EFFECTS OF DIFFERENT SOIL TESTING PHILOSOPHIES ON CREEPING BENTGRASS (*Agrostis palustris* Huds.) AND ANNUAL BLUEGRASS (*Poa annua*) PUTTING GREENS

By

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**ABSTRACT**

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Sufficiency Level of Available Nutrient (SLAN) and Minimum Levels for Sustainable Nutrition (MLSN) are two of the philosophies used for soil test interpretation in turfgrass management. A study was conducted from 2019 – 2020 to compare the effects of SLAN and MLSN nutrient recommendations on a ‘Penn A-4’ creeping bentgrass green (*Agrostis palustris* Huds.) and on a mix stand of annual bluegrass (*Poa* annua) and ‘Penncross’ creeping bentgrass green grown on United States Golf Association specification rootzone. This study was a split plot with three factors and three replications. The whole plot included three levels: MLSN, SLAN and nitrogen (N) fertilized control treatment. The subplot included two levels: trafficked and non-trafficked. Soil samples were collected in spring and autumn to a depth of 15 cm. Turfgrass color, quality, and NDVI were measured monthly. In 2019, nutrient recommendation rate for MLSN was 73 kg N, 37 kg P and 60 kg K $ha^{-1}$; SLAN was 73 kg N, 56 kg P and 222 kg K $ha^{-1}$; and N-fertilized control was 73.2 kg N $ha^{-1}$. There were no differences among treatments for NDVI, color and quality but the SLAN philosophy had the highest soil P and K levels in autumn of 2019. In 2020, nutrient recommendation rate for MLSN was 73 kg N, 38 kg P and 67 kg K $ha^{-1}$; SLAN was 73 kg N, 31 kg P and 216 kg K $ha^{-1}$; and N-fertilized control was 73 kg N $ha^{-1}$. Both philosophies exhibited higher quality and healthier color compared to N-fertilized control. SLAN philosophy had the highest soil P level but there were no differences in soil K levels between the two philosophies in autumn of 2020.

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# INTRODUCTION

Conducting a soil test on putting greens is a common and highly recommended practice in developing a turfgrass fertility program because it provides nutrient recommendations that correct nutrient deficiencies and sustain turf quality (Christians, 1993; Landschoot, 2017). However, a soil sample from the same location can have different nutrient recommendations due to different extractants, calibration data, and interpretation philosophies used by laboratories (Turner & Waddington, 1978; Christians, 1993; Carrow, 1995; Skorulski, 2001; Carrow et al., 2004).

Soil test interpretation is the process of developing nutrient application recommendations from soil test results, turfgrass species, soil texture and other climatic information (Shearman & Rieke, 1972; Christians, 1993; Beard & Beard, 2005). It involves the use of an equation or a guideline known as a soil testing philosophy. This component of the soil test process is highly debated for the past few decades due to the different existing philosophies with regards to soil test interpretation (McLean, 1977; Klicker, 1990; Schlossberg & Simmons, 2012). The three common soil testing philosophies currently used in turfgrass management are Sufficiency Level of Available Nutrient (SLAN), Base Cation Saturation Ratio (BCSR), and Minimum Levels for Sustainable Nutrition (MLSN).

SLAN philosophy was originally designed for agriculture (Mitscherlich, 1909) and equations were modified to create localized guidelines for turfgrasses and soil properties of each state (Carrow, 1995). MLSN philosophy has a generalized guideline based on multiple turfgrass sites (Woods et al., 2014) that is customizable by estimating the expected nutrient use of turfgrass over time at a specific location (Woods, 2016a).

The objective of this study was to evaluate the effects of SLAN and MLSN nutrient recommendations on creeping bentgrass (*Agrostis palustris* Huds.) and annual bluegrass (*Poa annua*) grown on United States Golf Association (USGA) specification rootzone. Specifically, to compare the soil nutrient levels, normalized difference vegetation index (NDVI), turfgrass color and turfgrass quality of SLAN and MLSN treatments under trafficked and non-trafficked conditions.

# LITERATURE REVIEW

## Sufficiency Level of Available Nutrient (SLAN)

The SLAN philosophy is based on a general mathematical expression of the Law of Diminishing Returns where increases in yield of a crop per unit of available nutrient decreases as the level of available nutrient approaches sufficiency (Mitscherlich, 1909). This philosophy was refined through extensive correlation and calibration studies (Christians, 1993). Once a high correlation between plant growth rate and soil test result is established, field tests are conducted to calibrate and determine suitable nutrient levels to achieve the desired growth rate and identify which levels would induce deficiency and toxicity (Hull, 2008). Calibration studies can be difficult because of varying plant response to each element and soil type. Christians (1993) mentioned that the calibration of nutrient recommendations for turf is challenging because of the diversity of soils used and variety of turfgrass species that are being grown.

### *SLAN ranges*

SLAN recommendations are categorized into different ranges: low, medium, high, and very high (Carrow et al., 2004). A low range means that there is an 80-100% probability that nutrient application will produce a growth response. A medium range means that there is a 50% probability that a nutrient application will produce a growth response. A high range means that nutrient application will have a slight or no growth response. A very high range means that any additional nutrient application may cause a nutrient imbalance or toxicity. Carrow (2004) demonstrated that SLAN ranges also varied depending on the laboratory extractant and soil type (Table 1).

Table 1. Typical soil test SLAN sufficiency ranges for phosphorus and potassium [a]

| Nutrient | Soil | Medium sufficiency ($mg\ kg^{-1}$) | Extractant |
|---|---|---|---|
| Phosphorus | All | 15-30 | Mehlich I |
| | | 26-54 | Mehlich II |
| | | 15-30 | Bray P-1 |
| | | 12-28 | Olsen |
| | | 10-20 | Morgan |
| Potassium | Sand | 75-175 | Ammonium acetate (pH 7.0) |
| | Others | 100-235 | Ammonium acetate (pH 7.0) |
| | Sand | 50-116 | Mehlich III |
| | Others | 75-176 | Mehlich III |
| | Sands | 50-100 | Mehlich I |
| | Others | 90-200 | Mehlich I |
| | All | 155-312 | Olsen |
| | All | 120-174 | Morgan |

[a] Source: Carrow et al. (2004)

*Phosphorus correlation studies at MSU*

From 1993 to 1995, MSU scientists (Rieke et al., 1995; Rieke et al., 1996; Rieke et al., 1998; Rieke et al., 1999) conducted phosphorus (P) fertility studies on ‘Penncross’ creeping bentgrass grown on an 85% sand, 15% peat USGA specification rootzone. Phosphorus treatments included in the fertility studies were no phosphorous application (control), 50 kg $ha^{-1}$ $yr^{-1}$, 100 kg $ha^{-1}$ $yr^{-1}$, 200 kg $ha^{-1}$ $yr^{-1}$, 200 kg $ha^{-1}$ (only in 1993), recommended amount of $P_2O_5$ based on Bray and Kurtz P-1 (Bray P-1) test, and $P_2O_5$ based on sodium bicarbonate (Olsen) test (Rieke et al., 1995; Rieke et al., 1996; Rieke et al., 1998; Rieke et al., 1999).

