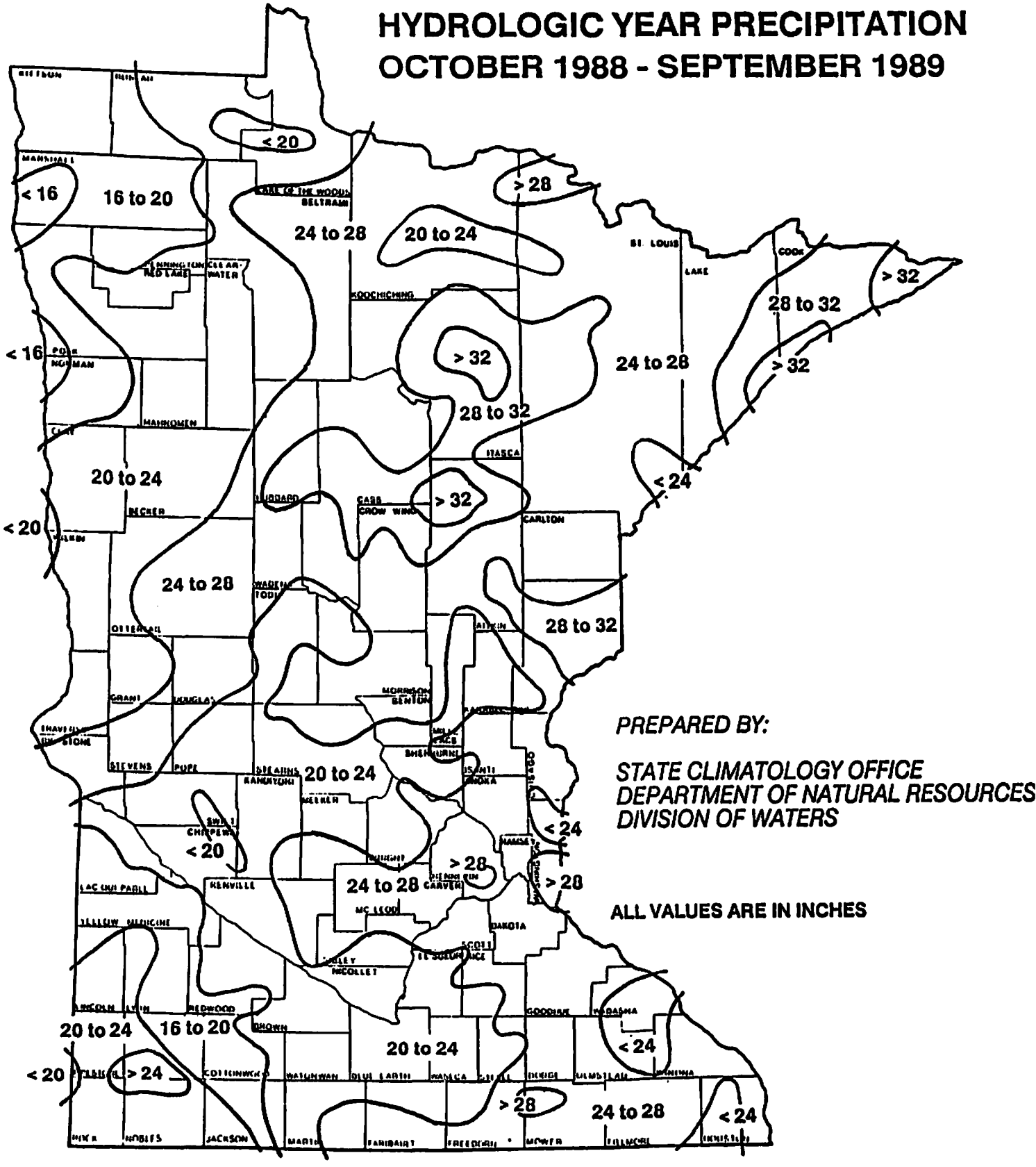

Fig. 2. The hydrologic year precipitation, October 1988 - September 1989. All values are in inches.

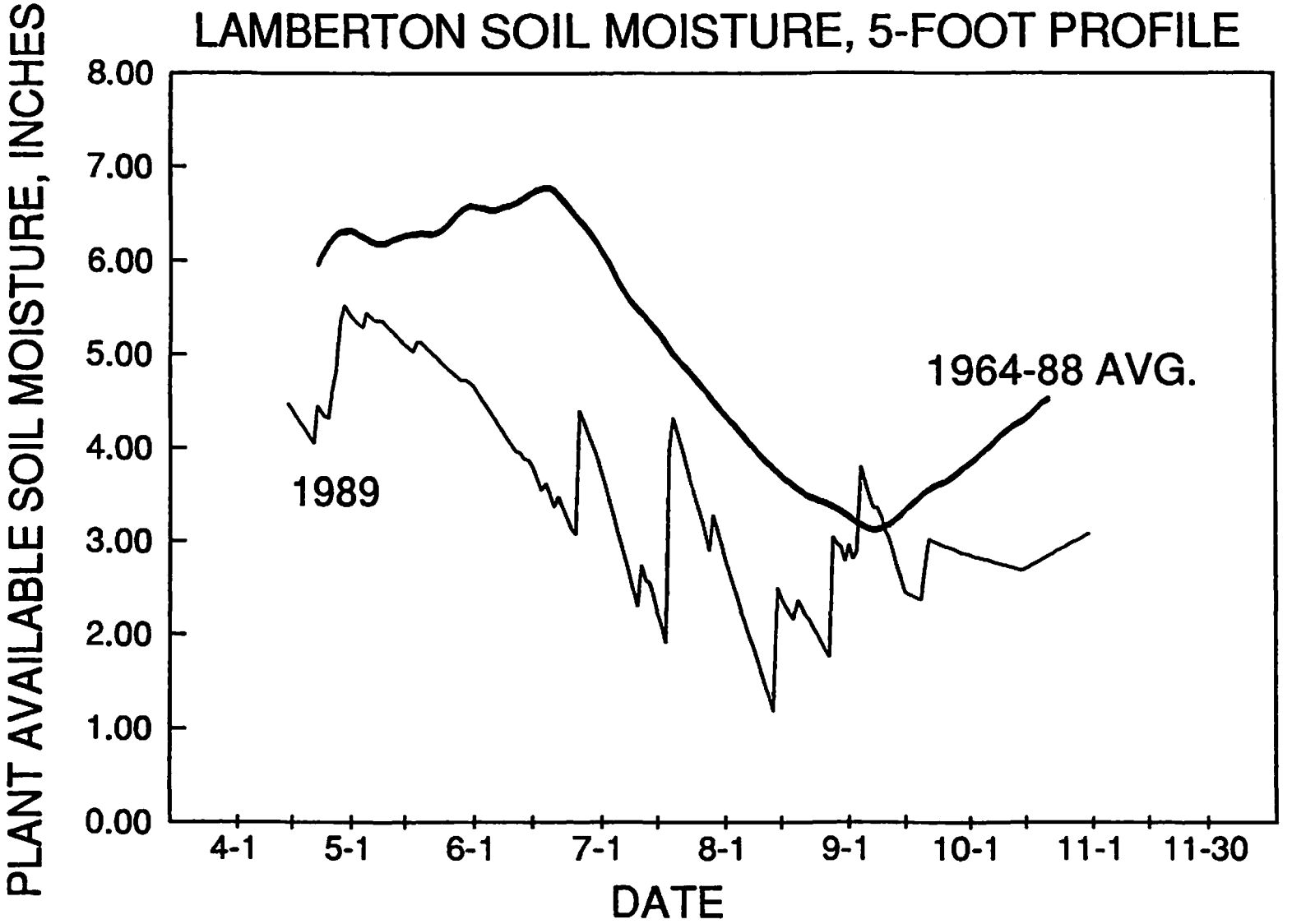

Fig. 3. Total plant available soil moisture in a 5-foot column of soil under corn during 1989 compared to the 1964-1988 mean, Lamberton.

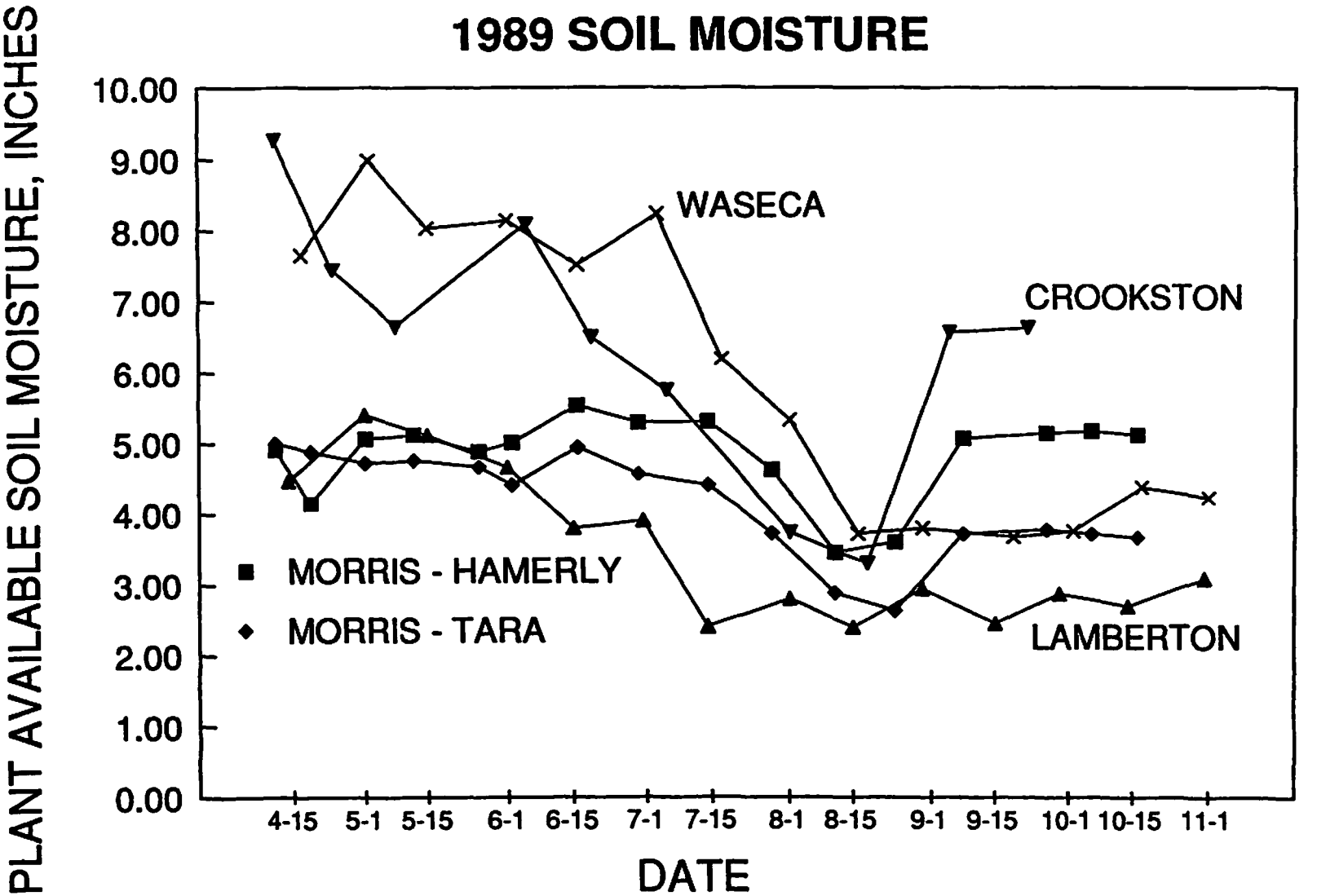

Fig. 4. Total plant available soil moisture in a 5-foot column of soil under corn at Lamberton, Morris, and Waseca, and under small grain at Crookston during the 1989 season.

