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RESEARCH

Predicting Cool-Season Turfgrass Response with Solvita Soil Tests, Part 1: Labile Amino-Nitrogen Concentrations

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ABSTRACT

Current turfgrass fertilizer recommendations do not account for potential mineralizable N in the soil. The Solvita Soil Labile Amino-Nitrogen (SLAN) test measures a labile fraction of soil N. This study was conducted across 9 yr (2008–2016) in Connecticut to determine if responses from predominately Kentucky bluegrass (*Poa pratensis* L.) and tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.] lawns are correlated to SLAN–N concentrations, and to determine the probability of turfgrass responses equaling or exceeding the response from benchmark urea rates in relation to SLAN–N concentrations. Randomized complete block design field experiments were set out with 23 rates of an organic fertilizer (0–2000 kg N ha^{-1} yr^{-1}) and four different rates of urea (50, 100, 150, and 200 kg N ha^{-1} yr^{-1}). Yearly spring soil samples were analyzed for SLAN–N concentrations, and turfgrass growth and quality responses were collected during the growing seasons. Turfgrass responded positively and linearly ($P < 0.001$) to SLAN–N concentrations, but correlations were relatively weak to moderate. When spring soil SLAN–N concentrations were ≥158, 165, 198, and 217 mg kg^{-1}, there was a ≥90% probability that overall combined responses across species and measured variables would be equal to or greater than responses obtained from 50, 100, 150, and 200 kg urea N ha^{-1} yr^{-1}, respectively. The SLAN test has promise as an objective soil test to categorize the N fertilization response potential of turfgrass soils, and this would be helpful in guiding N fertilization.

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Abbreviations: ISNT, Illinois soil nitrogen test; NDVI, normalized difference vegetative index; SLAN, soil labile amino-nitrogen; SOM, soil organic matter.

Nitrogen fertilizer recommendations for cool-season turfgrasses are typically between 24.5 and 49 kg N ha^{-1} per application, with usually two to four applications per year. Soil N mineralization potential, or a soil's inherent ability to provide plant-available N during the growing season due to the decomposition of soil organic matter (SOM) and release of labile N, is generally not accounted for in turfgrass N fertilization recommendations. There is a greater chance of under- or overfertilization of the turfgrass sward without a measure of the inherent N mineralization potential of a soil on which it is grown. This can lead to poor-quality turf and economic and environmental quality losses, and it can increase the incidence and severity of certain weed, insect, and disease pests.

Although various forms of soil N (e.g., ammonium, nitrate, organic, water-extractable, and total) can be measured accurately, none are currently used to guide N fertilization of turfgrasses. The lack of an objective test to estimate a soil's potential N-supplying capacity during the growing season for turfgrass has resulted in N fertilization practices that are based on subjective visual assessments or those that follow historical patterns without much, if any, change from year to year. Without an objective guide that

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adjusts N recommendations for different species, environments, and managements (Tremblay et al., 2012; Hatfield and Walthall, 2015), these current fertilization practices are basically "guessing" at what amount or rate of N is required to meet growth or quality goals. If turfgrass managers could categorize their soils' N mineralization potentials, they could customize their fertilizer rates to optimize turfgrass growth and quality and reduce the chance of under- or overapplying N. A simple, relatively inexpensive, and reasonably reliable soil test that quantifies a soil's N mineralization potential (i.e., the amount of labile N present) could be of great benefit in developing more accurate N fertilization recommendations.

The Illinois soil N test (ISNT) is a 5-h chemical analysis for labile soil N that makes use of alkali hydrolysis and heat to remove amine ($-NH_2$) groups from organic molecules, and then this is measured as NH_3 (Khan et al., 2001). The ISNT has been reported to correlate well with cool-season turfgrass growth and quality (Geng et al., 2014), and therefore there is potential for using it to predict turfgrass performance, to categorize the soil's mineralization potential, and to estimate the probability of turfgrass response to added N fertilizer. On a sandy-loam soil in Connecticut, Kentucky bluegrass (*Poa pratensis* L.) and tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.] lawn growth and quality increased linearly with increasing ISNT–N concentrations, and there was a low probability ($\leq$10%) of any further meaningful quality and growth responses to N fertilization when spring ISNT–N concentrations were $\geq$226 mg kg^{-1} across both species (Geng et al., 2014). With golf course fairways in Minnesota, ISNT results were spatially correlated over distances of 100 m or less, which suggested that bulking soils from four or five locations within a 100-m section of each fairway should be sufficient for measuring ISNT–N concentrations (Gardner et al., 2008). With more research, site-specific N fertilizer recommendations could be developed using soil labile N concentrations.

The Solvita Soil Labile Amino-Nitrogen (SLAN) test is a recently developed chemical analysis that measures soil labile N via alkali hydrolysis (Brinton, 2016). The SLAN test procedure is very similar to that of the ISNT—the same alkali solution (2 mol L^{-1} NaOH) is used in both tests—but the SLAN test incubation is 24 h and is performed at room temperature. The SLAN test has two advantages over the ISNT: heating is not needed, and fewer reagents are required. The SLAN test presumably measures a similar fraction of chemically labile soil N to the ISNT, because the same reactant is used at the same concentration despite differences in incubation time and temperature. The two tests were well correlated in the same sandy-loam soil, supporting cool-season turfgrasses as reported herein (Moore et al., 2019).

Currently, there are few reports in the literature on the SLAN test under field conditions. It has been evaluated on a silt-loam soil in upper-state New York (Salon et al., 2016); on a loam soil in Michigan (Rutan, 2017); on silt loam, loam, loamy sand, sandy loam, and sandy soils in Idaho (Rogers et al., 2018); and on a sandy-loam soil in Ontario (Chahal and van Eerd, 2018). Results have been mixed with respect to predicting crop performance in relation to soil SLAN–N concentrations. To date, there have been no reports of using the SLAN test in a turfgrass system.

Because of a lack of reports on the use of the SLAN test under field conditions in general, and with turfgrasses specifically, the first objective of this study was to determine if turfgrass performance can be predicted by SLAN–N concentrations from a single spring soil sample (which is consistent with current industry practices). If turfgrass response was correlated to SLAN–N concentrations, a second objective was to determine the probability of turfgrass response equaling or exceeding the response from benchmark urea N rates in relation to SLAN–N concentrations, and to use these concentrations to categorize the turf soil's potential response to N fertilization.