After establishment, the turf had minimal growth and exhibited visual symptoms of P deficiency (purplish and gray green appearance) across all treatments. In autumn of 1994, P soil tests indicate that available P levels were low except for plots treated with 200 kg $P_2O_5$ $ha^{-1}$ $yr^{-1}$, with nutrient recommendations based on Bray P-1 test and Olsen test. Moreover, the application of 200 kg $P_2O_5$ $ha^{-1}$ (only in 1993) had a similar soil P level with 100 kg $P_2O_5$ $ha^{-1}$ $yr^{-1}$ treatment, indicating that it is important to regularly apply P sources throughout the year on new sand-based greens (Rieke et al., 1995).

In 1995, severe P deficiency was observed in the control plots and 50 kg $P_2O_5$ $ha^{-1}$ $yr^{-1}$ caused mild deficiency symptoms compared to the control treatment but had produced unacceptable turf quality. Those treated with 200 kg $P_2O_5$ $ha^{-1}$ in 1993 (without further application) commonly displayed P deficiency symptoms. Plots applied with 100 kg $P_2O_5$ $ha^{-1}$ $yr^{-1}$ had an acceptable turf quality, but soil P levels were moderately low (14.2 mg P $kg^{-1}$). Based on these turf quality ratings, Rieke et al. (1996) recommended 14 mg $kg^{-1}$ as an adequate soil P level for sand-based greens.

Table 2. Michigan State University Phosphorus Correlation Study [a]

| P Treatment | Bray P-1 Test Results | | |
|---|---|---|---|
| | 1993 | 1994 | 1995 |
| | mg P $kg^{-1}$ | | |
| Control | 1.85 b | 2 b | 2.5 d |
| 50 kg $ha^{-1}$ $yr^{-1}$ | 2 b | 1.65 b | 4.65 cd |
| 100 kg $ha^{-1}$ $yr^{-1}$ | 2.5 b | 4.2 b | 14.2 bc |
| 200 kg $ha^{-1}$ $yr^{-1}$ | 6.2 a | 16.2 a | 31 a |
| 200 kg $ha^{-1}$ in 1993 only | 7.4 a | 4.7 b | 5.4 cd |
| based on Bray P-1 | 7.4 a | 13.2 a | 23.4 ab |
| Based on Olsen test | 5.9 a | 14.7 a | 23.5 ab |

[a] Rieke et al. (1996)

**Basic Cation Saturation Ratio (BCSR)**

BCSR is another soil testing philosophy adapted from agriculture. Bear et al. (1945) defined that an ideal soil has an optimal balance of exchangeable cations in the following percentages: 65% calcium (Ca), 10% magnesium (Mg), 5% potassium (K), and 2% hydrogen (H). Based on these percentages of an ideal soil, Bear and Toth (1948) formed the following cation equivalent ratios: 6.5 Ca: 1 Mg, 13 Ca: 1 K, 3.25 Ca: 1 H, and 2 Mg: 1 K. Graham (1959) refined the composition of an ideal soil into 65 to 85% Ca, 6 to12% Mg, and 2.5 to 5% K. Many professional soil testing laboratories base their nutrient recommendations on Graham's percentages, but many laboratories still use Bear and Toth's cation ratios (St. John, 2005).

St. John and Christians (2013) advised not to use BCSR philosophy as the only basis in developing a turfgrass fertility program for low cation exchange capacity (CEC) and/or calcareous sand-based rootzones. They found difficulties in determining cation ratios in the sand and silica samples due to low CEC and dissolution of calcium carbonate ($CaCO_3$). Low concentration of exchangeable cations due to low CEC was a source of variability and error when calculating cation percentages. Some methods of soil analysis dissolve calcium carbonate ($CaCO_3$) resulting to high Ca:K and Ca:Mg ratios. It was observed that soil samples can have an ideal cation percentage for a particular element, but still be deficient in that element due to the low CEC found in sandy soils. They also found that that creeping bentgrass can tolerate a wide range of cation ratios.

**Minimum Levels for Sustainable Nutrition (MLSN)**

Recent trends in reduced inputs and increased sustainability led to the development of MLSN as an alternative to SLAN (Woods et al., 2014; Meentemeyer & Whitlark, 2016). The MLSN guideline was based on 16,163 soil samples collected to a 10 cm depth from good performing turfgrass sites (Woods et al., 2016). A set of 13,062 of these soil samples were collected in North America and submitted to PACE Turf from October 1991 to August 2014. Another set of 3,101 soil samples were collected in Asia and submitted to Asian Turfgrass Center from March 2007 to July 2014.

To develop guidelines that would be accurate when Mehlich-3 extractant is used, certain values for CEC and pH should be satisfied prior to adding samples to the working data set. Individual soil samples should have a CEC of less than 6 cmol/kilogram to remove soils with high nutrient holding capacity from the data set, and a pH range of 5.5 to 8.5 (Woods et al., 2014; Woods et al., 2016).

In the end, 3,683 soil samples were added to the working data set (Woods et al., 2016). MLSN guidelines (Table 3) were identified with three-parameter log-logistic distribution using EasyFit distribution-fitting software from Mathwave (Woods et al., 2014; Woods et al., 2016).

Table 3. Minimum Levels for Sustainable Nutrition Guidelines [a]

| Nutrient | mg kg $^{-1}$ |
|---|---|
| Potassium | 37 |
| Phosphorus | 21 |
| Calcium | 331 |
| Magnesium | 47 |
| Sulfur as sulfate | 7 |

[a] Source: PACE Turf (2014)

**Differences between SLAN AND MLSN**

*Equations*

MSU Soil Plant and Nutrient Lab (SPNL) uses the following SLAN equations to calculate recommended $P_2O_5$ and $K_2O$ for golf course putting greens:

lbs. $P_2O_5$ per 1000 ft $^{-2}$ = 3.4 – (0.17* Olsen or Bray P-1 result in parts per million) (eq. 1)

lbs. $K_2O$ per 1000 ft $^{-2}$ = 6.3 – (0.04* ammonium acetate K result in parts per million) (eq. 2)

Woods (2016) developed the following MLSN equation:

$$a + b - c = Q \qquad \text{(eq. 3)}$$

*a* represents the amount of nutrient used by the grass which can be computed using two methods: (1) based on nitrogen use of the turfgrass where *a* is 1/8 N for P while ½ N for K; and (2) using temperature-based growth potential (GP) of the turfgrass.

*b* represents the amount of nutrient levels in the soil to maintain good turf quality and can be found in the MLSN guideline (Table 1).

*c* represents the amount of nutrient that was already in the soil which can be identified through laboratory soil analysis using Mehlich-3 soil test.

*Laboratory soil analysis*

Chemical reagents used in laboratory soil analysis mimic how plants extract certain nutrients from the soil. The extractants used have tremendous influence on the soil testing philosophies, demonstrating that it is important to also review these laboratory soil analyses when evaluating soil test interpretation philosophies.

