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Evaluation of Nitrogen Stabilizers to Improve Corn Yield and Plant Nitrogen Status

By: Michelle Leinfelder-Miles, Delta Farm Advisor

Introduction:

Nitrogen (N) is part of a balanced, natural cycle in the environment among the atmosphere, soil, plants, animals, and water. Nitrogen is the most important element needed by crops, and we often add nitrogen fertilizer to optimize crop productivity. Nitrogen use in agricultural systems must be reported for regulatory compliance under the Irrigated Lands Regulatory Program and the Dairy Order to help ensure that a greater fraction of the applied N is recovered in the harvested crop and not lost to the environment. Nitrogen management gives consideration to the four R's:

- Right source: selecting a fertilizer source that matches with crop need and minimizes losses,
- Right rate: applying the right amount based on crop need and nutrient availability through other sources,
- Right time: applying the nutrient when the crop can use it,
- Right place: fertilizer placement that optimizes the crop's ability to use it.

The four R's address management considerations (e.g. fertilizer program, irrigation), but site characteristics (e.g. soil, cropping system, weather conditions) also influence N recovery in the crop. Also important to improving crop N recovery is understanding barriers to adopting best management practices, such as costs or risks to crop quality or yield.

While the four R's articulate four principles for nitrogen management, the N cycle in cropping systems is complicated. Nitrogen can be introduced and lost by various paths. We generally add N with fertilizer or organic matter amendments – such as crop residues, compost, or manure. Fertilizers provide N in plant-available forms – ammonium (NH_4^+) and nitrate (NO_3^-). Organic matter amendments must be mineralized before the N is available for plant uptake. Mineralization is a process that involves soil biology converting organic N to NH_4^+. The timeline of this conversion will depend on the properties of the amendment, environmental conditions – such as soil temperature and moisture, and the activity and abundance of soil microbes.

In the soil, NH_4^+ has different fates. It can be immobilized by microorganisms, taken up by plants, fixed to soil particles due to its positive charge, volatilized to ammonia gas (i.e. lost from the system), or converted to NO_3^- – a process known as nitrification. Nitrification is a two-step process. The first step is the conversion of NH_4^+ to nitrite (NO_2^-) by *Nitrosomonas* bacteria. The second step is the conversion of NO_2^- to nitrate (NO_3^-) by *Nitrobacter* bacteria. These two steps generally occur in close succession to prevent the accumulation of NO_2^- in the soil. Conditions that affect nitrification include soil aeration, moisture, temperature, pH, clay and cation content, NH_4^+ concentration, among others. Just as NH_4^+ has different fates in the soil, so too does NO_3^-. Plants preferentially take up NO_3^-, but if NO_3^- is present when plants are not in need of it, then NO_3^- may be immobilized by microorganisms, volatilized to nitrogen gas (i.e. lost from the system), or leached out of the rootzone (i.e. lost from the system).

Technologies have been developed to mitigate N losses from the system. These technologies are collectively known as enhanced efficiency fertilizers (EFF) and include additives, physical barriers, and chemical formulations that stop, slow down, or decrease fertilizer losses. Nitrogen stabilizers, slow-release fertilizers, and polymerized fertilizers are examples of EEF. Nitrogen stabilizers are fertilizer additives intended to improve crop N use efficiency and reduce N losses to the environment by interrupting the microbial processes that change N to its plant-available forms. We developed a trial to evaluate two N stabilizer products with the objective of determining whether the treatments improved corn silage yield or plant N status compared to fertilizer alone.