MATERIALS AND METHODS

Field Plot Layout and Management

A field experiment was conducted at the Plant Science Research and Education Facilities at the University of Connecticut, Storrs, CT (41°47′ N, 72°13′ W; 203 m asl) from 2008 through 2016. The plots were located on a Paxton fine sandy-loam soil (a coarse-loamy, mixed, active, mesic Oxyaquic Dystrudept). On 3 Sept. 2007, two separate randomized complete block experiments were set out about 20 m apart from one another. Treatments were rates of an organic fertilizer (Suståne all natural 5–0.87–3.3 [N–P–K] with the total N grade of 5% composed of 0.4% ammoniacal N, 0.4% water-soluble organic N, and 4.2% water-insoluble organic N; Suståne Natural Fertilizer), applied at 0, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 950, 1000, 1500, and 2000 kg N ha^{-1} yr^{-1}. Additional treatments included four rates of urea [$CO(NH_2)_2$] at 50, 100, 150, and 200 kg N ha^{-1} yr^{-1}. The purpose of including the urea treatments was to establish benchmark values so that turfgrass responses from organic fertilizer plots could be compared with responses obtained from a known urea rate. Plot size was 1 × 1 m. After the plots were set out in 2007, the organic fertilizer was applied by hand and incorporated with a rototiller to a depth of 15 cm. In one area of the study, Kentucky bluegrass ('America') was seeded into the plots at a rate of 2.2 kg ha^{-1}, and in an adjacent area ~20 m from the bluegrass, a turf-type tall fescue blend ('Crossfire II', 'Dynasty', and 'Shortstop II') was seeded into the plots at a rate of 6.7 kg ha^{-1}.

The organic fertilizer was reapplied by hand in November or early December of each year from 2008 to 2016 after all yearly turfgrass response data were collected on the established plots, except in 2011 (due to a miscommunication). During these reapplications, the plots were solid-tine aerified (15.9 mm) with a Toro Greens Aerator 09010 and Procore 648 (The Toro Company), and then the organic fertilizer was applied and raked by hand into the aerification holes to incorporate the organic fertilizer into the soil and prevents the buildup of organic fertilizer on the soil surface (Martin et al., 2017).

From 2008 through 2016 (except in 2012, due to an oversight), urea was applied to the plots by hand in equal split applications (May, June, September, and October). A 45–0–0 (N–P–K) urea fertilizer with NutriSphere-N (Andersons Golf Products) was used from 2008 to 2015 (excluding 2012), and a 25–0–5 (N–P–K) 50% slow-release (polymer-coated) urea fertilizer with muriate of potash and iron sucrate (LESCO) was used in 2016. After each urea application, plots were irrigated if no sufficient rainfall was imminent. Phosphorus as triple superphosphate [$Ca(H_2PO_4)_2$] and potassium as muriate of potash (KCl) were applied by hand on the urea-only plots at the first N application date each year of the study to supply 21.4 and 40.7 kg ha^{-1} yr^{-1} of P and K, respectively.

Plots were mowed with a Scag Tiger Cub mower (Scag Power Equipment) to a height of 75 mm as needed, and clippings were returned. Once per month, however, clippings were removed and collected so that yields and foliar N concentrations could be determined. Supplemental irrigation was applied as needed to prevent wilt (this was infrequent). Pest control for broadleaf and grassy weeds, and for white grubs (Scarabaeidae), was applied as needed.

Data Collection and Sampling Procedures

Turfgrass growth was measured as clippings yield, and quality indicators included normalized difference vegetative index (NDVI), chlorophyll index, clippings total N concentrations, and clippings total N uptake. Beginning in 2008, NDVI and chlorophyll index measurements were taken from all plots approximately every 2 wk throughout the growing season (late April or early May to October or November) with a FieldScout TCM 500 NDVI Turf Color Meter and a FieldScout CM 1000 Chlorophyll Meter (Spectrum Technologies), respectively. Ten measurements were taken from each plot and the average measurements were recorded for each plot on each date. All measurements were taken on dry days between 1000 and 1400 h. Chlorophyll meter measurements were taken with the meter positioned ~1 m above the turf canopy.

Clipping yields were obtained once per month from May through October from 2008 to 2016 with the exception of 2012, when only 5 mo worth of clipping yields were collected for Kentucky bluegrass, and only 4 mo worth of clipping yields were collected for tall fescue, due to weather-related reduced growth during the spring and early summer of that year. From 2008 through 2013, clipping samples were collected at a height of 76 mm from two random 0.1-m^2 areas in each plot with hand shears immediately after reflectance measurements (either on the same day or on the day after). From 2014 through 2016, a Toro SR4 Super Recycler push mower (The Toro Company) set at an 83-mm height with a bagging attachment was used to harvest clippings from a 0.25-m^2 area.

The harvested clippings were oven dried at 65°C for a minimum of 48 h and weighed. From 2008 to 2012, after dry weights were obtained, grass clipping samples from individual plots from different months within the same year were not bulked but kept separate for N analyses; from 2013 to 2016, after dry weights were obtained, grass clippings samples from different months within the same year were bulked into a single sample to save on analytical expenses. Clipping samples were ground to pass a 0.5-mm sieve using a Cyclone laboratory sample mill (UDY Corporation). These samples were analyzed for total N concentrations using the combustion method described by Bremner (1996). From 2008 to 2010, an Elementar CHNOS combustion analyzer (Elementar Americas) was used, and from 2011 to 2016, a LECO TruMac CN Macro Determinator (LECO Corporation) was used. Monthly clipping dry weights were summed within each year for each plot. For grass tissue samples from 2008 to 2012, yield-weighted total N concentrations were determined by multiplying each month's foliar N concentration by that month's fraction of clippings dry weight out of the yearly total for that plot (i.e., the monthly clippings dry weight divided by the annual sum of clippings dry weights for each plot), and adding up each of the months' values for each plot. For turfgrass tissue samples from 2013 to 2016, clippings from each month were combined prior to grinding and analyzing for each plot separately, so the resulting total foliar N concentrations were already yield weighted. Turfgrass tissue N uptake was determined by multiplying the yearly, yield-weighted foliar N concentration by the yearly, total clippings dry weights for each plot.