To calculate SLAN nutrient recommendations, MSU Soil and Plant Nutrient Laboratory (SPNL) uses Olsen and Bray P-1 extractants to analyze available P while ammonium acetate extractant is used to analyze exchangeable K, Ca, and Mg. Mehlich-3 test results are used to compute nutrient recommendations based on MLSN philosophy. Mehlich-3 is a universal extractant that analyzes available P, exchangeable K, Ca, and Mg.

Table 4. Common laboratory soil extractants used for turfgrass management

| Extractant | Nutrient |
|---|---|
| Sodium Bicarbonate (Olsen) [a]<br>Bray and Kurtz P-1 (Bray P-1) [b] | Available phosphorus |
| Ammonium acetate [c] | Exchangeable potassium, calcium, and magnesium |
| Mehlich-3 [d] | Available phosphorus<br>Exchangeable potassium, calcium, and magnesium |

[a] Laverty, J. C. (1963)
[b] Bray, R. H., and Kurtz, L. T. (1945)
[c] Chapman, H. (1965)
[d] Mehlich, A. (1984)

Frank et al. (2011) reported that Olsen test correlates with crop response to P fertilization on both calcareous and noncalcareous soils. Bray P-1 test correlates with yield response on most acid and neutral soils in the region. It also reported that Mehlich-3 test results correlate with Olsen test results on highly calcareous soils and non-calcareous soils while it only correlates with Bray P-1 for non-calcareous soils. Olsen extractant should be used when analyzing calcareous soils, Bray P-1 method should be used on acidic soils, and Mehlich-3 can be used on either acidic or calcareous soils.

Another study comparing Mehlich-3, Olsen, and Bray P-1 procedures for P in Calcareous soils concluded that Olsen and the Mehlich-3 have similar ability to the Bray-P1 for estimating available P on neutral and slightly acid soils (Mallarino, 1995). Mallarino (1995) suggests that either Olsen or Mehlich-3 method would be better than the Bray-P1 test when conducting a single soil-test for P on calcareous soils or across soils varying in soil pH.

Warncke & Brown (2011) reported that either ammonium acetate or Mehlich-3 may be used to extract K. It also suggested that Mehlich-3 is a satisfactory extractant for K, Ca and Mg on non-calcareous soils. Mehlich-3 is not recommended for analyzing Ca and Mg from calcareous soils.

**Research comparing SLAN AND MLSN**

In an ongoing Scandinavian Turfgrass Environment Research Foundation (STERF) project called Sustainable P fertilization on golf courses (SUSPHOS), the P applications according to MLSN guidelines, SLAN nutrient recommendations and Scandinavian Precision Fertilization (SPF) were compared (Hesselsøe et al., 2021). One green was chosen out on five different golf courses in Europe (Norway, Sweden, Holland, and Germany) and in Asia (China). The five greens had different turfgrass species, soil nutrient levels and climatic conditions. MLSN treatment had P application if Mehlich-3 P soil test is below 18 mg $kg^{-1}$. SLAN treatment had P application if Mehlich-3 P soil test is below 54 mg $kg^{-1}$. SPF treatment received a fixed amount of phosphorus, 12% of the nitrogen (N) rate, each month during the growing season. Superphosphate (0-20-0) as a phosphorus source was added once a month. According to STERF

SUSPHOS 2020 report, preliminary results from 2017-2020 showed no decrease in turfgrass quality due to reduced P rates in any of the trials (Hesselsøe et al., 2021).

# MATERIALS AND METHODS

## Site Description

The research was conducted in 2019 and 2020 on two USGA putting greens at Hancock Turfgrass Research Center (HTRC), East Lansing, MI. The first putting green was a 'Penn A-4' creeping bentgrass (A4). The second putting green was a mix stand of 80% annual bluegrass and 20% 'Penncross' creeping bentgrass (MIX). Each putting green had an area of 9.14 $m^2$.

## Site Maintenance

The putting greens received an approximately 2 mm of irrigation per day. Mowing was performed three times per week at a 3.1 mm height using a triplex greens mower (Greensmaster 3150-Q, The Toro Company, Bloomington, MN). Sand topdressing was applied weekly at rate of 2 mm from May to October. Fungicides were applied on 14-day intervals to suppress dollar spot (*Sclerotinia homoeocarpa*). Insecticide was applied as needed for cutworm suppression. Wetting agents were applied on 30-day intervals to avoid localized dry spot.

## Experimental Design

The experimental design was a split plot with three factors and three replications. The whole plot (soil testing philosophy) included three levels: MLSN, SLAN and nitrogen (N) fertilized control treatment. The subplot (traffic) included two levels: trafficked and non-trafficked. The repeated measures (measurement dates) included 3 dates in 2019 and 5 dates in 2020. Each putting green was divided into nine 1.8 m x 4.6 m whole plots that were split into two subplots (Figure 1 and 2).

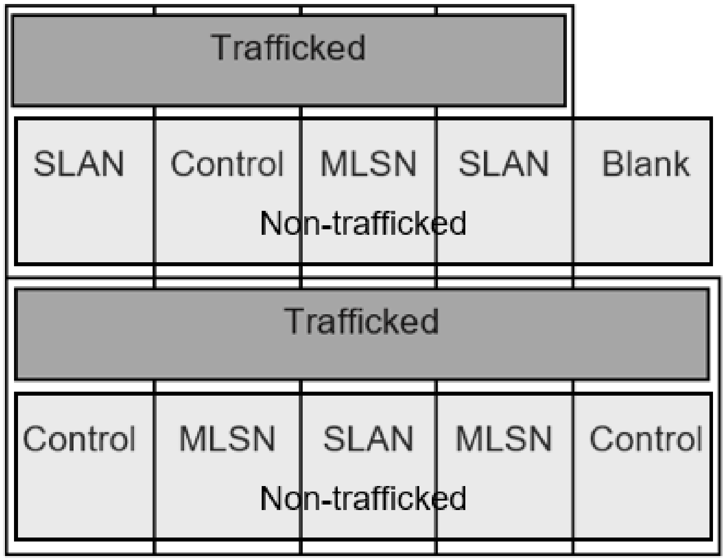


Figure 1. Experimental design and research plot map of mix stand of annual bluegrass and ‘Penncross’ creeping bentgrass putting green.

