**Effects of banded versus broadcast application of ESN, turkey manure, and different approaches to measuring plant N status on tuber yield and quality in Russet Burbank potatoes**

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**Summary**

The use of Environmentally Smart Nitrogen (ESN; Nutrien, Ltd.; 44-0-0) applied as a topdress at emergence is considered to be a best management practice in growing potatoes in Minnesota. However, this approach results in a portion of the ESN prills accumulating in the furrows between planting hills, where the N may not be accessible to plants. Banded application into the hills may prevent this N loss and improve N uptake and yield. Turkey manure is a slow-release N source that provides organic matter and stimulates microbial activity. Nitrogen management after emergence typically includes repeated applications of liquid urea and ammonium nitrate (UAN), with frequency and rates informed by petiole NO3--N concentrations. A more precise measure of plant N status is the N nutrient index (NNI), based on whole-plant N concentration. Both measures of N status can be estimated more cheaply and at higher resolution using remote sensing. The purposes of this study were to: (1) evaluate the potential of optimizing N uptake through banded application of ESN at emergence, (2) assess the value of turkey manure applied before planting as an organic amendment in potato production, (3) evaluate the effectiveness of NNI relative to petiole NO3--N concentration as a measure of crop N needs, and (4) evaluate the potential for remote-sensing-based estimates of both NNI and petiole NO3--N concentration to inform N management decisions. Sixteen treatments were applied in a randomized complete block design with four replicates. Total, marketable, and U.S. No. 1 yields were high in all treatments, including the control, and higher at intermediate N rates (140 to 220 lbs·ac-1 total N) than at higher rates (240 – 300 lbs·ac-1 total N), suggesting that substantial N was provided by sources other than fertilizer, such as soil organic matter and NO3--N in irrigation water. Banded application of ESN at emergence decreased yields, possibly due to mechanical damage during application or excessive fertilizer concentrations close to the young plants. Turkey manure increased tuber specific gravity but had no other effects on tuber yield or quality. The treatments used to compare the effectiveness of different measures of plant N status produced nearly identical regimens of UAN applications and produced very similar tuber yield and quality results. However, the treatment in which applications were based on direct measurement of NNI omitted the fourth and final application of 20 lbs·ac-1 N as UAN, and this treatment had the highest tuber specific gravity in this group of treatments. Overall, unlike the previous year, our results did not support banding ESN at emergence as a solution to prill loss from topdress application. The use of turkey manure before planting increased tuber specific gravity. It may be that regular use of turkey manure over many years would begin to have additional effects on potato yield or quality. It is likely that the effects of N management treatments would be greater in a field or year in which tuber yield is more limited by the application of N.

**Introduction**

Environmentally Smart Nitrogen (ESN; Nutrien Ltd.; 44-0-0) is a polymer coated urea product developed to release N over a 60-80 day period under Minnesota growing conditions. Use of ESN as an N source for potatoes is considered to be a best management practice because N release is reduced relative to uncoated urea during in the early part of the growing season, when potato root systems are small, reducing N losses.

The recommended timing and method of ESN application is at emergence and as a topdress followed by incorporation into the hill. This recommendation is based on effectiveness of crop response in previous studies and convenience of application and incorporation. However, a portion of the ESN applied in this way ends up in the furrow, which may reduce the ability of potato roots to access the N once it is released.

Turkey manure is an amendment that can supply a slow-release from of N and, at the same time, add organic matter to the soil. As long as manure is applied at least 120 days before harvest, it is considered an acceptable amendment for potato production. Because manure stimulates microbial activity in the soil, it is also considered a beneficial amendment for improving soil health.

Nitrogen applied at emergence is generally supplemented with an aqueous solution of urea and ammonium nitrate (UAN) in multiple low-rate applications in the summer, as well as a small amount of N provided at planting. The total amount of N applied in a season is based on multiple factors, including the potato cultivar, grower yield goals, the previous crop, and soil organic matter content. The frequency and size of summer UAN applications is often determined by the results of petiole NO3--N testing. Petiole NO3--N concentration is an estimate of whole-plant nitrogen status. This would be more accurately measured using whole-plant sampling to measure the nitrogen nutrition index (NNI), but the labor and analysis costs that this would entail make measuring NNI impractical in production systems. Although petiole NO3--N analysis is much cheaper than NNI, even this approach is too costly to provide the high-resolution information required for precision agriculture. Remote sensing has been proposed as a low-cost yet accurate method to measure crop N status.