There were some missing data for the benchmark urea plots: the clippings yield data record sheet was lost in 2010, and although collected, urea plot responses in 2012 were not included, since urea was not applied in that year. Consequently, the urea benchmark values for these missing data were estimated for each species and variable separately by regressing data from urea plots with data from compost plots of equal seasonal N rate (50, 100, 150, and 200 kg N ha^{-1} yr^{-1}) across all the years with uncompromised data, and then using the predictive equations to estimate the missing benchmark values. These estimated urea benchmark values where then used in the subsequent statistical analyses.

Beginning in 2008, soil samples were taken from the plots in late April or early May of each year before treatments were applied and before collection of turfgrass response measurements. Soil cores were collected from each plot to a depth of 10 cm below the thatch layer using an 18-mm-diam. soil probe. Four soil cores were taken from each plot from 2008 to 2013, and 10 soil cores were taken from each plot from 2014 to 2016. Soil cores from the same plot and the same sampling date were combined into a single sample, air dried, and sieved to 2 mm without grinding. Soil samples from only the organic fertilizer plots were analyzed for SLAN–N concentrations using the Solvita SLAN test (Woods End Laboratories) following company guidelines (Brinton, 2016). For this method, a dried and sieved (but not ground) 4-g soil sample was placed into a 50-mL plastic cup, and this cup was placed inside a 250-mL glass jar. Twenty milliliters of 2 mol L^{-1} NaOH were added directly to the soil sample. A colorimetric NH_3–sensing gel probe was placed in the glass jar in the air space surrounding the small plastic cup. The glass jar was sealed with a silicone-gasketed lid and left at room temperature for 24 h. The NH_3 molecules released via alkali hydrolysis with NaOH volatilize and diffuse into the probe gel. After the incubation, the probe's color was read with a digital color reader (DCReader, Woods End Laboratory) to determine the amount of NH_3 emitted from the sample, and soil test values were reported as SLAN–N in milligrams per kilogram.

Statistical Analyses

The data were pooled across the entire 9 yr of the study for each measured variable so that broad-sense inferences could be made about turfgrass performance across many years. For the relationship of turfgrass responses to SLAN–N concentrations, relative values were used for data analyses because turfgrass responses vary year to year. Relative values reduce the year-to-year variability. Plateau responses were not observed with any of the variables measured as a function of SLAN–N concentrations, and therefore relative values were calculated by first taking the mean of the six highest values for a particular variable within a given year and within a given species (plots receiving both urea and organic fertilizer treatments were included). Next, each value for that particular variable was divided by the average value from the six high-performing plots to obtain the relative value (this step was performed on plots receiving both urea and organic fertilizer).

Statistical analyses were performed using various procedures of the SAS/STAT 14.3 software (SAS Institute, 2017). The REG procedure was used to analyze the simple linear regression model for turfgrass relative growth and quality responses in relation to SLAN–N concentrations. Binary logistic regression was performed using the LOGISTIC procedure with the model $\{a + bx = \ln[\pi/(1 - \pi)]\}$, where a is the intercept, b is the slope, x is the SLAN–N concentration, and π is the probability of turfgrass response being equal to or greater than the benchmark values. Binary logistic regression calculated the probability that, for any given SLAN–N concentration, turfgrass response from a plot receiving organic fertilizer will be equal to or exceed a benchmark value. In this study, the benchmark values were the yearly mean turfgrass growth and quality responses obtained from each of the four different urea N rates (50, 100, 150, and 200 kg ha^{-1} yr^{-1}) plots. For the binary logistic regression procedure, turfgrass responses from the organic fertilizer plots were pooled within years and within species to generate binary variables in relation to the urea responses. If the organic fertilizer plot's response was equal to or exceeded the urea benchmark value, then a value of 1 was assigned, and if not, a value of 0 was assigned. Therefore, the equation to estimate the probability (π) at any given SLAN–N concentration (x) under these conditions was $\pi = 1 - \{1/[1 + \mathrm{EXP(INTERCEPT} + \mathrm{SLOPE}X)]\}$. There was no need to convert turfgrass growth and quality responses into relative values, as was performed for the linear regression models, because they were converted to binary variables (1 or 0) in relation to urea responses from that same year. The binary responses for each variable were pooled across years for the logistic regression models. An additional binary logistic regression model was constructed by pooling the binary responses from all variables into a single variable (all) to determine overall probability outcomes to SLAN–N concentrations across all variables. In this model, each variable was given equal weight with respect to its influence on the overall model outcomes. Significance of the logistic regression models was determined by the Wald test, where the null hypothesis is that the slope parameter is equal to zero. The null hypothesis was rejected when $P \leq 0.05$.

Predicted critical concentrations of SLAN–N that were equal to or exceeding a urea benchmark value at selected P levels of 0.33, 0.67, and 0.90 were calculated by using the slope and intercept parameters obtained from the binary logistic regression model described above. Therefore, the equation to predict a SLAN–N critical concentration (x) at the selected probabilities (π) of 0.33, 0.67, and 0.90 under the conditions of the binary coding was $X = \{\mathrm{LN}[1/(1 - \pi) - 1] - \mathrm{INTERCEPT}\}/\mathrm{SLOPE}$.