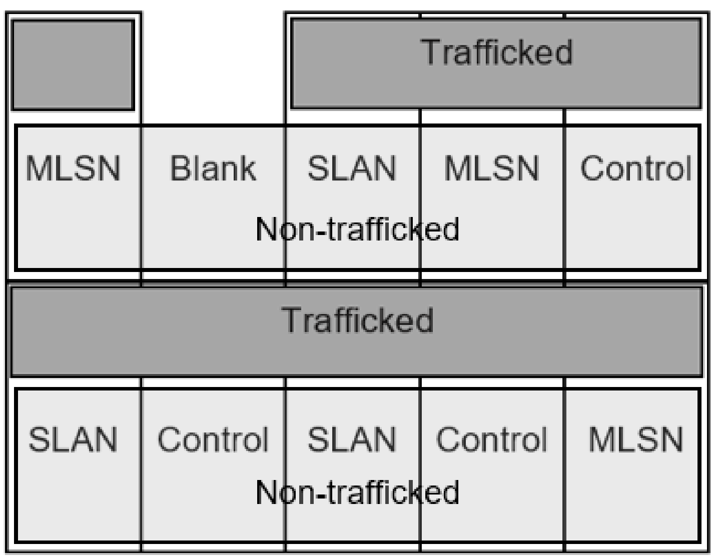


Figure 2. Experimental design and research plot map of ‘Penn A-4’ creeping bentgrass putting green.

## Soil Testing Philosophy Treatments

Soil test results are needed to calculate the nutrient recommendations for each soil testing philosophy treatment. Soil samples were collected to a depth of 15 cm. One soil sample was collected from each putting green in May 2019. One soil sample was collected per plot in November 2019 and October 2020. Soil samples were sent to the MSU SPNL to conduct soil analysis. Since the soil pH was equal or above 6.5, Olsen extractant was used to determine soil available P. 1 M ammonium acetate ($NH_4OAc$) extractant was used to measure exchangeable K. Olsen and ammonium acetate soil test results were used to calculate nutrient recommendations for the SLAN treatment. Whereas Mehlich-3 extractant was used to measure both soil available P and exchangeable K and the Mehlich-3 soil test results were used to calculate nutrient recommendations for the MLSN treatment.

Based on the May 2019 soil test results, the calculated P and K recommendations in 2019 for the SLAN treatment were four times and four and a half times higher than the MLSN treatment, respectively (Table 5).

Table 5. 2019 nutrient application rates

| Soil Testing Philosophy [a] | Nitrogen | Phosphorus | Potassium |
|---|---|---|---|
| | ——kg $ha^{-1}$—— | | |
| MLSN | 73.24 | 36.41 | 59.94 |
| SLAN | 73.24 | 146.91 | 266.58 |
| Nitrogen fertilized control | 73.24 | - | - |

[a] MLSN, Minimum Levels for Sustainable Nutrition; SLAN, Sufficiency Level of Available Nutrient

In the second year, a new nutrient recommendation was calculated based on November 2019 soil test results. The MLSN and SLAN treatments had similar amount of recommended P, but the amount of recommended K on SLAN plots was three times greater than MLSN plots (Table 6).

Table 6. 2020 nutrient application rates

| Soil Testing Philosophy [a] | Putting Green [b] | Nitrogen | Phosphorus | Potassium |
|---|---|---|---|---|
| | | kg ha$^{-1}$ | | |
| MLSN | A4 | 73.24 | 38.08 | 68.35 |
| | MIX | 73.24 | 37.59 | 67.38 |
| SLAN | A4 | 73.24 | 29.78 | 215.32 |
| | MIX | 73.24 | 32.22 | 217.27 |
| Nitrogen fertilized control | A4 and MIX | 73.24 | - | - |

[a] MLSN, Minimum Levels for Sustainable Nutrition; SLAN, Sufficiency Level of Available Nutrient
[b] A4, ‘Penn A-4’ creeping bentgrass; MIX, ‘Penncross’ creeping bentgrass and annual bluegrass

Urea (46-0-0) was used as N source, monoammonium phosphate (10-22-0) was used as N and P sources and sulfate of potash (0-0-42) as the K source. Urea and monoammonium phosphate were applied biweekly. Sulfate of potash was applied once a month from July to October 2019 and from April to October 2020.

**Traffic Treatments**

Traffic treatments were applied six passes per day and three times weekly to simulate approximately 470 rounds of golf per week from July to October 2019 and from April to October 2020. Traffic treatments were implemented using a golf traffic simulator (49.9 kg) modified with extra weight (68 kg). It was built using a roller (0.53 m in length; covering 0.266 m$^2$ with each revolution) covered with “Black Widow” Softspikes (Laskowski et al., 2018).

**Data Collection**

Turfgrass quality was rated monthly based on visual rating scale with 1 being poorest and 9 being best, a rating of 6 or above was considered acceptable, while turfgrass color was rated monthly based on visual rating scale with 1 being light green to 9 being dark green (Morris & Shearman, 1998). NDVI values were taken monthly using the Field Scout TCM 500 Turf Color

Meter (Spectrum Technologies Inc.), which quantitatively measure light reflectance in the red and near-infrared spectral bands and establishes an objective color evaluation for turf. NDVI values range from 0.000 to 1.000 with values closer to 1.000, indicating a relatively darker green color.

**Statistical Analysis**

The A4 and MIX putting greens were analyzed separately. Data were analyzed through PROC MIXED using Statistical Analysis Software (SAS, 2016). Normality and Homogeneity of variances assumptions were checked. Normality of the residuals was assessed by visual inspection of the histogram of the residuals and normal probability plot for the residuals. When normality assumption was satisfied, no transformation was needed. Homogeneity of variances was assessed using Levene's test at $\alpha=0.05$. When Levene's test revealed significant differences among the variances from interaction of factors, unequal variance model was used for further analyses.

For each response variable, whichever variance-covariance structure that had the lowest Akaike's Information Criterion (AIC) and Bayesian information Criterion (BIC) values among the analyzed variance-covariance structure was used in all further analyses. Analysis of Variance (ANOVA) was used to determine if there is a significant difference among treatment means. When a significant difference was detected ($P < 0.05$), means were separated using Least Significance Difference (LSD) pairwise comparison.

## RESULTS AND DISCUSSION

### Soil Test Results

*May 2019 test results*

At the beginning of the study in May 2019, both putting greens had low soil P and K levels (Table 7). It was also observed that the results from Olsen P and Mehlich P analyses are not different, while similar values were observed in ammonium acetate K and Mehlich K analyses. The amount of P and K recommended based on May 2019 soil test results for SLAN plots were four times and four and a half times higher than MLSN plots in 2019.

Table 7. May 2019 soil test results

| Putting Green [a] | Olsen P | Mehlich P | Ammonium Acetate K | Mehlich K |
|---|---|---|---|---|
| | mg $kg^{-1}$ | | | |
| A4 | 2.5 | 5.0 | 17 | 17 |
| MIX | 4.0 | 2.3 | 21 | 17 |

[a] A4, ‘Penn A-4’ creeping bentgrass; MIX, ‘Penncross’ creeping bentgrass and annual bluegrass

*Phosphorus*

The SLAN treatment had the highest soil P value among soil testing philosophy treatments in November 2019 (Table 8). Nutrient recommendations based on SLAN philosophy correct deficiencies and immediately buildup soil nutrient levels to maintain sufficiency levels (McLean, 1997).  Meanwhile, there was no significant difference between the MLSN treatment and N-fertilized control in November 2019 (Table 8).

