Turfgrass nutrient guidelines, peer review, and potassium

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I've long considered conventional soil guidelines to be *broken*. By that, I mean the guidelines[1] are either substantially different from the amount required to produce good turf or are impossible to reach.[2] It just doesn't make sense to apply nutrients in an attempt to chase target levels in the soil, when those nutrient applications don't have an effect on turfgrass performance.

Soil testing can be a bit of a numbers game. But it doesn't have to be that way. There is a large amount of published research showing turf response to various nutrient levels in the soil. It is also possible to estimate how much of each element the grass may use, as a function of nitrogen use and growth. I worked with Larry Stowell and Wendy Gelernter from PACE Turf[3] to develop a new set of guidelines – guidelines that were simple, based on research,[4] environmentally responsible, and that accounted for the amount of nutrients used by the grass.

When the minimum levels for sustainable nutrition (mlsn) guidelines[5] were announced in 2012, I expected there to be more objection to them. I was looking forward to some detailed discussions about turfgrass soil testing and soil nutrient guidelines. The discussion at that time never materialized, at least not publicly.

This year, however, some pointed questions and concerns about these guidelines have reached me, with thoughts that the nutrient guidelines may be too low, or that managing turf using these guidelines may have negative long term ramifications.[6] These are important questions, and this is a good discussion to have.

Last week, a turfgrass scientist wrote to me with some specific concerns about the guidelines and the methodology used to move forward with the mlsn guidelines. I welcome this chance to provide more explanation of the reasoning behind the guidelines, and to elaborate a bit on turf nutrient guidelines in general, and potassium (K) specifically.

Radical changes and the scientific method

The first concern is on how we have developed and introduced the mlsn guidelines.

> I think we need to be very careful that radical changes in soil test recommendations, such as you are proposing, are backed by the scientific method. You have a hypothesis and you have collected data to support that hypothesis. However, you have not vetted those methods, results, or interpretation of the results through the peer-review process.

[1] There is not just one set of "conventional" guidelines. An example of the conventional approach is these of guideline ranges given by Carrow et al. in their 2003 paper: http://ticpass.lib.msu.edu/cgi-bin/flink.pl?recno=93213.

[2] The Penn State guideline for potassium on putting greens is an outstanding example (http://bit.ly/psu_green); the cation exchange capacity (CEC) of most putting green rootzones are too low to ever reach the "optimum" level, no matter how much K one would apply.

[3] http://www.paceturf.org

[4] Much of which suggests older guidelines were higher than necessary for some nutrients.

[5] Micah Woods, Larry Stowell, and Wendy Gelernter. Just what the grass requires: using minimum levels for sustainable nutrition. *Golf Course Management*, pages 132–138, January 2014. URL http://bit.ly/gcm_mlsn

[6] For more on this topic, see http://bit.ly/K_supply

Soil nutrient guidelines and the resultant fertilizer recommendations are not usually peer-reviewed. A comprehensive article on this topic by Carrow et al.[7] is in *GCM*. At the state level I have seen many extension bulletins or fact sheets with soil test interpretation guidelines. Guidelines for turfgrass, as best as I can tell, are usually put together by reviewing some peer-reviewed research and by looking at the normal range of soil nutrients in soils from a particular region.

[7] R.N. Carrow, L. Stowell, W. Gelernter, S. Davis, R.R. Duncan, and J. Skorulski. Clarifying soil testing: III. SLAN sufficiency ranges and recommendations. *Golf Course Management*, 72(1): 194–198, January 2004

Guidelines will be based to some degree on the results of multiple research projects that have been peer-reviewed, but the guidelines themselves will not be peer-reviewed. In that sense, the MLSN guidelines are the same as any other guidelines, with a large improvement. That is, we have reviewed existing guideline levels, we have made extensive studies of peer-reviewed research to ensure the MLSN guidelines are reasonable, and we have supplemented this with data from the soils at hundreds of good-performing turfgrass sites to ensure that high quality turfgrass can indeed be grown on soils with nutrient levels at or above the MLSN guidelines.

Although the MLSN guidelines might seem like "radical changes," I would consider them an update and significant improvement on conventional guidelines that themselves were not peer-reviewed. Doug Soldat, a soil scientist from the University of Wisconsin, consider the MLSN guidelines as "likely more accurate"[8] than traditional soil test interpretation.

