Using temperature to predict turfgrass growth potential (GP) and to estimate turfgrass nitrogen use

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ABSTRACT

Based on the optimum temperatures for turfgrass growth, generally considered to be in the range of 16 to 24°C for cool-season grasses and 27 to 35°C for warm-season grasses, it is possible to model the potential for the grass to grow at any temperature. This is the turfgrass growth potential (GP), a value ranging from 0, meaning no growth is possible, to 1, meaning the temperature is at an optimum for that grass to grow. The GP is useful in turfgrass management planning. This document describes how to calculate GP and introduces one practical application of this model: estimating turfgrass nitrogen requirements.

Figure 1: For both cool-season and warm-season grasses, the growth potential can be used to predict how temperature will influence the growth of any grass, anywhere in the world: a) December, Barcelona; b) June, Sydney; c) September, Tokyo; d) February, Bangkok.

Grasses that utilize the C_3 photosynthetic pathway are termed cool-season grasses and can grow most rapidly at a temperature of 16 to 24°C. Grasses that use the C_4 photosynthetic pathway are able to photosynthesize efficiently at high temperatures. These are termed warm-season grasses and are expected to grow most rapidly at a temperature range of at least 27 to 35°C.

In addition to temperature, the leaf nitrogen status, plant water status, and the quantity of photosynthetically active radiation (PAR) all influence turfgrass growth. These four factors – temperature, nitrogen, water, and light – essentially control how the turf will grow. Turfgrass managers can easily modify the nitrogen and the water, but can do very little about the temperature or light.

By estimating the growth potential (GP), the influence of temperature on turfgrass growth at any given time can be predicted. Knowing and anticipating the effect of something that cannot be controlled allows turfgrass managers to refine the turfgrass practices that can be adjusted.

What is growth potential?

Turfgrass managers know that grasses change their growth rate as the temperatures change throughout the year, or as different grasses are grown in different climates (Figure 1). At its most simple, the GP can be understood as a way to put a numerical value on the ability of the grass to grow at a certain temperature.

The GP (Equations 1 and 2) was developed by PACE Turf (Gelernter and Stowell, 2005) to describe the relationship between turfgrass growth and temperature. The equation to calculate GP compares the actual temperature to the optimum temperature for growth, and then returns a value between 0 and 1. Low values of GP predict slow growth or if the value is close to 0, dormant turf. At a value of 0.5, the GP predicts that temperatures are such that the grass can grow at 50% of its maximum rate, and when the GP is 1, grass has the potential to grow at its maximum rate.

Because turfgrass management, at its core, is really about controlling the growth rate of the grass, it can be useful to assign a numerical value to the effect of temperature on growth. This index is GP.

Calculating the growth potential

We start by identifying the center of the optimum temperature range. For cool season (C_3) grasses, which have an optimum range of 16 to 24°C, this is 20°C. For warm-season (C_4) grasses, with the optimum range of 27 to 35°C, this is 31°C[1]. As the

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[1]Although growth of C_3 grass declines as temperatures increase beyond the optimum range, for C_4 grasses there is not

