Understanding Turfgrass Nutrient Requirements[1]

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[1] A handout to supplement the presentation on this topic made at Osaka, Japan, on 5 June 2012

Turfgrass nutrient requirements are related to the growth rate of the grass. The amount of an element necessary to apply as fertilizer can be determined based on the amount of that element in the soil and on the growth potential of the grass for a specified time period. If there is more of an element in the soil than the grass requires, then none of that element needs to be added as fertilizer. This presentation describes the procedures involved in understanding plant nutrient requirements. Recognizing that grasses grow in soil, it begins with an explanation of soil pH and cation exchange capacity (CEC), discusses the minimum level of sustainable nutrition (MLSN) guidelines, and closes with an explanation of leaf nutrient levels and using the temperature-based growth potential model to schedule nitrogen applications.

Soil pH

We begin by recognizing that turfgrasses grow in soil. The soil pH is a measure of the hydrogen ion activity $\{H^+\}$ in soil solution and it is usually measured in a 1:1 mixture of soil and deionized water. Because pH has such an influence on so many chemical reactions in the soil, we can consider it to be a master variable, and it is useful to understand just what pH is, so that we can better understand turfgrass nutrient requirements.

Pure water, H_2O, consists of H_2O, some dissociated H^+, and some dissociated OH^-. The pH of pure water is 7, which means that the hydrogen ion activity is 0.0000001 moles/L, or 10^{-7}.[2] If the pH of a solution is 7, it is considered neutral, if the pH is less than 7, it is considered acidic, and if the pH is more than 7, it is considered basic (or alkaline).

[2] The pH is represented as the negative logarithm of the hydrogen ion activity in solution, so if the activity is 0.0001 or 10^{-4}, the pH is 4, if the activity is 0.00001 or 10^{-5}, the pH is 5, and so on.

Turfgrass plants can grow well when the soil pH[3] is in the range from 5.5 to 8.3. There are five things turfgrass managers should be aware of about soil pH.

[3] The soil pH as measured by taking the pH of a solution of 1 part deionized water and 1 part soil.

1. At a pH below 5.5, soluble aluminum in soil solution may increase, and that aluminum can be toxic to roots. Therefore, the soil pH should generally be maintained at or above 5.5.

2. At a pH of 8.4 or above, the alkalinity is high and is affected by more than calcium carbonate, and there is probably a sodium problem.

3. Soil microbial activity and thus the decomposition of organic matter is increased at higher pH. If the pH is below 5.5, another reason to increase the pH is to stimulate microbial activity.

4. Some turfgrass diseases are more active at moderate to alkaline pH and are suppressed at lower pH.[4]

[4] Diseases more damaging at higher pH include take-all patch (*Gaeumannomyces graminis* var. *avenae*) of creeping bentgrass and summer patch (*Magnaporthe poae*) of kentucky bluegrass.

5. Some micronutrients such as iron, manganese, copper, and zinc are less soluble and are considered less available in alkaline soils. However, turfgrass roots emit phytosiderophores that act as natural chelating agents to obtain micronutrients from the soil. Also, the roots adjust the pH of the rhizosphere to a range more suitable for micronutrient solubility.

In summary, turfgrass managers should know the soil pH and should take steps to adjust the soil pH to be within the range of 5.5 to 8.3, if it is outside of that range.

Cation Exchange Capacity

Cation exchange capacity (CEC) is a measure of the soil's ability to reversibly adsorb cations. It is, in short, a measure of the soil's net negative charge, and it is reported in units of millimoles of charge per kilogram of soil, or $mmol_c\ kg^{-1}$.[5]

[5] CEC has sometimes been reported in units of milliequivalents of charge per 100 grams of soil, or in centimoles of charge per kilogram of soil, but it is most sensible to use units of $mmol_c\ kg^{-1}$.

Mineral elements such as calcium, magnesium, and potassium are dissolved in soil solution, held on exchange sites, and taken up by the plant in their ionic forms: calcium as Ca^{2+}, magnesium as Mg^{2+}, and potassium as K^+. The CEC of the soil is important because it gives an indication of how much of these mineral elements can be held by the soil.

Even in sand rootzones with low CEC, such as those commonly used for golf course putting greens, there are relatively high amounts of nutrients held on the exchange sites. For example, a sand with a typical CEC of 30 $mmol_c\ kg^{-1}$, if it held 20 mmol of Ca^{2+}, 6 mmol of Mg^{2+}, and 4 mmol of K^+, would be holding a supply of those elements equal to 401 ppm[6] Ca, 73 ppm Mg, and 156 ppm K. As we will see in the next section, those are more than enough Ca, Mg, and K to meet the requirements of the grass.

[6] 1 ppm is one part per million, equivalent to 1 mg per kg.