[8] Douglas J. Soldat. How reliable is soil testing? *The Grass Roots*, pages 8–11, May-June 2013

On introduction of new ideas

> In order to get the scientific community to back your work and ideas, the expectation is that you publish the work in a journal such as *Crop Science* or *Soil Science* so that your methods, analysis, and interpretation are adequately critiqued to judge their validity. This will undoubtedly lead to further testing by others to confirm your results. Once it has gone through this process, then most scientists will embrace the results and apply them.

I agree with this in general, but as mentioned in the previous section, soil nutrient guidelines are not typically peer-reviewed. We do want these guidelines to be critiqued, scrutinized, and tested; to that end, we have communicated both formally and informally at conferences and in various media about the MLSN guidelines and the methods used for development.

The guidelines and the methods used to develop them were presented in 2012 as "Minimum Levels for Sustainable Nutrition (MLSN)" at The Bouyoucos Conference on the Advances in Research on Soil Biological, Chemical and Physical Properties for Sustainable Constructed Rootzones.[9] At the 2012 Crop Science Society of America conference, we presented "Development of minimum levels for sustainable nutrition soil guidelines using data mining and distribution fitting software."[10] We wrote "Just what the grass requires:

[9] The conference proceedings can be downloaded at this link: `http://bit.ly/pace_bouyoucos`.

[10] This is the abstract: `http://ticpass.lib.msu.edu/cgi-bin/flink.pl?recno=213256`

using minimum levels for sustainable nutrition"[11] for *GCM* this year to further explain how to use the MLSN guidelines. The MLSN project Global Soil Survey[12] started last year, with samples being submitted from good-performing turf areas in multiple countries, to test, validate, and refine the MLSN guidelines. This project will be discussed in a presentation at the 2014 CSSA annual meeting.

[11] The article can be read at this link: http://bit.ly/gcm_mlsn

[12] http://www.paceturf.org/journal/global_soil_survey

I agree with my correspondent that for the MLSN guidelines to be widely-adopted[13] by scientists, publication in peer-reviewed journals will be required. And that is our intention. Not because it is a requirement of soil testing guidelines, but because we want to communicate in the standard scientific way.

[13] I would like to see this method of soil test interpretation and calculation of nutrient requirements taught in turfgrass classes, and for that to happen, some peer-reviewed articles are going to be necessary.

As an aside, just because something is published in a peer-reviewed journal does not mean it is correct. For an interesting discussion about this, see Andrew Gelman's blog, where he discussed "a larger problem with the scientific communication system, the idea that once something is published in a journal, it is presumed to be true and it takes a lot of work to dislodge even gross errors."[14]

[14] This quote is at http://bit.ly/gelman_tols; for more, about disagreement with authors that "appear to have the attitude, so natural among those of us who do science for a living, that *peer-reviewed publication* is a plateau or resting place: the idea is that acceptance in a journal – especially a highly selective journal such as PNAS – is difficult and is a major accomplishment, and that should be enough," see http://bit.ly/gelman_hurricanes

While I acknowledge that writing about the MLSN guidelines in peer-reviewed publications is the way to get the idea accepted and adopted by scientists, the publication of something in a peer-reviewed journal is not a confirmation that something is right or wrong. The scientific method involves making hypothoses, testing them, trying to prove them wrong, and trying to find a better explanation for a phenomenon. Publishing in peer-reviewed journals is the standard form of communication of scientific results and among scientists, but it is not, in and of itself, the scientific method.

What, really, is the effect of potassium?

AFTER THOSE INTRODUCTORY REMARKS, which are more on the philosophy of this type of work, we turn to the specific topic of K and the amount required.

> I have no idea if the MLSN guidelines you are proposing for K or any other element are too low. I have never studied potassium fertilization during my career, so do not claim to be an expert and do not want to debate you about the topic since I do consider you an expert on K. My questions . . . were just cursory evaluations of your publications and what little I know about potassium fertilization, so they were admittedly simplistic. I did do a quick literature search and found numerous publications (see attached) where high tissue K had a positive effect on stress tolerance in turfgrass and I did not even get into the literature on other crops. So, there is data out there suggesting that higher K levels can impact performance above and beyond turfgrass quality or crop yield.

