Ubiquitous Chlorine Performs Vital Tasks In Turf

By Richard J. Hull

Although chlorine (Cl) is the most abundant micronutrient in most plant tissues, Turner and Hummel (1992) reported that "deficiency symptoms or beneficial responses of turfgrasses to Cl have not been reported." This apparent inconsistency reflects the simple fact that Cl is ubiquitous in nature, and deficiency symptoms are never observed in turfgrasses or any other plants.

It was not until 1954 that Broyer and his colleagues reported the general requirement of plants for Cl (Broyer et al. 1954). They were able to demonstrate Cl deficiency symptoms in plants only after filtering the air entering their Berkeley, Calif., greenhouses and growing plants on nutrient solutions prepared with doubly recrystallized salts to remove all Cl.

While the Cl content of plant tissues normally ranges between 2 to 20 milligrams per gram dry matter (parts per thousand), the Cl content required for optimum growth is in the range of 0.2-0.4 mg/g (Marschner, 1995). Apparently there are no data on the specific Cl requirements of turfgrasses, but it is unlikely their needs are different from those of most other plants.

Since a Cl insufficiency is not likely, the turf manager need be little concerned about supplying this nutrient, but that does not mean it is unimportant.

Cl uptake by roots

Cl is present in soils and water as the monovalent anion chloride (Cl^-). Most salts of chloride are soluble, making Cl^- highly mobile in soils and easily leached below the root zone when rainfall or irrigation exceed evapotranspiration. Cl would become insufficient for plant needs were it not supplied continuously through atmospheric deposition.

Wave action causes sea water to be thrown into the air, and that introduces Cl^- ions into the atmosphere. Marschner (1995) estimates that the annual crop requirement for Cl of 4 pounds to 8 pounds per acre is supplied by rain even at inland locations. In oceanic climates, the supply of Cl in rainfall is about 10 times the amount removed by crops.

Cl is absorbed by roots from the soil solution as Cl^- ions, but the membrane transporter involved apparently is not very efficient. A nutrient solution containing .1 mM Cl^- was shown to satisfy the Cl needs of white clover, but reducing that to 0.01 mM Cl^- caused a 50- percent decline in shoot dry weight (Chisholm and Blair, 1981).

Cl deficiency has yet to be reported for turfgrasses. That is not to say that turf never experiences insufficient Cl for optimum growth.

By comparison, plants can satisfy a much greater phosphorus need from a solution phosphate concentration substantially less than .01 mM. While Cl^- uptake by roots is likely an active process, it may occur through transporters involved in the absorption of other anions (e.g. nitrate, phosphate or sulfate).

Cl functions in plants

Although Cl is often the most abundant micronutrient, its exact functions in plants are not well understood. Nevertheless, several Cl functions are generally recognized (Table 1).

Oxygen evolution in photosynthesis: Four electrons are drawn from the oxygen atoms of two water molecules to initiate the electron transport in photosynthesis that eventually leads to the reduction of CO_2 and the production of sugars (Fig. 1). The oxidized oxygen from the two waters forms a molecule of O_2 that is released to the atmosphere.

The four electrons reduce four manganese atoms ($4Mn^{3+} + 4e^- \longrightarrow 4Mn^{2+}$) as we described in an earlier article on manganese in turf (Hull, 2001). When these four Mn atoms surrender their electrons to photosynthetic electron transport, they acquire four positive charges.

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TABLE 1

Functions of chlorine in plants

- Stabilizes the protein components of the oxygen evolving complex of Photosystem II in photosynthetic electron transport.
- Stimulates the hydrogen-pumping ATPase of tonoplast that energizes ion transport and accumulation in vacuoles.
- In some plants, Cl- is counter ion for K+ influx during stomate opening.
- Serves as an osmotic solute in maintaining proper water relations between plant and soil solution.
- Is essential for cell division and cell enlargement possibly by interacting with auxin activity.
- Stimulates asparagine synthetase thereby contributing to nitrogen transport in some plants.

SOURCE: BASED IN CARROW ET AL. 2001

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The protein configuration in Photosystem II, where this process occurs, would be destabilized by the additional 4+ charges were they not balanced by 4- charges contributed by four soluble Cl^- ions. In this way, free Cl- ions in the chloroplasts balance the transient + charges within the O_2 evolving complex so it can oxidize water efficiently. This function of Cl is essential for photosynthesis, and chloroplasts are the last to lose their Cl when that element is withheld.

Ion concentration in vacuoles: When turf is fertilized, many of the ions absorbed by roots from the soil are stored in the large vacuoles of root cells. From there, these nutrient ions will be used as they are needed. However, for ions to be concentrated in vacuoles, an electrical gradient must be created across the vacuole membrane — the tonoplast. This electrical gradient (positive inside the vacuole) is achieved by a positive hydrogen atom (H^+) pumping ATPase in the tonoplast that uses ATP to transport H^+ (protons) into the vacuole making the inside positive.

There is a similar H^+ pumping ATPase in the cells' plasma membrane that is activated by positive potassium (K^+) ions but the one in the tonoplast is activated by Cl^- ions. It appears that for plants to use nutrients efficiently, temporary accumulation in vacuoles is required and that requires Cl.