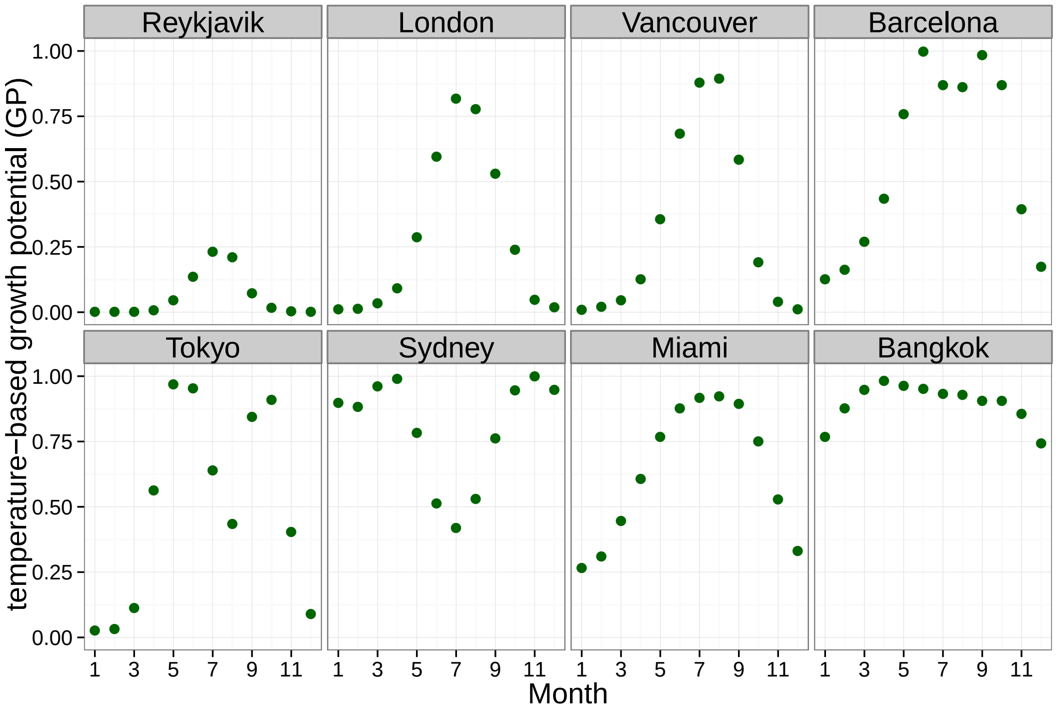

Figure 2: Growth potential of eight cities calculated using Equation 1; for Miami and Bangkok the warm-season GP is shown; all other cities are shown with cool-season GP.

temperature moves away from the optimum, the potential of the grass to grow at its maximum rate is decreased. The GP provides a simple way to predict that growth.[2] Equation 1 gives the standard form of the growth potential equation:

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

where,

GP = growth potential, on a scale of 0 to 1

e = 2.71828, a mathematical constant

t = average temperature for a location, in °C

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 suggest 5.5 for C_3 and 7[3] for C_4

such a decline because photorespiration does not occur. The actual growth of C_4 grasses seems to remain constant or actually increase as temperature rise above the optimum range. For practical purposes of using the GP, this does not matter because the average temperature, even in the hottest locations at which turfgrass is grown, remain within the optimum range.

[2] A more complex growth model would require information that is not readily available, namely the maximum potential growth rate of a specific grass variety combined with, at a minimum, knowledge of the effect of temperature, plant water status, leaf nitrogen content, and photosynthetic irradiance on the growth of the grass. The temperature-based growth potential is a simplification but it is easy to use and effective as a planning and management tool.

[3] For the equations using the Fahrenheit temperature scale, see Gelernter & Stowell (2005). I sometimes use a variance of 8.5 for C_4 grasses; a variance of 7 for C_4 grasses matches almost exactly the original equation of Gelernter & Stowell. Variance of 8.5 predicts slightly more growth away from the optimum temperature than does the original equation.

The equation written in this form (Equation 2) gives the same result:

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

The GP can be easily calculated using a spreadsheet formatted for your own requirements. PACE Turf have also prepared a spreadsheet for calculating the monthly GP. This can be downloaded at http://www.paceturf.org/index.php/public/ipm_planning_tools as the *Climate Appraisal Form* which is conveniently available in both metric and Fahrenheit temperature scales. These spreadsheets have also been formatted to calculate an estimate of monthly nitrogen requirements.

Figure 2 shows the GP for eight world cities, on a monthly basis, and those same data are shown in Table 1. The average temperatures used in Equation 1 to calculate monthly GP for these cities are from the World Meteorological Organization climatological normals data, available at http://www.wmo.int/datastat/wmodata_en.html.