Before considering the publications that describe experiments in which more K had a positive effect on stress tolerance, I need to make an important distinction. Grass grows in soil and obtains most of its nutrients from the soil. The amount of K available to the grass, or with alternative wording, supplied to the grass, is the amount in the soil combined with the amount added as fertilizer.[15] So when we consider the results of experiments that investigate the effect of K application, one must consider not only the fertilizer supply, but also the supply from the soil.

[15] I've written about this for the case of K and rooting (`http://bit.ly/k_roots`). Although a number of papers were cited showing that K increases root development and branching, when one reads the papers, it is apparent that an elimination of a K deficiency provides the benefit.

Figure 1: These are plants of Penn A-1 creeping bentgrass grown from seed in a greenhouse at Cornell University during my graduate school research. The amount of K in the soil is highest at left, and lowest at right. No K was applied as fertilizer.

Figure 1 shows what a profound difference there can be in grass performance with different levels of soil K. The dead grass at right, if it had been supplied with K, would have given a great response. The grass at left, which was not supplied with any K fertilizer, but which had an ample supply of K from the soil, would not have much response to K fertilizer, if any, because the grass already has enough K.

As seen in Figure 1, a K deficiency has disastrous effects. The MLSN guidelines have been developed to ensure that such deficiencies are avoided, by keeping the grass supplied with enough K at all times.

In that context, considering how much K is available to the grass, let's look at the "numerous publications where high tissue K had a positive effect on stress tolerance in turfgrass."

Water relations of two Cynodon *turf cultivars as influenced by potassium*

In this experiment[16] by Miller and Dickens, the turf was grown in a soil with 8 ppm K. This is very low. Nitrogen was applied at $9.8\,\mathrm{g\,m^{-2}\,mo^{-1}}$ creating a high plant requirement for K in a soil deficient in K.[17] Naturally, adding K had a positive effect. The authors conclude that "under conditions of low soil K concentration, K fertilization can have a significant impact on leaf water potential and the plant's ability to prevent leaf tissue damage brought on by drought."

[16] `http://ticpass.lib.msu.edu/cgi-bin/flink.pl?recno=61150`

[17] For more about nitrogen-driven nutrient demand by turfgrass, see the paper on this by Kussow et al.: `http://bit.ly/161KyWm`

Application of the MLSN guidelines ensure that the soil K remains above a low level. In the experiment described, the MLSN guidelines approach would have supplied equivalent amounts of K as were used to produce the beneficial effects in this experiment.

Nutrient Accumulation and Associated Root Characteristics in Response to Drought Stress in Tall Fescue Cultivars

Huang[18] grew tall fescue in a soil with 176 ppm K.[19] Then drought stress was applied to some of the plants. The treatments were the application of drought stress, or continued irrigation. Nutrient contents of shoots and roots were then measured. This experiment did not test the effect of increasing or decreasing K supply to the grass and it is not clear from this experiment that changes in K supply would have an effect on drought tolerance.

[18] http://ticpass.lib.msu.edu/cgi-bin/flink.pl?recno=72616

[19] The soil nitrogen was reported as 106 ppm, which is extremely high and is equivalent to a single application of fast-release N at a rate of 15.8 $g\,m^{-2}$. In the 2 mo of growth before the drought treatment was initiated, the grass was supplied with N at 17 $g\,m^{-2}$.

Effects of Mineral Nutrition on High Temperature Induced Growth Retardation of Kentucky Bluegrass

In this experiment[20] by Pellet and Roberts, grass was grown in solution cultures, not in soil, at two levels (high and low) of N, P, and K. Note that the low level was "designed to be below" the range required for good turfgrass development. Even so, the level of K "had little influence on the degree of resistance of Kentucky bluegrass to high temperatures" and "neither P nor K levels affected resistance of plants to high temperatures." There was an interaction with N; at high levels of N, more K was required. The MLSN guidelines, by predicting expected plant use of K based on site-specific N rates, account for this interaction, ensuring the grass is always supplied with enough K.[21]

[20] http://ticpass.lib.msu.edu/cgi-bin/flink.pl?recno=12707

[21] This is demonstrated in the K requirement calculator (https://asianturfgrass.shinyapps.io/mlsn_K/ where the K fertilizer requirement is shown to change when the N application rate is changed.