Table 8. Phosphorus test results in November 2019

| | Olsen P | | Mehlich P | |
|---|---|---|---|---|
| | A4 [a] | MIX [b] | A4 | MIX |
| | mg kg$^{-1}$ | | | |
| November 2019 [c] | | | | |
| MLSN | 6.3 b [d] | 6.3 b | 1.7 b | 2.0 b |
| SLAN | 12.0 a | 11.3 a | 8.7 a | 8.7 a |
| N-fertilized control | 4.0 b | 4.7 b | 2.0 b | 1.3 b |

[a] A4, 'Penn A-4' creeping bentgrass
[b] MIX, 'Penncross' creeping bentgrass and annual bluegrass
[c] MLSN, Minimum Levels for Sustainable Nutrition; SLAN, Sufficiency Level of Available Nutrient
[d] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

The increase in the P test results of the SLAN treatment in November 2019 led to a decrease in P recommendations based on SLAN philosophy for the following year. Despite this adjustment, the SLAN treatment still had the highest P test results across all treatments in October 2020 (Table 9). P does not normally leach to any significant degree, so it tends to accumulate in the soil surface (Shearman & Rieke, 1972). Since SLAN plots received a high supply of P in 2019, a large portion of the applied P was fixed and/or immobilized in the soil. Some of the soluble P are fixed and transformed to its inorganic form (Carrow et al., 2001). It is only when there is a decrease in soil P levels that inorganic P will be released and become soluble P, thereby buffering against the rapid changes in the available P (Aamlid & Hesselsøe, 2020).

The SLAN treatment had a lower Olsen P test result in October 2020 (Table 9) compared to November 2019 (Table 8). Soils with low P levels have higher capacity to bind P (Haden et al., 2007) and limit P availability. It was possible that some of the soluble P from P fertilizers were immobilized in the soil and converted to organic P (Carrow et al., 2001). Other causes may also be the low amount of P applied in 2020, and nutrient loss through plant uptake, clipping removal, and leaching (Soldat & Petrovic, 2005).

The MLSN treatment had a significantly lower Olsen P test result than the SLAN treatment in October 2020 (Table 9). This was caused by the low amounts of P applied on MLSN plots during 2019 and 2020 (Table 5 and 6).

Table 9. Olsen P test results in October 2020

| Soil testing philosophies [a] | Olsen P | |
|---|---|---|
| | A4 [b] | MIX [c] |
| | mg kg$^{-1}$ | |
| MLSN | 5.5 b [d] | 3.9 b |
| SLAN | 8.4 a | 8.4 a |
| N-fertilized control | 3.6 c | 3.9 b |

[a] MLSN, Minimum Levels for Sustainable Nutrition; SLAN, Sufficiency Level of Available Nutrient
[b] A4, ‘Penn A-4’ creeping bentgrass
[c] MIX, ‘Penncross’ creeping bentgrass and annual bluegrass
[d] Means followed by the same letter are not significantly different according to Fisher’s Protected LSD (P = 0.05).

*Potassium*

Similar with P, the SLAN treatment had the highest soil K levels in November 2019. The MLSN treatment and N-fertilized control were not significantly different from each other and were significantly lower than the SLAN treatment (Table 10). It suggests that the amount of K applied on MLSN plots was considerably low to create an accumulation of K in the soil. The K test results of N-fertilized control were expected to be low treatment since there was no K applied.

Table 10. Potassium test results in 2019

| | Ammonium acetate K | | Mehlich K | |
|---|---|---|---|---|
| | A4 [a] | MIX [b] | A4 | MIX |
| | mg kg$^{-1}$ | | | |
| November 2019 [c] | | | | |
| MLSN | 17.0 b [d] | 14.0 b | 15.7 b | 16.7 b |
| SLAN | 24.7 a | 23.3 a | 24.7 a | 27.7 a |
| N-fertilized control | 11.7 b | 12.0 b | 13.0 b | 10.3 c |

[a] A4, ‘Penn A-4’ creeping bentgrass
[b] MIX, ‘Penncross’ creeping bentgrass and annual bluegrass
[c] MLSN, Minimum Levels for Sustainable Nutrition; SLAN, Sufficiency Level of Available Nutrient
[d] Means followed by the same letter are not significantly different according to Fisher’s Protected LSD (P = 0.05).

In October 2020, the soil testing philosophies had a significant effect on ammonium acetate K (for both putting greens) and Mehlich K (only in MIX putting green) test results. It was also interesting to notice that K test results between the SLAN and MLSN treatments in October 2020 were not statistically different, despite the large difference in the amount of K applied for each treatment. Sandy soils have small soil surface area which limits the number of cation exchange (CE) sites. Exchangeable K has relatively lower strength of adsorption to the CE sites than other cations (i.e., $Al^{+3}$, $Ca^{+2}$, $Mg^{+2}$) (Carrow et al., 2001). Potassium becomes more prone to leaching especially from sand-based rootzones with heavy irrigation (Shearman & Rieke, 1972). Thus, any excess K applied on SLAN plots may have leached from the rootzone.

Table 11. Potassium test results in October 2020

| Soil testing philosophies [a] | Ammonium acetate K | | Mehlich K |
|---|---|---|---|
| | A4 [b] | MIX [c] | MIX |
| | mg kg$^{-1}$ | | |
| MLSN | 16.7 a [d] | 9.4 a | 11.6 a |
| SLAN | 17.1 a | 12.3 a | 13.6 a |
| Nitrogen fertilized control | 8.4 b | 3.4 b | 6.6 b |

[a] MLSN, Minimum Levels for Sustainable Nutrition; SLAN, Sufficiency Level of Available Nutrient
[b] A4, 'Penn A-4' creeping bentgrass
[c] MIX, 'Penncross' creeping bentgrass and annual bluegrass
[d] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

**Normalized Difference Vegetation Index**

Table 12. Analysis of variance for the fixed effects of soil test philosophy, traffic, and date on NDVI in 2019 and 2020

| | Normalized Difference Vegetative Index (NDVI) | | | |
|---|---|---|---|---|
| | 2019 | | 2020 | |
| | A4 [a] | MIX [b] | A4 | MIX |
| Soil Testing Philosophy (S) | NS[†] | NS[†] | NS | NS |
| Traffic (T) | NS | NS | NS | NS |
| Date (D) | * | * | * | * |
| S x T | NS | NS | NS | NS |
| S x D | NS | NS | NS | NS |
| T x D | NS | NS | * | * |
| S x T x D | NS | NS | NS | NS |

[a] A4, ‘Penn A-4’ creeping bentgrass
[b] MIX, ‘Penncross’ creeping bentgrass and annual bluegrass
[*] Significant at the 0.05 level of probability.
[†] Not significant at the 0.05 level of probability.

<u>Traffic and date interaction</u>

Traffic x date interaction was significant in 2020 (both putting greens) (Table 12). Non-trafficked plots had increasing NDVI values over time (Table 14). The highest NDVI value was measured on October 14 while the lowest NDVI value was measured on June 19. Similar with the date effect in 2019, this increase in NDVI values was due to the accumulation of N, P and K throughout the growing season and the cool temperatures at the end of the year.

