Effect of Irrigation Method and Late Season Nitrate-Nitrogen Concentration on Sucrose Production by Sugarbeets[1]

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For maximum sucrose production by sugarbeets (*Beta vulgaris* L.) in southern Idaho, the available soil nitrogen (N) level should be highest during early July, when the plant N uptake (N_{up}) rate is highest, and lowest by the latter part of August (1, 12)[3]. Inadequate N during the early growth stages limits root and sucrose yield, whereas excess N stimulates top growth, increases root impurities, and decreases sucrose percentage and extractable sucrose (7). Inadequate irrigation limits root and sucrose yields, whereas overirrigation leaches N and may affect the sugarbeet response to N application (2, 6, 9, 11).

Maintaining optimum levels of available N for plant growth depends upon proper N-fertilizer application, either as a preplant or side-dress application, in relation to the N available from soil sources (1, 3). However, overfertilization with N may occur even with an adequate testing program due to overestimation of the yield potential or yield reductions due to poor stands, insect damage, disease, other nutrient deficiencies, or adverse climatic factors. If the available N supply in the soil is too high for the expected yield during the season, mid- to late- season removal of part or all of the excess N may improve beet quality and sucrose production.

Nitrate-nitrogen (NO_3-N) accumulates on or near the ridge surface in furrow-irrigated sugarbeets. This concentration increases as the season progresses, due to water and NO_3-N movement towards the drying surface. The NO_3-N below and near the irrigation furrow decreases at each irrigation because of N leaching below the furrow, movement of NO_3-N towards the drying surface, and N_{up} by the plants. Rainfall sufficient to move the accumulated NO_3-N into the root zone may have beneficial effects on plant growth early in the season. However, if sufficient NO_3-N is washed into the root zone late in the season, it may stimulate vegetative growth and have detrimental effects on both sucrose percentage and sucrose yield. Sprinkler irrigation rather than furrow irrigation presumably prevents the NO_3-N accumulation on the soil surface. As a result, sucrose percentage and

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sucrose yield may be greater under sprinkler than furrow irrigation, especially in irrigated areas where rainfall is concentrated in the late summer or early fall.

This paper summarizes studies on the effects of irrigation method and the reduction in NO_3-N late in the season, at different N levels, on sucrose production by sugarbeets.

Materials and Methods

Three field experiments were conducted on a Portneuf silt loam soil (Xerollic Calciorthid; coarse-silty, mixed, mesic) near Twin Falls, Idaho. This soil has a weakly cemented hardpan at the 16- to 20-in depth that has little effect on water movement when saturated, but may restrict root penetration. Adequate phosphorus (P) fertilizer (44 lb P/A) was broadcast on all experimental areas before seedbed preparation. Adequate potassium was present from soil and irrigation water sources.

Experiment 1 plot area had been cropped to barley without fertilizer the previous year, and a soil test predicted 100 lb of fertilizer N/A was needed for maximum sucrose yield. Two irrigation methods (furrow and sprinkler) and two irrigation treatments (nonleached and leached) were used as main plots with four N-fertilization rates (50, 100, 150, and 200 lb N/A) as subplots; all were replicated four times.

Experiment 2 plot area had been cropped to barley (straw burned) without fertilizer the previous year, and a soil test predicted 296 lb of fertilizer N/A was needed for maximum sucrose yield. Two furrow irrigation treatments (nonleached and leached) were used as main plots with three N rates (0, 100, and 200 lb N/A) as subplots; all were replicated two times.

Experiment 3 plot area had been cropped to sugarbeets without fertilizer the previous year and a soil test predicted sufficient available residual N for maximum sucrose yield. Two cropping treatments (no sudangrass and sudangrass) and two N rates (100 and 200 lb N/A) were used; all were furrow-irrigated and replicated four times in a randomized block.

Sugarbeets (*Beta vulgaris* L.) were planted in 24-in rows on April 15 and replanted May 12 because of poor stand in Experiment 1, on April 14 in Experiment 2, and April 21 in Experiment 3. In early June, plants were thinned to a within-row spacing of approximately 12 in. Piper sudangrass (*Sorghum sudanense*) was planted in Experiment 3 plots by a broadcast application on July 9 just before the last cultivation at the rate of 100 lb/A.