Nitrogen, Potassium, and Irrigation Effects on Water Relations of Kentucky Bluegrass Leaves

Carroll and Petrovic[22] grew Kentucky bluegrass in soil with 9 ppm K. This is low. Nitrogen was applied at rates from 3.5 to 17.5 $g\,m^{-2}\,mo^{-1}$. K was applied at 1.75 to 17.5 $g\,m^{-2}\,mo^{-1}$; this gave N/K fertilizer ratios of 10:1, 2:1, 1:1, and 1:5. "A small change in the N/K ratio, such as from 2:1 to 1:1, did not appreciably change [bulk leaf osmotic potential at full turgor]; however, larger N/K ratio changes substantially altered [bulk leaf osmotic potential at full turgor]," they wrote. "Increasing the supply of K 10-fold caused [bulk leaf osmotic potential at full turgor] to decrease 0.2 MPa under daily irrigation, indicating the influence of K addition alone on [bulk leaf osmotic potential] is limited."

[22] http://ticpass.lib.msu.edu/cgi-bin/flink.pl?recno=20167

The two objectives of this experiment were "to obtain an empirically based equation that would predict stomatal resistance as a function of leaf turgor, and to determine the effect of N, K, and irrigation frequency on the turgor maintenance characteristics of Kentucky bluegrass leaves." This was needed "before physiologically based turfgrass water-use and stress-index computer simulation models can be developed." Although at the extreme differences in N/K ratios, in turf watered daily, the bulk leaf osmotic potential at full turgor was different, the practical effect of this wasn't detected. For the plants receiving these same treatments, but irrigated on a

5 d schedule, "moisture loss and stress development were clearly rapid . . . with loss of leaf turgor and leaf folding apparent in all containers by the fourth day."

Note that if the MLSN guidelines were applied to Kentucky bluegrass grown in this soil, substantial amounts of K would be used because the soil is so low in K.

Effects of Nitrogen and Potassium Fertilization on Perennial Ryegrass Cold Tolerance During Deacclimation in Late Winter and Early Spring

In this experiment[23] by Webster and Ebdon, the soil was high in K, at 121 ppm, and the treatments were five rates of N and three rates of K. At the high N rates, adding more K *reduced* survival. Another negative effect of K at high N was more disease. Higher rates of K "increased the severity of low temperature disease (*Typhula incarnata*) by as much as 25 % to 35 % over low K."

[23] http://ticpass.lib.msu.edu/cgi-bin/flink.pl?recno=111993

The positive effects of adding K occurred at the lower rates of N. Let's look just at the lower rates of N, when N was applied at 4.9 , 14.7 , and 24.5 $g\,m^{-2}\,yr^{-1}$. At those N rates, for plants exposed to cold temperature in late winter, the lethal temperature at which 50 % of the plants died was −12.4 °C when the high rates of K were applied; the lethal temperature was −11.2 °C when the lowest rate of K (4.9 $g\,m^{-2}\,yr^{-1}$) was applied. So that is a 1.2 °C effect – a positive one.

But for plants exposed to cold temperature in early spring, the effect goes away, even at the low N rates. In early spring, 50 % of the plants died at −9.5 °C when the high rates of K were applied; the lethal temperature was −10.3 °C when the lowest rate of K was applied. So that is a 0.8 °C effect – a negative one.

I don't see that this is a convincing case for adding K. And the data here show there are substantial risks to adding K, especially when the N rates are high.

Irrigation and Potassium Effects on Poa pratensis *L. Fairway Turf*

Shearman et al.[24] applied K at 0 , 20 , 40 , and 60 $g\,m^{-2}\,yr^{-1}$ at sites with soil K of 318 and 343 ppm. Irrigation treatments were applied at both sites at 100 , 80 , and 60 % of evapotranspiration. "There were no significant irrigation or potassium nutrition treatment effects on turfgrass color or quality under the conditions of this study, and no data are presented for turfgrass color or quality," they wrote. There were effects of K on plant stiffness and ball roll distance and leaf temperature.

[24] http://ticpass.lib.msu.edu/cgi-bin/flink.pl?recno=106300

This project was conducted at two sites over two years and there was not a K effect on turfgrass quality.

Potassium fertilization responses as affected by sodium

Snyder and Cisar[25] applied N at 10 $g\,m^{-2}\,mo^{-1}$ to a soil green and to a USGA sand green. K was applied at rates up to 5 $g\,m^{-2}\,mo^{-1}$.