The objectives of this study were to (1) evaluate the potential of optimizing N uptake by applying ESN closer to the growing root systems of potato plants, (2) assess the value of turkey manure applied before planting as an organic amendment in potato production, (3) evaluate the effectiveness of NNI relative to petiole NO3--N concentration as a measure of crop N needs, and (4) evaluate the potential for remote-sensing-based estimates of both NNI and petiole NO3--N concentration to inform N management in potato production.

**Methods**

*Study design*

The study was conducted in 2020 on a Hubbard loamy sand soil at the Sand Plain Research Farm in Becker, MN. The previous crop was rye. Sixteen treatments were applied in a randomized complete block design with four replicates. These treatments are summarized in Table 1.

*Soil sampling*

Pre-treatment soil samples to a depth of six inches were collected on April 10 and sent to the University of Minnesota Research Analytical Laboratory (St. Paul, MN) to be analyzed for Bray P; NH4OAc-extractable K, Ca, and Mg; Ca(H2PO2)2 / Ba-extractable SO4-S; hot-water-extractable B; DTPA-extractable Cu, Fe, Mn, and Zn; soil water pH; and LOI soil organic matter content. NO3--N concentrations in two-foot soil samples collected on the same date were measured using a Wescan Nitrogen Analyzer. Results are presented in Table 2.

*Planting*

All plots received 200 lbs·ac-1 MOP (0-0-60) and 200 lbs·ac-1 SulPoMag (0-0-22-22S-11Mg) broadcast on April 17, supplying 164 lbs·ac-1 K2O and 22 lbs·ac-1 S. ESN was broadcast at 318 lbs·ac-1 in plots receiving treatment 4 on April 21 to provide 140 lbs·ac-1 N. Turkey manure was applied to treatments 9 and 10 at 3 T·ac-1 on April 22, providing 18 lbs·ac-1 N.

Cut “A” Russet Burbank seed (2-3 oz) was planted in all plots on April 24, with 12” spacing within rows and 36” spacing between rows. Before row closure, a furrow was dug along either side of the furrow in each planting row of treatment 5, approximately 2 – 4 inches away from and 2 inches below the seed potatoes. ESN was banded into these furrows, and the furrows were closed back up before row closure.

Belay was applied in-furrow at planting for beetle control, along with the systemic fungicide Quadris. At row closure, a planting fertilizer blend was mechanically banded into each treatment. All treatments received 173 lbs·ac-1 DAP (18-46-0), 141 lbs·ac-1 SulPoMag, 184 lbs·ac-1 MOP, 2 lbs·ac-1 ZnSO4 (17.5% S, 35.5% Zn), and 3 lbs·ac-1 Boron 15 (15% B), supplying 40 lbs·ac-1 N, 102 lbs·ac-1 P2O5, 181 lbs·ac-1 K2O, 40 lbs·ac-1 S, 20 lbs·ac-1 Mg, 1 lb·ac-1 Zn, and 0.6 lbs·ac-1 B. Weeds, diseases, and insects were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling.

*Hilling and post-hilling fertilizer applications*

Immediately prior to hilling on May 19, granular urea (treatments 2 and 3) or ESN (treatments 10-16) was applied by hand next to each hill in the appropriate treatments. In treatments 6 and 8, ESN was applied in a broad band along the top of each hill. In treatment 7, ESN was banded by hand into a furrow dug into the side of each hill, approximately 2 – 4 inches to the side of and 2 inches below the seed potatoes.

With some exceptions, each plot in treatments 2 and 4-7 received 10 lbs·ac-1 N, and each plot in treatments 12-16 received 20 lbs·ac-1 N, as 28% UAN on Jun 22 and July 2, 13, and 23. On July 2, treatment 1 received the UAN designated for treatment 2. The July 13 UAN application was delayed until July 16 in treatment 15 pending the results of tissue NO3--N analyses on petioles collected on July 7, which were needed to determine the application rate to be used. Finally, based on NNI results from whole-plant samples collected on July 7, it was determined that treatment 13 would receive no UAN on July 23.