RESULTS

Weather Data

Weather data, with 30-yr normals, are shown in Fig. 1. It was cooler than normal in 2009 during the May through October growing season (6% lower than the normal high monthly temperature); the 2010, 2012, 2015, and 2016 growing seasons were notably warmer than normal (4.9, 1.8, 6.0, and 6.1% higher than normal high monthly temperatures, respectively). Monthly minimum temperatures during the May through October growing season were all above normal, except for 2009. Precipitation during the May through October growing season in 2011 was 60% greater than normal, with 349 mm of rain falling in August. Years 2009, 2012, and 2013 had 14, 20, and 16% more rain than normal, respectively, during the May through October growing season; 2010, 2015, and 2016

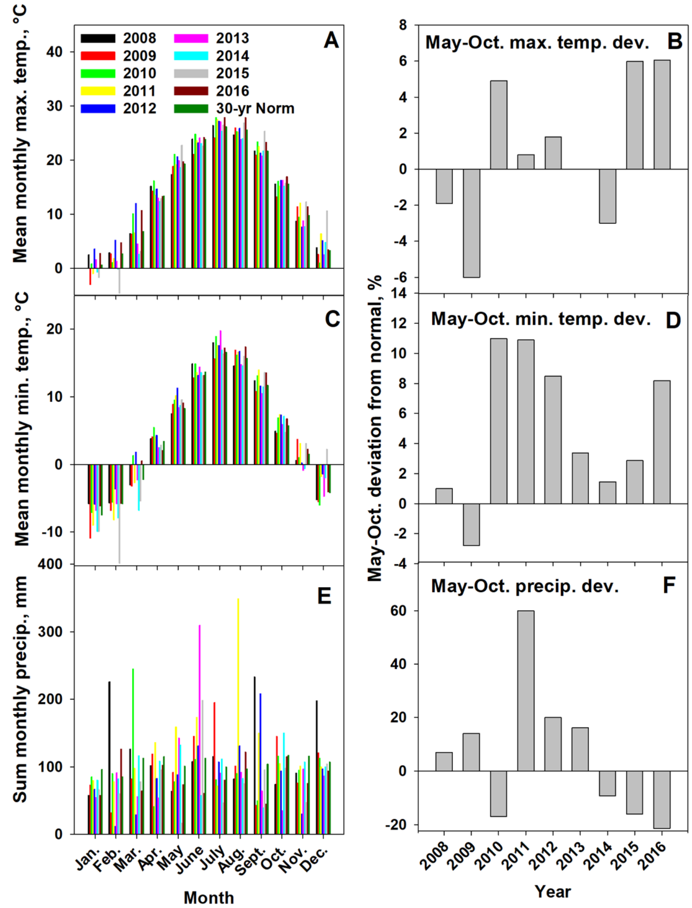

Fig. 1. Mean monthly (A) maximum (max.) and (C) minimum (min.) temperatures (temp.), and (E) monthly precipitation (precip.) sums, with associated May through October deviations (dev.) from normal for (B) maximum and (D) minimum temperature and (F) precipitation sums for the study period 2008 through 2016, Storrs, CT.

had 17, 16, and 21% less rain than normal, respectively, during the May through October growing season.

Turfgrass Growth and Quality Responses in Relation to Solvita Labile Amino-Nitrogen Concentrations

As SLAN–N concentrations increased, there was a significant ($P < 0.001$) linear increase in turfgrass responses (Fig. 2). Although the linear models were highly significant, there was considerable variation in the responses resulting in relatively low to moderate coefficients of determination (r^2 ranged from 0.044 to 0.337). Surprisingly, there were no plateau responses in relation to the SLAN–N concentrations, given the yearly applications of organic fertilizer. For every variable, the model fits were generally better for tall fescue than for Kentucky bluegrass, except for relative clippings yield, where both were about the same. The relative responses associated with the urea treatments, averaged across years, are overlaid onto the organic fertilizer responses in Fig. 2 and represent the benchmark comparison values. This overlay forms the basis for the binary logistic regression analyses for predicting the probability of responses above and below the benchmark urea values in relation to the SLAN–N concentrations.

Probability of Turfgrass Response Equaling or Exceeding the Benchmark Urea Values in Relation to Solvita Labile Amino-Nitrogen Concentrations

All binary logistic regression models were highly significant ($P < 0.0001$). The probability curves in Fig. 3, generated from equations with the binary logistic regression coefficients presented in Table 1, show that, in general, turfgrass soils with higher SLAN–N concentrations correspond with higher probabilities of equaling or exceeding the responses of that obtained from urea rates of 50, 100, 150, and 200 kg N ha^{-1} yr^{-1}. Across all variables and species separately and combined, the predicted critical concentrations of SLAN–N that would equal or exceed the response of that obtained from all urea rates ranged from 70 to 147, 104 to 195, and 137 to 252 mg kg^{-1} at $P = 0.33$, 0.67, and 0.90, respectively. At these predicted critical SLAN–N concentration ranges, there would be a 33, 67, and 90% chance of obtaining a response to N