Estimating nitrogen requirements

One of the most useful applications of the GP is in estimating how much nitrogen the grass may use. Because the GP is a value between 0 and 1, we can

Month	Reykjavik	London	Vancouver	Barcelona	Tokyo	Sydney	Miami	Bangkok
1	0.00	0.01	0.01	0.13	0.03	0.90	0.27	0.77
2	0.00	0.01	0.02	0.16	0.03	0.88	0.31	0.88
3	0.00	0.03	0.04	0.27	0.11	0.96	0.45	0.95
4	0.01	0.09	0.13	0.43	0.56	0.99	0.61	0.98
5	0.04	0.29	0.36	0.76	0.97	0.78	0.77	0.96
6	0.14	0.60	0.68	1.00	0.95	0.51	0.88	0.95
7	0.23	0.82	0.88	0.87	0.64	0.42	0.92	0.93
8	0.21	0.78	0.89	0.86	0.43	0.53	0.92	0.93
9	0.07	0.53	0.58	0.98	0.84	0.76	0.89	0.91
10	0.02	0.24	0.19	0.87	0.91	0.95	0.75	0.91
11	0.00	0.05	0.04	0.39	0.40	1.00	0.53	0.86
12	0.00	0.02	0.01	0.17	0.09	0.95	0.33	0.74

Table 1: Calculated GP for C_4 grasses at Miami and Bangkok and for C_3 grasses at other cities, by month, using Equation 1.

simply choose the maximum amount of nitrogen that we would want to apply in a day, week, or month, and then multiply that by the GP to give the predicted amount of nitrogen the grass will use during that time. If we set a maximum amount of nitrogen that the grass may use at one time, then as the GP decreases, so also will the predicted nitrogen use decrease.

The GP is based on the optimum temperatures for photosynthesis of C_3 and C_4 grasses. In order to produce maximum carbohydrates and roots, it makes sense to ensure the grass is supplied with nitrogen in adequate amounts corresponding to the ability of the grass to photosynthesize. When the grass is not able to grow because temperatures are too cool, there is little reason to supply nitrogen. Using the GP to predict how much nitrogen the grass may use throughout the year as the temperature changes offers turfgrass managers another tool to optimize the plant's carbohydrate production.

Estimated nitrogen use of the grass, based on maximum monthly use of 3.5 g N m^{-2} for C_3 species and 4 g N m^{-2} for C_4 species, is given in Table 2. These data are the result of multiplying the monthly GP by the selected maximum monthly N rate.[4]

The maximum nitrogen rate is something that is very site-specific. As an example, If I were growing fine fescue (*Festuca* spp.), I may set the maximum nitrogen at about 1.5 g N m^{-2} mo^{-1}. I would never use 3.5 g N m^{-2} for that grass. Not only can one change the maximum nitrogen amount based on grass species, but one must adjust the maximum nitrogen rate based on what type of turfgrass conditions one is trying to produce. I find it most useful to slightly underestimate how much N the grass may use. Remember, we can always put more fertilizer, but if we have put too much, we can't take it back.

[4]A simple conversion factor for fertilizers is to remember that 5 g N m^{-2} is equivalent to 1 lb N/1000 ft^2; 1 g N m^{-2} is equivalent to 0.2 lb N/1000 ft^2.

At Sydney, I might set the maximum at 2 g N m^{-2} mo^{-1}, which gives an annual estimated N use of 19.2 g N m^{-2}. Then, if I were using a growth regulator such as trinexapac-ethyl, I would reduce the N rate a further 20% or so. But I could still use the GP and these simple calculations to estimate when the grass would use the most N.

At Reykjavik, recognizing that there is a large amount of traffic on the turf during the long summer days, and seeing that the temperatures are so cool that the grass is not easily able to grow quickly to recover from that traffic, I may set the maximum at 5 g N m^{-2} mo^{-1}.

Applications, modifications, and extensions

Use of GP is not something that is fixed or must be done in a certain way. The GP is not how the grass grows – GP is not reality. What it is, however, is a simple method that can be used to estimate the reality of how grass grows, and can then be put to use to assist in turfgrass management.

As an example, one may choose to set an optimum temperature (t_o in Equation 1) of 18°C for *Poa annua* rather than the standard 20°C for C_3 grasses. And if I were working with GP for kikuyugrass (*Pennisetum clandestinum*), I would use an optimum temperature of about 25°C, rather than the standard of 31°C used for other warm-season grasses. The idea is to use GP to represent the reality of how turf growth is influenced by temperature. GP is simply an index of how the turf may grow, and the turf manager can put this index to use in a number of ways.