Stomate functioning: For CO_2 to enter leaves while O_2 and H_2O vapor exits, pairs of epidermal guard cells must become turgid and open the stomates. This occurs during periods of light when the solute content of guard cells increases and water flows in making the cells turgid.

The solutes involved are mostly K^+ ions that are pumped into guard cells from surrounding cells. The influx of K^+ must be electrically balanced by anions that, in most plants, are organic acids made from starch through photosynthesis. Guard cells are the only epidermal cells that have chloroplasts and are capable of photosynthesis. However, some plants have few if any chloroplasts in their guard cells, so they must import Cl^- ions to balance the influx of K^+.

At this time, there is no clear explanation for the role of Cl in cell division and expansion.

Osmotic adjustment: In order to maintain proper water status, plants must be able to adjust the solute content of their cells in response to changes in soil water availability.

As with guard cells, organic molecules partly serve this function, but when osmotic changes are rapid or severe, inorganic ions must be imported from the soil solution.

This role is often played by K^+ ions, but in many situations Cl^- also is utilized. Plant adjustment to salinity stress frequently involves the import and storage of Cl^- within vacuoles.

The extension of stigmas during anthesis of grass flowers requires a rapid influx of solutes and Cl^- along with K^+ serves this function. Many specialized rapid osmotic changes such as the movement of *Mimosa* leaves when touched, require the transport of Cl^- ions. Xylem and phloem transport also depends on the influx of Cl^- from surrounding cells in many plants. Although other ions can often substitute for Cl^-, osmotic adjustment is probably the plant function most sensitive to a Cl deficiency.

Cell division and expansion: The most common Cl deficiency symptom is a slowing of growth and a reduced leaf size (Marschner, 1995). Smaller leaves result from a reduction in cell divisions and the failure of cells to expand fully. This is more than an inadequate osmotic adjustment providing insufficient cell turgor to drive cell enlargement.

At this time, there is no clear explanation for the role of Cl in cell division and expansion. However, 4-Cl-Indoleacetic acid (4-Cl-IAA) has been isolated from several legumes during seed development (Pless et al., 1984), and the highest concentrations corresponded with the time of maximum water accumulation and cell enlargement. This chlorinated auxin is about 10 times more active than IAA. While its presence has not been confirmed as a general occurrence during cell enlargement, it might indicate that chlorinated growth regulators are essential for full auxin function.

More than 130 chlorinated organic compounds have been detected in plants (Engvild 1986), but their functions remain largely unknown.

Chlorine in turfgrass management

As indicated at the outset of this discussion, a Cl deficiency has yet to be reported for turfgrasses. That is not to say that turf never experiences insufficient Cl for optimum growth.

Deficiency in grasses normally involves wilting along the margins of leaves followed by necrosis. Reduced leaf growth is also evident, but these deficiency symptoms have been observed on grain crops under laboratory conditions. They would be much less easily detected on fine-leaved turfgrasses.

Chlorine is highly mobile in both xylem and phloem of plants so it is readily distributed to sites where its need is greatest. This further reduces the likelihood of Cl ever being truly deficient.

Nevertheless, the turf manager should be mindful that Cl is essential and optimum turf performance depends upon adequate Cl being present and in proper proportion with other elements. While Cl will normally be sufficient, it is still useful to include it in fertilizers. This is not a problem because the most common source of K is KCl, and that alone will more than meet the Cl needs of plants.

TABLE 2

Causes of high Cl levels in turfgrass management

- Using irrigation water high in Cl- salts.
- Seawater flooding or spray and salt water intrusion in ground water.
- Capillary movement upward from saline water table or subsoil.
- Insufficient leaching of Cl- due to low rainfall and irrigation or poor soil drainage properties.

SOURCE: BASED IN CARROW ET AL. 2001

On sand-based putting greens, where leaching of anions is likely and turf clippings are removed, an incipient Cl deficiency may occur

On sand-based putting greens, where leaching of anions is likely and turf clippings are removed, an incipient Cl deficiency may occur. In other less well-drained sites, there is the potential of excess Cl^- reducing the uptake of nitrate and even phosphate or promoting excess nitrate immobilization in the vacuoles of root and leaf cells.

Thus, applying half of the K as K_2SO_4 may insure an appropriate balance between Cl^- and other nutrient anions.

In turf management, excess Cl is more like-

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ly to be a problem especially where salinity levels are high (Carrow et al., 2001). Turfgrasses vary in their sensitivity to salinity with the most sensitive exhibiting toxicity symptoms when Cl concentrations become .3 to .5 percent of leaf dry weight. Tall fescue and perennial ryegrass can tolerate Cl^- levels in the soil solution of 40 mM while bermudagrass and paspalum can grow without injury in 100 mM Cl^-.

Excess Cl^- levels are likely to result from both environmental and management factors (Table 2).

Chlorine toxicity can cause leaf chlorosis and markedly reduce growth rates. It can be mitigated by using sulfate salts as fertilizer materials and by increasing the calcium levels of the soil. Clipping removal may also reduce Cl toxicity over time, especially if other corrective measures are taken. While Cl is the micronutrient required in the greatest amount, it's among the least likely to be deficient.

Fertility management should consider Cl requirements especially on light readily drained soils or sands where clipping removal is standard. However, the potential for Cl toxicity must also be considered on poorly drained soils where poor quality water is being applied. Balancing the Cl supply to turf is a reasonably challenging aspect of turfgrass management.

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