Proposed Guidelines for Sulfur and Chloride in Turfgrass Soils

by Wendy Gelernter, Ph.D. and Larry J. Stowell, Ph.D.

Bottom line: Monitoring sulfur and chloride levels in soils is becoming more important with the continued use of fertilizers and amendments that contain these elements. Analysis of the PACE database of soils from golf courses around the country has revealed that the major impact of excess sulfur and chloride is their contribution to soil salinity. On this basis, we have proposed guidelines that take into account the different salt tolerances of several key turf types. The data suggests that while previously proposed sulfur guidelines of 50 ppm are desirable, levels of 130, 460 and 800 ppm will still support growth of good quality turf for poa, bentgrass/ryegrass or bermudagrass, respectively. Guidelines for chloride have not been previously published, but our analysis shows that keeping levels below 90, 400 or 700 ppm for poa, bentgrass/ryegrass or bermudagrass, respectively, will help to keep soil salts below the levels that damage turf.

There is little information available on guidelines for levels of sulfur and chloride in soils. This is because these nutrients are rarely too low for growth of healthy turf. And until recently, they have rarely been too high either. This situation may be about to change, however, as the continued use of fertilizer amendments that contain sulfur and chloride is changing in the world of turf management.

Fertilizers and amendments that contain sulfur have been important tools in turf management for many years. Calcium sulfate (gypsum) is used to improve water chemistry as well as to manage soil sodium, while potassium sulfate is commonly used to correct potassium deficiencies. Acid injection introduces sulfur into irrigation water as a means of dealing with high bicarbonate levels, and sulfur coating of urea is used to promote slower release of nitrogen into the soil. And these are just a few of the many sulfur-containing products that are used on a regular basis at golf courses.

As useful as these sulfur-containing products are, there is a potential problem — after prolonged use of these products, we have seen a build-up of sulfur (primarily in the form of sulfates) in soil at some locations, particularly in the case of gypsum applications to the soil. This observation has caused us to ask several questions:

1. Is the build-up of sulfur in soil a problem for turf health?
2. What levels of sulfur can cause damage to turf?
3. If sulfur levels get too high from prolonged use of a product such as gypsum (calcium sulfate), what is the impact of switching to an alternate source of calcium that contains chloride (for example calcium chloride) instead of sulfate?
4. Will chloride eventually build up in the soil, and if so, what levels of chloride can cause damage to turf?

It takes a village

To answer these questions, we conducted a soil survey of golf course soils, in cooperation with superintendents from around the U.S. who provided over 7,000 samples from greens and fairways. Brookside Laboratories in New Knoxville, OH ran the chemical analyses (Soil ECs were determined using a 1:2 water soil dilution and then converting the value obtained to a saturated paste equivalent value by using the equation: Saturated paste equivalent = 2.1*(1:2 dS/m) + 0.5 $r^2 = 0.76$, $p<0.001$).

We then subjected the data to statistical analysis so that we could study the trends that emerged and summarize the information in the form of new nutritional guidelines.

The strength of this process and of the resulting conclusions rests on the very large database that we have at our disposal, thanks to the many superintendents who have served as research cooperators on this study. The more samples we get to look at in this way, the more useful and more robust our conclusions are. So, thanks to all of you who contributed your time, your experience (and your soils!). Your efforts will be of benefit not just to the people reading this *PACE Insights*, but to the turfgrass industry in general, since all of our conclusions on turfgrass nutrition are published on the "public" page of the PACE website.

Starting with sulfur

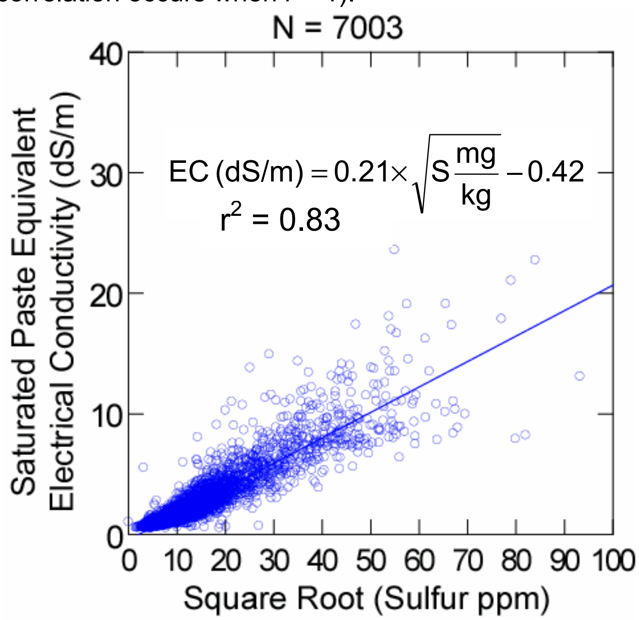
Sulfate ($SO4^{2-}$) is the form in which the plant's roots take up sulfur. Although it is an important nutrient that is required for healthy plant growth, it is in good supply in almost all soils. One possible exception is new sand greens, which may have insufficient sulfur (less than 5 ppm) in the early months of growth.