One can make long-term plans by looking at average monthly, weekly, or daily temperatures, calculating the relevant GP, and planning based on those normal temperatures. One can also make short-term plans by looking at forecast temperatures for the next day or week, calculating an ac-

Month	Reykjavik	London	Vancouver	Barcelona	Tokyo	Sydney	Miami	Bangkok
1	0.0	0.0	0.0	0.4	0.1	3.1	1.1	3.1
2	0.0	0.0	0.1	0.6	0.1	3.1	1.2	3.5
3	0.0	0.1	0.2	0.9	0.4	3.4	1.8	3.8
4	0.0	0.3	0.4	1.5	2.0	3.5	2.4	3.9
5	0.2	1.0	1.2	2.7	3.4	2.7	3.1	3.9
6	0.5	2.1	2.4	3.5	3.3	1.8	3.5	3.8
7	0.8	2.9	3.1	3.0	2.2	1.5	3.7	3.7
8	0.7	2.7	3.1	3.0	1.5	1.9	3.7	3.7
9	0.3	1.9	2.0	3.4	3.0	2.7	3.6	3.6
10	0.1	0.8	0.7	3.0	3.2	3.3	3.0	3.6
11	0.0	0.2	0.1	1.4	1.4	3.5	2.1	3.4
12	0.0	0.1	0.0	0.6	0.3	3.3	1.3	3.0
Annual	2.6	12.1	13.4	24.2	20.9	33.7	30.5	43.1

Table 2: Example of monthly and annual estimated nitrogen requirement of grasses, in units of g N m^{-2}, based on a maximum monthly application of 4 g N m^{-2} at Miami and Bangkok and 3.5 g N m^{-2} at the other locations.

tual GP based on the current situation rather than on the average.

For C_3 grasses, high-temperature stress can be a concern. Based on the adjustments one makes to Equation 1, one can get an index of just how much stress the grass may be under during the hottest months of the summer.

I think it is interesting to look at GP before scheduling core aerification and other disruptive maintenance practices. I always like to minimize disruption to the playing surface, and if these maintenance activities can be scheduled at a time with a high GP, the recovery time will be fast, and disruption time minimized.

Nitrogen is not the only element that can be managed based on GP. For many turfgrass sites the amount of nitrogen applied controls the uptake of other macronutrients (Petrovic et al., 2005; Kussow and Houlihan, 2006), and therefore the GP approach could easily be adapted for those elements as well.[5]

More information

I have written extensively about GP and its application in turfgrass management. These documents provide more information and examples.

1. Understanding turfgrass nutrient requirements, http://calendar.asianturfgrass.com/understanding_turfgrass_nutrient_requirements_5june2012.pdf
2. Nutrient requirements of tropical turfgrass, http://www.files.asianturfgrass.com/20130311_woods_handout_nutrient_requirements_tropical_turfgrass.pdf
3. Turfgrass nitrogen requirement and growth potential, http://bit.ly/NGD58X
4. En español, Predecir los requerimientos nutricionales y el crecimiento del césped, http://files.asianturfgrass.com/gp_aedg_abril_2013.pdf
5. 日本語で，芝草の栄養要求を理解する，http://calendar.asianturfgrass.com/understanding_turfgrass_nutrient_requirements_5june2012_jp.pdf

These documents also provide additional explanations of GP and its practical use.

- This article from *GCM* explaining GP: http://www2.gcsaa.org/GCM/2005/march05/pdfs/Weatherrole108-113.pdf
- Blog post from Jason Haines explaining how he uses GP to optimize turfgrass performance at Pender Harbour Golf Club: http://penderharbourgolf.blogspot.ca/2012/09/how-much-nitrogen.html

[5] This approach is implemented in the minimum levels for sustainable nutrition (MLSN) guidelines. For more information see http://www.paceturf.org/index.php/journal/minimum_level_for_sustainable_nutrition.

References

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

Wayne Kussow and Steven Houlihan. The new soil test interpretations for Wisconsin golf turf. *The Grass Roots*, pages 19–25, May-June 2006.

A.M. Petrovic, D. Soldat, J. Gruttadaurio, and J. Barlow. Turfgrass growth and quality related to soil and tissue nutrient content. *International Turfgrass Society Research Journal*, 10:989–997, 2005.