Nutrients in the Soil

Grasses obtain the mineral elements they need from the soil. There are 14 essential mineral elements for plants (Table 1) and 3 essential nonmineral elements. The nonmineral elements, hydrogen, oxygen, and carbon, are taken up by plants as water or carbon dioxide gas.

Nonmineral	Mineral
Hydrogen	Nitrogen
Oxygen	Phosphorus
Carbon	Potassium
	Calcium
	Magnesium
	Sulfur
	Boron
	Chlorine
	Iron
	Manganese
	Zinc
	Copper
	Molybdenum
	Nickel

Table 1: The 17 essential elements for plants, divided into nonmineral and mineral

Soil nutrient analyses (soil tests) are conducted to determine how much of an element is available in the soil, and to determine if that element should be applied as fertilizer, and how much fertilizer should be applied. Let's consider the mineral elements as it relates to soil tests.

- Nitrogen is tested in the soil but the fertilizer recommendation is based off of predicted plant requirements. This is because the grass uses almost all of the nitrogen that is applied, assuming nitrogen is applied in reasonable amounts, and therefore the amount of nitrogen in the soil is not a good predictor of how much should be applied as fertilizer.

- The amount of available phosphorus is tested in the soil to develop a fertilizer recommendation.
- The amount of available potassium is tested in the soil to develop a fertilizer recommendation.
- Calcium and magnesium are almost always at sufficient levels in the soil when the pH is at 5.5 or higher. It is rare to require application of these elements, but they are measured in a soil test.
- The amount of available sulfur (measured as sulfate) in the soil is tested to develop a fertilizer recommendation.
- Boron, chlorine, zinc, copper, molybdenum, and nickel are sometimes tested for and sometimes not. These elements are required in such small amounts by grass and I am not aware of any deficiencies of these elements ever occurring.
- Iron is often tested for but the soil test is rarely used to develop a fertilizer recommendation.
- Manganese is often tested for and the calculated manganese availability index (MAI)[7] can be used to determine if manganese should be applied.

[7] The MAI is calculated based on Mehlich 3 extractant data as MAI = 101.7 - 15.2*(pH) + 3.75*(Mn-ppm)

As a general rule, the most important things to measure in the soil are pH, phosphorus, and potassium. If those are known, an effective fertilizer program can be developed. Modern laboratory techniques make it easy to measure a lot of additional elements simultaneously, but what is really important is pH, phosphorus, and potassium.

Interpreting a Soil Test Report

Dr. Larry Stowell from PACE Turf (`http://www.paceturf.org/`) and I have developed the minimum levels for sustainable nutrition (MLSN) guidelines for interpreting Mehlich 3 soil test results for turfgrass.[8] The MLSN guidelines are simple, and they are based on a rigorous review of soil tests from good-performing turfgrass sites. From a database of over 16,000 soil samples, we selected those that are classified as having good turf, that have a pH in the range of 5.5 to 7.5, and those with a low estimated cation exchange capacity of less than 60 $\text{mmol}_c\ \text{kg}^{-1}$. This selected about 1,500 samples, from which Dr. Stowell fit a log-logistic model to the observed soil test data. This allows us to define the soil nutrient concentration at which a certain amount of the soil tests are above or below a certain level.

[8] The Mehlich 3 extracting solution is a widely-used standard method for soil tests and the solution contains 0.2 *N* acetic acid, 0.25 *N* ammonium nitrate, 0.015 *N* ammonium flouride, 0.13 *N* nitric acid, and 0.001 *M* EDTA with a pH of 2.5.

Element	MLSN (ppm)
Potassium	35
Phosphorus	18
Calcium	360
Magnesium	54
Sulfur	13

Table 2: The minimum levels for sustainable nutrition (MLSN) guidelines as of 1 June 2012

For the MLSN guidelines (Table 2), we chose the 10% level to set the target guidelines, meaning that 10% of the samples in the database were below the guideline but were still performing well. The goal of the MLSN guidelines is to provide a scientific and data-based approach to interpreting soil tests for turfgrass sites, making sure that there is a high probability of good turfgrass performance, while minimizing unnecessary application of fertilizer.

The turfgrass rootzone is often at a depth of about 10cm. In that case, in a sand rootzone, 1m² to a depth of 10cm has a mass of 150 kg. One gram of any element applied to 1m² and distributed evenly throughout the top 10cm is expected to increase the amount of that element in the soil by 6.7 ppm. Likewise, the harvesting of that element will decrease the amount of that element in the soil by 6.7 ppm for each gram of element harvested in 1m².

Elemental Content of Turfgrass Leaves

In the dry matter of turfgrass leaves, after the leaf water has evaporated, we can expect the approximate concentrations of mineral elements to be as shown in Table 3.