Nitrogen fertilizer (NH_4NO_3) was applied below and to the side of the irrigation furrow as a side-dressing in early June in Experiments 1 and 3, and broadcast preplant ($Ca(NO_3)_2$) in Experiment 2.

All plots were irrigated when their soil moisture reached prescribed levels based on estimated evapotranspiration (8), except when the plots were intentionally leached (Fig. 1).

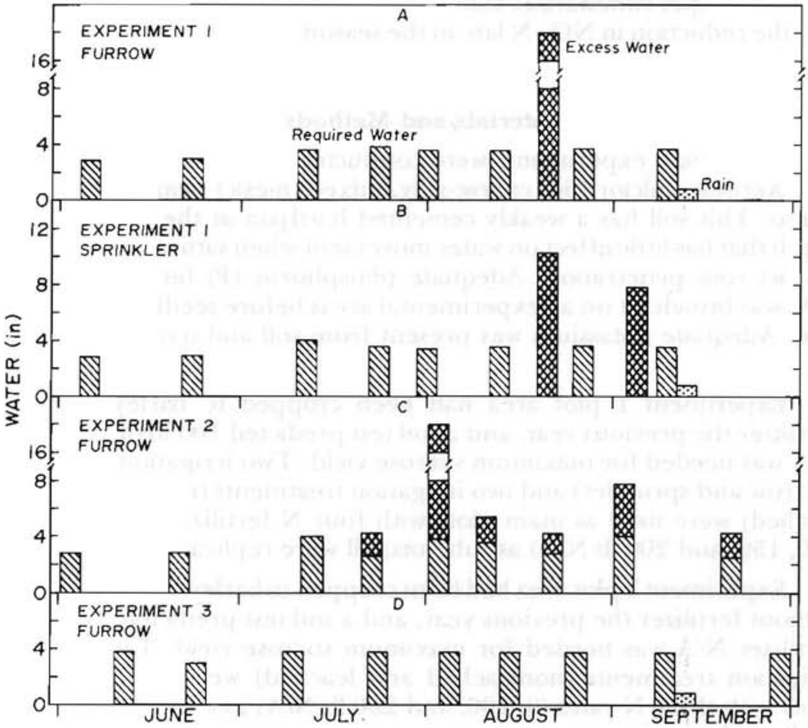

Figure 1.—Irrigation water applied and rainfall. (Total irrigation water applied from 6/1 to 9/30, based on estimated evapotranspiration, was 28, 30, and 33 in, while the leaching fraction was 18, 24, and 0 in in Experiments 1, 2, and 3, respectively. Irrigations previous to 6/1 are not shown.)

Irrigation water in Experiment 1 was applied to alternate furrows (every other furrow, alternating furrows at each irrigation) during the first two irrigations. After the side-dressed fertilizer application, the third irrigation (June 22) was applied to all furrows. Beginning with the fourth irrigation (July 11), and for the remainder of the season, half of each replication was furrow-irrigated using alternate furrows, and the other half sprinkler-irrigated. Half of the sprinkler- and furrow-irrigated areas was leached with about 18 in of water in late August and early September (Fig. 1A, B).

Experiment 2 had irrigation water applied to alternate furrows on all plots the first five irrigations. Beginning with the sixth irrigation (July 22), half the plots were irrigated using alternate furrows and half using every furrow. Areas with every furrow irrigated received 14.2 in of extra irrigation water on the seventh irrigation (Aug. 2). The time and duration of the alternate and every-furrow irrigation treatments were the same, except for the seventh irrigation (Fig. 1C).

Experiment 3 was irrigated using alternate furrows at prescribed levels based on evapotranspiration for the entire season (Fig. 1D).

Weekly petiole samples consisting of 24 of the youngest, fully mature leaves were taken at random from each plot at each sampling date. The petioles were cut into 0.25-in sections, dried at 65°C, ground to pass through a 40-mesh sieve, subsampled, and analyzed for NO_3-N. Petiole NO_3-N concentration was determined by the phenoldisulfonic acid method using a water extract of the petioles for Experiments 1 and 3 (12), and using a nitrate specific ion electrode for Experiment 2 (10).

In late October, the beet roots were harvested for Experiments 1 and 3 by taking eight 30-ft rows, and in Experiment 2 by taking six uniform 10-ft row sections. Sucrose content was determined on two samples (30 lb each) of randomly selected roots from each plot by a sugar company using their standard procedures.