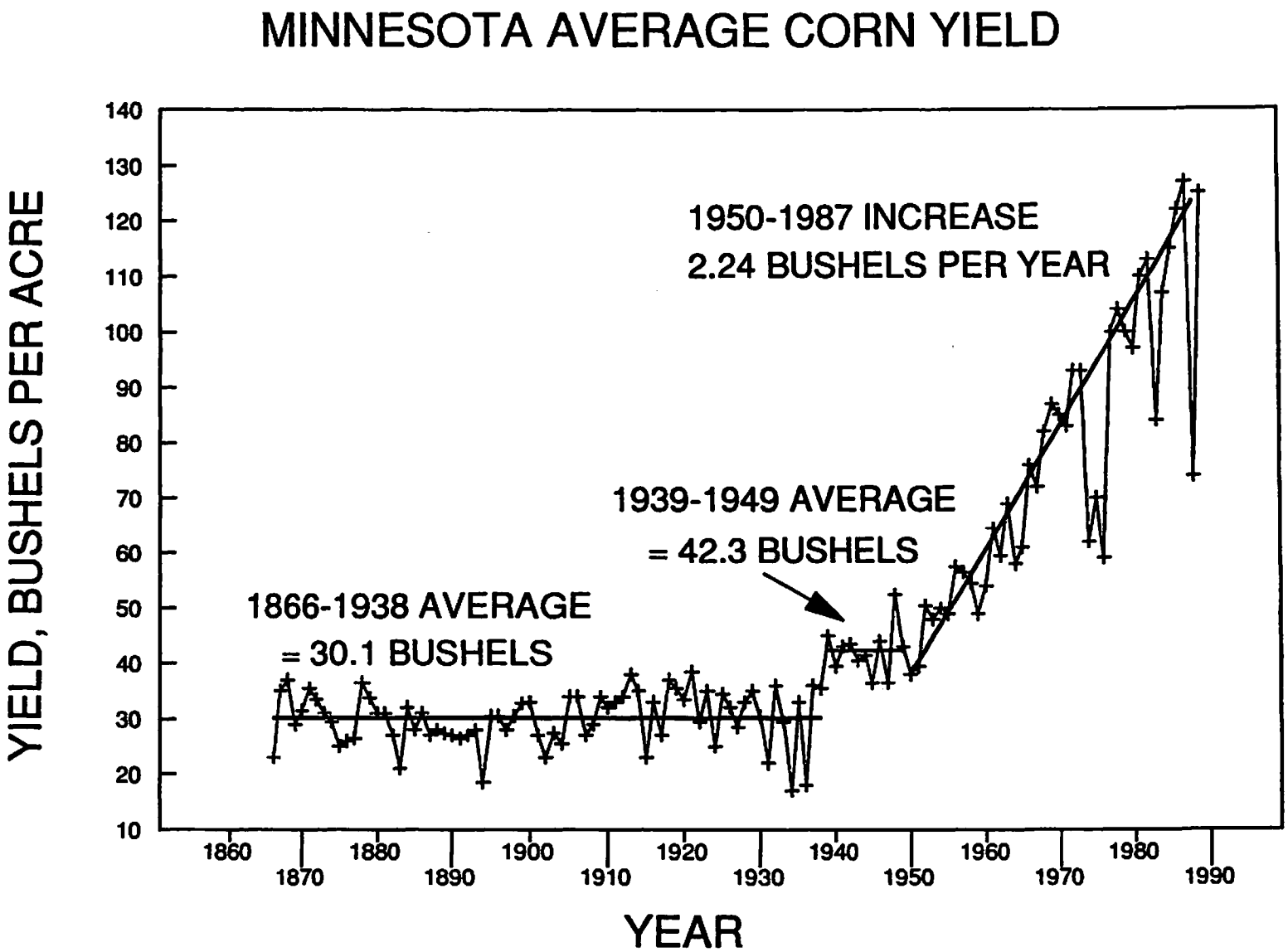

Fig. 5. State mean annual corn yields, 1866-1989. The general yield trend for these periods is shown by the solid lines. (Data source: Minnesota Crop and Livestock Reporting Service).

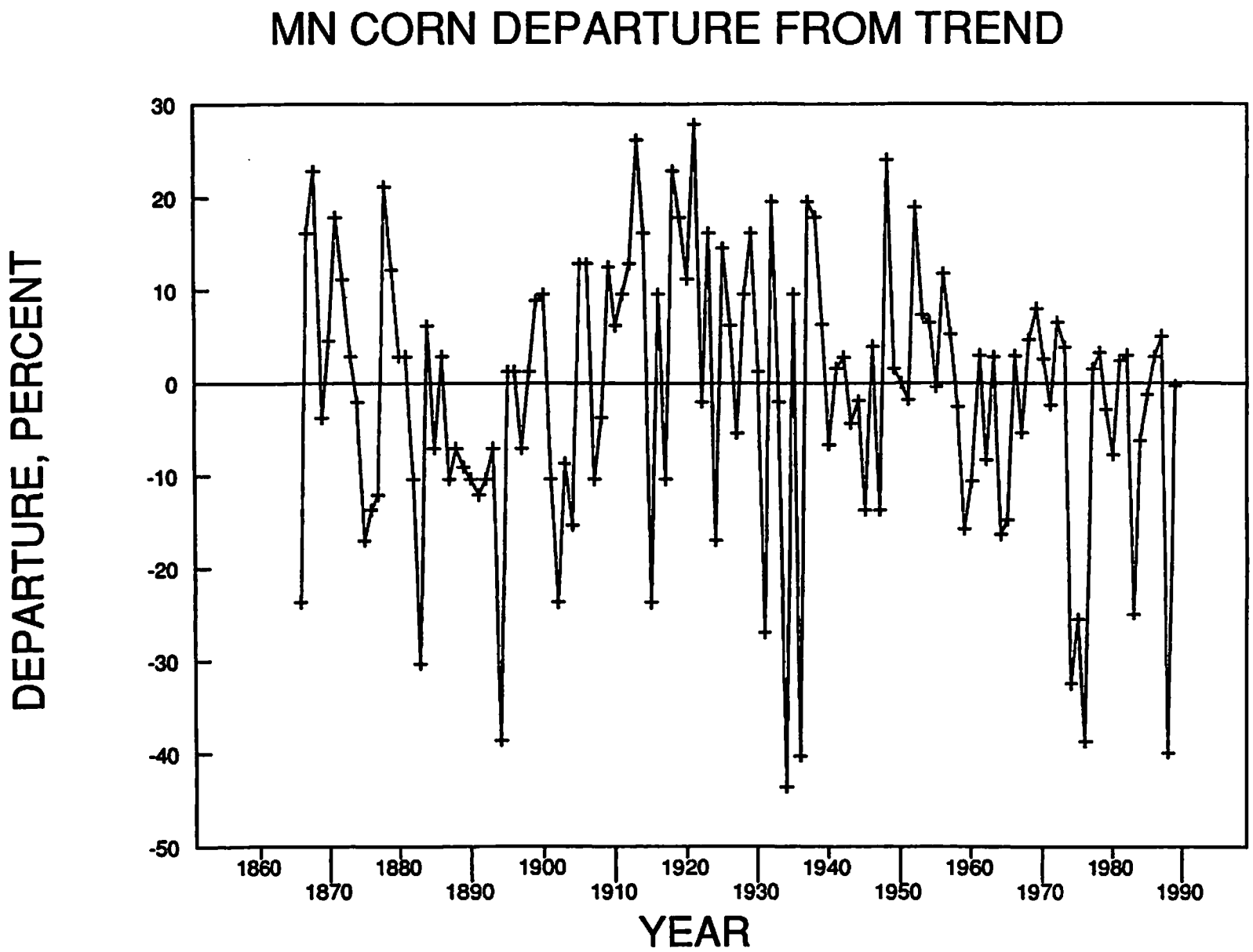

Fig. 6. Percent departure of the mean annual corn yields, 1866-1989, from the general trend lines shown in Fig. 5.

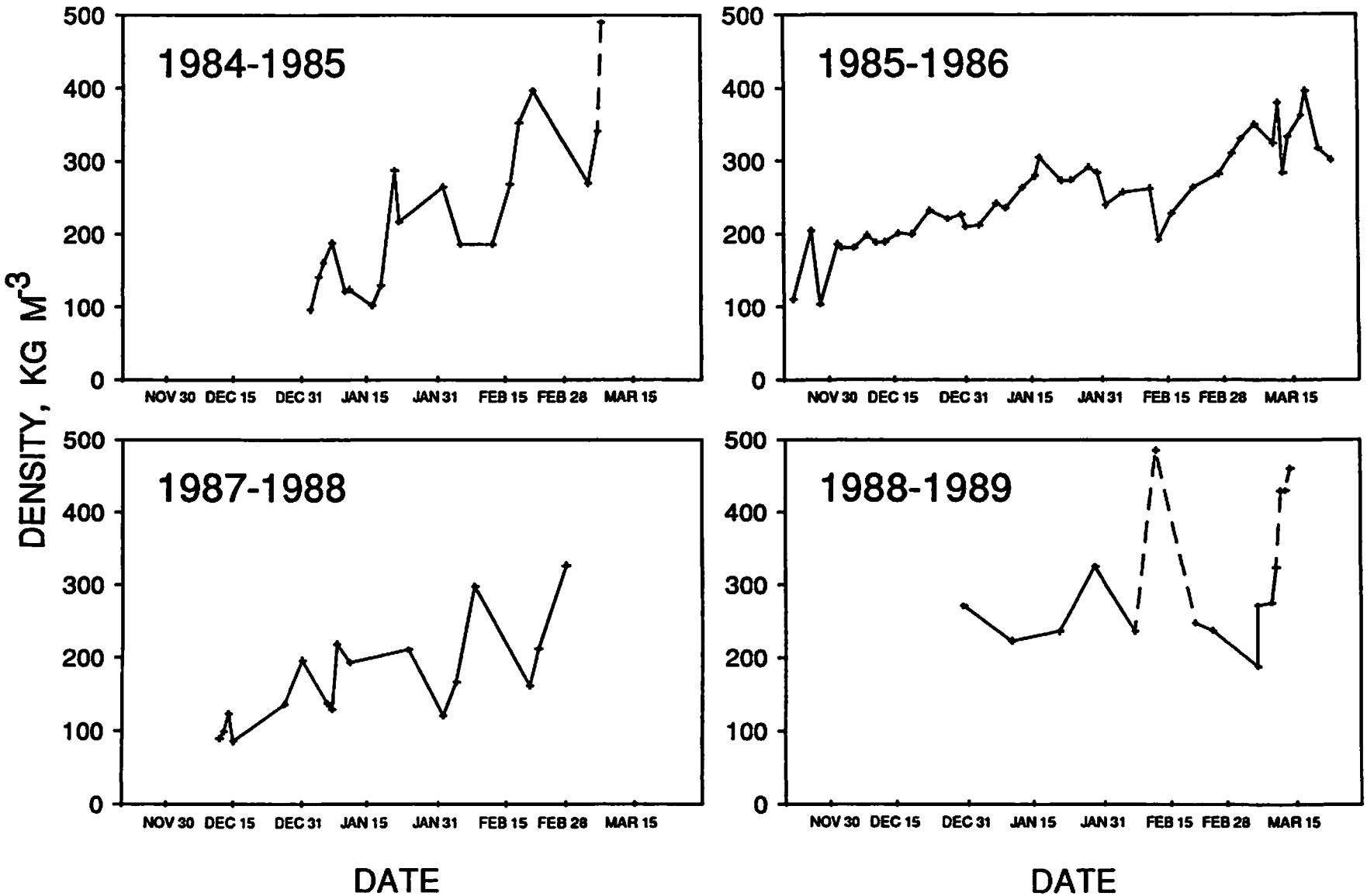

Fig. 7. Density changes of the snowpacks during four minutes at St. Paul. Samples representing isolated snow drifts rather than a continuous snowpack are noted by dashed lines.

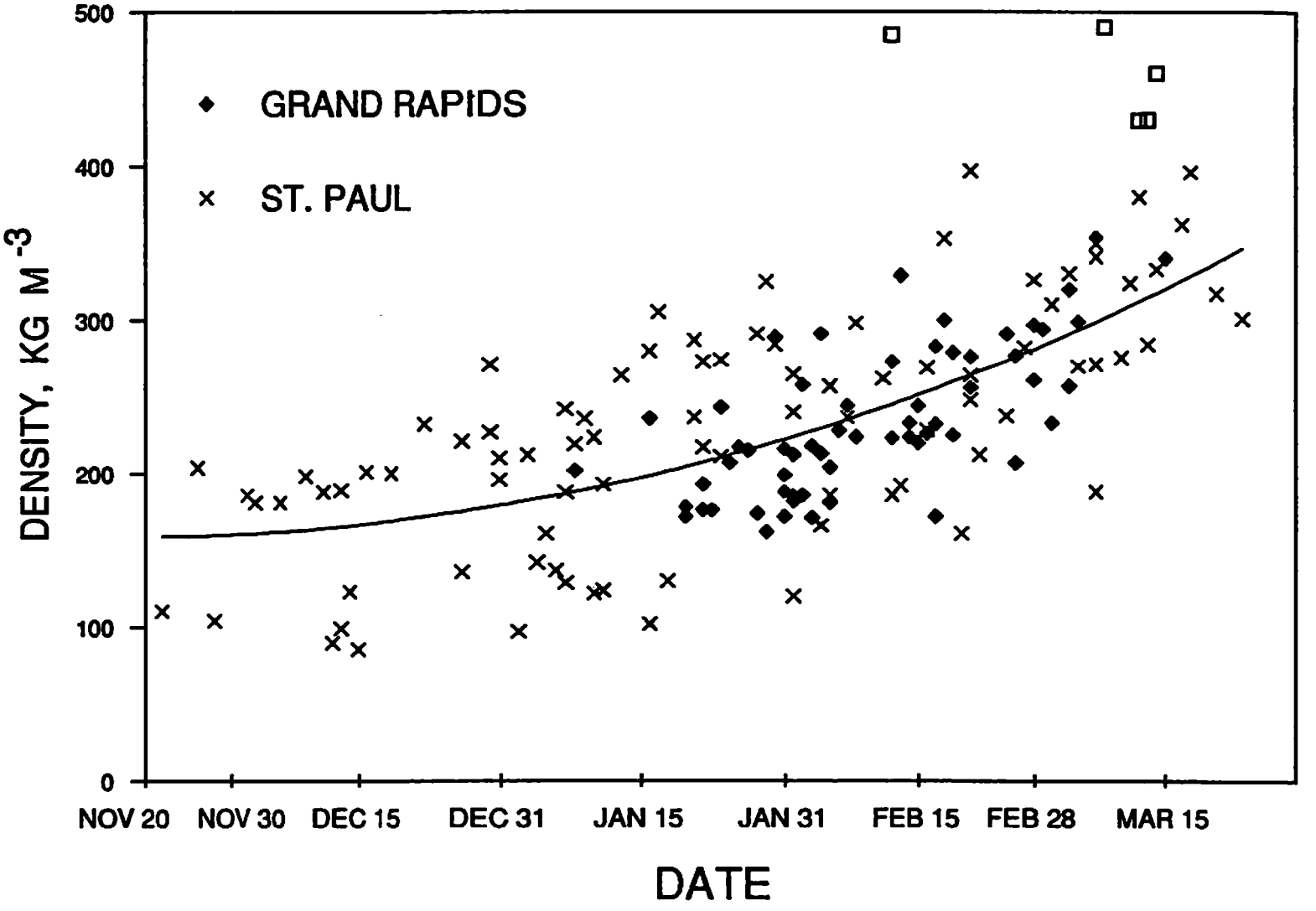

Fig. 8. Density change of the snowpacks at Grand Rapids and St. Paul. The five boxes represent the densities of isolated snow drifts and were not used to obtain the best-fit line. Grand Rapids data courtesy of Forest Service, USDA.