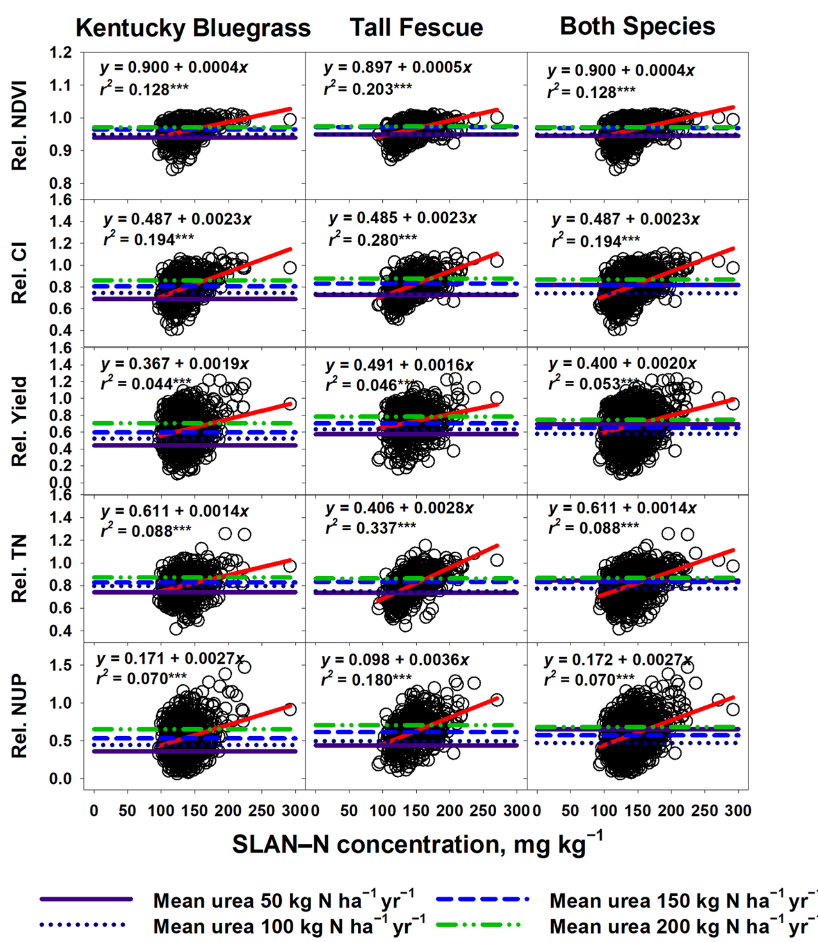

Fig. 2. Organic fertilizer plots' relative (rel.) normalized difference vegetative index (NDVI), chlorophyll index (CI), clippings yield (yield), clippings total N concentration (TN), and clippings total N uptake (NUP) responses in relation to Solvita Soil Labile Amino-Nitrogen (SLAN)–N concentrations for Kentucky bluegrass, tall fescue, and both species combined when managed as a lawn. Data are pooled across years for a study conducted in Storrs, CT, from 2008 through 2013. Horizontal lines represent the mean, averaged across years, for the relative responses from the urea treatments.

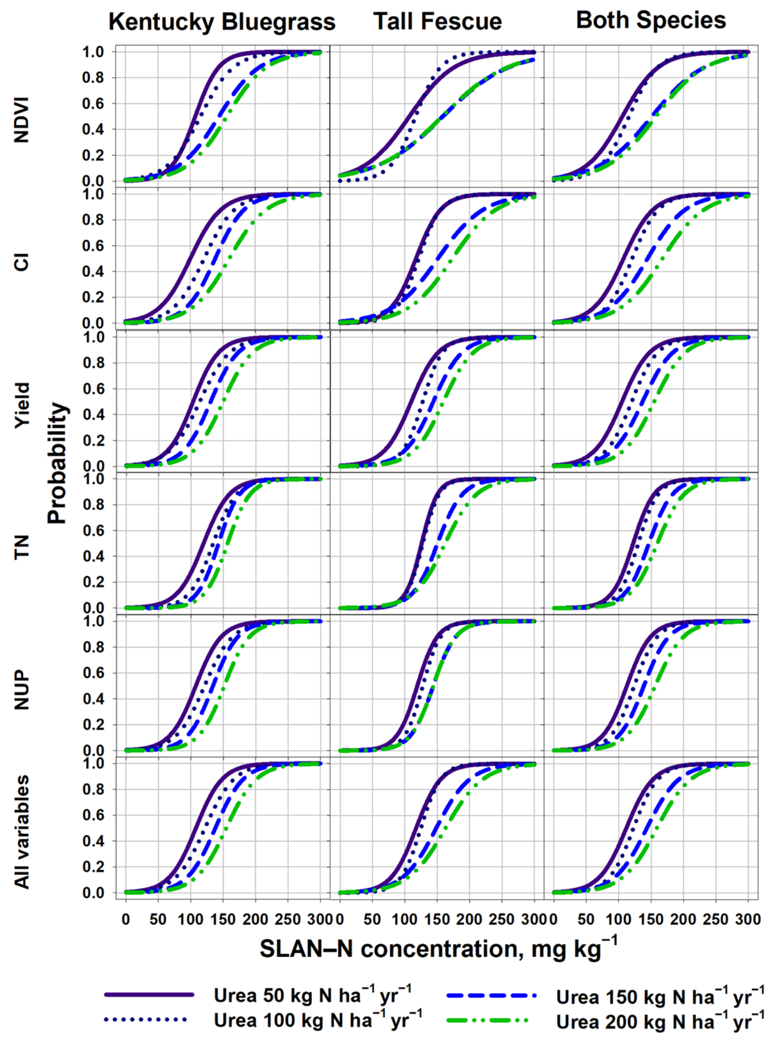

Fig. 3. Probability curves of obtaining normalized difference vegetative index (NDVI), chlorophyll index (CI), clippings yield (yield), clippings total N concentration (TN), and clippings total N uptake (NUP) responses from the organic fertilizer plots equal to or greater than the responses obtained from urea treatments at rates of 50, 100, 150, and 200 kg N ha^{-1} yr^{-1} in relation to Solvita Soil Labile Amino-Nitrogen (SLAN)–N concentrations for Kentucky bluegrass, tall fescue, and both species combined when managed as a lawn. Data are pooled across years for a study conducted in Storrs, CT, from 2008 through 2013.

fertilization that was equal to or greater than the response from urea rates at 50 to 200 kg N ha^{-1} yr^{-1}, respectively, depending on the variable or variables of interest, and the quality of turfgrass desired.

DISCUSSION

Turfgrass Response in Relation to Solvita Labile Amino-Nitrogen Concentrations

In all cases, the linear relationships between all five turfgrass performance indicators and SLAN–N concentrations included in this study were positive and highly significant ($P < 0.001$, Fig. 2). However, the amount of variation explained by the linear relationship (as indicated by r^2) was relatively low to moderate (between 4 and 34%), indicating the highly variable nature of soil labile N concentrations. Even with this high variability, the overall significant positive linear trend to the data provides an indication that SLAN–N concentrations have utility as a predictor for turfgrass performance (with moderate confidence), especially when taking into account the inherent biological variability with SOM mineralization and labile N. Considering that the current N fertilizer recommendations for turfgrass do not assess existing labile soil N nor account for its availability, this is a step forward in using objective methods to guide N fertilization.