Element	%
Nitrogen	4
Potassium	2
Phosphorus	0.5
Calcium	0.5
Magnesium	0.2
Sulfur	0.1
Iron	0.01
Manganese	0.005

Table 3: The normal levels of mineral elements in the dry matter of creeping bentgrass leaves

Based on the amount of mineral elements in the leaves, and the estimated amount of clippings harvested and removed per year, we can estimate the amount of elements removed from the soil each year (Table 4). We can also convert the MLSN guideline, normally shown in ppm, to a mass of element in units of g m^{-2} (Table 4). This information tells us how much of an element is in the soil and how much we harvest each year through clipping removal.

You will notice in Table 4 that for N, Fe, and Mn, the MLSN levels are not given. This is because we will base the application of N on growth potential (described in the next section), and for Fe we will apply for color, as necessary, and for Mn we will use the MAI to determine application requirement. For other micronutrients, those shown in Table 1 but not included in Table 4, the probability of a deficiency is practically zero so we do not concern ourselves with them in the making of fertilizer recommendations.[9]

[9] The amount of those micronutrients required by the grass is minuscule, and they are usually present in trace amounts in some fertilizers, in irrigation water, and in the soil. If we supply the major nutrients in the proper amounts, the grass will develop a root system that is able to obtain the necessary micronutrients without supplemental application.

Now that we have all this information, it is simple to determine how much of an element we need to apply as fertilizer. We know that at the MLSN level (Table 2), there is enough of that element in the soil to produce excellent turfgrass conditions. So we want to make sure the soil has the nutrient at or above the MLSN level. We can estimate the amount of an element that will be harvested from the soil each year (Table 4). The amount A in equation 1 gives us the total amount of an element needed in the soil to keep the soil above the MLSN guideline.

$$A = MLSN\,(g\,m^{-2}) + Harvest\,(g\,m^{-2}) \tag{1}$$

To find how much of an element needs to be applied as fertilizer (F), we then subtract the actual amount on a soil test, which we can denote as $Soil_{test}$ and express in units of g m^{-2}.

$$F\ (g\ m^{-2}) = A - Soil_{test} \qquad (2)$$

In Table 4, the estimated annual harvest of each element is shown, along with the amount of that element in the soil at the MLSN target level that was shown in Table 2.

Element	in leaves %	in leaves ppm	Estimated harvest g m^{-2} yr^{-1}	MLSN ppm	MLSN g m^{-2}
N	4	40,000	16	NA	NA
K	2	20,000	8	35	5.2
P	0.5	5,000	2	18	2.7
Ca	0.5	5,000	2	360	53.7
Mg	0.2	2,000	0.8	54	8.1
S	0.1	1,000	0.4	13	1.9
Fe	0.01	100	0.04	NA	NA
Mn	0.005	50	0.02	NA	NA

Table 4: Normal amounts of elements in turfgrass leaves, estimated amount harvested per year assuming clipping production of 400 g m^{-2}, and amount of each element in the soil at the MLSN level

Using potassium as an example, let's work through Equations 1 and 2 to determine the fertilizer recommendation, or F. We can imagine that we have tested a putting green soil and found it to contain 55 ppm potassium. For potassium, A (the amount we need to keep above MLSN guidelines) is 5.2 + 8 = 13.2 g m^{-2}. The soil test of 55 ppm is converted to g m^{-2} by dividing by 6.7 (assuming a 10 cm deep rootzone) to give a $Soil_{test}$ level of 8.2 g m^{-2}. Equation 3 gives the amount of potassium required as fertilizer.

$$F = 13.2 - 8.2 = 5g\ m^{-2} \qquad (3)$$

Note that if F is a negative number (less than zero), none of that element needs to be applied, for there is already more than enough in the soil to meet the plant requirements. We will reevaluate the fertilizer requirement for that element at the next time of soil testing.

Growth Potential as a Tool to Predict Nitrogen Requirements

THE GROWTH POTENTIAL (Equations 4 and 5) was developed by PACE Turf [10] to describe the relationship between turfgrass growth and temperature. Cool season (C_3) grasses have their greatest growth rate when the temperature is about 20°C, with slower growth at lower or higher temperatures; warm-season grasses (C_4) have their greatest growth rate when the temperature is about 31°C, with slower growth at cooler temperatures. The growth potential equations provide a simple way to predict that growth.