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

Carl Rosen, Florian Lauer, Louise America, Peter Bierman, and Gary Korbel[2]

ABSTRACT: This experiment was conducted at the Sand Plains 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 of nitrogen fertilizer were applied. Boron applications (4 lb B/A) did not reduce the incidence of hollow heart or brown center. At the early harvest date (Aug. 2), boron applications increased yield of 7-14 oz potatoes. Nitrogen fertilizer significantly increased vine yields but had variable effects on tuber yields. At the early harvest date, tuber yield decreased as nitrogen increased from 70 to 140 lbs N/A. In Russet Burbank at the late harvest, tuber yield increased as nitrogen increased from 70 to 140 lbs. There was little response as nitrogen was increased from 140 to 280 lb N/A. In Reddale, where vines died back by the second harvest, tuber yields increased with increasing nitrogen. Potatoes killed early that have been fertilized with high rates of nitrogen may yield less than those that have been fertilized with lower nitrogen rates. This relationship depends somewhat on the amount of nitrate leaching that occurs during the season. Incidence of hollow heart or brown center was greatest in the largest size tubers. Within a size category nitrogen had no effect on these disorders; however, since nitrogen promoted larger tuber size there was a greater number of tubers that exhibited hollow heart or brown center with higher nitrogen rates. Nitrogen uptake by the potato plant increased with increasing rates of nitrogen application. At the early harvest (vines killed July 26), levels in the vine ranged from 41 - 116 lb N/A while at the late harvest (vines killed September 5) levels ranged from 9 - 49 lb N/A. Levels in the tubers at the early harvest ranged from 63 - 85 lb N/A while at the late harvest levels ranged from 92 - 149 lb N/A. Vines killed early may provide significant nitrogen to subsequent crops. Mineralized soil nitrogen provided 38 - 52 lb N/A for crop uptake when low rates of fertilizer nitrogen were applied. Nitrate levels in potato petiole sap monitored by quick tests generally correlated well ($r^2 = 0.95$) with petiole nitrates determined by conventional laboratory procedures. Significant soil nitrate movement was detected at the 280 lb N/A rate compared to the 70 and 140 lb N/A rates.

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.

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[1] Support for this project was provided by Old Dutch Foods Research Fund. A special thanks is extended to Glenn Titrud for assistance in plot maintenance.

[2] Extension Soil Scientist, Soil Science Department, Professor, Horticulture Department, Junior Scientist, Graduate Assistant, and Research Technician, respectively.

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.

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 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 20, 1989 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 25), and 35 or 105 lb N/A at hilling (June 8). Each plot consisted of four, 20 ft rows. Rainfall was supplemented with overhead irrigation to supply water needs. Monthly irrigation and rainfall through the season were as follows: April - 1.2" rainfall, no irrigation; May 4.0" rainfall, no irrigation; June - 1.3" rainfall, 3.0" irrigation; July - 2.5" rainfall, 5.5" irrigation; August - 3.6" rainfall, 4.4" 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) = $10^{(4.9-1.085 \log t)}$ 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 nitrates were determined in samples collected July 27 and September 7. 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'.

Nitrates in soil water were 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 26 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 7 -14 oz potatoes at the early harvest date (Table 1). Nitrogen rate had significant effects on tuber yield and size distribution at both harvest dates. At the early harvest (August 2), tuber yields decreased with increasing N rate for both cultivars. Most growth at the high N rates was still in the vine rather than the tuber. At the late harvest (September 14), Russet Burbank yields increased up to 140 lb N/A, but Reddale yields increased linearly with nitrogen rate up to 280 lb N/A. Most of this increase in Reddale yield was due to an increase in the larger size tubers. Differences in response to nitrogen by these two cultivars can be explained by their vine growth (Tables 2 and 3). Nitrogen fertilizer dramatically increased vine yield of both cultivars at both harvest dates. Vines remained greener later in the season with the highest nitrogen rate, although Russet Burbank vines were slower to die back than Reddale. Thus, at the time of the second harvest, Russet Burbank potatoes supplied with 280 lb N/A were delayed in maturity and translocation from the vines to the tubers was not complete. Boron application had no effect on vine yields.

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 either cultivar or either harvest date. 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.

Nutrient Concentrations and Uptake. Slight symptoms of boron toxicity were observed one week after the second boron application. Older leaves exhibited a scorching and upward curling of the margins. This condition was only temporary as younger leaves appeared healthy and plant growth appeared normal within one week after symptoms were observed. Concentrations of boron in leaves sampled July 3 averaged 30 ppm in the control and 78 ppm in the treated plots (Table 6). Concentrations of boron in tubers increased with boron application at both harvest dates, but to a much lower degree than in the leaves (Tables 7 and 8). The lack of boron accumulation in the tuber reflects the immobility of this element in the plant. As expected, total nitrogen concentrations in leaves sampled July 3 and in tubers sampled at both harvest dates increased with increasing nitrogen application. Signs of nitrogen deficiency (general plant yellowing) were apparent at the lowest nitrogen rate toward the end of July. Otherwise, plants appeared very healthy up to this point.

Except for the increase in tissue boron, boron applications had no effect on concentrations of other elements in the leaf sampled July 3 (Table 6) or in the tubers sampled at the early and late harvest dates (Tables 7 and 8). Nitrogen fertilizer significantly increased leaf concentrations of iron, but decreased concentrations of boron. Tuber concentrations of calcium and zinc increased with nitrogen fertilizer at both harvests. Tuber potassium, manganese, and boron increased with increasing nitrogen at the early harvest date. Tuber magnesium, phosphorus, and potassium decreased with increasing nitrogen at the late harvest. Reddale leaves sampled July 3 had higher concentrations of nitrogen, phosphorus, iron, and zinc but lower concentrations of calcium, magnesium, and manganese. Reddale tubers had higher concentrations of nitrogen, phosphorus, magnesium, iron, zinc, copper, and boron, but lower concentrations of calcium 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, calcium, iron, manganese, and boron, but less magnesium than Russet Burbank. At the later harvest, Reddale vines accumulated more phosphorus, iron, and manganese, but less potassium and magnesium 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.

Nutrient uptake by tubers is presented in Tables 9 and 10. Boron applications increased boron uptake at both the early and late harvest, but had no effect on uptake of other nutrients. At the early harvest, Reddale accumulated greater quantities of phosphorus, copper, and boron, but lower

quantities of nitrogen, potassium, calcium, magnesium, and manganese compared to Russet Burbank. At the late harvest, Reddale accumulated more iron, but less nitrogen, potassium, magnesium, calcium, and manganese than Russet Burbank. At the early harvest, nitrogen uptake was slightly increased as nitrogen fertilizer applications increased. The effect of increased nitrogen on nutrient accumulation was not that great because of depressed yields at the high nitrogen rates. Phosphorus, potassium, magnesium, and boron uptake were actually lower at the high nitrogen rates compared to the lower rates. At the later harvest date, nitrogen, calcium, manganese, and zinc uptake increased with nitrogen rate.

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. For Russet Burbank, there was little uptake after the first harvest. In other words, most of the nitrogen had already been absorbed by July 26. The average uptake of nitrogen by Russet Burbank was less than 9 lb N/A during the month of August. For Reddale there was actually less nitrogen accounted for in September than in July. This apparent decrease in N was probably due to vines that had died and decomposed and could not be accounted for in the late harvest. Another interesting point to note is that potatoes grown at the 70 and 140 lb N/A rate took up more nitrogen than was actually applied. This indicates that under the conditions of the experiment, significant nitrogen was mineralized from the soil. As much as 50 - 60 lb N/A over the growing season was mineralized. In contrast, at the highest nitrogen rate, 80 - 100 lb N/A of fertilizer nitrogen remained in the soil and was not taken up by the vines or tubers. Increased nitrogen rate also increased nitrogen content of the vines. If high rates of nitrogen are used and the vines are killed early, there could be a significant contribution of nitrogen to the following crop.

Leaf and Petiole Total Nitrogen and Nitrate-N Concentrations. Nitrogen status of the plant every two weeks starting one week after hilling as measured by various procedures is presented in Table 12. 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 ($r^2 = 0.95$) between the quick test and the conventional nitrate test. The equation relating the two tests is $y = 10.83x + 598.6$, where x is the concentration of nitrate-N in the petiole sap (ug/ml) from the quick test and y is the predicted concentration (ug/g or ppm) based on the water extract from dried tissue. 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. Another year of data is needed to calibrate the quick test with the conventional laboratory test.

Soil and Water Nitrate Levels Through the Growing Season. As expected, variability in the soil nitrate levels was high, particularly at the higher nitrogen rate (Table 13). However, mean concentrations seemed to generally follow nitrogen application rates. Soil nitrate-N concentrations were highest in samples collected within the row compared to samples collected between the rows. There was little difference between soil nitrate levels in the 70 and 140 lb N/A plots. However, at the 280 lb N/A rate, there was an increase in residual nitrate in the field. Similar trends were also observed in the water samples collected at the 2.5 foot and 4.5 foot depths (Figures 2, 3 and 4). Nitrate-N levels at the 2.5 foot depth peaked at mid-season and then declined. Levels at the 4.5 foot depth were generally low for the 70 and 140 lb N/A rates, indicating that little movement beyond the root zone took place. In contrast, for the 280 lb N/A rate, nitrate-N levels were high at the 2.5 foot depth through most of the season and then decreased. Nitrate-N levels at the 4.5 foot level gradually increased through the season, indicating significant movement of N beyond the root zone at this nitrogen rate.

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

			Harvest Date									
			August 2					September 14				
			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	65.3	252.6	99.1	0.0	417.0	77.8	368.3	144.8	25.6	616.5
	0	140	73.2	246.6	90.3	0.0	410.1	68.0	395.1	188.3	19.5	670.9
	0	280	83.0	220.5	81.4	0.0	384.9	84.1	361.0	214.8	31.0	690.9
	4	70	66.5	257.2	114.0	0.0	437.7	80.3	361.1	113.1	18.1	572.6
	4	140	76.9	223.4	106.9	0.0	407.2	67.4	377.6	196.5	19.7	661.2
	4	280	83.3	201.0	101.8	0.0	386.1	85.9	348.4	194.8	24.5	653.6
Reddale	0	70	11.2	190.0	169.3	3.4	373.8	15.4	136.0	329.9	57.5	538.7
	0	140	13.4	150.4	206.8	17.6	388.2	20.0	130.0	346.9	85.5	582.4
	0	280	14.4	138.6	170.6	18.6	337.7	27.7	147.5	308.1	179.4	662.6
	4	70	9.0	165.8	211.7	10.9	397.4	16.9	138.1	325.2	69.4	549.6
	4	140	13.7	142.2	210.8	16.3	383.1	23.7	144.1	340.6	106.6	615.0
	4	280	12.3	146.6	182.4	11.0	352.3	28.1	134.6	313.1	177.0	652.8
Analysis of Variance												
Cultivar (C)												
	Russet B		74.7	233.6	98.9	0.0	407.2	77.3	368.6	175.4	23.1	644.3
	Reddale		12.3	155.6	191.9	13.0	372.1	22.0	138.4	327.3	112.6	600.2
Signif.			**	**	**	**	**	**	**	**	**	**
B rate (B)												
	0		43.4	199.8	136.2	6.6	385.3	48.8	256.3	255.5	66.4	627.0
	4		43.6	189.4	154.6	6.4	394.0	50.4	250.6	247.2	69.2	617.5
Signif.			NS	NS	*	NS	NS	NS	NS	NS	NS	NS
N rate (N)												
	70		38.0	216.4	148.5	3.6	406.5	47.6	250.9	228.3	42.6	569.4
	140		44.3	190.7	153.7	8.5	397.1	44.8	261.7	268.1	57.8	632.4
	280		48.3	176.7	134.1	7.4	365.3	56.5	247.9	257.7	103.0	665.0
Signif.			NS	**	NS	NS	*	**	NS	NS	**	NS
Linear			*	**	NS	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

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 26).