The trafficked plots had lowest NDVI value on June 19 while the highest NDVI value was on July 17. The increase in NDVI values was due to the N, P and K application. However, NDVI values started to decrease from July 17. The negative effect of traffic application on turfgrass initially showed in August 14.

Significant difference between trafficked and non-trafficked treatments were only found on October 14 (Table 13 and 14). This shows that continuous traffic application can negatively affect turfgrass growth and these effects will manifest at the end of growing season.

Table 13. Interaction of traffic and date on NDVI of A4 in 2020 [a]

| Effect | Normalized Difference Vegetative Index (NDVI) | | | | |
|---|---|---|---|---|---|
| | June 19 | July 17 | August 14 | September 16 | October 14 |
| | 0.000 – 1.000 [b] | | | | |
| Trafficked | 0.674 a[c]C[d] | 0.713 aA | 0.705 aB | 0.712 aAB | 0.700 bB |
| Non-trafficked | 0.695 aD | 0.716 aB | 0.708 aC | 0.716 aB | 0.733 aA |

[a] A4, 'Penn A-4' creeping bentgrass
[b] Taken using Field Scout TCM 500 Turf Color Meter.
[c] Lowercase letters represent significant differences within a column.
[d] Uppercase letters represent significant differences within a row.
[c, d] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

Table 14. Interaction of traffic and date on NDVI of MIX in 2020 [a]

| Effect | Normalized Difference Vegetative Index (NDVI) | | | | |
|---|---|---|---|---|---|
| | June 19 | July 17 | August 14 | September 16 | October 14 |
| | 0.000 – 1.000 [b] | | | | |
| Trafficked | 0.645 a[c]D[d] | 0.692 aA | 0.677 aB | 0.674 aBC | 0.661 bB |
| Non-trafficked | 0.661 aB | 0.691 aA | 0.688 aA | 0.685 aA | 0.693 aA |

[a] MIX, 'Penncross' creeping bentgrass and annual bluegrass
[b] Taken using Field Scout TCM 500 Turf Color Meter.
[c] Lowercase letters represent significant differences within a column.
[d] Uppercase letters represent significant differences within a row.
[c, d] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

Date main effect

Date main effect was significant in 2019 (both putting greens) (Table 12). For A4 putting green, the ranking of NDVI values among measurement dates is in the following order: October 24 > August 30 > September 26 (Table 15). October 24 had the highest NDVI value because creeping bentgrass and annual bluegrass are cool-season grasses and are well-adapted to cool temperatures (Turgeon & Kaminski, 2019). Moreover, the continuous fertilizer application throughout the growing season may have resulted to a healthier turfgrass growth in October.

Table 15. Date main effect in 2019

| Date | Normalized Difference Vegetative Index (NDVI) | |
|---|---|---|
| | A4 [a] | MIX [b] |
| | 0.000 – 1.000 [c] | |
| August 30 | 0.671 b [d] | 0.651 ab |
| September 26 | 0.656 c | 0.648 b |
| October 24 | 0.697 a | 0.658 a |

[a] A4, ‘Penn A-4’ creeping bentgrass
[b] MIX, ‘Penncross’ creeping bentgrass and annual bluegrass
[c] Taken using Field Scout TCM 500 Turf Color Meter.
[d] Means followed by the same letter are not significantly different according to Fisher’s Protected LSD (P = 0.05).

**Turfgrass Color**

Table 16. Analysis of variance for the fixed effects of soil test philosophy, traffic, and date on turfgrass color in 2019 and 2020

| | Color | | | |
|---|---|---|---|---|
| | 2019 | | 2020 | |
| | A4 [a] | MIX [b] | A4 | MIX |
| Soil Testing Philosophy (S) | NS[†] | NS | * | * |
| Traffic (T) | NS | * | * | * |
| Date (D) | * | * | * | * |
| S x T | NS | NS | NS | NS |
| S x D | NS | * | NS | NS |
| T x D | * | NS | * | * |
| S x T x D | NS | NS | NS | NS |

[a] A4, 'Penn A-4' creeping bentgrass
[b] MIX, 'Penncross' creeping bentgrass and annual bluegrass
[*] Significant at the 0.05 level of probability.
[†] Not significant at the 0.05 level of probability.

Soil testing philosophy and date interaction

Soil testing philosophies x date interaction was significantly different for turfgrass color in 2019 (for MIX putting green only) (Table 16). On August 30, the MLSN and SLAN treatments were not significantly different from each other and had higher turfgrass color value than N-fertilized control. All soil testing philosophies treatments had no differences in the subsequent dates (Table 17), suggesting that difference in P and K application did not affect the turfgrass color of the MIX putting green after a six months of treatment application.

The SLAN treatment had consistent turfgrass color values throughout the growing season. Meanwhile, the MLSN treatment and N-fertilized control had an increase in turfgrass color values. The lowest value was observed on August 30 and increased in September 29.

Table 17. Interaction of soil testing philosophies and date on color of MIX in 2019 [a]

| Soil Testing Philosophies [b] | Color [c] | | |
|---|---|---|---|
| | August 30 | September 29 | October 24 |
| MLSN | 6.2 a[d]B[e] | 6.5 aA | 6.5 aA |
| SLAN | 6.5 aA | 6.7 aA | 6.5 aA |
| Nitrogen fertilized control | 5.5 bB | 6.5 aA | 6.3 aA |

[a] MIX, 'Penncross' creeping bentgrass and annual bluegrass
[b] MLSN, Minimum Levels for Sustainable Nutrition; SLAN, Sufficiency Level of Available Nutrient
[c] Visually assessed on a 1 (light green) to 9 (dark green) rating scale.
[d] Lowercase letters represent significant differences within a column.
[e] Uppercase letters represent significant differences within a row.
[d, e] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

Main effect of soil testing philosophy

Soil testing philosophy was significant in 2020 for both putting greens (Table 16). For MIX putting green, no statistical difference was found between the MLSN and SLAN treatments while N-fertilized control had the lowest turfgrass color value (Table 18). For A4 putting green, N-fertilized control had the higher turfgrass color value among treatment while the MLSN and SLAN treatment were not statistically different from each other (Table 18). The darker green color with bluish or purplish areas observed on N-fertilized control plots is a common visual symptom of P deficiency (Carrow et al., 2001) due to low P content in the soil.

Table 18. Effects of soil testing philosophies on turfgrass color in 2020

| Soil Testing Philosophies [a] | Color [b] | |
|---|---|---|
| | A4 [c] | MIX [d] |
| MLSN | 7.5 b [e] | 6.8 a |
| SLAN | 7.6 b | 6.8 a |
| Nitrogen fertilized control | 7.9 a | 6.5 b |

[a] MLSN, Minimum Levels for Sustainable Nutrition; SLAN, Sufficiency Level of Available Nutrient
[b] Visually assessed on a 1 (light green) to 9 (dark green) rating scale.
[c] A4, 'Penn A-4' creeping bentgrass
[d] MIX, 'Penncross' creeping bentgrass and annual bluegrass
[e] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

Traffic and date interaction

Traffic x date interaction was significant in 2019 (for A4 putting green only) and 2020 (both putting greens) (Table 16). In 2019, the trafficked treatment had significantly lower turfgrass color value than the non-trafficked treatment for all dates (Table 19). Turfgrass color values in trafficked treatment plots increased over time, possibly due to N application or the low temperatures in autumn. The non-trafficked treatment had a consistent turfgrass color value throughout the growing season.