Results and Discussion

Experiment 1

The overall effect of N fertilizer was to significantly increase beet root yield at the two higher N levels as compared with the 50-lb/A rate (Fig. 2A). However, because the sucrose percentage decreased as each applied-N level increased, there was no significant change in sucrose production at different N rates. Although there was no significant change in sucrose production, there was a steady decline in sucrose yield with each N addition above the 50-lb/A rate.

The soil test for available N (1) indicated that approximately 100 lb of applied N/A would be required for the expected root yield of 27 T/A. However, the 50-lb/A rate was adequate at the relatively low production level attained because of replanting. Petiole analysis confirmed that sufficient or excess N (2, 12) was available for maximum production on all N treatments (Fig. 3).

Sprinkler-irrigated sugarbeets consistently produced slightly greater root and sucrose yields at the three lower N levels as compared with those furrow-irrigated (Fig. 2B); yet the differences were significant only at the 100-lb/A N rate. The sucrose percentage decreased as N rate increased for both irrigation methods. However, there were no significant differences in sucrose percentage between the two irrigation methods. Nevertheless, sprinkler-irrigated sugarbeets produced an average of 5% more sucrose than did furrow-irrigated sugarbeets at the three lower N levels.

There was no rainfall from July 7 to September 10, which favored the accumulation of NO_3-N in the ridges of the furrow-irrigated

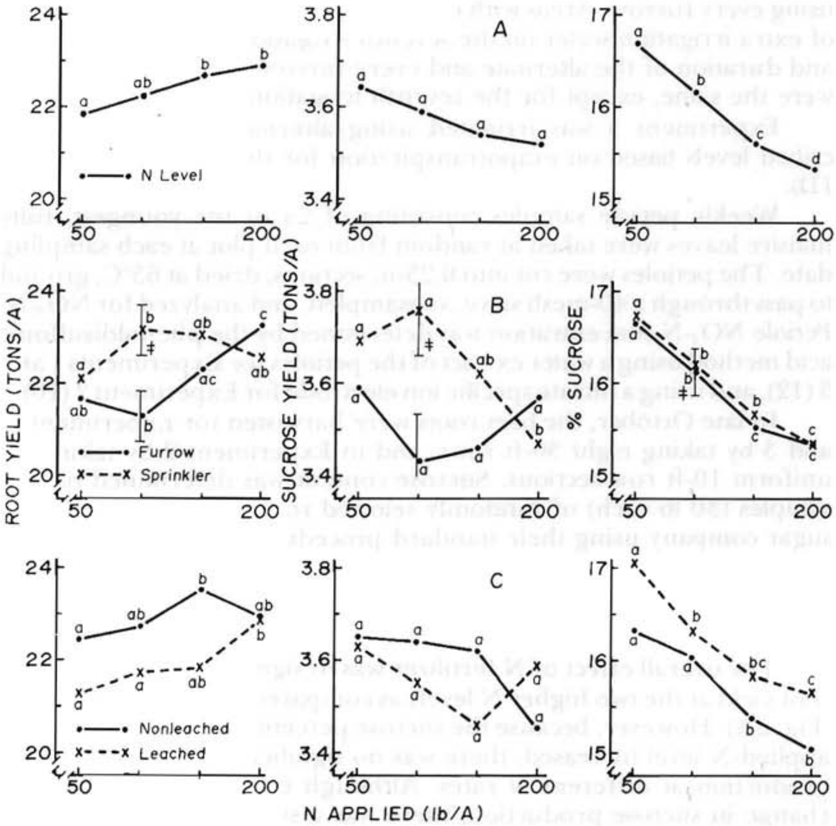

Figure 2.—Effect of N, irrigation method, and leaching on root yield, sucrose yield, and sucrose percentage of sugarbeets in Experiment 1. (Means within a method of irrigation followed by the same letters are not significantly different at the 5% level according to Duncan's Multiple Range Test. ‡ Tukey's value (w). Means with differences larger than w are significantly different at the 5% level.)

sugarbeets. Rainfall on September 10 (0.63 in) and 20 (0.19 in) was sufficient to move part or all the NO_3-N accumulated in the ridges into the root zone. Contrary to expectations, the NO_3-N concentrations in the petioles of the sprinkler-irrigated beets generally were higher than those in furrow-irrigated beets (Fig. 4A, B) during the latter part of the season (average furrow-irrigated, petiole NO_3-N $(\hat{Y}) = \ln 3164 - 0.026 \times$ sampling date (x), r = 0.99; average sprinkler-irrigated, petiole NO_3-N $(\hat{Y}) = \ln 3752 - 0.019 \times$ sampling date (x), r = 0.88). The sucrose percentage with the two forms of irrigation, however, was comparable (Fig. 2B).