Excess levels of sulfur are rarely, if ever, known to cause direct damage to turf. However, the accumulation of negatively charged sulfate ions in the soil can cause a big increase in soil salinity, we have found. This increase can be enough to result in salinity damage to turf in some cases, as we will show below.

Sulfur and salinity

We were fortunate to be able to combine the results from over 7,000 greens and fairways in our investigation of the contribution that sulfate makes to soil salinity. As illustrated in Figure 1, there is a very strong relationship between these two factors, indicating that if sulfur levels go up in the soil, soil salinity (as measured in terms of electrical conductivity) will also rise.

Figure 1. The cause and effect relationship between soil sulfur levels and soil electrical conductivity (EC). 7,003 soil samples from greens and fairways were evaluated using the Mehlich III extraction for sulfur. The correlation, or relationship, between sulfur and EC is described by the equation below and illustrated by the graph below. The r^2, or correlation coefficient value of 0.83 indicates a strong relationship between EC and sulfur concentration (the strongest possible correlation occurs when $r^2 = 1$).



What about sulfur and black layer?

Several researchers feel strongly that addition of sulfur or sulfur derivatives (sulfate, sulfuric acid injection, potassium sulfate, etc) to soil or water should be avoided (Berndt, 1996; Vargas, 1994). They reason that because sulfur is required for black layer to form, adding it to the soil will promote the problem.

While we agree that the appearance of black layer is cause for concern, we do not believe that the use of sulfur-containing products is the major cause of black layer. Instead, the cause of black layer is lack of oxygen in the soil (anaerobic soils). It is only when soils are anaerobic that the sulfate-reducing bacteria that produce black layer can survive. You can have loads and loads of excess sulfur in the soil, but if the soil is well aerated, you will not have sulfate-reducing bacteria in the soil (oxygen is poisonous to them) and you will not have black layer. On the flip side, you should not be misled into thinking that the absence of black layer means that your soils are well aerated. It is possible to have anaerobic soils that are very unhealthy for turf growth, but if soil sulfur levels are low, there will be no black layer whatsoever.

For these reasons, black layer should be seen as a symptom — not the cause — of the much more serious underlying problem of lack of oxygen in the soil. Without oxygen, turf roots cannot grow, and the plant will rapidly decline. Soils that are waterlogged, compacted, sealed by algae and slime or poorly draining are likely to be anaerobic, whether or not black layer is present. These conditions need to be addressed through aeration, sand topdressing and/or drainage improvement programs to avoid further turf declines. Whether or not you add sulfur-containing products to these soils will have little effect on addressing the underlying cause of the problem — lack of oxygen.

Concern about the link between sulfur and black layer has caused some superintendents to avoid the use of sulfur-containing products such as gypsum, and to keep soil sulfate concentrations at 50 ppm or less. However, the results of PACE's soil survey show that good-performing turf is possible at sulfur levels that exceed 50 ppm (Figure 2) with no obvious decrease in quality. For this reason, we have concluded that the major danger that sulfur poses to turf quality is *not* as an instigator of black layer, but primarily as a component of soil salinity.

This leads to the next logical question which is: exactly how much sulfate is too much for healthy turf? To answer this question, we used the equation shown in Figure 1 above, and generated answers for three different turf types that have three different sensitivities to soil salinity (see Table 1). Note that depending on the type of turf you are managing, the guidelines for sulfur differ markedly.