Table 19. Interaction of traffic and date on turfgrass color of A4 in 2019 [a]

| Traffic | Color [b] | | |
|---|---|---|---|
| | August 30 | September 29 | October 24 |
| Trafficked | 6.0 b[c]B[d] | 7.0 bA | 7.2 bA |
| Non-trafficked | 8.0 aA | 8.0 aA | 8.2 aA |

[a] A4, 'Penn A-4' creeping bentgrass
[b] Visually assessed on a 1 (light green) to 9 (dark green) rating scale.
[c] Lowercase letters represent significant differences within a column.
[d] Uppercase letters represent significant differences within a row.
[c, d] Means followed by the same letter are not significantly different according to Fisher's Protected LSD ($P = 0.05$).

The non-trafficked treatment had a higher turfgrass color value than the trafficked treatment for most dates in 2020 (Table 20 and 21). The non-trafficked plots had a higher turfgrass color value on the first measurement date (June 19) due to the lingering effects of continuous traffic application in 2019. On July 17 and August 14, difference between traffic treatments were not significantly different. Similar to NDVI results, non-trafficked treatment had a higher turfgrass color value than trafficked treatment on September 16 and October 14. These observations suggest that continuous traffic application makes the turfgrass color lighter, especially at the end of growing season.

The non-trafficked treatment had a higher color value on the last measurement date (October 14) compared to the first measurement date (June 19). The N application increased the turfgrass color value. However, the opposite was observed in the trafficked treatment. Last measurement date had a lower turfgrass color value than the first measurement date. Continuous traffic application counteracted the effect of N application and decreased the turfgrass color value.

Table 20. Interaction of traffic and date on turfgrass color of A4 in 2020 [a]

| Traffic | Color [b] | | | | |
|---|---|---|---|---|---|
| | June 19 | July 17 | August 14 | September 16 | October 14 |
| Trafficked | 7.4 b[c]B[d] | 7.1 aBC | 8.2 aA | 7.0 bC | 7.1 bBC |
| Non-trafficked | 7.9 aB | 7.4 aC | 8.3 aA | 8.0 aAB | 8.0 aAB |

[a] A4, 'Penn A-4' creeping bentgrass
[b] Visually assessed on a 1 (light green) to 9 (dark green) rating scale.
[c] Lowercase letters represent significant differences within a column.
[d] Uppercase letters represent significant differences within a row.
[c, d] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

Table 21. Interaction of traffic and date on turfgrass color of MIX in 2020 [a]

| Traffic | Color [b] | | | | |
|---|---|---|---|---|---|
| | June 19 | July 17 | August 14 | September 16 | October 14 |
| Trafficked | 6.4 b[c]B[d] | 7.0 aA | 7.1 aA | 5.8 bC | 6.2 bBC |
| Non-trafficked | 6.9 aAB | 6.9 aAB | 7.1 aA | 6.7 aB | 6.8 aAB |

[a] MIX, 'Penncross' creeping bentgrass and annual bluegrass
[b] Visually assessed on a 1 (light green) to 9 (dark green) rating scale.
[c] Lowercase letters represent significant differences within a column.
[d] Uppercase letters represent significant differences within a row.
[c, d] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

Traffic main effect

Traffic main effect was significant in 2019 for MIX putting green only (Table 16). The non-trafficked treatment had a darker color than trafficked greens (Table 22). The lighter green color on trafficked plots resulted from the wear and abrasive forces on the leaf blades (Alderman et al., 2019).

Table 22. Traffic main effect on turfgrass color of MIX in 2019 [a]

| Traffic | Color [b] |
|---|---|
| Trafficked | 5.9 b [c] |
| Non-trafficked | 6.9 a |

[a] MIX, ‘Penncross’ creeping bentgrass and annual bluegrass
[b] Visually assessed on a 1 (light green) to 9 (dark green) rating scale.
[c] Means followed by the same letter are not significantly different according to Fisher’s Protected LSD (P = 0.05).

**Turfgrass Quality**

Table 23. Analysis of variance for the fixed effects of soil test philosophy, traffic, and date on turfgrass quality in 2019 and 2020

| | Quality | | | |
|---|---|---|---|---|
| | 2019 | | 2020 | |
| | A4 [a] | MIX [b] | A4 | MIX |
| Soil Test Interpretation Philosophy (S) | NS | NS | NS | * |
| Traffic (T) | * | * | NS | NS |
| Date (D) | * | * | * | * |
| S x T | NS | NS | NS | NS |
| S x D | NS | * | NS | * |
| T x D | * | NS | * | * |
| S x T x D | NS | NS | NS | NS |

[a] A4, 'Penn A-4' creeping bentgrass
[b] MIX, 'Penncross' creeping bentgrass and annual bluegrass
[*] Significant at the 0.05 level of probability.
[†] Not significant at the 0.05 level of probability.

Soil testing philosophy and date interaction

In both years, soil testing philosophy x date interaction was significant for MIX putting green only (Table 23). In 2019, N-fertilized control had a significantly lower turfgrass quality than the MLSN and SLAN treatments on August 30 (Table 24). However, all treatments had no significant difference in turfgrass quality ratings on September 29 and October 24.

Table 24. Interaction of soil testing philosophies and date on quality of MIX in 2019 [a]

| Soil Testing Philosophies [b] | Quality [c] | | |
|---|---|---|---|
| | August 30 | September 29 | October 24 |
| MLSN | 6.2 a[d]A[e] | 6.5 aA | 6.5 aA |
| SLAN | 6.5 aA | 6.7 aA | 6.5 aA |
| Nitrogen fertilized control | 5.5 bB | 6.6 aA | 6.6 aA |

[a] MIX, 'Penncross' creeping bentgrass and annual bluegrass
[b] MLSN, Minimum Levels for Sustainable Nutrition; SLAN, Sufficiency Level of Available Nutrient
[c] Visually assessed on a 1 (poor) to 9 (best) rating scale.
[d] Lowercase letters represent significant differences within a column.
[e] Uppercase letters represent significant differences within a row.
[d, e] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

In 2020, no statistical difference was found between the MLSN and SLAN treatments while N-fertilized control had the lowest turfgrass quality (Table 25). SLAN and MLSN treatments provided better turfgrass quality than N-fertilized control after two years of treatment application.