The differences in sucrose production between the irrigation

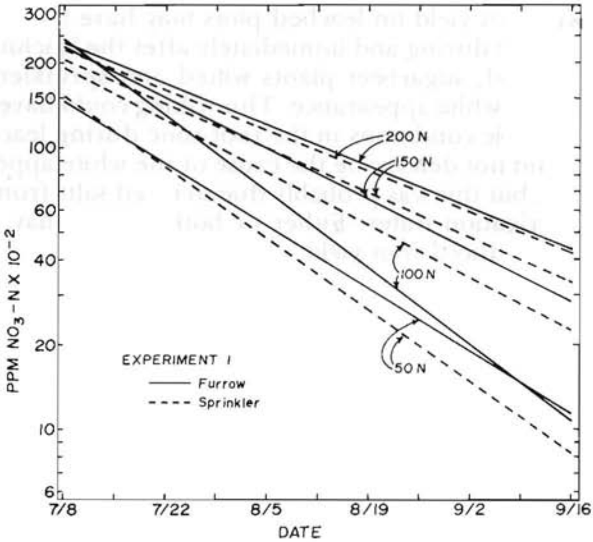

Figure 3.—Nitrate-nitrogen concentration in sugarbeet petioles at various sampling dates using two methods of irrigation and four N rates in Experiment 1.

methods resulted mainly from differences in root production. Petiole analysis indicated the N nutrition was not a contributing factor in these differences on three of the N treatments (Fig. 3). However, furrow-irrigated beets receiving 100 lb N/A had a substantial reduction in petiole NO_3-N from midseason as compared with sprinkler-irrigated beets at the same N treatment. This indicated a growth factor or N difference on this treatment that we could not account for, but may have been the contributing factor in the significant difference in root and sucrose yields at this N treatment. If differences do exist between furrow- and sprinkler-irrigated beets, the cause may be due to growth characteristics of the plant under the two forms of irrigation. Haddock (6) showed that sugarbeets grown under sprinkler irrigation had a higher top:root ratio and a greater top yield. In our work, sugarbeets grown under sprinklers seemed to have a higher leaf area index and a more erect growth enabling a possible greater efficiency in use of the radiant energy.

Increased irrigation water application to leach NO_3-N from the root zone late in the season reduced beet root yield as compared with nonleached areas at the three lower levels of applied N (Fig. 2C). However, leaching increased sucrose percentage from 0.3 to 0.75% and averaged 0.52%. As a result of the root decrease and sucrose percentage increase with leaching, no significant effect was found on sucrose production.

The lower root yield on leached plots may have been caused by adverse conditions during and immediately after the leaching period. During this period, sugarbeet plants wilted and sprinkler-irrigated plant leaves had a white appearance. This wilting could have been due to partial anaerobic conditions in the root zone during leaching (13). However, we did not determine the cause of the white appearance of the beet leaves, but this was probably due to dried salts from water of guttation or irrigation water. Either or both factors may have contributed to the reduced root yield.

Petiole analysis indicated that available N supply decreased after the period of heavy water application under both irrigation methods (Fig. 4A, B). Sufficient N was still available to keep the plants at a high NO_3-N level, particularly on the higher levels of applied N. Earlier