Cultivar	B rate lb B/A	N rate lb N/A	F.W. Yield T/A	Nutrient N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
				lb/A					oz/A				
Russet B	0	70	10.76	44.6	3.3	104.1	41.9	27.3	7.16	6.86	0.78	2.52	1.06
	0	140	13.44	66.0	4.1	118.6	43.8	35.2	9.00	5.97	0.77	2.77	1.14
	0	280	17.82	112.9	6.5	158.1	49.3	41.1	9.35	9.86	1.38	4.03	1.32
	4	70	12.12	50.7	3.6	113.5	43.8	29.6	8.32	6.86	0.93	2.91	2.08
	4	140	13.98	65.2	4.2	127.1	42.1	35.3	7.73	6.37	0.91	2.54	2.51
	4	280	15.78	97.9	5.2	141.8	47.3	38.6	8.90	9.46	1.12	4.47	2.43
Reddale	0	70	10.05	36.4	3.9	89.6	35.8	17.1	9.94	5.96	0.68	2.80	0.97
	0	140	15.26	65.6	5.7	136.6	49.0	26.7	9.25	7.28	0.91	3.15	1.35
	0	280	20.50	122.8	8.6	173.3	57.0	38.8	19.63	12.16	1.76	5.34	1.66
	4	70	12.25	46.4	4.8	113.2	41.4	20.7	9.62	7.87	1.06	3.91	2.17
	4	140	16.26	69.7	6.4	142.1	51.0	30.9	11.72	7.70	1.11	3.52	3.47
	4	280	18.95	110.5	7.6	160.4	54.2	36.9	14.93	10.91	1.30	4.15	2.81
Analysis of Variance													
Cultivar (C)													
	Russet B		13.98	72.9	4.5	127.2	44.7	34.5	8.41	7.56	0.98	3.21	1.76
	Reddale		15.55	75.2	6.2	135.9	48.1	28.5	12.51	8.65	1.14	3.81	2.07
Signif.			*	NS	**	NS	*	**	**	*	NS	*	**
B rate (B)													
	0		14.64	74.7	5.4	130.1	46.1	31.0	10.72	8.01	1.05	3.44	1.25
	4		14.89	73.4	5.3	133.0	46.6	32.0	10.20	8.19	1.07	3.59	2.58
Signif.			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
N rate (N)													
	70		11.30	44.5	3.9	105.1	40.7	23.7	8.76	6.88	0.86	3.04	1.57
	140		14.73	66.6	5.1	131.1	46.5	32.0	9.43	6.83	0.93	3.00	2.12
	280		18.26	111.0	7.0	158.4	52.0	38.8	13.20	10.60	1.39	4.50	2.05
Signif.			**	**	**	**	**	**	**	*	**	NS	**
Linear			**	**	**	**	**	**	**	**	**	NS	**
Quad.			NS	NS	NS	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	NS	NS	NS
B X N			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 7).

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	3.78	10.3	0.8	31.6	14.1	9.4	5.98	2.07	0.38	0.52	0.36
	0	140	7.20	19.7	1.4	46.7	24.4	19.3	7.99	3.24	0.52	1.33	0.64
	0	280	12.21	50.7	3.1	72.7	33.3	32.1	12.97	4.44	1.20	1.22	0.94
	4	70	2.80	8.6	0.7	26.6	9.3	6.7	4.56	1.22	0.26	0.25	0.29
	4	140	6.07	19.8	1.5	44.7	20.0	16.3	7.07	2.55	0.39	0.90	0.74
	4	280	11.16	47.6	2.8	69.9	29.4	28.8	12.56	3.94	0.84	0.94	1.13
Reddale	0	70	2.38	18.4	1.2	21.9	15.4	6.7	12.74	4.17	0.63	0.92	0.33
	0	140	3.24	16.8	1.6	28.2	18.4	9.4	15.52	4.31	0.41	1.23	0.38
	0	280	7.99	46.4	3.1	52.5	38.0	24.5	16.69	8.55	0.96	1.51	0.84
	4	70	2.27	12.0	1.4	21.7	16.2	7.0	15.13	4.69	0.68	1.17	0.49
	4	140	4.91	22.4	2.1	41.1	25.8	12.9	20.62	6.75	0.78	1.91	0.76
	4	280	7.24	38.0	2.6	47.5	27.0	20.4	18.91	6.37	0.59	0.95	0.90
Analysis of Variance													
Cultivar (C)													
	Russet B		7.20	26.1	1.7	48.7	21.7	18.8	8.52	2.91	0.60	0.86	0.68
	Reddale		4.67	25.7	2.0	35.5	23.4	13.5	16.60	5.81	0.68	1.28	0.61
Signif.			**	NS	*	**	NS	**	**	**	NS	**	NS
B rate (B)													
	0		6.13	27.0	1.9	42.3	23.9	16.9	11.98	4.46	0.68	1.12	0.57
	4		5.74	24.8	1.8	41.9	21.3	15.3	13.14	4.25	0.59	1.02	0.72
Signif.			NS	NS	NS	NS	*	NS	NS	NS	NS	NS	**
N rate (N)													
	70		2.81	12.3	1.0	25.4	13.7	7.4	9.60	3.04	0.49	0.72	0.37
	140		5.36	19.7	1.6	40.2	22.1	14.5	12.80	4.21	0.53	1.34	0.63
	280		9.65	45.7	2.9	60.7	31.9	26.5	15.28	5.82	0.90	1.16	0.94
Signif.			**	**	**	**	**	**	NS	*	NS	NS	**
Linear			**	**	**	**	**	**	NS	**	*	NS	**
Quad.			NS	NS	NS	NS	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	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 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 2			September 14		
		Tuber Size					
		4-7 oz	7-14 oz	> 14 oz	4-7 oz	7-14 oz	> 14 oz
B rate lb B/A	N rate lb N/A	% Incidence					
0	70	1.0	6.3	8.3	3.0	13.4	58.2
0	140	0.0	12.1	20.2	2.9	19.0	54.0
0	280	0.0	3.0	65.0	6.0	11.2	45.5
4	70	3.0	11.0	29.2	0.0	20.0	61.4
4	140	2.0	15.1	57.7	5.0	11.2	52.4
4	280	1.0	11.0	31.3	3.0	9.3	46.1
B rate (B)							
	0	0.3	7.1	31.2	4.0	14.5	52.6
	4	2.0	12.4	39.4	2.7	13.5	53.3
Signif.		NS	*	NS	NS	NS	NS
N rate (N)							
	70	2.0	8.6	18.8	1.5	16.7	59.8
	140	1.0	13.6	38.9	4.0	15.1	53.2
	280	0.5	7.0	48.1	4.5	10.2	45.8
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	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 2			September 14		
		Tuber Size					
		4-7 oz	7-14 oz	> 14 oz	4-7 oz	7-14 oz	> 14 oz
B rate lb B/A	N rate lb N/A	% Incidence					
0	70	1.0	10.0	0.0	2.0	26.0	64.6
0	140	3.0	6.0	0.0	2.0	20.0	59.2
0	280	1.0	7.0	0.0	1.0	18.4	69.8
4	70	6.0	11.0	0.0	6.0	4.0	37.5
4	140	1.0	6.0	0.0	0.0	20.0	49.1
4	280	3.0	4.0	0.0	3.0	16.3	54.2
B rate (B)							
	0	1.7	7.7	0.0	1.7	21.5	64.5
	4	3.3	7.0	0.0	3.0	13.4	46.9
Signif.		NS	NS	--	NS	NS	NS
N rate (N)							
	70	3.5	10.5	0.0	4.0	15.0	51.0
	140	2.0	6.0	0.0	1.0	20.0	54.1
	280	2.0	5.5	0.0	2.0	17.3	62.0
Signif.		NS	NS	--	NS	NS	NS
Linear		NS	NS	--	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 July 3 (74 days after planting).

Cultivar	B rate lb B/A	N rate lb N/A	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
			Nutrient									
			%					ppm				
Russet B	0	70	3.89	0.20	4.13	1.22	0.95	97	132	17	278	27
	0	140	4.63	0.21	4.11	1.30	1.11	95	122	16	219	24
	0	280	5.23	0.23	4.26	1.21	1.01	100	114	17	276	25
	4	70	4.13	0.23	4.40	1.21	0.99	97	151	21	297	89
	4	140	4.52	0.22	3.96	1.23	1.12	93	105	16	179	87
	4	280	5.09	0.22	4.18	1.27	1.05	93	123	16	205	61
Reddale	0	70	4.22	0.39	4.06	0.88	0.56	100	68	20	164	41
	0	140	4.57	0.36	3.64	0.94	0.64	106	59	21	184	31
	0	280	5.71	0.40	3.90	0.89	0.60	113	109	27	144	30
	4	70	4.44	0.39	3.94	0.87	0.59	104	71	23	209	91
	4	140	4.77	0.38	3.57	0.85	0.60	110	61	24	113	89
	4	280	5.71	0.39	4.04	0.88	0.63	114	91	24	154	53
Analysis of Variance												
Cultivar (C)												
	Russet B		4.58	0.22	4.17	1.24	1.04	96	124	17	242	52
	Reddale		4.87	0.39	3.86	0.89	0.60	108	76	23	161	56
Signif.			**	**	**	**	**	**	**	**	**	NS
B rate (B)												
	0		4.71	0.30	4.01	1.07	0.81	102	101	19	211	30
	4		4.74	0.30	4.02	1.05	0.83	102	100	20	193	78
Signif.			NS	NS	NS	NS	NS	NS	NS	NS	NS	**
N rate (N)												
	70		4.17	0.30	4.13	1.04	0.77	99	105	20	237	62
	140		4.62	0.29	3.82	1.08	0.87	101	87	19	174	58
	280		5.42	0.31	4.09	1.06	0.82	105	109	21	195	43
Signif.			**	NS	NS	NS	NS	NS	*	NS	NS	**
Linear			**	NS	NS	NS	NS	*	NS	NS	NS	**
Quad.			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	**
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 7. Nutrient concentrations in tubers as affected by N rate and boron - early harvest (Aug. 2).

Cultivar	B rate lb B/A	N rate lb N/A	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
			Nutrient									
			-------- % -------			---------- ppm ----------						
Russet B	0	70	0.83	0.19	1.92	302	945	62	8.9	9.0	2.1	4.1
	0	140	0.97	0.19	2.08	334	972	125	9.6	11.4	2.3	4.9
	0	280	1.26	0.18	2.19	438	983	86	11.2	14.2	2.7	5.0
	4	70	0.94	0.19	2.01	318	978	99	10.1	10.8	2.6	5.8
	4	140	1.03	0.18	2.06	337	971	117	9.7	11.7	2.3	6.7
	4	280	1.29	0.18	2.22	437	1042	85	11.3	13.3	2.2	7.4
Reddale	0	70	1.07	0.28	2.22	213	1246	142	8.8	14.2	4.4	9.1
	0	140	1.34	0.27	2.21	240	1224	158	9.0	15.7	4.4	8.3
	0	280	1.55	0.27	2.35	336	1171	210	11.1	22.5	5.4	8.4
	4	70	1.05	0.27	2.21	215	1169	193	9.2	16.0	4.8	9.7
	4	140	1.29	0.28	2.26	266	1213	202	9.7	18.7	5.1	10.4
	4	280	1.49	0.27	2.31	318	1202	144	10.8	19.5	4.9	10.1
Analysis of Variance												
Cultivar (C)												
	Russet B		1.06	0.19	2.08	361	982	96	10.1	11.7	2.3	5.7
	Reddale		1.30	0.27	2.26	265	1204	175	9.8	17.8	4.8	9.3
Signif.			**	**	**	**	**	**	NS	**	**	**
B rate (B)												
	0		1.17	0.23	2.16	311	1090	131	9.7	14.5	3.5	6.6
	4		1.18	0.23	2.18	315	1096	140	10.1	15.0	3.6	8.4
Signif.			NS	NS	NS	NS	NS	NS	NS	NS	NS	**
N rate (N)												
	70		0.98	0.23	2.09	262	1084	124	9.2	12.5	3.5	7.2
	140		1.16	0.23	2.15	294	1095	151	9.5	14.4	3.5	7.6
	280		1.40	0.23	2.27	382	1099	131	11.1	17.4	3.8	7.7
Signif.			**	NS	**	**	NS	NS	**	**	NS	*
Linear			**	NS	**	**	NS	NS	**	**	NS	**
Quad.			NS	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	NS	**
B X N			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 14).

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	0.93	0.24	2.05	299	1084	95	10.4	11.5	3.8	3.9
	0	140	1.04	0.22	2.01	300	1036	91	11.1	13.1	3.7	4.1
	0	280	1.21	0.20	1.96	366	1025	111	11.3	15.4	4.7	4.5
	4	70	1.02	0.26	2.18	319	1177	94	11.7	13.1	3.7	5.0
	4	140	0.99	0.20	1.91	286	1008	115	10.6	12.4	3.8	5.2
	4	280	1.08	0.20	1.89	341	964	125	10.8	16.0	4.9	5.7
Reddale	0	70	1.13	0.30	2.26	186	1191	235	9.0	18.4	5.9	7.8
	0	140	1.17	0.29	2.14	215	1182	181	9.2	18.3	5.6	6.9
	0	280	1.42	0.27	2.07	264	1089	207	10.2	21.6	6.4	6.8
	4	70	1.01	0.30	2.08	190	1114	234	9.1	17.3	6.2	7.8
	4	140	1.18	0.29	2.13	226	1122	262	9.3	19.6	6.2	8.1
	4	280	1.23	0.26	1.89	224	1009	265	9.3	18.7	5.8	7.6
Analysis of Variance												
Cultivar (C)												
	Russet B		1.04	0.22	2.00	318	1049	105	11.0	13.6	4.1	4.7
	Reddale		1.19	0.28	2.09	218	1118	231	9.3	19.0	6.0	7.5
Signif.			**	**	*	**	*	**	**	**	**	**
B rate (B)												
	0		1.15	0.25	2.08	272	1101	154	10.2	16.4	5.0	5.6
	4		1.08	0.25	2.01	264	1066	182	10.1	16.2	5.1	6.6
Signif.			NS	NS	NS	NS	NS	NS	NS	NS	NS	**
N rate (N)												
	70		1.02	0.27	2.14	248	1142	165	10.1	15.1	4.9	6.1
	140		1.10	0.25	2.05	257	1087	162	10.0	15.9	4.8	6.0
	280		1.23	0.23	1.95	299	1022	177	10.4	17.9	5.5	6.1
Signif.			**	**	*	**	**	NS	NS	**	NS	NS
Linear			**	**	**	**	**	NS	NS	**	*	NS
Quad.			NS	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 9. Nutrient uptake by tubers as affected by nitrogen and boron - early harvest (August 2).