*ESN urea release* in situ

Urea release from ESN prills installed *in situ* was monitored in three plots each of treatments 4, 5, 7, 8, and 12. At the time of ESN application for the treatment, immediately after row closure (treatments 4 and 5) or hilling (treatments 7, 8, and 12), ten flat mesh packets, each containing three grams of ESN, were buried four inches below the soil surface in the furrow between a field buffer row and each of three plots. The packets were installed in the furrow adjacent to the plots to avoid disturbing the fertilizer placement within the plots. From each plot, a packet was removed periodically and the ESN prills were separated from soil, roots, and other debris and weighed. Cumulative urea release across the season was estimated as the percent change in prill mass between burial and removal, accounting for the mass of the prill coats (taken to be 0.13 g per 3-g sample, based on previous research). Prills were installed in the treatments receiving ESN broadcast before planting or banded at planting (treatments 4 and 5) on April 24 and removed on April 27, May 1, 8, 18, and 27, June 11 and 30, July 20, August 8, and September 15 (3, 7, 14, 24, 33, 48, 67, 87, 108, and 144 days after planting, respectively). Prill were installed in the treatments receiving ESN topdressed or banded at emergence (treatments 7, 8, and 12) on May 19 and removed on May 22 and 27, June 4, 11, 18, and 30, July 13, August 3, and September 3 and 15 (3, 8, 16, 23, 30, 42, 55, 76, 107, and 119 days after emergence, respectively).

*Prill collection from furrows*

ESN prills were collected from the soil surface on May 27, from all treatments receiving ESN (treatments 4-8 and 10-16). In each plot, the prills were collected from 15 square feet in a separate part of the same furrow where the prill packets were installed.

*Aboveground plant assessments*

Plant stand was assessed in the central 18 feet of each of the central two rows of each plot (36 planted tubers in total) on May 27 (8 days after emergence fertilizer was applied). The number of stems per plant was determined on June 9 (21 days after emergence) for 10 plants in the same area where stand was assessed. On June 16 and 24, July 7 and 22, and August 4 (28, 36, 49, 64, and 77 days after emergence), terminal leaflet chlorophyll contents (leaf greenness) from the fourth mature leaf from the shoot tip were measured for 20 leaves per plot using a SPAD-502 Chlorophyll Meter (Konica Minolta). On the same dates, the petiole of the fourth mature leaf from the shoot tip was collected for 20 leaves per plot. Petioles were dried at 140°F until their weight was stable, ground, and analyzed for NO3--N concentration using a Wescan Nitrogen Analyzer.

In addition, canopy cover was evaluated using both the Canopeo application and a CropScan NIR Analyzer. Canopeo readings were taken on May 27, June 4, 8, 16, and 23, July 6, 13, 22, and 28, August 5, 11, 17, and 25, and September 3 and 8 (every 4 – 13 days from 8 to 112 days after emergence). Cropscan readings were taken on the same days, except that the readings on July 6, 22, and 28, August 5 and 11, and September 8 were instead conducted on July 7, 23, and 27, August 3 and 10, and September 11, respectively (every 4 – 14 days from 8 to 115 days after emergence).

*Whole-plant samples and nitrogen nutrition index (NNI)*

At four times during the season, tubers and vines were sampled from three plants per plot from treatments 1, 6, and 11 – 16. Fresh weight, dry weight, and tissue N concentration was determined for tubers and vines separately from each plot’s sample. Dry weights were used to calculate dry tuber and vine biomass per acre, and these were multiplied by tuber and vine N concentration, respectively, to calculate tuber, vine, and total N uptake. Total N uptake was divided by total dry biomass per acre to calculate whole-plant N concentration. This was divided by the critical N concentration, which was calculated from the formula:

Critical % N = 5.37 \* biomass (Mg/ha)-0.45.

The whole-plant N concentration divided by the critical N concentration is the nitrogen nutrition index (NNI). Values less than zero indicate N deficiency, while values greater than zero indicate that tissue N concentration exceeds plant requirements.

Whole-plant samples were collected on June 24, July 7 and 22, and August 4.

*End-of-season vine and tuber harvest*

Vines were sampled from 10 feet of each of the two central rows of each plot on September 15. A subsample from each vine sample was weighed, dried at 140°F until its weight was stable, and re-weighed. The N concentrations of the subsamples were determined using an Elementar CNS Element Analyzer. The data were used to estimate per-acre aboveground N uptake. Vines were chopped in all rows on September 16, 145 days after planting and 120 days after emergence.