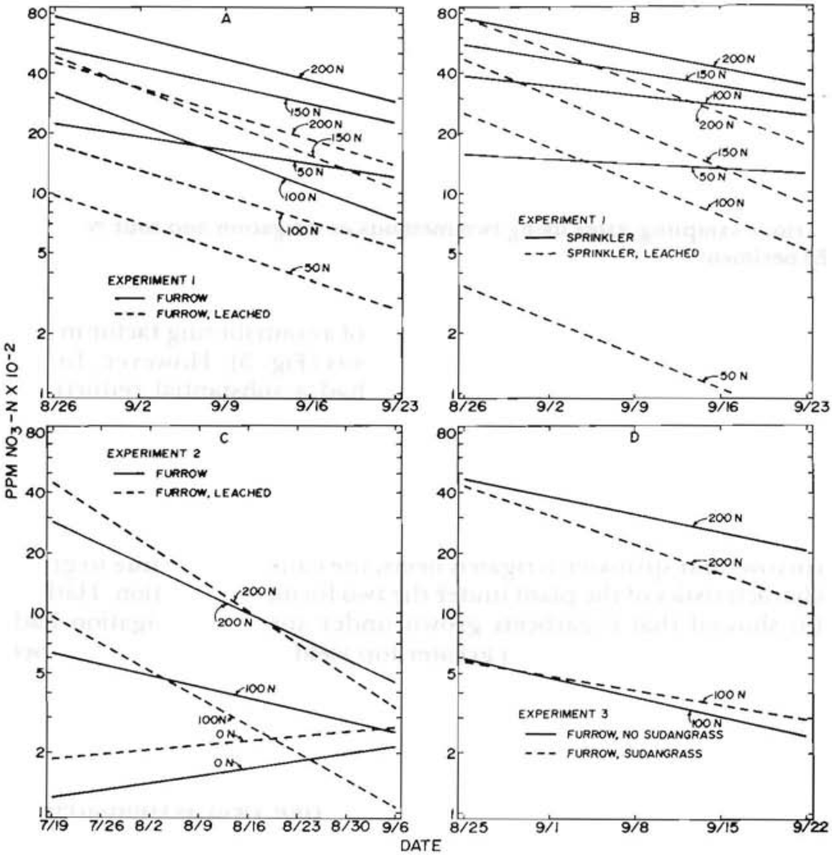

Figure 4.—The effect of late season removal of NO_3-N from the root zone on petiole NO_3-N concentration of sugarbeets in Experiments 1, 2, and 3.

leaching of N might have caused a more desirable available soil-N decrease and a sufficient sucrose percentage increase to make leaching a potentially feasible practice. Also, the plant NO_3-N level could be more easily controlled on a sandy, low mineralization capacity soil than on the silt loam used in this experiment. However, the intentional leaching will increase the possibility of contaminating groundwater with NO_3-N.

Experiment 2

As N-fertilizer rates increase, root and sucrose yields significantly increased, but percentage sucrose at both levels of irrigation water was not affected (Fig. 5A). However, there was no significant or noticeable difference between these yield factors and the level of irrigation. Petiole analysis indicated that part of the NO_3-N was leached below the root zone, denitrified, or reduced in availability to the plant on the plots receiving N fertilizer (Fig. 4C). For the no-N treatment, NO_3-N in the petioles increased throughout the season and was consistently higher at the higher irrigation level. Apparently, at these low-to-adequate levels of N, only small amounts of the potentially available N was