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	70.1	16.0	161.9	2.6	8.0	8.4	1.20	1.24	0.28	0.56
	0	140	72.5	14.0	155.0	2.5	7.3	15.0	1.16	1.36	0.24	0.60
	0	280	83.3	12.1	144.1	2.9	6.5	9.1	1.16	1.48	0.32	0.52
	4	70	78.5	15.9	167.6	2.6	8.1	13.2	1.36	1.44	0.36	0.76
	4	140	76.0	13.8	153.2	2.5	7.3	13.5	1.16	1.36	0.24	0.80
	4	280	87.0	12.4	149.0	2.9	7.0	9.1	1.24	1.44	0.28	0.80
Reddale	0	70	63.6	16.5	131.5	1.3	7.4	13.2	0.84	1.32	0.40	0.88
	0	140	79.1	15.8	129.8	1.4	7.2	14.1	0.80	1.44	0.44	0.76
	0	280	70.8	12.3	106.4	1.5	5.3	14.6	0.76	1.64	0.40	0.60
	4	70	63.1	16.4	132.1	1.3	7.0	18.6	0.92	1.56	0.44	0.96
	4	140	71.0	15.6	124.7	1.5	6.7	18.0	0.80	1.64	0.40	0.92
	4	280	71.8	13.4	113.6	1.6	5.9	11.8	0.84	1.56	0.40	0.80
Analysis of Variance												
Cultivar (C)												
	Russet B		77.9	14.0	155.1	2.7	7.4	11.4	1.21	1.39	0.29	0.67
	Reddale		69.9	15.0	123.0	1.4	6.6	15.1	0.83	1.53	0.41	0.82
Signif.			*	**	**	**	**	NS	**	NS	**	**
B rate (B)												
	0		73.2	14.4	138.1	2.0	6.9	12.4	0.99	1.41	0.35	0.65
	4		74.6	14.6	140.0	2.1	7.0	14.0	1.05	1.50	0.35	0.84
Signif.			NS	NS	NS	NS	NS	NS	NS	NS	NS	**
N rate (N)												
	70		68.8	16.2	148.3	1.9	7.6	13.4	1.08	1.39	0.37	0.79
	140		74.6	14.8	140.6	2.0	7.1	15.2	0.98	1.45	0.33	0.77
	280		78.2	12.5	128.3	2.2	6.2	11.2	1.00	1.53	0.35	0.68
Signif.			NS	**	*	*	**	NS	NS	NS	NS	*
Linear			*	**	**	**	**	NS	NS	NS	NS	**
Quad.			NS	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	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 10. Nutrient uptake by tubers as affected by nitrogen and boron - late harvest (September 14).

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	112.4	28.9	247.9	3.6	13.1	18.5	2.00	2.28	0.72	0.76
	0	140	141.2	29.4	271.8	4.0	14.0	19.6	2.40	2.84	0.84	0.92
	0	280	159.8	26.0	258.3	4.8	13.5	23.2	2.40	3.28	0.96	0.96
	4	70	112.9	28.2	240.3	3.5	13.0	16.4	2.04	2.32	0.64	0.92
	4	140	130.6	26.9	252.3	3.8	13.3	24.1	2.24	2.60	0.76	1.08
	4	280	138.1	25.8	241.0	4.4	12.3	25.6	2.20	3.28	1.00	1.16
Reddale	0	70	96.0	25.5	191.7	1.6	10.1	32.6	1.24	2.52	0.80	1.08
	0	140	108.6	26.7	198.3	2.0	11.0	26.2	1.40	2.68	0.84	1.00
	0	280	135.9	26.2	198.6	2.5	10.5	32.0	1.56	3.32	1.00	1.04
	4	70	89.4	26.0	182.8	1.6	9.8	31.0	1.28	2.44	0.88	1.12
	4	140	110.5	27.5	201.5	2.1	10.6	39.9	1.40	2.92	0.96	1.20
	4	280	120.4	25.2	185.1	2.2	9.9	42.0	1.44	2.96	0.92	1.16
Analysis of Variance												
Cultivar (C)												
	Russet B		132.5	27.5	251.9	4.0	13.2	21.2	2.21	2.77	0.82	0.97
	Reddale		110.1	26.2	193.0	2.0	10.3	34.0	1.39	2.81	0.90	1.10
Signif.			**	NS	**	**	**	**	**	NS	NS	**
B rate (B)												
	0		125.6	27.1	227.8	3.1	12.0	25.4	1.83	2.82	0.86	0.96
	4		117.0	26.6	217.1	2.9	11.5	29.8	1.77	2.75	0.86	1.11
Signif.			NS	NS	NS	NS	NS	NS	NS	NS	NS	**
N rate (N)												
	70		102.7	27.2	215.7	2.6	11.5	24.6	1.64	2.39	0.76	0.97
	140		122.7	27.6	231.0	3.0	12.2	27.5	1.86	2.76	0.85	1.05
	280		138.5	25.8	220.7	3.5	11.6	30.7	1.90	3.21	0.97	1.08
Signif.			**	NS	NS	**	NS	NS	*	**	NS	NS
Linear			**	NS	NS	**	NS	NS	*	**	NS	NS
Quad.			NS	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	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 lb N/A	Early Harvest Vines	Early Harvest Tubers	Early Harvest Total	Late Harvest Vines	Late Harvest Tubers	Late Harvest Total
		lb N/A			lb N/A		
Russet B	70	47.6	74.3	122.0	9.4	112.7	122.1
	140	65.6	74.2	139.8	19.8	135.9	155.7
	280	105.4	85.1	190.5	49.2	148.9	198.1
Reddale	70	41.4	63.4	104.7	15.2	92.7	107.9
	140	67.7	75.0	142.7	19.6	109.6	129.2
	280	116.6	71.3	187.9	42.2	128.1	170.4
Analysis of Variance							
Cultivar (C)							
	Russet B	72.9	77.9	150.8	26.1	132.5	158.6
	Reddale	75.2	69.9	145.1	25.7	110.1	135.8
Signif.		NS	*	NS	NS	**	**
N rate (N)							
	70	44.5	68.8	113.3	12.3	102.7	115.0
	140	66.6	74.6	141.2	19.7	122.7	142.4
	280	111.0	78.2	189.2	45.7	138.5	184.2
Signif.		**	NS	**	**	**	**
Linear		**	*	**	**	**	**
Quad.		NS	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. Comparison of nitrogen and nitrate-N concentration in leaves (leaflet + petiole), petioles, and petiole sap at six sampling dates.

		Sampling Date														
		June 8 (56 DAP[1])					June 20 (74 DAP)					July 3 (84 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	5.62	3.63	5737	22057	1697	4.75	2.47	1886	9456	1079	4.01	1.77	609	3713	225
	140	5.81	3.64	5955	21726	1973	5.36	2.89	4621	18759	1714	4.57	2.58	4092	17147	1809
	280	5.77	3.73	6347	22844	2088	5.67	3.04	6965	21842	1816	5.16	2.95	7051	24539	2458
Reddale	70	5.90	3.94	7388	22386	1863	5.27	3.33	3683	15941	1235	4.33	2.09	1027	6400	641
	140	5.80	4.04	8255	22763	1978	6.01	3.73	5646	21016	1540	4.67	2.93	2513	15795	1293
	280	5.89	3.99	7659	25181	1951	6.32	3.90	6479	22877	1736	5.71	3.42	5197	24434	2014
Analysis of Variance																
Cultivar (C)																
Russet B		5.73	3.67	6013	22209	1919	4.26	2.80	4490	16685	1536	4.58	2.43	3917	15133	1497
Reddale		5.86	3.99	7767	22443	1931	5.85	3.65	5269	19945	1504	4.87	2.81	2912	15543	1316
Signif.		NS	**	**	NS	NS	**	**	**	**	NS	**	**	**	NS	NS
N rate (N)	70	5.76	3.79	6563	22221	1780	5.01	2.90	2784	12699	1157	4.17	1.93	818	5057	433
	140	5.80	3.84	7105	22244	1976	5.68	3.31	5133	19887	1627	4.62	2.76	3302	16471	1551
	280	5.83	3.86	7003	24013	2019	5.97	3.47	6722	22359	1776	5.42	3.18	6124	24486	2236
Signif.		NS	NS	NS	NS	**	**	**	**	**	**	**	**	**	**	**
Linear		NS	NS	NS	NS	*	**	**	**	**	**	**	**	**	**	**
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 12. Con't.

Cultivar	N rate lb N/A	July 17 (98 DAP) Kjeldahl N Leaf	Kjeldahl N Petiole	Water extractable NO_3-N Leaf	Water extractable NO_3-N Petiole	Quick test Sap NO_3-N Petiole	July 31 (112 DAP) Kjeldahl N Leaf	Kjeldahl N Petiole	Water extractable NO_3-N Leaf	Water extractable NO_3-N Petiole	Quick test Sap NO_3-N Petiole	August 14 (126 DAP) Kjeldahl N Leaf	Kjeldahl N Petiole	Water extractable NO_3-N Leaf	Water extractable NO_3-N Petiole	Quick test Sap NO_3-N Petiole
		---- % ----		--- ug/g ---		- ug/ml -	---- % ----		--- ug/g ---		- ug/ml -	---- % ----		--- ug/g ---		- ug/ml -
Russet B	70	3.33	1.14	61	384	39	2.99	1.18	66	181	3	2.86	1.23	62	57	1
	140	3.50	1.64	1166	5360	557	4.27	1.57	339	1391	50	3.65	1.44	113	419	24
	280	4.78	2.81	3809	16901	1932	4.92	2.56	2290	11557	1149	4.49	2.09	639	4445	170
Reddale	70	3.63	1.15	87	325	26	3.01	1.09	402	265	1	3.07	1.20	148	63	4
	140	3.76	1.47	454	2912	313	3.72	1.36	262	1320	28	3.30	1.25	182	994	36
	280	4.74	2.75	2634	14904	1835	4.78	2.33	2254	10363	998	4.31	1.97	1113	6632	299
Analysis of Variance																
Cultivar (C)																
Russet B		3.87	1.87	1679	7548	843	8.06	1.77	898	4376	401	3.67	1.59	271	1640	65
Reddale		4.01	1.79	1058	6047	7124	3.84	1.60	972	3983	342	3.56	1.47	481	2363	113
Signif.		NS	NS	**	NS	NS	NS	*	NS	NS	NS	NS	NS	*	**	NS
N rate (N)																
	70	3.48	1.15	74	355	32	3.00	1.14	234	223	2	2.97	1.22	105	60	3
	140	3.63	1.56	810	4136	435	3.99	1.47	300	1356	39	3.48	1.34	147	707	30
	280	4.76	2.78	3221	15902	1884	4.85	2.44	2272	10960	1074	4.40	2.03	876	5538	235
Signif.		**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
Linear		**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
Quad.		**	NS	NS	NS	NS	**	NS	**	**	**	NS	NS	*	**	NS
Interaction																
C X N		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS

Table 13. Soil nitrate-N concentrations at the early (July 27) and late (Sept. 7) harvest.

N rate	Depth	Sampling Date: July 27 In Row	July 27 Betwn Row	Sept. 7 In Row	Sept. 7 Betwn Row
lb/A	Ft.	lb NO_3-N/half acre[1]			
70	0-1	4.8 ± 1.8	3.6 ± 1.0	6.3 ± 1.9	5.3 ± 1.7
	1-2	1.6 ± 0.5	1.1 ± 0.6	2.3 ± 0.8	1.9 ± 0.7
	2-3	1.9 ± 1.4	1.4 ± 1.4	1.5 ± 0.5	1.1 ± 0.4
	Total	8.2 ± 2.1	6.0 ± 2.8	10.0 ± 3.0	8.3 ± 2.4
Total lbs NO_3-N/A in field[2]		14.1 ± 3.9		18.3 ± 5.1	
140	0-1	6.1 ± 1.6	4.5 ± 1.3	7.3 ± 2.5	5.7 ± 2.3
	1-2	5.0 ± 4.3	1.5 ± 0.7	2.5 ± 1.1	1.8 ± 0.8
	2-3	8.0 ± 5.7	1.9 ± 1.0	1.5 ± 0.7	0.9 ± 0.5
	Total	19.1 ± 8.6	7.8 ± 1.6	11.2 ± 3.9	8.5 ± 3.4
Total lbs NO_3-N/A in field		26.8 ± 8.9		19.7 ± 7.0	
280	0-1	19.6 ± 9.9	8.2 ± 3.0	9.4 ± 2.4	6.3 ± 1.8
	1-2	56.8 ± 42.6	6.7 ± 12.8	3.2 ± 1.8	1.7 ± 0.4
	2-3	23.0 ± 17.9	9.4 ± 24.2	2.1 ± 1.1	1.0 ± 0.3
	Total	99.4 ± 50.4	24.5 ± 40.2	14.8 ± 4.9	9.1 ± 2.1
Total lbs NO_3-N/A in field		123.8 ± 47.6		23.9 ± 5.4	

[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.