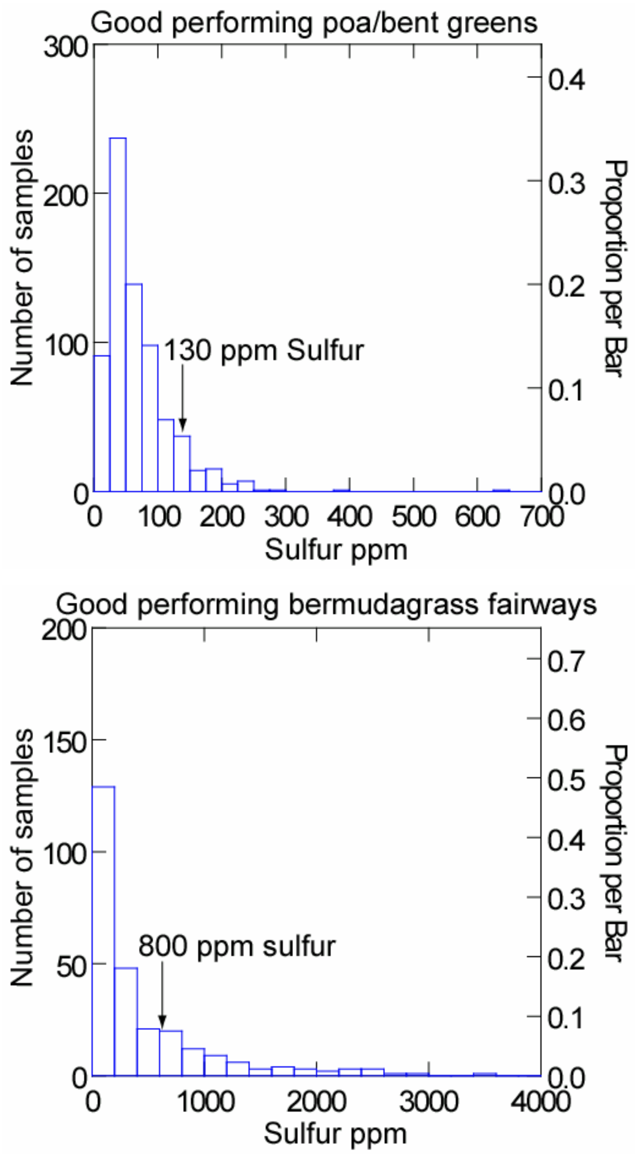
Table 1. Proposed guidelines for EC, sulfur, chloride and sulfur plus chloride combined. The "target ECs" below represent a "safe" salinity level that should promote sustainable growth for the turf types listed.) In order to prevent salinity-related damage,the target EC values are set lower than the EC damage thresholds of 3, 6 and 8 dS/m (for poa, bent/rye and bermudagrass, respectively) that we have published elsewhere. Based on similar logic, the guidelines for chloride and sulfur below are set at 50% of the levels that appear to cause damage to turf based on the equations shown in Figures 1, 3 and 5.

	Poa	Bent/Rye	Bermuda
Target EC dS/m	**2**	**4**	**6**
Chloride ppm	**90**	**400**	**700**
Sulfur ppm	**130**	**460**	**800**
Chloride+ Sulfate ppm	**200**	**800**	**1300**

But wait: there's more to this story

Of course, sulfate is only one of many ions that contribute to soil salinity. Sodium, potassium, magnesium and chloride can be other contributors, depending on the soil and on the amendments that you are adding to it. Since chloride-containing fertilizers and amendments can be substituted for sulfur-containing products, let's now take a look at the role that chloride can play in turf quality and salinity accumulation.

Figure 2. Proposed sulfur guidelines vs. results of soil survey. To prevent build-up of soil salts as a result of high sulfur levels in the soil, a guideline of 130 ppm sulfur was proposed for greens that were primarily poa, and a guideline of 800 ppm for bermudagrass fairways. The two graphs below show that the majority of good-performing samples fell within these guidelines. The data base contained samples from 695 good-performing greens and 266 good-performing fairways.