[10] Wendy Gelernter and Larry Stowell. Improved overseeding programs 1. the role of weather. *Golf Course Management*, pages 108–113, March 2005

$$GP = e^{-0.5(\frac{t-t_o}{var})^2} \qquad (4)$$

GP = growth potential, on a scale of 0 to 1
e = 2.71828, a mathematical constant
t = actual temperature
t_o = optimum temperature, 20 for C_3 grass, 31 for C_4 grass
var = adjusts the change in GP as temperature moves away from t_o; I use 5.5 for C_3 and 8.5 for C_4

This equation gives the same result.

$$GP = \frac{1}{e^{0.5(\frac{t-t_o}{var})^2}} \tag{5}$$

We can make use of the growth potential by relating the nitrogen requirement of the grass to the growth potential. Empirical observations of turfgrass growth rates and nitrogen amounts to create the desired playing conditions for golf course turf in 2012 give us a maximum monthly nitrogen use rate[11] of about 3.5 g N m^{-2} for creeping bentgrass, 4 g N m^{-2} for korai, and 5 g N m^{-2} for bermudagrass. We can then simply calculate the estimated nitrogen requirement for a given amount of time by multiplying the growth potential times the maximum nitrogen rate.

[11] These estimates are general and only serve as a starting point. Every golf course will have a slightly different maximum level, based on the desired growth rate of the grass. We can make the grass grow faster with more nitrogen, and slower with less nitrogen, and these values are based on standard conditions.

Table 5 shows the calculated growth potential and then the estimated monthly nitrogen requirement for Osaka; Table 6 shows the same data for Tokyo.

Month	Temperature °C	C_4 GP	C_3 GP	Bentgrass	Korai g N m^{-2}	Bermuda
January	5.5	0.01	0.03	0.1	0.0	0.1
February	5.8	0.01	0.04	0.1	0.0	0.1
March	8.6	0.03	0.12	0.4	0.1	0.2
April	14.6	0.16	0.62	2.2	0.6	0.8
May	19.2	0.38	0.99	3.5	1.5	1.9
June	23.0	0.64	0.86	3.0	2.6	3.2
July	27.0	0.90	0.44	1.6	3.6	4.5
August	28.2	0.95	0.33	1.2	3.8	4.7
September	24.2	0.73	0.75	2.6	2.9	3.6
October	18.3	0.33	0.95	3.3	1.3	1.6
November	12.9	0.10	0.43	1.5	0.4	0.5
December	7.9	0.02	0.09	0.3	0.1	0.1

Table 5: Average monthly temperatures at Osaka with calculated growth potential and estimated monthly nitrogen requirements

The growth potential can be calculated on a daily, weekly, or monthly basis, with a corresponding nitrogen requirement, to estimate how much nitrogen fertilizer may be required by the grass during that time period. Note that these estimates are of how much nitrogen the grass will use, so fertilizer nitrogen applications should be made in advance to supply the desired amount of nitrogen during the given time period.

Month	Temperature °C	C_4 GP	C_3 GP	Bentgrass	Korai g N m^{-2}	Bermuda
January	5.2	0.01	0.03	0.1	0.0	0.0
February	5.6	0.01	0.03	0.1	0.0	0.1
March	8.5	0.03	0.11	0.4	0.1	0.2
April	14.1	0.14	0.56	2.0	0.6	0.7
May	18.6	0.35	0.97	3.4	1.4	1.7
June	21.7	0.55	0.95	3.3	2.2	2.7
July	25.2	0.79	0.64	2.2	3.2	4.0
August	27.1	0.90	0.43	1.5	3.6	4.5
September	23.2	0.66	0.84	3.0	2.6	3.3
October	17.6	0.29	0.91	3.2	1.2	1.4
November	2.6	0.10	0.40	1.4	0.4	0.5
December	7.9	0.02	0.09	0.3	0.1	0.1

Table 6: Average monthly temperatures at Tokyo with calculated growth potential and estimated monthly nitrogen requirements

Light and Growth Potential

It is not 100% accurate to consider only temperature when calculating growth potential, because the amount of light available also has an influence on turfgrass growth. The growth potential as calculated by equation 4 works well for C_3 grasses because of the relatively low light requirements of C_3 grasses – these grasses can only use about half of the available sunlight in photosynthesis. Therefore, I do not think it is necessary to adjust the growth potential calculations for C_3 grasses.

For C_4 grasses which can use all of the available sunlight for photosynthesis, shade causes a greater relative reduction in growth than it does for C_3 grasses. Therefore, the growth potential should probably be reduced somewhat for C_4 grasses during times of cloudy weather. Data on temperature, precipitation, and sunshine hours for major Japanese cities have been plotted at `http://climate.asianturfgrass.com/node/8`. As a general suggestion, I would reduce the growth potential by 20% for C_4 grasses when there are less than 200 monthly sunshine hours, and I would keep the full growth potential when there are more than 200 monthly sunshine hours.

References

Wendy Gelernter and Larry Stowell. Improved overseeding programs 1. the role of weather. *Golf Course Management*, pages 108–113, March 2005.