[25] http://ticpass.lib.msu.edu/cgi-bin/flink.pl?recno=105421

They concluded that "when fertilized with N at the rate of $10\,g\,m^{-2}\,mo^{-1}$, bermudagrass visual quality generally was reduced by K fertilization rates below $5\,g\,m^{-2}\,mo^{-1}$, both on a native soil and on a USGA green, and clipping yields were reduced occasionally."

Application of the MLSN guidelines at this site, for the reported soil test K levels and N application rates, would have recommend application of K rates exceeding $5\,g\,m^{-2}\,mo^{-1}$.

The Effects of Fertilization on Recovery of Kentucky Bluegrass Turf from Summer Drought

At Blacksburg, Virginia, Schmidt and Breuninger[26] grew Kentucky bluegrass in a soil with 48 ppm K. After a drought in the fifth year of this study, the effects of adding K at 6 or $12\,g\,m^{-2}\,yr^{-1}$ were measured, as clipping yield after the drought (recovery). Adding K increased the recovery of yield as measured on clipping yields taken on 12 August 1966 following a summer drought. Averaged across all N and P treatments, the yield was 12.6, 16.8, and $16.6\,g\,m^{-2}$ for annual K rates of 0, 6, and $12\,g\,m^{-2}\,yr^{-1}$.

[26] http://ticpass.lib.msu.edu/cgi-bin/flink.pl?recno=1174

At a starting soil test level[27] of 48 ppm, and at the N rates used in this experiment, the MLSN guidelines would recommend K application at rates from 5.6 to $13\,g\,m^{-2}\,yr^{-1}$ at this site. That is, the MLSN guidelines would recommend the same amount of K that was used to achieve the maximum drought recovery.

[27] The site is described as having soil K of $95\,kg\,ha^{-1}$ which is equivalent to 48 ppm; however, data collected during the experiment show soil K at about four times that level, which would be impossible to achieve at the rates of K applied in the experiment. Thus, there is some confusion about these results.

Na^+ and K^+ Accumulation in Perennial Ryegrass and Red Fescue Accessions Differing in Salt Tolerance

Krishnan and Brown[28] grew perennial ryegrass and red fescue "in an ebb-and-flow water bath filled with half-strength Hoagland solution and NaCl." This experiment is not measuring the effect of K; it is looking at salinity tolerant accessions and what ions accumulate in the leaves. K was not a treatment.

[28] http://ticpass.lib.msu.edu/cgi-bin/flink.pl?recno=150951

Response of 'Captiva' St. Augustinegrass to Shade and Potassium

Cai et al.[29] grew St. Augustinegrass in different amounts of shade and with different K rates in sand and potting mix in a glasshouse. Clippings were removed. No fertilizer was applied at establishment. The soil K for this study is not reported. Adding K in this experiment increased root weight and turf quality. Based on the known effects of K, it seems likely that the K added as treatments was necessary to correct a soil deficiency.

[29] http://ticpass.lib.msu.edu/cgi-bin/flink.pl?recno=192077

Concluding notes

BECAUSE K IS USED BY GRASS in such large quantities, second only to N,[30] it is to be expected that there will be effects of adding K as fertilizer, usually positive in the cases where the soil cannot supply

[30] Except for seashore paspalum, which often uses K at similar rates to N.

enough K to meet the grass requirements. The benefit of K comes from eliminating a deficiency, in most cases. The MLSN guidelines have been developed to ensure that enough K is supplied to meet the grass requirements and to ensure there will never be a deficiency.

When we look at the results of K experiments, it is common to see an effect when one is correcting a K deficiency. The addition of K beyond the amount to correct the deficiency gives one of three results. It improves turf performance, it causes problems, or more often, no effect is observed. Because the effect can go in either direction – good or bad – and because there often is no effect, a reasonable explanation is that there is no consistent benefit to addition of K beyond the amount that is required to supply the plant with the amount that it will use.[31]

As a practical matter, adding more K than the grass can use is a waste. Eventually the extra K will leach, unless one increases cation exchange capacity (CEC) to match the amount of K added.

[31] A notable and particularly interesting exception is the recent research at Rutgers showing anthracnose suppression when K is applied at rates more than 3 times higher than the grass can use: `http://usgatero.msu.edu/v13/n2-2.pdf`. A number of questions arise from this result: what is the mechanism by which this occurs, would it occur if other salts were added when grass is supplied with low rates of N, and would the result be the same if the grass were supplied with recommended rates of N?