Chloride and turf quality

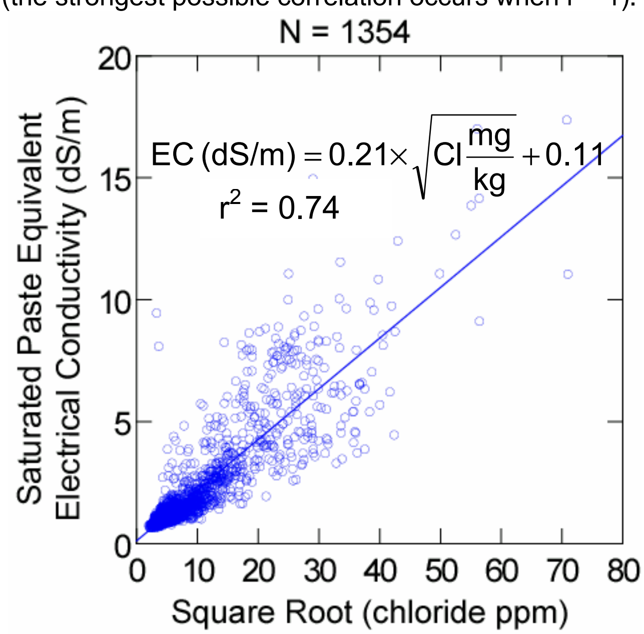
Turf can apparently tolerate higher levels soil chloride (Cl^-) than many other plants because Cl^- is removed from leaf tips (which is where it accumulates) by mowing. Because Cl^- does not appear to directly cause damage to turfgrass, there are no published guidelines on optimum soil chloride levels for turf.

Chloride and salinity

When we took a look at soil chloride levels in 1,354 samples from greens and fairways, we saw a relationship between chloride and salinity that was similar to the relationship between sulfur and salinity (Figure 3). This means that chloride ions can be an important contributor to soil salinity, in the same way as sulfate ions can. In other words, use of amendments or fertilizers that contain either of these ions can lead to a gradual build-up of salts that can ultimately damage turf. It is only through regular leaching programs that the excess levels of sulfur, chloride and other salts can gradually be lowered to levels that are better for turf growth.

How much chloride is too much? For the answer to this question, let's take a look at Table 1 and Figure 4. We see from Table 1 that depending on whether you are growing poa, bentgrass or bermudagrass, your turf can probably tolerate chloride levels of 90, 400 or 700 ppm, respectively. As expected, Figure 4 shows that the large majority of samples fell well within these guidelines.

Figure 3. The cause and effect relationship between soil chloride levels and soil electrical conductivity (EC). 1,354 soil samples from greens and fairways were evaluated using a 1:10 soil:water dilution, a Cl electrode and the potentiometric known addition method for chloride. The correlation between chloride and EC is described by the equation below and illustrated by the graph below. The r^2, or correlation coefficient value of 0.74 indicates a relatively strong relationship between EC and chloride concentration (the strongest possible correlation occurs when $r^2 = 1$).

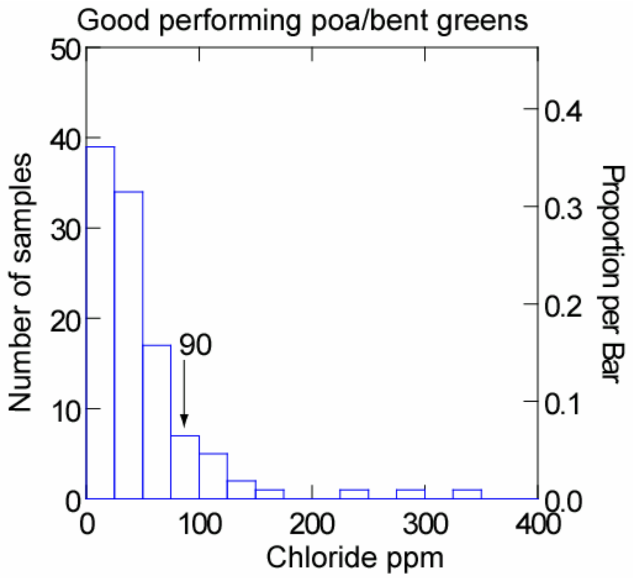


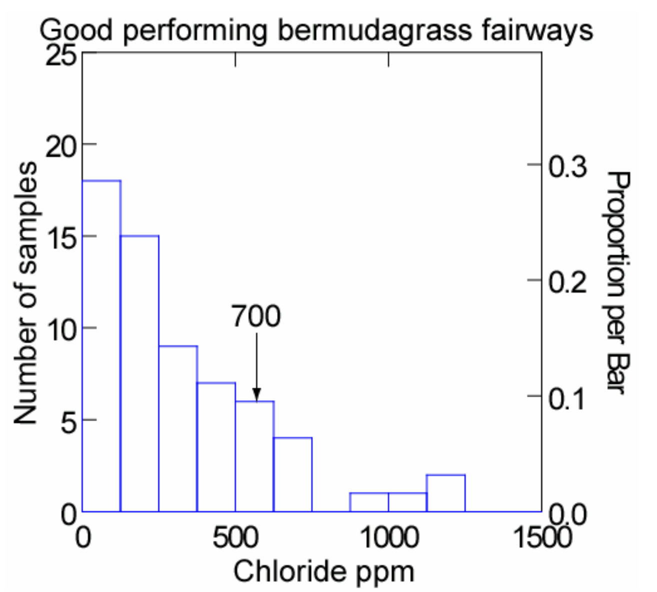
Monitor both sulfate and chloride

If you look at Table 1, you will notice that the guidelines do not only track levels of chloride and levels of sulfur in the soil, but they also track the combined effects of chloride PLUS sulfur. Why is this necessary?