Presently, there are few peer-reviewed papers reporting on the SLAN test under field conditions. Across nonmanured, irrigated production fields in southern Idaho representing silt loam, loam, sandy loam, loam, loamy sand, and sand soils, concentrations of SLAN–N were below the detection limit in >30% of the samples at the 0- to 30-cm sampling depth, and 92% of the samples from the 30- to 60-cm sampling depth were below the detection limit (Rogers et al., 2018). Reported SLAN–N concentrations above the detection limit ranged from 25

Table 1. Binary logistic regression coefficients and parameters for turfgrass responses in relation to Solvita Soil Labile Amino-Nitrogen test concentrations at different benchmark urea N rates. Turfgrass responses are normalized difference vegetation index (NDVI), chlorophyll index (CI), clippings yield (yield), clippings total N concentration (TN), clippings total N uptake (NUP), and all variables combined (all). Data are reported for years 2008 through 2016 from a study conducted in Storrs, CT. The Wald *P* value for every model was <0.0001.

		Kentucky bluegrass			Tall fescue			Both species		
Variable	Urea N rate	Slope	Intercept	Max.-rescaled r^2	Slope	Intercept	Max.-rescaled r^2	Slope	Intercept	Max.-rescaled r^2
	kg ha^{-1} yr^{-1}									
NDVI	50	0.055	−5.936	0.208	0.029	−3.076	0.094	0.036	−3.803	0.126
	100	0.039	−4.499	0.153	0.051	−5.982	0.209	0.045	−5.204	0.186
	150	0.032	−4.616	0.137	0.020	−3.113	0.063	0.025	−3.703	0.093
	200	0.033	−5.096	0.143	0.020	−3.128	0.064	0.026	−4.123	0.104
CI	50	0.042	−4.184	0.138	0.052	−6.029	0.211	0.043	−4.652	0.160
	100	0.042	−5.092	0.180	0.058	−6.975	0.253	0.049	−5.952	0.221
	150	0.044	−6.119	0.218	0.028	−4.258	0.117	0.034	−4.896	0.155
	200	0.035	−5.539	0.157	0.029	−5.095	0.128	0.031	−5.161	0.137
Yield	50	0.051	−5.203	0.176	0.048	−5.235	0.175	0.047	−4.908	0.168
	100	0.043	−4.832	0.168	0.064	−8.159	0.307	0.050	−5.980	0.222
	150	0.047	−6.105	0.225	0.045	−6.417	0.231	0.043	−5.827	0.210
	200	0.044	−6.507	0.221	0.043	−6.876	0.231	0.042	−6.438	0.216
TN	50	0.050	−5.983	0.221	0.081	−10.245	0.377	0.062	−7.574	0.291
	100	0.055	−7.408	0.285	0.079	−10.060	0.376	0.066	−8.567	0.340
	150	0.062	−8.796	0.341	0.052	−7.859	0.293	0.055	−8.069	0.309
	200	0.057	−8.980	0.319	0.041	−6.719	0.219	0.048	−7.710	0.267
NUP	50	0.051	−5.437	0.189	0.064	−7.634	0.272	0.054	−6.099	0.219
	100	0.046	−5.560	0.202	0.072	−9.167	0.345	0.056	−6.946	0.266
	150	0.052	−6.921	0.262	0.057	−8.224	0.318	0.052	−7.192	0.276
	200	0.051	−7.715	0.274	0.044	−6.974	0.234	0.046	−7.143	0.248
All	50	0.049	−5.252	0.183	0.052	−6.072	0.213	0.048	−5.327	0.189
	100	0.044	−5.370	0.193	0.064	−7.971	0.295	0.053	−6.464	0.244
	150	0.046	−6.310	0.228	0.038	−5.669	0.189	0.040	−5.720	0.198
	200	0.043	−6.588	0.215	0.034	−5.583	0.164	0.038	−5.971	0.187

to 100 mg kg^{-1}, which would fall within the lower 10% of the SLAN–N concentrations reported in our study. In a 2-yr study at one location on a sandy-loam soil with field crops and cover crops, the SLAN test (and other soil health tests) did not consistently detect treatment differences nor produce consistent significant, positive correlations with soil quality and crop yield (Chahal and van Eerd, 2018). In both years of the study, SLAN–N was negatively correlated with soil organic C, and negatively correlated with marketable tomato (*Solanum lycopersicum* L.) yield in one of the 2 yr. The reported SLAN–N concentrations for cover crop treatments ranged from 86 to 105 mg kg^{-1}, and these values would fall within the lower 10% of the SLAN–N concentrations reported in our study. The perennial nature of the turfgrass systems and the long-term repeated application of organic fertilizers in our study most likely were responsible for the higher SLAN–N concentrations reported herein. There also may have been some immobilization of soil labile N occurring with cover crop incorporation in the study reported by Chahal and van Eerd (2018). It is also likely that longer term studies are needed to confidently access the relationship between SLAN–N concentrations and crop yields and soil quality, or that the SLAN test correlates better for certain crops or in certain soils, but not for others.

Across a 5-yr study, Kentucky bluegrass and tall fescue lawn responses were positive and linearly related with labile soil N, as measured by the ISNT (Geng et al., 2014). By the fifth year of the study, r^2 values of the linear regressions were in the range of 0.50 to 0.65 across all response variables except for total N in the clippings responses, which were slightly lower (r^2 = 0.30 to 0.60). Even though SLAN–N is well correlated with ISNT–N (Moore et al., 2019), turfgrass responses to soil labile N concentrations in the sandy-loam soil generally showed better fits when determined by the ISNT than when determined by the SLAN test (Fig. 2) based on comparison of results from this study and the results of Geng et al. (2014). Unfortunately, the ISNT is not generally offered at soil testing laboratories because of its complexity, cost, and poor predictive ability under some conditions. The SLAN test, however, is becoming more widely included as part of soil health assessments at these laboratories.

Probability of Turfgrass Response Equaling or Exceeding the Benchmark Urea Values in Relation to Solvita Labile Amino-Nitrogen Concentrations

Previous research has suggested that labile soil N concentrations as determined by the ISNT from a spring sampling could be used to determine the probability of obtaining an N fertilization response in Kentucky bluegrass and tall fescue lawns equal to or exceeding the mean response of 150 and 200 kg N ha^{-1} yr^{-1} from urea (Geng et al., 2014). When ISNT–N critical concentrations, combined across both species, were $\geq$226 mg kg^{-1}, there was a high probability ($\geq$90%) of obtaining an NDVI response equal to or greater than the mean NDVI response obtained from urea rates of 150 and 200 kg N ha^{-1} yr^{-1}. Conversely, when ISNT–N critical concentrations were $\leq$149 mg kg^{-1}, there was a very low probability ($\leq$10%) that the NDVI responses would be equal to or greater than the mean NDVI response obtained from urea rates of 150 and 200 kg N ha^{-1} yr^{-1}.