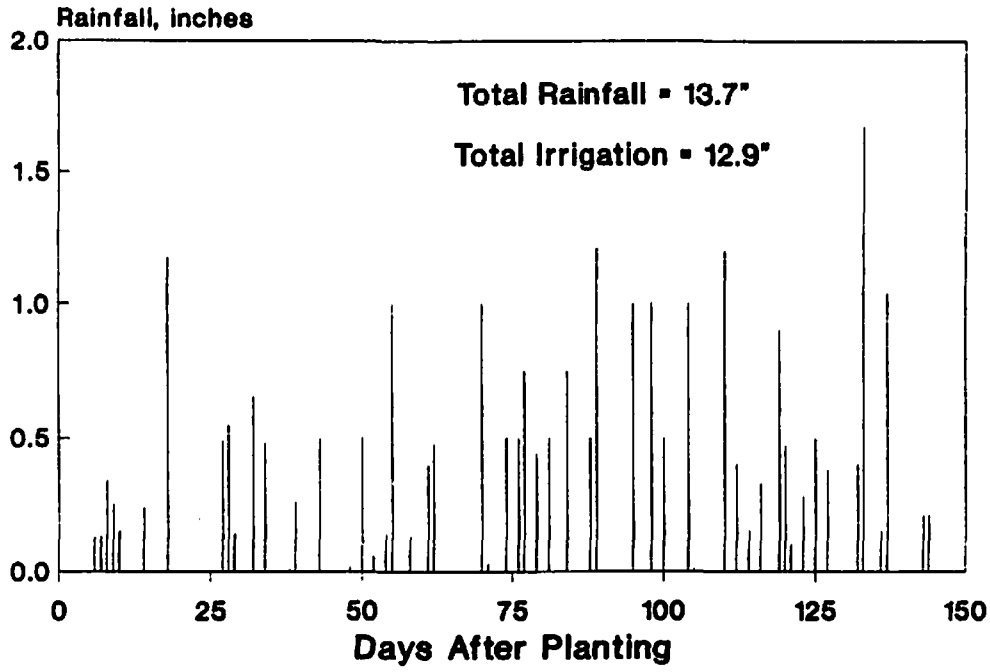

Figure 1. Rainfall and irrigation at Becker, MN during the 1989 growing season.

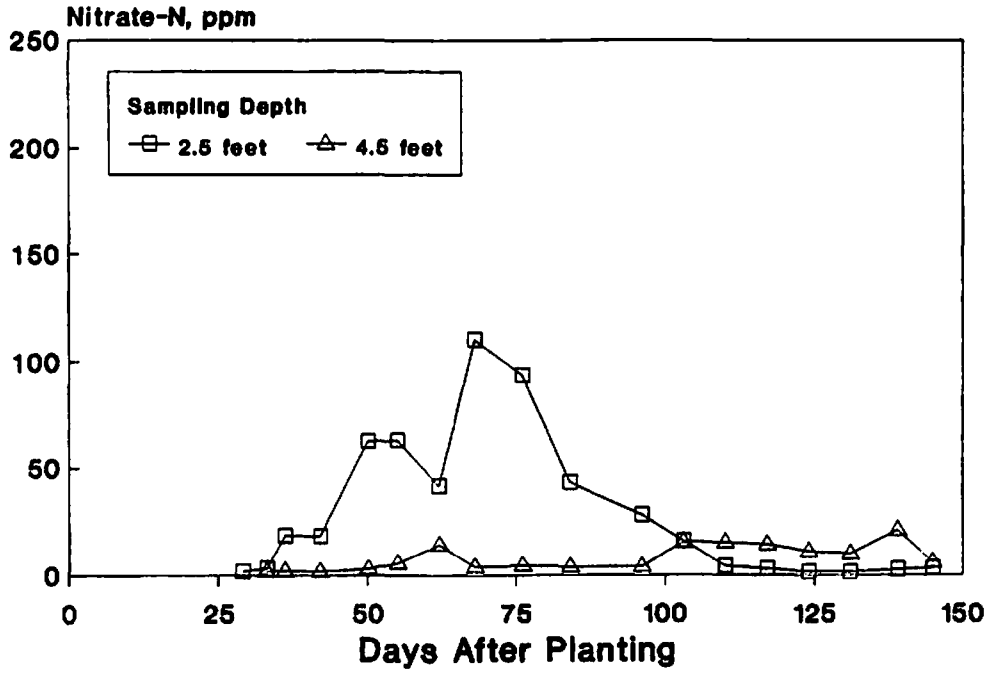

Figure 2. Nitrate-N concentrations in soil water at two depths during the 1989 growing season. Nitrogen application rate was 70 lb N/A.

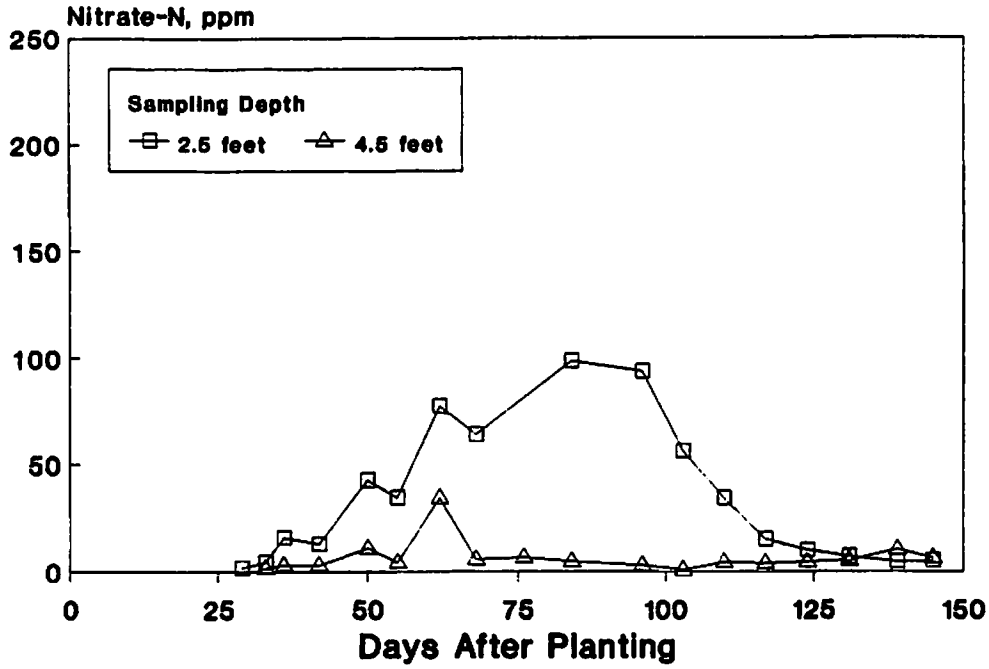

Figure 3. Nitrate-N concentrations in soil water at two depths during the 1989 growing season. Nitrogen application rate was 140 lb N/A.

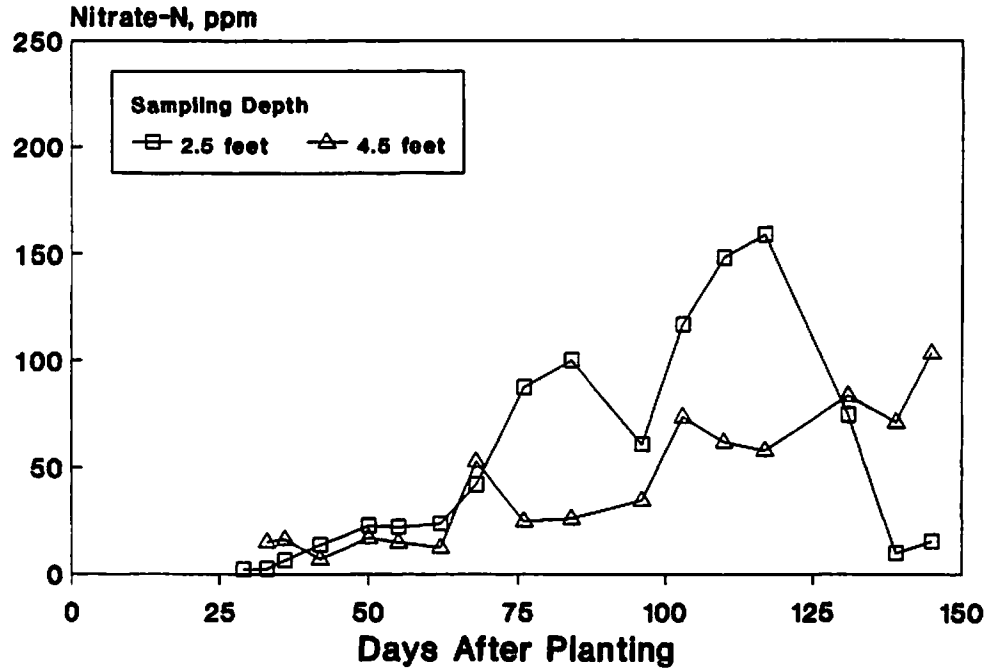

Figure 4. Nitrate-N concentrations in soil water at two depths during the 1989 growing season. Nitrogen application rate was 280 lb N/A.

1989 WEATHER DATA
NORTHWEST EXPERIMENT STATION, CROOKSTON, MN

T.E. Cymbaluk[1]

Nineteen eighty-nine was a drier year than the weather records show. The last 6 years, since 1984, the rainfall has been below normal with a total deficit of 14.47 inches. The drought of 1988 depleted the subsoil moisture, and 1989 was not a moisture-replenishing year. A precipitation a deficit of 2.48 inches occurred in 1989 with eight of the twelve months below normal. There were no precipitation events in 1989 that could be classified as a "soaker", precipitation in large enough quantity to thoroughly wet the soil profile and reach field capacity. During 1989, the precipitation usually came in a quarter-inch or less. The 1989 growing season had only 14 rains greater than a quarter of an inch of moisture.

Eight of the 12 months were below normal in regard to temperature. The average temperature in 1989 was 37.18° F. The highest temperature for 1989 occurred on August 3 at 100° F. The coldest day of the year occurred on January 10, a -36° F.

The ground frost reached a maximum depth of 41.5 inches by March 21. Surface thaw began on March 28 and by April 30, the ground frost was completely gone.

The last frost of the spring was on May 6, 1989 (28° F). The first hard killing frost occurred on September 22, 1989 (27° F). This made a 139-day frost-free period for 1989.

Table 1. Weather summary for 1989 with 90-year averages for precipitation and mean temperatures.

	Precipitation		Mean Temperatures	
Month	1989	1890-1979	1989	1890-1979
	------- inches -------		---------- °F ---------	
January	1.01	0.56	6.3	3.7
Febuary	0.13	0.59	-1.5	8.1
March	1.64	0.84	17.2	22.9
April	0.39	1.57	39.6	41.4
May	4.56	2.59	57.7	54.6
June	2.71	3.56	63.2	64.4
July	0.56	3.09	73.2	69.6
August	5.05	2.90	68.6	67.4
September	0.89	2.16	56.6	57.5
October	0.27	1.43	42.2	45.3
November	0.75	0.78	21.3	26.7
December	0.23	0.60	1.8	11.5
Total	18.19	20.67	Mean 37.2	39.4

Please refer to title page of this publication for information regarding application and use of this article.

1 Junior Scientist, Northwest Experiment Station, University of Minnesota, Crookston, MN.

Table 2. Records broken or matched at the Northwest Experiment Station, Crookston, MN in 1989.

Highest Maximum Temperature

Date	Old Record	New (1989)
	-------- °F	----------
July 4	92 (1940)	94
August 1	98 (1930)	99
August 3	96 (1893)	100
September 30	86 (1976)	86
October 24	71 (1973)	78
October 25	72 (1901)	79

Lowest Maximum Temperature

Date	Old Record	New (1989)
	--------- °F	----------
April 9	27 (1962)	26
April 8	25 (1950)	24
May 5	38 (1931)	37
June 13	54 (1917)	54
August 5	70 (1912)	66
August 20	65 (1902)	64
October 2	44 (1950)	39
November 16	14 (1903)	11
December 20	-18 (1916)	-19
December 21	-12 (1916)	-15

Highest Minimum Temperature

Date	Old Record	New (1989)
	-------- °F	----------
August 1	73 (1936)	73
August 2	71 (1964)	74

Lowest Minimum Temperature

Date	Old Record	New (1989)
	--------- °F	----------
January 9	-34 (1930)	-34
January 10	-32 (1979)	-36
August 5	45 (1957)	42
October 2	23 (1974)	13
October 3	22 (1965)	19
October 6	19 (1954)	15
October 8	17 (1986)	16
December 17	-25 (1901)	-25

ZINC APPLICATION ON SUGARBEET 1988-1989

John A. Lamb and Allan W. Cattanach[1]

OBJECTIVE:

Twenty years ago studies were conducted at the Northwest Experiment Station that suggested that sugarbeet may have responded to zinc. An update was needed to put the uncertainty to rest and to improve the soil test recommendations in Minnesota and North Dakota. With this in mind a study was conducted in 1988 and 1989 with the objective to determine if production practices developed in the last 20 years (varieties and quality payment system) influenced the response of sugarbeet to zinc fertilization.