The products in our trial were Vindicate (Corteva Agriscience) and Agrotain Plus (Koch Agronomic Services). Vindicate delays the nitrification process by inhibiting the *Nitrosomonas* bacteria that converts NH_4^+ to NO_2^-. Vindicate has bactericidal activity, and the active ingredient is nitrapyrin. Agrotain Plus has two modes of action – reducing ammonia volatilization and delaying nitrification. Ammonia volatilization is the conversion of NH_4^+ in the soil to ammonia gas (NH_3) in the atmosphere, and it is reduced by inhibiting the urease enzyme. Ammonia volatilization is most problematic when the N source is urea-based and not incorporated or watered into the soil. The active ingredients of Agrotain Plus are Dicyandiamide (DCD), which delays nitrification, and N-(n-butyl)-thiophosphoric triamide (NBPT), which reduces volatilization. DCD has bacteriostatic activity, which means it slows the metabolism of *Nitrosomonas*. We hypothesized that N stabilizers would improve yield and N uptake over the fertilizer-only treatment, providing growers with a tool for nutrient stewardship.

Methods:

The trial took place in San Joaquin County on a DeVries sandy loam soil. The field had a winter wheat crop that was cut for forage in the late spring. Dry manure was applied to the field between wheat harvest and corn planting, which occurred on May 24, 2018. The variety was Golden Acres 7718. At-planting fertilizer provided approximately 12 lb N per acre (4-10-10). Sidedress fertilizer application occurred on June 21st and provided approximately 105 lbs N per acre (UAN 32). Four treatments were applied at sidedress, when plants were at V3-4 stage of development. The N stabilizers were applied at the label rates, and the treatments were: 1) Vindicate at 35 fluid ounces per acre, 2) Agrotain Plus at 3 pounds per acre, 3) combination of Vindicate and Agrotain Plus at aforementioned rates, and 4) fertilizer-only, no stabilizer product ("untreated"). Plots were 35 feet across (i.e. fourteen 30-inch rows), in order to adapt to equipment of different widths, by 900 feet long. Treatments were randomly applied in three replicate blocks. Aside from the treatments, the trial was managed by the grower in the same manner as the field.

We evaluated soil N status, plant N status, and silage yield. Prior to planting, 20 soil cores were randomly collected from across the trial and aggregated by foot-increments, down to two feet. Mid-season leaf and soil samples were collected when the corn was in the R1 stage (i.e. silking). Soil was collected from 10 in-row locations in each treatment, and aggregated by foot-increments, down to two feet. Leaves were sampled from ten plants in each treatment, sampling the leaf one-below and opposite the earleaf. Harvest occurred on September 20th. All fourteen rows were harvested for weight, and samples were collected at the silage pit for aboveground biomass N analysis. The samples were dried at 60ºC for 48 hours for calculating dry matter (DM). Post-harvest, 10 in-row soil cores were collected to one-foot depth and aggregated for each treatment. Laboratory analyses were conducted by Ward Laboratories (Kearney, NE; https://www.wardlab.com/). We used Analysis of Variance to detect differences in treatments and Tukey's range test for means separation (JMP statistical software). Treatments were considered statistically different if the P value was less than 0.05.

Results and Discussion:

There were no statistically significant differences among treatments for plant tissue N, yield, dry matter, or total N removed at harvest (Table 1). Mid-season leaf N averaged 2.88 percent across treatments, and aboveground biomass N at harvest averaged 1.12 percent. At mid-season, leaf N from 2.7 to 3.5 percent indicates that the plants had sufficient N to carry the crop to harvest, and at harvest, whole plant N from 1.0 to 1.2 percent indicates that the N fertilization program was adequate for maximizing yield.[1] Calculated to 30 percent dry matter, average yield across treatments was 38.8 tons/acre, and dry matter was 35 percent. There was a trend for the two treatments with Vindicate to have a higher N removed than the two treatments without it, but the difference was not statistically significant. The low coefficient of variation (CV), which is a measure of variability in relation to the mean, indicates low variability among replicates for all of these parameters.

Table 1. Plant N, yield, dry matter (DM), and N removed results for the 2018 N stabilizer efficacy trial. There were no significant differences among treatments.