Similar to the probability predictions in relation to ISNT–N critical concentrations presented in Geng et al. (2014), we were able to develop probability curves of cool-season turfgrass responses in relation to SLAN–N critical concentrations (Fig. 3) using the parameter coefficients in Table 1. When spring soil SLAN–N critical concentrations were $\geq$158, 165, 198, and 217 mg kg^{-1}, there was a 90% or greater probability that overall combined responses would be equal to or greater than responses obtained from 50, 100, 150, and 200 kg urea N ha^{-1} yr^{-1}, respectively (Table 2). This suggests that the need for additional N would be greatly reduced when SLAN–N concentrations reached these levels in the sandy-loam soil at our site for expected responses equivalent to 50, 100, 150, and 200 kg urea N ha^{-1} yr^{-1}, respectively. Conversely, when spring SLAN–N critical concentrations were $\leq$97, 109, 126, and 140 mg kg^{-1}, there was only a 33% or lower probability that overall combined responses would be equal to or greater than responses obtained from 50, 100, 150, and 200 kg urea N ha^{-1} yr^{-1}, respectively (Table 2). This suggests that there would be a good chance of obtaining positive responses from N fertilization to meet low- to high-quality expectations.

Table 2. Predicted Solvita Soil Labile Amino-Nitrogen (SLAN)–N concentrations for all variables combined at selected probabilities (*P*) of equaling or exceeding benchmark urea rate responses of turfgrass quality and growth at different urea rates based on the logistic regression coefficients in Table 1.

Urea N rate	$P \geq$ urea benchmark	SLAN–N Kentucky bluegrass	Tall fescue	Both species
kg ha^{-1} yr^{-1}		mg kg^{-1}		
50	0.33	93	104	97
	0.67	122	131	127
	0.90	153	160	158
100	0.33	106	113	109
	0.67	138	136	136
	0.90	172	159	165
150	0.33	122	130	126
	0.67	153	167	161
	0.90	186	206	198
200	0.33	138	142	140
	0.67	171	183	178
	0.90	206	227	217

All the binary logistic regression models were statistically significant ($P < 0.0001$), indicating that the SLAN test could be used to predict the probability of predominantly Kentucky bluegrass or tall fescue lawns equaling or exceeding urea benchmark responses with moderate confidence prior to a fertilizer application. There was considerable variability in the models, however, as indicated by the relatively low to moderate maximum-rescaled r^2 values (Table 1). This was not unexpected, considering the inherent variability associated with SOM mineralization and labile N conversions in soils during and across growing seasons (Bundy and Meisinger, 1994).

Categorizing Nitrogen Responsiveness of Turfgrass Soils and Guiding Turfgrass Nitrogen Fertilization Based on Solvita Labile Amino-Nitrogen Concentrations

Selected probabilities (P = 0.33, 0.67, and 0.90) of equaling or exceeding benchmark responses from the four urea rates can be used to create response categories based on how likely it is that turfgrass will equal or exceed urea benchmark responses based on SLAN–N concentrations (Fig. 4). Subsequently, decisions can be made about how much N fertilization cool-season turfgrass lawns should receive to match performance goals obtained from common urea N rates. Although we acknowledge that the P levels of 0.33, 0.67, and 0.90 are somewhat arbitrary, we think they represent a reasonable delineation of response categories in relation to N fertilization. The coefficients provided in Table 1 will allow for the determination of SLAN–N critical concentrations for any desired P level. The probability curves generated for the combined responses of all variables across both bluegrass and tall fescue from the organic fertilizer plots that are equal to or greater than the responses obtained from urea treatments at rates of 50, 100, 150, and 200 kg N ha^{-1} yr^{-1}, delineated with P = 0.33, 0.67, and 0.90 obtained from Table 2, are shown in Fig. 4A, 4B, 4C, and 4D, respectively. From these, probability of response categories to N fertilization for these categories that match urea benchmark responses are suggested. To illustrate this, an expanded plot for the 50 kg N ha^{-1} yr^{-1} urea treatment is shown in Fig. 4E.

Using these categories for cool-season turfgrass lawns in our climate, we can suggest that when SLAN–N critical concentrations are associated with $P \leq 0.33$, there is a very high to high probability of obtaining a positive response to additional N fertilization in relation to the urea benchmark values; when SLAN–N critical concentrations are between P = 0.33 and P = 0.67, there is a high to moderate probability of obtaining a positive response to additional N fertilization in relation to the urea benchmark values; when SLAN–N critical concentrations are between P = 0.67 and P = 0.90, there is a moderate to low probability of obtaining a positive response to additional