MATERIALS AND METHODS:

Zinc fertilizer application studies were conducted at three locations in 1988 and four locations in 1989. Table 1 lists the locations and DTPA zinc soil test. Four zinc rates (0, 10, 20, and 40 lb zinc/A) in 1988 and five rates (0, 2.5, 5, 7.5, and 10 lb zinc/A) in 1989 were preplant broadcast applied and incorporated as zinc sulfate. At all locations variety KW 1745 was overplanted in 22-inch rows mid-April and thinned to 125 beets per 100 feet of row (29,700 plants/A). The plots were machine harvested late September and quality analyses were by the American Crystal Sugar Company Tare Lab, East Grand Forks, MN.

Table 1. The location and DTPA zinc soil test for zinc study 1988 and 1989.

Year	Location	Soil Test (ppm 0-6 inches)
1988	Crookston, MN (NWES)	0.3
1988	Perley, MN	0.3
1988	Maynard, MN	0.6
1989	Amenia, ND	0.3
1989	Felton, MN	0.5
1989	Crookston, MN (NWES)	0.3
1989	Sacred Heart, MN	0.6

RESULTS AND DISCUSSION:

Zinc applications on sugarbeet was researched in 1968 and 1969 by Dr. Soine, Soil Scientist, NWES. From these results it was concluded that there was a trend towards yield increase with the addition of zinc fertilizer (Table 2). The evidence was not conclusive enough to recommend use of this practice to growers. With production changes such payment system and varieties, new data was needed to determine if zinc fertilization is needed. The current soil test for zinc on other crops at the University of Minnesota uses a DTPA extractant and is quite reliable. A soil test of 0 to 0.5 ppm is classified as low, 0.5 to 1.0 ppm as marginal, and greater than 1.0 ppm as adequate.

Please refer to title page of this publication for information regarding application and use of this article.

1 Soil Scientist, Northwest Experiment Station, University of Minnesota, Crookston, MN; and Extension Sugarbeet Specialist, North Dakota State University and University of Minnesota, Fargo, ND.

Table 2. The effect of zinc fertilization on sugarbeet in 1968 and 1969.

	1968			1969 - 4 locations		
Zinc Rate	Root Yield	Sugar	Impurity Index	Root Yield	Sugar	Impurity Index
lb Zn/A	T/A	%	---	T/A	%	---
0	16.4	12.9	904	18.5	15.7	763
10	18.0	13.3	824	19.0	15.7	761
40	18.6	13.4	824	18.5	15.7	729

The locations used in the study in 1988 and 1989 had soil tests in the low or marginal categories (Table 1). This was done to ensure the best probability of a yield response to zinc application. The results from seven locations in 1988 and 1989, Tables 3 and 4, indicate that the use of zinc fertilizer is still not nessessary. Root yield, sugar concentration, recoverable sugar, and impurity index were not affected by zinc fertilization at any of the seven locations. At this time zinc application for sugarbeet production is not recommended even with soil test values in the low category.

Table 3. The effect of zinc fertilization on sugarbeet root yield, sugar concentration, recoverable sugar, and impurity index in 1988.

Zinc Rate	Root Yield	Sugar	Recoverable Sugar		Impurity Index
lb $ZnSO_4$/A	T/A	%	lb/A	lb/T	---
0	11.8	17.3	3735	314	627
10	12.3	17.5	3935	317	626
20	12.4	17.4	3922	316	596
40	12.3	17.3	3889	314	623
Statistical Analyses					
Location	*	**	*	**	**
Zinc Rate	NS	NS	NS	NS	NS
Location * Rate	NS	NS	NS	NS	NS
C.V. %	12.5	3.2	13.6	4.0	12.2

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

Table 4. The effect of zinc fertilization on sugarbeet root yield, sugar concentration, recoverable sugar, and impurity index in 1989.

Zinc Rate	Root Yield	Sugar	Recoverable Sugar		Impurity Index
lb Zn/A	T/A	%	lb/A	lb/T	---
0	16.2	14.9	4271	263	797
2.5	15.8	15.0	4263	268	788
5.0	15.7	15.1	4245	267	783
7.5	15.9	15.1	4258	266	799
10.0	16.2	15.2	4266	263	812
Statistical Analyses					
Location	**	**	**	**	**
Zinc Rate	NS	NS	NS	NS	NS
Linear	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS
Location* Rate	NS	NS	NS	NS	NS
C.V. %	11.0	2.7	11.9	3.7	9.4

** is the 0.01 significance level, respectively.

PHOSPHORUS APPLICATION ON SUGARBEET 1987-1989

John A. Lamb[1]

OBJECTIVE:

In recent years a concern has arisen among producers about the use of phosphorus. Historically sugarbeet ground has been overfertilized with phosphorus. In the last 15 years the phosphorus recommendations have been reduced to the point that very little has been applied. The objective of this study is to reevaluate the phosphorus recommendations for sugarbeet under improved production practices.

MATERIALS AND METHODS:

A phosphorus rate study was conducted over three years, 1987-1989, on a Wheatville loam at the Northwest Experiment Station. Five phosphate rates (0, 20, 40, 60, and 80 lb P_2O_5/A) as triple superphosphate (0-44-0) were applied spring 1987, fall 1987, and fall 1988. The fall soil tests each year were 9 lb/A in 1987, 9 lb/A in 1988, and 12 lb/A in 1989. Variety KW 3265 was overplanted in mid-April each year and thinned back to a population of 125 beets per 100 feet of row (29,700 plants/A). Each study was machine harvested mid-September and quality determined at the American Crystal Sugar Quality Lab, East Grand Forks, MN.

RESULTS AND DISCUSSION:

The growing conditions through the duration of this study were diverse. In 1987, sufficient rainfall occurred to produce an excellent sugarbeet crop. The fall of 1987 was the start of the current drought we are experiencing. In the 1988 cropping year the plants under went severe drought stress. The winter snows and early planting date in 1988-1989 were the reason the 1989 yield data was better than 1988. The early planting date allowed for quick plant establishment and excellent stands because of the better soil moisture conditions.

Tables 1 and 2 list the root yield, sugar concentration, recoverable sugar, and impurity index for 1987 and 1988, respectively. Even though the yield levels were considerably different in both years, the nonresponse to phosphorus was the same. As reported earlier the sodium bicarbonate phosphorus soil test in each year was 9 lb/A. This is in the low testing category where the probability of plant response to phosphorus fertilization is very good. This phenomenon has been observed in the past in field experiments on spring wheat and soybeans in northwest Minnesota. Evidently one of two possibilities exist to explain this: 1) sugarbeet is not a phosphorus responsive plant or, 2) the soil test used does not measure the capacity of the soil to provide phosphorus to the plant.

In 1989, a very large root yield and recoverable sugar per acre response occurred of 7.8 T/A and 1798 lb/A, respectively (Table 3). The sugar concentration was decreased approximately 0.5 %. Recoverable sugar per ton and impurity index were not effected by phosphorus fertilization in 1989. Phosphorus responses of these magnitudes are very unusual and were not expected particularly in view of the lack of response in 1987 and 1988. Why did the larger yield response occur? In 1989 the phosphorus plots were severely stunted by root maggot feeding. The sugarbeet plants that recieved phosphorus must have been growing faster and not stressed as much as the plant with no phosphorus. This allowed the plants to survive the stress from root maggot feeding better.

Please refer to title page of this publication for information regarding application and use of this article.

1 Soil Scientist, Northwest Experiment Station, University of Minnesota, Crookston, MN.

Table 1. The effect of phosphorus on sugarbeet root yield, sugar concentration, recoverable sugar, and impurity index in 1987 at NWES.

P Rate	Root Yield	Sugar	Recoverable Sugar		Impurity Index
lb P_2O_5/A	T/A	%	lb/A	lb/T	---
0	21.9	16.6	6561	300	623
20	22.7	16.7	6796	299	709
40	22.1	16.8	6750	305	593
60	23.3	16.0	6618	285	719
80	23.3	16.8	6996	300	699
Statistical Analyses					
Phosphorus	NS	NS	NS	NS	NS
Linear	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS
C.V. %	6.9	3.4	7.1	4.5	12.2

Table 2. The effect of phosphorus on sugarbeet root yield, sugar concentration, recoverable sugar, and impurity index in 1988 at NWES.

P Rate	Root Yield	Sugar	Recoverable Sugar		Impurity Index
lb P_2O_5/A	T/A	%	lb/A	lb/T	---
0	12.7	17.5	4088	322	535
20	13.4	17.5	4355	323	522
40	14.4	17.6	4673	324	541
60	14.0	17.7	4604	328	483
80	13.0	17.8	4273	330	472
Statistical Analyses					
Phosphorus	NS	NS	NS	NS	NS
Linear	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS
C.V. %	13.9	3.3	15.8	4.1	11.8

Table 3. The effect of phosphorus on sugarbeet root yield, sugar concentration, recoverable sugar, and impurity index in 1989 at NWES.

P Rate	Root Yield	Sugar	Recoverable Sugar		Impurity Index
lb P_2O_5/A	T/A	%	lb/A	lb/T	---
0	13.7	14.6	3502	256	847
20	19.0	14.4	4717	249	905
40	19.0	14.0	4534	239	962
60	21.5	14.3	5300	247	896
80	17.6	13.9	4202	239	918
Statistical Analyses					
Phosphorus	**	NS	*	NS	NS
Linear	*	++	++	NS	NS
Quadratic	**	NS	**	NS	NS
C.V. %	13.3	4.0	13.9	5.9	13.0

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

With the 1989 response and other references in the literature it can be concluded that sugarbeets need phosphorus to grow and if the phosphorus is not supplied to the plant from the soil phosphorus fertilization is needed. Work is needed to understand the phosphorus dynamics in Red River Valley soils to understand what governs the phosphorus availibility to plants. From this information a more accurate soil test method could then be developed.

COMPARISON OF SPRING-APPLIED DCD-UREA AND UREA OF HARD RED SPRING WHEAT IN NORTHWESTERN MINNESOTA

J.A. Lamb, T.E. Cymbaluk, and P. Nesse[1]

OBJECTIVE:

This study was conducted to compare the agronomic effects on spring wheat of DCD treated urea and urea.

MATERIALS AND METHODS:

A two-year study was conducted at the Northwest Experiment Station and in Mahnomen County in 1988 and 1989, respectively. Urea (46-0-0) and DCD-urea (47-0-0) was applied and incorporated in the spring at rates of 0, 40, 80, 120 and 160 lb N/A. The soil test NO_3^--N to 2-feet was 50 and 43 lbs N/A in 1988 and 1989, respectively. Marshall wheat was planted the last week of April with a press wheel double disk drill. In 1989 whole plant samples were taken at soft dough for N uptake. In both years, the plots were machine harvested with grain yields and protein determined and reported at 13.5% moisture. At the Mahnomen site, soil samples were taken after harvest to a depth of five feet and divided into one-foot increments.

RESULTS AND DISCUSSION:

The use of DCD-urea was intended to reduce N losses to leaching and denitrification. At the time of this study, northwest Minnesota was experiencing a drought, thus neither of the N loss conditions occurred. The Northwest Experiment Station experienced the fifth dryest growing season in 100 years in 1988. At the Mahnomen County location, the environmental conditions were much more favorable for wheat production in 1989 although the crop did suffer some drought stress during the growing season.

Grain Yield: In both years, grain yield responded to N fertilizer application (Table 1). At Crookston the response was quadratic with the maximum grain yield, 27.6 bu/A, a 3.9 bu/A increase, occurred with the addition of 40 lb N/A. In 1989 there was a source by N rate interaction ($P \leq 0.10$). The urea-fertilized wheat grain yield was maximized with 80 lb N/A applied and the DCD-urea treated wheat had a maximum grain yield at 120 lb N/A.

Grain Protein: Grain protein was increased both years of the study by N application (Table 1). Nitrogen source did not significantly affect this response. In 1988 the increase was linear and thus a maximum protein concentration was not reached. At Mahnomen County in 1989, the maximum grain protein occurred with the addition of 120 lb N/A. This data also indicates the inverse relationship between grain yield and grain protein. In situations with low yield (1988), the protein concentration is greater than when the grain yields are high (1989).

Forage Yield, N Concentration, N Uptake and Apparent Fertilizer N use Efficiency: Nitrogen source did not affect forage yield, N concentration or N uptake at soft dough in 1989 (Table 2). The application of N increased each parameter linearly so a maximum was not reached at even 160 lb N/A. The greatest N fertilizer use efficiency, 47%, occurred at 80 lb N/A which is the same as where maximum grain yield occurred with the urea source of N. This fertilizer use efficiency is similar to results from other N rate studies in northwestern Minnesota using 15N·

Residual Soil Nitrate-N: The application of N increased the residual nitrate-N content into a five-foot depth significantly (Fig. 1). At N rate of 80 lb/A or less, the residual nitrate-N was the same for both N sources. At N rates greater than 80 lb/A, the nitrate-N content was, on the average, greater in soil which had urea applied as N source.

Please refer to title page of this publication for information regarding application and use of this article.

[1] Soil Scientist and Junior Scientist, Northwest Experiment Station, University of Minnestoa, Crookston, MN; and former Mahnomen County Agricultural Agent, Minnesota Extension Service, Mahnomen, MN.

Table 1. The effect of N source and rate on grain yield and protein in 1988 and 1989.