Table 25. Interaction of soil testing philosophies and date on quality of MIX in 2020 [a]

| Soil Testing Philosophies [b] | Quality [c] | | | | |
|---|---|---|---|---|---|
| | June 19 | July 17 | August 14 | September 16 | October 14 |
| MLSN | 6.7 a[d]AB[e] | 6.8 aA | 6.5 aAB | 6.3 aB | 6.5 abAB |
| SLAN | 6.8 aA | 6.7 abAB | 6.5 aAB | 6.3 aB | 6.7 aAB |
| Nitrogen fertilized control | 5.7 bC | 6.3 bB | 6.8 aA | 5.5 bC | 6.2 bB |

[a] MIX, 'Penncross' creeping bentgrass and annual bluegrass
[b] MLSN, Minimum Levels for Sustainable Nutrition; SLAN, Sufficiency Level of Available Nutrient
[c] Visually assessed on a 1 (poor) to 9 (best) rating scale.
[d] Lowercase letters represent significant differences within a column.
[e] Uppercase letters represent significant differences within a row.
[d, e] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

Traffic and date interaction

Traffic x date interaction was significant in 2019 (A4 putting green only) and in 2020 (both putting greens) (Table 23). Generally, non-trafficked plots had a higher turfgrass quality compared to trafficked plots (Table 26, 27 and 28).

Table 26. Interaction of traffic and date on turfgrass quality of A4 in 2019 [a]

| Traffic | Quality [b] | | |
|---|---|---|---|
| | August 30 | September 29 | October 24 |
| Trafficked | 6.0 b[c]B[d] | 7.0 bA | 7.0 aA |
| Non-trafficked | 8.0 aA | 8.0 aA | 7.6 aB |

[a] A4, 'Penn A-4' creeping bentgrass
[b] Visually assessed on a 1 (poor) to 9 (best) rating scale.
[c] Lowercase letters represent significant differences within a column.
[d] Uppercase letters represent significant differences within a row.
[c, d] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

Table 27. Interaction of traffic and date on turfgrass quality of A4 in 2020 [a]

| | Quality [b] | | | | |
|---|---|---|---|---|---|
| Effect | June 19 | July 17 | August 14 | September 16 | October 14 |
| Trafficked | 7.1 b[c]A[d] | 7.2 aA | 7.2 bA | 6.0 bB | 7.0 bA |
| Non-trafficked | 7.7 aAB | 7.4 aB | 7.9 aAB | 7.7 aAB | 8.0 aA |

[a] A4, 'Penn A-4' creeping bentgrass
[b] Visually assessed on a 1 (poor) to 9 (best) rating scale.
[c] Lowercase letters represent significant differences within a column.
[d] Uppercase letters represent significant differences within a row.
[c, d] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

Table 28. Interaction effect of traffic and date on turfgrass quality of MIX in 2020 [a]

| Traffic | Quality [b] | | | | |
|---|---|---|---|---|---|
| | June 19 | July 17 | August 14 | September 16 | October 14 |
| Trafficked | 6.3 a[c]AB[d] | 6.7 aA | 6.1 bB | 5.7 bC | 6.1 bB |
| Non-trafficked | 6.4 aB | 6.6 aAB | 7.1 aA | 6.4 aB | 6.8 aB |

[a] MIX, 'Penncross' creeping bentgrass and annual bluegrass
[b] Visually assessed on a 1 (poor) to 9 (best) rating scale.
[c] Lowercase letters represent significant differences within a column.
[d] Uppercase letters represent significant differences within a row.
[c, d] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

Traffic main effect

Traffic main effect was significant in 2019 for MIX putting green only (Table 23). The non-trafficked treatment had a higher turfgrass quality than the trafficked treatment (Table 26). Creeping bentgrass has a fair wear tolerance (Harivandi, 2002; Turgeon & Kaminski, 2019). Due to the continuous wear and abrasion, the simulated traffic application decreased the uniformity of the trafficked plots compared to non-trafficked plots.

Table 29. Traffic main effect on turfgrass quality of MIX in 2019 [a]

| Traffic | Quality [b] |
|---|---|
| Trafficked | 5.9 b [c] |
| Non-trafficked | 6.9 a |

[a] MIX, 'Penncross' creeping bentgrass and annual bluegrass
[b] Visually assessed on a 1 (poor) to 9 (best) rating scale.
[c] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

## Soil Testing Philosophy and Traffic Interaction

One of the objectives of this study was to compare the effects of SLAN and MLSN nutrient recommendation under trafficked and non-trafficked conditions. Recommended K based on SLAN philosophy was higher than MLSN in 2019 (Table 5) and 2020 (Table 6). Since K fertilization improves wear tolerance of creeping bentgrass (Shearman & Beard, 1973), it was hypothesized that MLSN and SLAN treatments would be statistically different, in terms of turfgrass color and quality, particularly under trafficked conditions. However, soil testing philosophy x traffic interaction was not significant in turfgrass color and quality (Table 16 and Table 23). The absence of these interactions implied that the relatively high K applied on SLAN plots did not improve wear tolerance and had the same effect on turfgrass color and quality whether it was trafficked or not.

## CONCLUSIONS

In the first year, the SLAN treatment had the highest soil P and K values on both putting greens by the end of growing season. All treatments did not have any difference in NDVI, turfgrass color and turfgrass quality in 2019.

Recommendation for P based on MSU SPNL SLAN equation was effective in building up soil P levels resulting to a lower P recommendation for the following year. In 2020, P recommendations based SLAN philosophy was slightly lower than P recommendation based on MLSN philosophy. Despite this adjustment, the SLAN treatment remained the highest in soil P test results across all treatments in October 2020. It was concluded that P recommendation based on SLAN philosophy encourages P fixation and/or immobilization resulting to adequate soil P levels for the following year.

Recommendation for K based on MSU SPNL SLAN equation was excessive particularly on a USGA (85% sand: 15% peat) specification rootzone. Even though the K recommendation based on SLAN philosophy was three times higher than MLSN philosophy, both treatments had no significant difference in October 2020 for soil K values. Potassium is easily lost through leaching in sandy rootzones due to the nature of exchangeable K. Moreover, the absence of testing philosophy x traffic interaction implied that the relatively high K applied on SLAN plots did not improve wear tolerance and had the same effect on turfgrass color and quality whether it was trafficked or not. Thus, it is recommended that the SLAN equations for K should be refined so a lower K recommendation will be produced.

Both soil testing philosophies, SLAN and MLSN, can provide an acceptable turfgrass color and quality on creeping bentgrass and annual bluegrass grown on USGA putting greens in Michigan. In the second year of this study, the MLSN and SLAN treatments had better turfgrass quality ratings compared to N-fertilized control in MIX putting greens. Although, the MLSN philosophy could be more economical to use due to its relatively lower nutrient recommendation rates.

There might be potential changes in turfgrass color and quality due to the difference in soil test values that were not observed in this study. Future research could include plant tissue analysis and leachate analysis to accurately determine other factors of nutrient loss. Research should be continued to evaluate the long-term effects of SLAN and MLSN on creeping bentgrass and mix stand of annual bluegrass and creeping bentgrass putting greens

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## LITERATURE CITED

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