Tubers were harvested on September 22 from the central 18 feet of the central two rows of each plot. Harvested tubers were sorted and graded on September 28-29. Twenty-five-tuber subsamples were collected for each plot, stored at 48°F, and assessed for hollow heart, brown center, and scab, and their specific gravity and dry matter content were determined. Tuber N concentrations were determined using an Elementar CNS Element Analyzer and used to estimate N uptake per acre into tubers. Vine and tuber dry biomass and N uptake were used to calculate NNI as described for whole-plant samples above.

*Data analysis*

Data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the MIXED procedure. Data were analyzed as functions of treatment and block. Means for each treatment and each level of application timing, application method, and their interaction, were calculated and post-hoc pairwise comparisons between treatments made using the LSMEANS statement with the DIFF option. Pairwise comparisons were only evaluated where the P-value of the relevant effect in the model was less than 0.10, and pairwise comparisons with P-values less than 0.10 were considered significant. In addition to pairwise comparisons, groups of treatments were compared using ten CONTRAST statements comparing:

1. the control treatment (treatment 1) and all treatments receiving urea or ESN (treatments 2-8 and 10-16),
2. the linear contrast on total N rate, with all treatments included,
3. the quadratic contrast on total N rate, with all treatments included,
4. treatments receiving ESN at or before planting (treatments 4 and 5) and similar treatments receiving ESN at emergence (treatments 6 and 7),
5. treatments in which ESN was banded (treatments 5 and 7) versus broadcast or topdressed (treatments 4 and 6),
6. treatments receiving turkey manure before planting (treatments 9 and 10) and similar treatments not receiving manure (treatments 1 and 8),
7. treatments receiving uncoated urea at emergence (treatments 2 and 3) and treatments receiving ESN at emergence (treatments 6 and 8),
8. treatments receiving all post-planting N at emergence (treatments 3 and 8) and those receiving some N as UAN later in the season (treatments 2 and 6),
9. treatments whose N status was evaluated based on tissue N or NO3--N concentrations (treatments 13 and 15) and those evaluated based on remote-sensing proxies for these concentrations (treatments 14 and 16), and
10. treatments whose N status was evaluated based on NNI (treatments 13 and 14) versus petiole NO3--N concentration (treatments 15 and 16).

**Results and discussion**

*Tuber yield, size, and grade*

Results for tuber yield, size, and grade are presented in Table 3. Total, marketable, and U.S. No. 1 yields were high even in the control treatment (treatment 1) and the manure-only treatment (treatment 9). The highest yields were observed in treatments receiving 140 to 220 lbs·ac-1 total N, and the quadratic contrast on N rate was significant for total yield, marketable yield, and yield of U.S. No. 1 tubers as a result. High yields even in control treatments and peak yield at an N rate in the range of 140 to 220 lbs·ac-1 total N are consistent with a large amount of N being provided by means other than fertilizer applications. The two most likely sources of non-fertilizer N are soil organic matter and irrigation water. Even though soil organic matter was low in this field (1.6%; Table 2), significant N mineralization can occur given proper environmental conditions. . The field received also 13.25 inches of irrigation water with a mean NO3--N concentration of 9.65 ppm, providing about 27.75 lbs·ac-1 NO3--N (6.27 lbs·ac-1 N) throughout the season. It is plausible that mineralization from soil OM and irrigation water nitrate contributed to the relatively low response to N fertilizer this year.

The treatment in which ESN was banded at emergence (treatment 7) had the lowest total tuber yield of any treatment receiving urea or ESN. The negative effect of banded application on yield may have been a result of placing the fertilizer too close to the roots of the young plants or to mechanical damage to the roots caused by digging the trenches in which the fertilizer was placed.

At roughly equivalent N rates, yield was not significantly related to the use of turkey manure. The use of petiole NO3--N concentration versus NNI versus remote-sensing proxies of either of these also had no significant effect on yield. The lack of yield response to how plant N status was measured can be attributed to how similar the N treatments intended to compare these approaches (treatments 13-16) ended up being in practice. Treatment 13 did not receive the fourth application of 20 lbs·ac-1 N, while treatment 15 received the third application three days later than the other three treatments, but they were otherwise treated identically.