When we looked at the relationship with soil salinity, we found that the combination of chloride plus sulfur also had a strong correlation with salinity (Figure 5), with an r^2 value of 0.92. This means that it is important not only to stay within the guidelines provided for chloride and sulfur alone, but also for the combined guideline value of sulfur and chloride together.

Figure 4. Proposed chloride guidelines vs. results of soil survey. To prevent build-up of soil salts as a result of high chloride levels in the soil, a guideline of 90 ppm chloride was proposed for poa greens, and a guideline of 700 ppm for bermudagrass fairways. The two graphs below show that the majority of good-performing samples fell within these guidelines. The data base contained samples from 108 good-performing greens and 63 good-performing fairways.



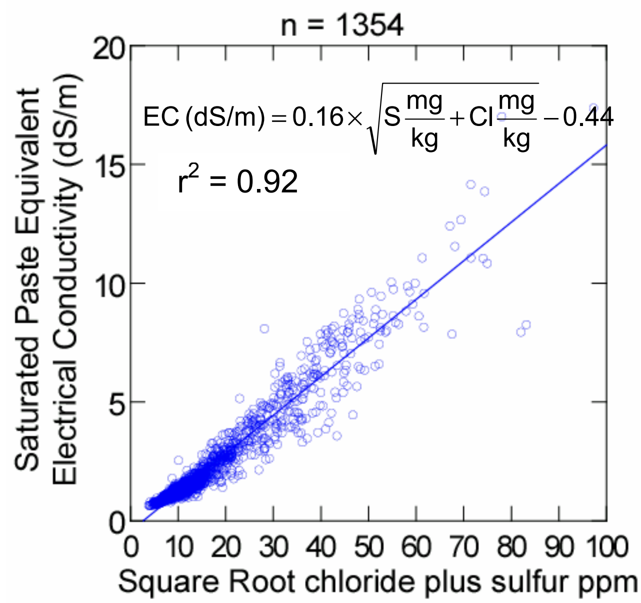


Translating theory into practice

Before we wrap up by proposing some practical steps that you can take to translate these findings into useful practices, we want to point out that the guidelines suggested above are fairly preliminary. We expect that they will be fine tuned over time as we verify them out in the field. That said, the conclusions we can draw so far are:

- Direct turf damage due to excessive levels of chloride or sulfur is very rare on golf course turf.
- Despite this fact, continued use of sulfur or chloride-containing amendments and fertilizers can contribute to soil salinity levels that can damage turf.
- Using the guidelines shown in Table 1, keep track of soil ECs, chloride and sulfur levels through twice-yearly soil testing programs. During periods of low rainfall, additional monitoring of ECs is required with the hand-held TDS-4 meter (PACE Reference 9:3)
- If you see EC, sulfur or chloride levels increasing towards the levels shown in Table 1, your first step should be to trigger leaching programs to move the offending salts down below the root zone.
- If sulfur or chloride are approaching the levels shown in Table 1, you should also avoid the use of products that contain the nutrient that is in excess until you see levels going well below the guideline values shown in Table 1. You should be able to find product substitutes in most cases that do the same job, but have the sulfur or chloride ions replaced with some other ion (for example, gypsum, which is calcium sulfate, can be replaced with calcium chloride in soils that are above the guideline for sulfate).

Figure 5. The cause and effect relationship between soil electrical conductivity (EC) and chloride PLUS sulfur. The correlation between chloride plus sulfur vs. EC is described by the equation below and illustrated by the graph below. The r^2, or correlation coefficient value of 0.92 indicates a very strong relationship between EC and chloride plus sulfur concentration (the strongest possible correlation occurs when $r^2 = 1$).



References

Berndt, WL. 1996. Golf Course Management, October, 1996.

Vargas, JM. 1994. Management of turfgrass diseases. Lewis Publishers, Boca Raton, FL.