Treatment	Midseason (R1) Leaf Total N (%)	Aboveground Biomass Total N (%)	Yield at 30% DM (tons/acre)	DM (%)	Total N Removed at Harvest (lbs N/acre)
Vindicate	2.97	1.12	40.4	0.37	272
Agrotain Plus	2.97	1.11	37.7	0.34	250
Vindicate and Agrotain Plus	2.71	1.16	38.7	0.34	269
Untreated	2.87	1.09	38.3	0.35	251
Average	2.88	1.12	38.8	0.35	261
CV (%)	4	2	3	3	5
P value	0.32	0.18	0.48	0.20	0.39

The pre-plant (post-dry manure application) soil nitrogen status was 17 ppm NO_3-N and 4 ppm NH_4-N for the 0-12 inch depth, and 7 ppm NO_3-N and 2 ppm NH_4-N for the 12-24 inch depth. When soil NO_3-N is below 25 ppm in the top foot of soil, it is recommended to apply N fertilizer in order to prevent yield reductions.[2] There were no differences among treatments in soil N status at the mid-season sampling, but there were differences at the post-harvest sampling (Table 2). Mid-season soil NO_3-N averaged 32 ppm across treatments in the top foot of soil, and 10 ppm in the second foot of soil, which is an adequate concentration to carry the crop through to harvest. Soil NH_4-N averaged 4 ppm and 2 ppm across treatments for the top foot and second foot, respectively. The CV was high for mid-season soil data, which indicates high variability among replicates. Post-harvest soil NH_4-N averaged 2ppm across treatments in the top foot of soil, but soil NO_3-N was higher than at any other time during the season, averaging 46 ppm across treatments. These results may indicate that the dry manure mineralized later in the season, after the peak demand of the corn. Post-harvest soil NO_3-N above 20 ppm is considered high and indicates that this crop was not deficient in N.[2] The low CV for NO_3-N indicates low variability among replicates. The significant differences among treatments are not well-understood, particularly

[1] Nutrient Management for Field Corn Silage and Grain in the Inland Pacific Northwest. https://www.cals.uidaho.edu/edcomm/pdf/PNW/PNW0615.pdf.

[2] Nutrient Management Guide – Silage Corn (Western Oregon). https://catalog.extension.oregonstate.edu/em8978.

as the control (fertilizer-only) treatment had soil NO_3-N that was not different from any of the treatments. Interestingly, Vindicate had the lowest post-harvest soil NO_3-N and a trend toward higher N removed (though not statistically higher), which may indicate that product use made N available at a time that optimized N uptake.

Table 2. Soil N status (as NO_3-N and NH_4-N) at mid-season and post-harvest samplings for the 2018 N stabilizer efficacy trial.

Treatment	Mid-season NO_3-N (ppm) 0-12 inches	Mid-season NO_3-N (ppm) 12-24 inches	Mid-season NH_4-N (ppm) 0-12 inches	Mid-season NH_4-N (ppm) 12-24 inches	Post-harvest NO_3-N (ppm) 0-12 inches	Post-harvest NH_4-N (ppm) 0-12 inches
Vindicate	33	10	4	2	38 b	2
Agrotain Plus	32	10	4	2	44 ab	2
Vindicate and Agrotain Plus	32	9	3	2	57 a	2
Untreated	31	12	4	2	43 ab	2
Average	32	10	4	2	46	2
CV (%)	25	31	20	36	7	19
P value	0.99	0.75	0.58	0.97	0.04	0.89

Summary:

N is part of a balanced, natural cycle in the environment and is the most important nutrient in cropping systems. Giving consideration to N management will help ensure that a greater fraction of the applied N is recovered in the harvested crop and not lost to the environment, and keeps growers in regulatory compliance. Enhanced Efficiency Fertilizers, such as N stabilizers, have been shown to improve crop yield in regions like the Midwest and the Northeast, and may help to mitigate N losses from the environment. In our trial, we evaluated the efficacy of N stabilizer products for improvements in corn silage yield or plant N status compared to fertilizer alone. Under the management and environmental conditions of this trial, we found no differences in yield or plant N status; however, plant and soil tests indicated that N was never limiting in the trial. If N was lost from the system, the loss was not large enough to result in N limitation in the control. Future study should test these products using different N sources and N rates (e.g. grower rate and grower rate minus 50 lbs N/acre). It may be possible to reduce the fertilizer N rate without sacrificing yield.

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