The percentage of yield represented by tubers over six or ten ounces was significantly related to treatment. The contrast comparing the control treatment (treatment 1) to the treatments fertilized with urea or ESN (treatments 2-8 and 10-16). The linear contrast on N rate for the percentage of yield in tubers over 6 or 10 ounces was significant, as was the quadratic contrast on N rate for yield in tubers over 6 ounces. Both of these effects of N rate are due to the relatively small tuber size in the control treatment (treatment 1) and the manure-only treatment (treatment 9), as N rate had a negligible effect on yield among the remaining treatments.

*Tuber quality*

Results for tuber quality are presented in Table 4. Treatment had no significant effects on the prevalence of hollow heart or scab. Brown center was only found in three plots, and two of these were in the treatment receiving turkey manure plus ESN (treatment 10), resulting in a marginally significant treatment effect and a significant effect of the contrast comparing the treatments receiving manure (treatments 9 and 10) and similar treatments receiving no manure (treatments 1 and 8).

Tuber specific gravity was related to treatment. It was lowest in the control treatment (treatment 1). The quadratic contrast on N rate was significant, with the highest specific gravity values found at intermediate N rates (140 – 240 lbs·ac-1 total N). Tuber specific gravity was higher in the treatments receiving turkey manure before planting (treatments 9 and 10) than in similar treatments that did not receive manure (treatments 1 and 8). The treatments in which plant N status was monitored based on NNI (treatments 13 and 14) had higher specific gravity than the treatments in which N status was measured based on petiole NO3--N concentration (treatments 15 and 16). The treatment in which NNI was measured directly from tissue tests (treatment 13) was also the one treatment in this comparison that did not receive 20 lbs·ac-1 N as UAN on the fourth application date (July 23), and it is therefore possible that withholding this fourth UAN application resulted in higher tuber specific gravity in this treatment.

Tuber dry matter content was also related to N treatment. The linear and quadratic contrasts on N rate were both significant, with the lowest tuber dry matter content in the manure-only treatment (treatment 9) and the highest in two treatments receiving 220 lbs·ac-1 total N (treatments 6 and 8, the two treatments receiving ESN topdressed at emergence).

**Conclusions**

Total, marketable, and U.S. No. 1 yields were high in all treatments, and the highest-yielding plots received 140 to 220 lbs·ac-1 total N, indicating that peak yield occurred at a relatively low N rate in this study. This suggests that N was supplied by some source other than the fertilizer treatments, such as soil organic matter and dissolved NO3--N in irrigation water.

Contrary to our expectations and in contrast to results from last year, banding ESN at emergence produced lower yields than any other approach to applying urea or ESN in this study. Any advantage banding produced in terms of reduced loss of prills to the furrows was much smaller than the disadvantages, which may have resulted from damage to the roots of the young plants, from either the concentrated placement of N fertilizer close to the plants or mechanical damage caused in placing that fertilizer.

At roughly equivalent N rates, the use of turkey manure had little effect on tuber yield and quality overall. However, manure application was associated with increased tuber specific gravity (but not dry matter content). It is possible that any other effects of applying turkey manure are cumulative over years of application and not evident in a single year.

For the most part, when post-hilling N rates were based on plant N status, it made little difference whether N was monitored using NNI or petiole NO3--N, nor whether N status was measured directly through tissue samples or by remote-sensing proxies of NNI or petiole NO3--N concentration, probably because the four treatments involved in these comparisons (treatments 13-16) had very similar N regimes in practice. However, the treatment in which N status was monitored through direct measurement of NNI (treatment 13) had the highest tuber specific gravity in this group. This treatment did not receive the fourth and final application of 20 lbs·ac-1 N as UAN, and this may explain the difference in tuber specific gravity.

It is likely that the effects of the N management strategies evaluated in this study would be greater in a field where yield was more limited by N fertilization.

**Table 1.** Treatments applied to evaluate the effects of banded versus topdress application of ESN, the use of turkey manure, and the use of petiole NO3--N concentration, NNI, or remote-sensing proxies of each to monitor plant N status.



**Table 2.** Initial soil characteristics of the study site.



**Table 3.** Effects of N treatment on tuber yield, size, and grade.



**Table 4.** Effects of N treatment on tuber quality.