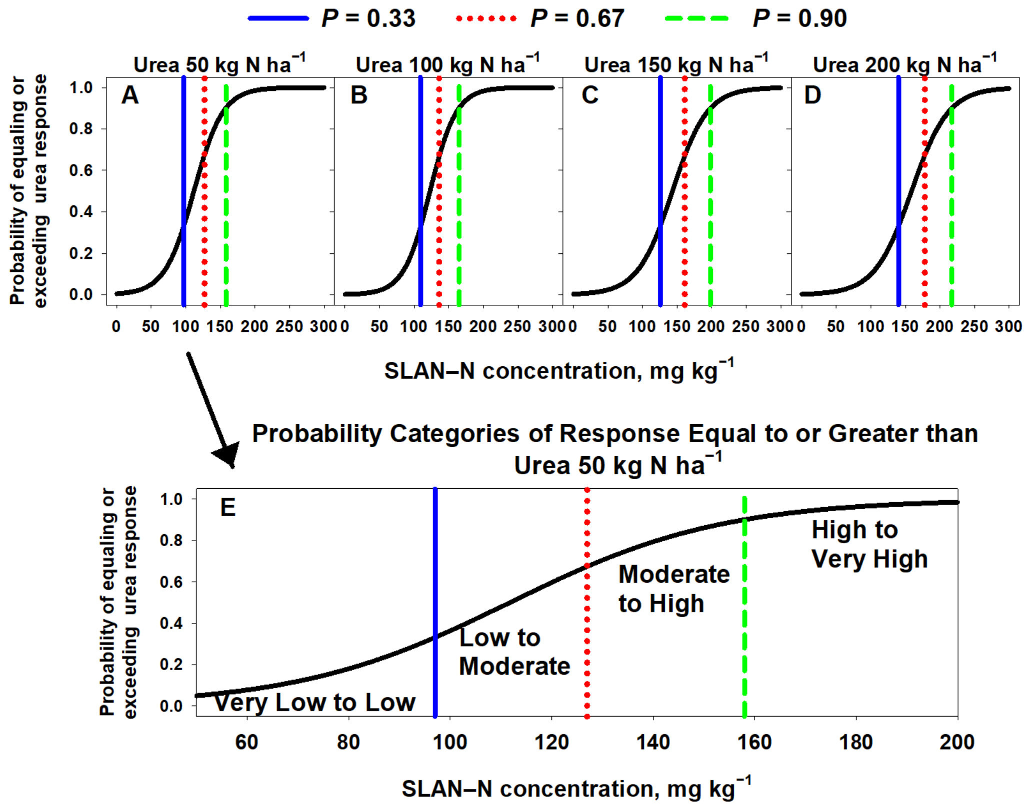

Fig. 4. Probability curves of all variables combined across Kentucky bluegrass and tall fescue lawn response from the organic fertilizer plots equal to or greater than the responses obtained from urea treatments at rates of (A) 50, (B) 100, (C) 150, and (D) 200 kg N ha^{-1} yr^{-1} in relation to Solvita Soil Labile Amino-Nitrogen (SLAN)–N concentrations. Categories of response to N fertilization for the 50 kg N ha^{-1} yr^{-1} treatment are shown in an expanded scale in Panel E. Solid, dotted, and dashed horizontal lines indicate P values of 0.33, 0.67, and 0.90, respectively, obtained from Table 2. Data are pooled across years and species for a study conducted in Storrs, CT, from 2008 through 2013.

N fertilization in relation to the urea benchmark values; and when SLAN–N critical concentrations are at $P \geq 0.90$, there is a low to very low probability of obtaining a positive response to additional N fertilization in relation to the urea benchmark values.

The ultimate goal of using the SLAN test to guide N fertilization for turfgrasses would be to determine a specific amount of N needed for optimum response for any specific SLAN–N concentration. Our current study was not designed to answer that question; follow-up calibration studies would be required to answer that. Depending on the level of turfgrass growth and quality desired (going from lower quality at 50 kg N ha^{-1} yr^{-1} to high quality in our climate at 150 and 200 kg N ha^{-1} yr^{-1}), however, we think it is logical to suggest that turfgrass lawn soils in our climate with SLAN–N critical concentrations below the $P = 0.33$ level would require the currently recommended full rate of N fertilizer for that species; turfgrass soils with SLAN–N critical concentrations between $P = 0.33$ and $P = 0.67$ levels would require two-thirds to one-half the currently recommended rate of N fertilizer for that species; turfgrass soils with SLAN–N critical concentrations between $P = 0.67$ and $P = 0.90$ would require one-half to one-third or less the currently recommended full rate of N fertilizer for that species; and that turfgrass soils with SLAN–N concentrations above the $P = 0.90$ would probably need little, if any, any additional N fertilizer with respect to the level of quality desired. This assumes that conditions for mineralization are similar to the conditions present across the 9 yr, one soil, and two turfgrass species represented by our data. Another approach to using the P values to guide N fertilization is for turfgrass managers to apply $(1 - P)\times$ the full rate of N fertilization, where P is the probability of equaling or exceeding the benchmark urea response based on the SLAN–N concentration.

These general N fertilizer recommendations for the response categories are speculative and more research is needed before we can quantify the amount of N fertilizer offset required for a given SLAN–N concentration. We think these categories and respective SLAN–N critical concentrations, however, could be used to establish a starting point to guide N fertilization and be modified based on turfgrass response at a specific lawn location.

CONCLUSIONS

This study suggests that cool-season turfgrass lawn responses are positively correlated to SLAN–N concentrations, and that turfgrass soils can be categorized by their probability of equaling or exceeding the responses of turfgrass fertilized with urea based on SLAN–N concentrations with reasonable confidence. The SLAN test may be helpful in developing more objective guides to N fertilization, or helpful in objectively categorizing turfgrass soils by their probability of equaling or exceeding urea benchmark responses. This moves N management for turfgrass away from the current subjective method for N rate recommendations.

The SLAN test should be able to detect turfgrass soils with high N mineralization potentials that would allow for reduced rates of N fertilizer applications without sacrificing turfgrass performance, as well as identifying low mineralization sites that justify higher N inputs. At our location, the SLAN test was performed on a single spring soil sample, which is consistent with current industry practices, and therefore the SLAN test would fit in easily with current routine lawn soil testing procedures.

This is a robust dataset across 9 yr and two commonly planted cool-season turfgrass species, but the data are from only one soil (sandy loam) at one location. Future research across more locations and environments could develop regional or localized calibration curves, which would enable the use of SLAN–N concentrations to quantify how much N fertilizer should be added to achieve turfgrass lawn responses similar to those typically obtained from common rates of urea. If research is conducted on a regional scale (i.e., accounting for different soil types and precipitation regimes), it is likely that more accurate and customized N fertilization recommendations could be made for different soils and precipitation regimes.

Conflict of Interest

Author William F. Brinton is CEO and Chief Science Officer for Woods End Laboratories. This company is the distributor of the Solvita SLAN test used and reported in the study. Karl Guillard, the corresponding author, has a research collaboration with Woods End Laboratories where he receives a 25 to 50% discount on the gel probes used in the research. William Brinton's input was for consultation and review of manuscripts. He had no influence on the reporting of the results or conclusions and could not prevent the reporting or publishing of the results of the study per signed agreement with the University of Connecticut.

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