	1988				1989			
	Grain Yield		Grain Protein		Grain Yield		Grain Protein	
N Rate	Urea	DCD	Urea	DCD	Urea	DCD	Urea	DCD
lb N/A	-- bu/A --		--- % ---		-- bu/A --		--- % ---	
0	24.7	22.6	13.0	13.3	44.3	42.1	11.3	11.4
40	27.6	27.4	14.2	13.8	58.7	54.7	12.3	12.1
80	27.4	26.3	14.1	14.1	65.1	61.7	13.1	13.6
120	25.1	27.8	14.4	14.1	60.0	63.6	14.0	13.5
160	24.7	26.0	14.6	14.9	59.2	62.0	13.7	13.7
Statistical Analyses								
Source	NS		NS		NS		NS	
N Rate	NS		**		**		**	
Linear	NS		**		**		**	
Quadratic	*		NS		**		**	
Source x N Rate	NS		NS		++		NS	
C.V. %	12.3		2.9		6.7		3.9	

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

Table 2. The effect of N source and rate on forage yield, N concentration, N uptake, and fertilizer use efficiency at soft dough in 1989.

	Forage Yield		Forage N Concentration		Forage N Uptake		Apparent N Efficiency Ave. of Both Sources
N Rate	Urea	DCD	Urea	DCD	Urea	DCD	
lb N/A	-- lb/A --		--- % ---		-- lb/A --		% Applied
0	4326	4988	1.04	0.78	44.0	39.1	-
40	5358	6020	0.86	1.07	45.9	63.6	33
80	6663	7453	1.17	1.07	77.4	81.6	47
120	6899	5847	1.47	1.21	102.9	72.4	38
160	6345	7846	1.18	1.37	75.5	107.1	31
Statistical Analyses							
Source	NS		NS		NS		
N Rate	**		**		**		
Linear	**		**		**		
Quadratic	NS		NS		NS		
Source x N Rate	NS		NS		NS		
C.V. %	20.4		21.9		33.4		

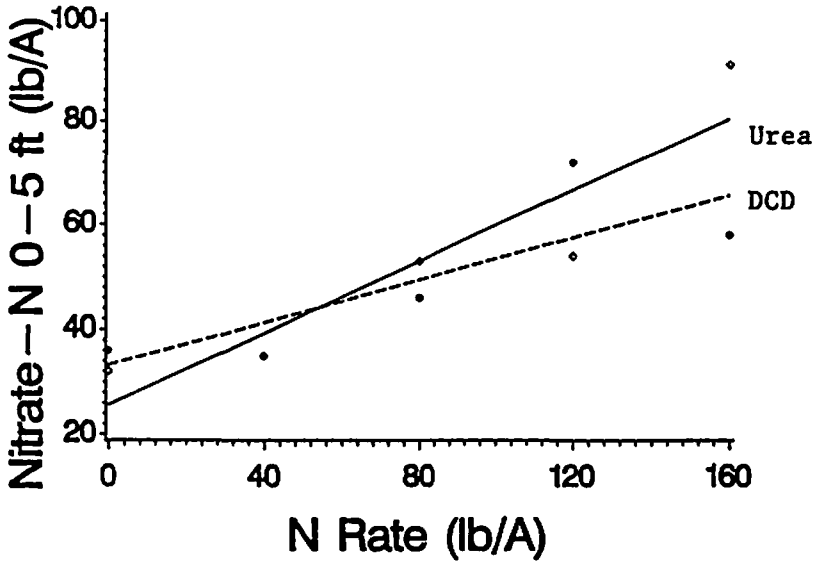

Figure 1. The effect of N source and rate on residual soil nitrate-N (0-5 ft) in 1989.

RESIDUAL NITROGEN STUDY AT LAMBERTON[1]

D.J. Fuchs and W.W. Nelson[2]

Abstract: Corn and soybean yields are usually greater in a rotation than in a monoculture system. This study was conducted to determine the nitrogen-rate response of corn and the ensuing year effect of residual nitrogen on soybean yields. The effect of 6 N-rates (0 - 400 lbs/ac) were examined in a corn-soybean rotation on a Normania loam. In all previous years, excluding 1988, N-rate response was noted for corn but not for soybeans. In 1989, for the first time since 1984, soybeans showed a significant positive N-rate response from increasing nitrogen rates applied on the previous corn crop. Corn yields demonstrated a non-linear response to increasing N-rates, characteristic of a diminishing return relationship.

(Annual report of this experiment has been included in past University of Minnesota, Soil Science Department's "Blue Book", and much of the previous data will not be repeated here.)

Methods & Materials: The experiment was initiated in 1984 on a Normania loam. Each plot is 30 by 48' with 8 replications each arranged in a randomized block design. In 1984, all 8 blocks were planted in corn. Starting in 1985, half the blocks have been in corn, the other half in soybeans, alternating each year. The treatments consist of six N-rates ranging from 0 to 400 #/Ac applied side dress as urea during the corn year. Addition management data is given in Table 1.

Results: Yields are given in Table 2.

Regression analysis was used to determine if there was a significant effect of nitrogen rate on corn and soybean yields. There was a significant non-linear relationship between nitrogen rates and corn yields (r^2 = 0.94, see Table 2 and Figure 1). Corn yields increased with increasing nitrogen rates until the 200 lbs/ac rate, then the yields began to decline (see Table 2 and Figure 1). In the past, corn had a significant response to nitrogen each year. In 1989, there was also a significant non-linear relationship between the residual nitrogen rates applied to corn in 1988 (r^2 = 0.95, see Table 2 and Figure 2). Three possible reasons for this are 1) that some of the residual nitrogen may act like starter fertilizer for the under developed soybean plants, providing easy access to nutrients until the soybean plant is able to manufacture its own and/or; 2) the soybean nodules become inactive when seed fill takes place. If nitrogen is deep, it will not inhibit nodulation but be available below the area of nodules (mostly 9-12 inches) where water is available during seed fill and still a major portion of nitrogen is needed and/or; 3) The drought of 1988 may have negatively effected populations of symbiotic bacteria, increasing the soybean dependence on available nitrogen sources in the soil. Previously, soybeans did not have a response to residual nitrogen.

Table 1. Corn and Soybean Management Information.

Item		Corn	Soybean
1988 Fall Primary Tillage:		Soil Saver	Soil Saver
Secondary Tillage	Type:	Digger (Twice)	Disk (Twice)
	Date:	25 April	11 May
Seed	Hybrid/Variety:	P 3732	Hardin
	Rate:	26,000 ppa	150,000 seeds/ac
	Date:	2 May	11 May
Herbicide	Brand:	Eradicane-Bladex	Treflan-Amiben
	Rate:	2.5 & 1.5 #/ac	0.75 & 2.5 #/ac
	Date:	25 April	11 May

[1] Funding provided by the Agricultural Experiment Station.

[2] Junior Scientist and Superintendent - University of Minnesota, Southwest Experiment Station, Lamberton, MN 56152, respectively.

Table 2. Corn and Soybean Yields.

Nitrogen (lbs./ac.)	Corn (bu./ac.)	Soybeans (bu./ac.)
0	97.0	40.2
50	116.2	40.9
100	121.8	43.5
150	129.0	43.3
200	128.8	45.3
400	127.6	46.2

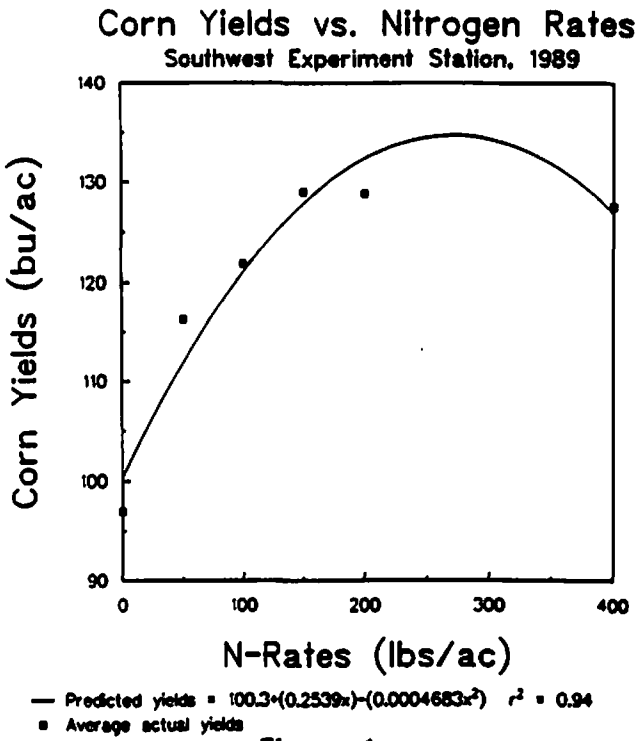

Figure 1.

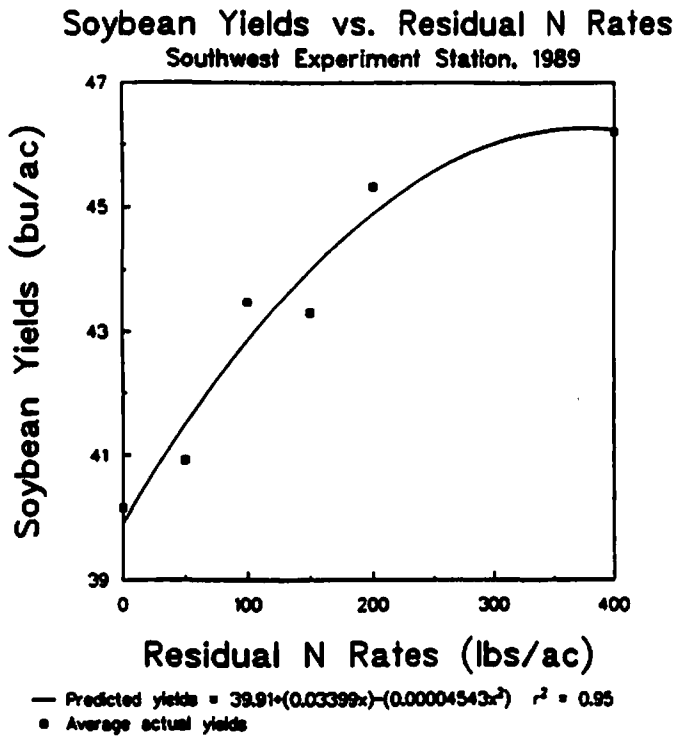

Figure 2.

THIRTY YEARS OF FIELD EXPERIMENTATION WITH NITROGEN SOURCE, PLACEMENT, AND TIME OF APPLICATION TO A WEBSTER CLAY LOAM AT THE SOUTHWEST EXPERIMENT STATION LAMBERTON, MN[1]

D.J. Fuchs and W.W. Nelson[2]

Abstract: Corn yields may be affected by different nitrogen management systems. This study was conducted to determine if differences exist between nitrogen forms (urea or ammonium nitrate), amounts ranging from 0 to 160 pounds N/Ac, and their time of application (fall, spring or sidedressed) and placement (surface, moldboard plow incorporation or sidedress) on corn yields. The effects were examined on continuous corn with 30-inch rows in a Webster clay loam. In 1989, there was little difference between the 80 and 160 pounds N/Ac treatments, probably because of residual nitrogen from the drought of 1988. The 0 & 40 pounds N/Ac treatments had lower yields with the check having the lowest yields. The time of application and N forms affected yields as they have in the past 30 years. The 30 year average of the treatments indicate that corn yields respond the greatest to N rate with a slight advantage to spring application with little difference between N forms.

(Annual reports of this experiment have been included in most of the University of Minnesota Soil Science Department "Blue Books" and much of this information will not be included here).

The fertilizer treatments have now been applied annually to the same plot area for 30 years. Each plot is 20' by 77.5' with the four replications arranged in a randomized block. After ear corn removal and stalk cutting, the fall treatments are broadcast on their respective plots and the entire area is then moldboard plowed to approximately 12 inches deep. The fall surface treatments are then broadcast with no further working of the plow area. Spring treatments are broadcast before seedbed preparations in late April or early May. The corn is planted in 30-inch rows at a plant population of 26,000 plants/A, using a band starter fertilizer of 8-24-12 at a rate of 180#/A over the entire experimental area, thus supplying an additional 14 #N/A to all plots. Sidedress treatments are broadcast in June and incorporated during cultivation.

1989 results: The 1989 yields from this experiment are given in Table 1. Also included are the 30-year averages (In 1976, no yields were obtained due to drought, thus only 29 years of data exist). The one-way analysis of variance (Table 2) indicates a significant treatment effect. The LSD for yield ($\alpha = 0.05$) is 16.8 bu/ac.

The results of 1989 did not completely follow the trend of the past where greatest yield response is to increasing N-rates. This may have been caused by residual nitrogen that was not used during the dry 1988 growing season and was available for use in 1989. The two highest yielding treatments were 80 pounds of N/Ac of urea spring applied and 80 pounds of N/Ac of ammonium nitrate sidedressed (see Table 1). However, there was no significant difference between those yields and the 160 pounds of N/Ac treatments (see Table 1). This year and in the past, there has been a moderate response to delayed application time, with the exception of the fall surface treatments. Urea nitrogen treatments had approximately a 2 bu/ac yield advantage over ammonium nitrate. This year, as in the past, there is little difference in yield between ammonium nitrate and urea treatments.

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[1] Funding provided by Agricultural Experiment Station

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