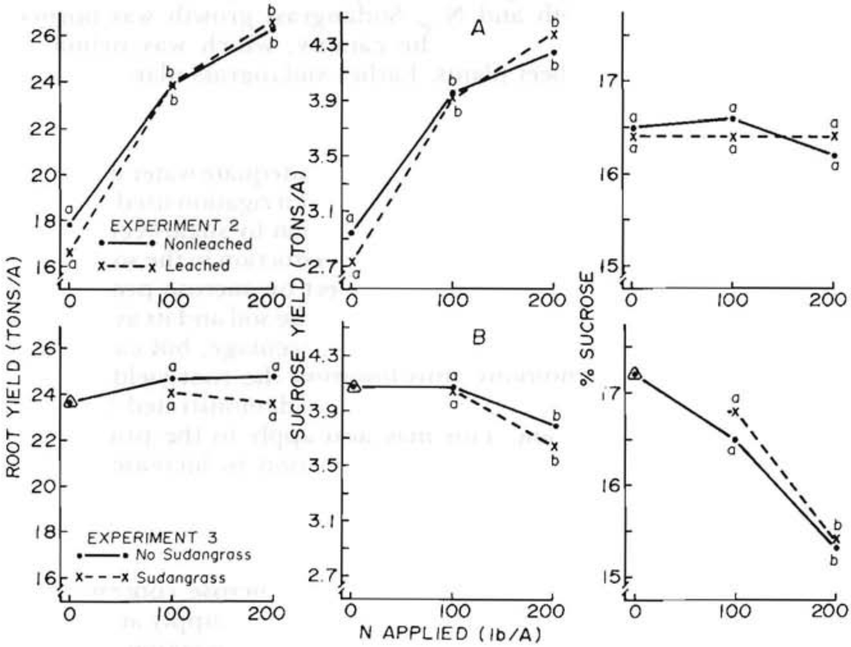

Figure 5.—Effect of N, leaching, and growth of sudangrass on root yield, sucrose yield, and sucrose percentage of sugarbeets in Experiments 2 and 3. (Δ = not used in statistical analysis. Means within a method of irrigation or cropping treatment followed by the same letters are not significantly different at the 5% level according to Duncan's Multiple Range Test.)

present in NO_3-N form and available for leaching. Nitrogen that did become available was primarily from mineralizable sources and was rapidly taken up by the plant. When every row was irrigated at the higher irrigation level, more soil was kept at optimum moisture levels for releasing mineralizable N, as was demonstrated on the no-N treatment by greater concentration of NO_3-N in the petioles throughout the season at the higher irrigation treatment. Therefore, on soils with a high mineralization capacity, leaching of NO_3-N may be advantageous when excess NO_3-N is present in the soil and the total available N is too high for maximum sucrose yield.

Experiment 3

In Experiment 3, adding N fertilizer had no effect on root yield, decreased sucrose percentage, and reduced sucrose yield above 100 lb N/A on both cropping treatments (Fig. 5B). There was no significant or noticeable difference between these yield factors and the cropping treatment. There was no indication that growth of sudangrass had any significant effect on the N supply of the sugarbeets (Fig. 4D). The development of a heavy sugarbeet canopy in mid-July caused inadequate sudangrass growth and N_{up}. Sudangrass growth was normal where there were openings in the canopy, which was primarily caused by skips in the beet plants. Earlier sudangrass plantings may have alleviated this problem, but would have interfered with weed control.

Our results indicate that in this soil when adequate water is applied as needed, except for one anomaly, the type of irrigation used has little effect on the N nutrition or sucrose production by sugarbeets. These experiments also indicated that the NO_3-N reduction in the soil during the latter part of the season had little effect on sucrose production. Treatments that reduced the NO_3-N level in the soil and its availability to the plant may have increased sucrose percentage, but caused adverse plant growth conditions, thus lowering the root yield. Consequently, sucrose yield benefits could not be demonstrated by using these practices on this soil. This may also apply to the practices of reducing the irrigation level late in the season to increase sucrose percentage. Reduction in water at this stage may increase sucrose percentage, but may also reduce plant growth and root production (4, 5).

These data support the hypothesis that sucrose concentration in the sugarbeet may be influenced more by the N supply and rate of N_{up} early in the season than by N available later in the season (2, 3, 11). If the sucrose concentration is basically determined early in the season by the rate of N_{up}, the N nutrition of the plant must be controlled by properly adding N fertilizer, either as a preplant or side-dressed application, based on an adequate soil test (1). The side-dressed N application after thinning and just before the period of increased N_{up}

would be preferred, not only for efficient N use (1), but N additions could be made using a revised expected yield based on stand, disease, planting date, plant emergence, and climatic factors. The application of optimum N levels early in the season with adequate water from either furrow or sprinkler irrigation should promote maximum sucrose production without further manipulating the N level in the soil or plant.

Summary

Field experiments were conducted to study the effect of irrigation method and the reduction of soil and plant NO_3-N late in the season, at different N levels, on sucrose production by sugarbeets. Our results indicated that on this soil the type of irrigation used has little effect on the N nutrition or sucrose production on sugarbeets when adequate water was applied as needed. Treatments that reduced the NO_3-N level in the soil and its availability to the plant may have increased sucrose percentage, but caused adverse conditions for plant growth and root production. Consequently, we could not show sucrose yield benefits from using these practices. For maximum sucrose yield, optimum amounts of N fertilizer, based on an adequate soil test, should be applied preplant or as a side-dress application. The side-dressing of N fertilizer after thinning and just before the period of increased N uptake would be preferred so that N could be added relative to a revised expected yield, based on climatic and plant conditions up to the time of N fertilizer application.

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