

Sodium Plays Role in Certain Turfgrass Processes

By Richard J. Hull

Sodium (Na) constitutes about 2.8 percent of the earth's crust, in similar proportion to potassium (K) at 2.6 percent. Both elements are chemically similar and exist in soils as monovalent cations (they have a single positive charge). As such, they are bound to cation exchange sites on soil colloids.

However, positive sodium ions (Na^+) attract a larger shell of hydration water than does positive potassium ions (K^+). This thicker hydration shell partially insulates the positive charge of Na^+ , making its electrostatic attraction to negative cation exchange sites slightly weaker than that of K^+ . Thus, while both ions have a concentration of .1 millimoles (mM) to 1 mM in the soil solution of temperate region soils, Na^+ is more readily leached to the subsoil by percolating rain or irrigation water.

In arid and semi-arid regions where leaching occurs less frequently, irrigated soils often contain 50 mM to 100 mM Na^+ (often as salt, NaCl). Such salt concentrations are toxic to many crop plants, including most turfgrasses.

Because high salt concentrations are common in soils of regions with limited rainfall or subject to tidal flooding, some plants have evolved mechanisms for tolerating excessive levels of Na^+ . These plants are classified as natrophobic species or halophytes and are characterized by absorbing large amounts of Na^+ and negative chlorine ions (Cl^-), transporting them through the xylem to leaves. Then they are sequestered in the vacuoles of mesophyll and parenchyma cells. The high salt content of leaves lowers the cell's water potential and establishes a water-potential gradient through the xylem to the roots, where water has a higher potential. Thus, water can be absorbed from saline or drying soils and transported to the leaves following the water-potential gradient. Such plants tend to have the succulent leaves characteristic of many dry-land or coastal marsh plants.

Some halophytic plants can excrete excess salts to their leaf surfaces through salt glands.

This feature is common to tidal marsh plants that grow in seawater and lose excreted salt to high tide floodwaters twice each day. Upland plants growing in saline soils can also have salt glands and discharge excess salts through them. Several warm-season turfgrasses possess salt glands, including bermudagrass, zoysiagrass and buffalograss.

In a recent study, K.B. Marcum et al. (2003) at Arizona State University in Phoenix reported that the density of salt glands on leaf surfaces of 15 zoysiagrass cultivars correlated positively with clipping production and turf quality when grown under high-salinity conditions. This confirms the long-held belief that salt-gland excretion contributes significantly to salinity tolerance in halophytic grasses. Since salt-gland density is a genetically controlled characteristic, these authors concluded that measuring salt-gland density should be a simple way of screening turfgrass genotypes for salt tolerance.

By comparison, most plants are intolerant of high Na^+ concentrations, and survive in the presence of elevated salt levels through root exclusion, efflux and sequestration of Na^+ . These plants are known as natrophobic species or glycophytes. The K^+ transport channels in their root cells discriminate against Na^+ often by a ratio of 25 to 1 or more. Still, some Na^+ will enter the cells in amounts that are potentially toxic. To eliminate this problem, Na^+ efflux pumps in root cell plasma membranes excrete Na^+ out of the cells back into the cell walls in exchange for positive hydrogen ions (H^+) that enter the cell. Root cells normally transport H^+ s across their plasma membrane into the cell wall (apoplasm), where the pH is lowered by two units below that of the cytoplasm. These H^+/Na^+ antiporters (H^+/Na^+ exchangers) can keep the cytoplasmic Na^+ levels to physiologically acceptable concentrations. If the H^+/Na^+ antiporters can't keep up with Na^+ influx, cortical and xylem parenchyma cells will accumulate the excess Na^+ in their vacuoles. The excess positive charges will be balanced by Cl^- ions entering from the soil or by organic acid anions



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(usually malate or citrate) synthesized within the root cells. This process retains potentially toxic Na^+ within the roots, preventing it from entering the stems and leaves where it could be handled less easily. If all these defensive strategies are overpowered by excessive soil salinity, the plant will exhibit salt injury symptoms and probably be killed.

These various protective processes are not equally evolved in all salt-sensitive plants, so there is considerable variation in the degree of salt tolerance between true glycophytes and true halophytes. Most turfgrasses are glycophytes, although some can tolerate substantial salinity if the onset of elevated salt concentrations is not too rapid. They can invoke most of the Na^+ excluding and sequestering mechanisms. Only seashore paspalum (*Paspalum vaginatum*), weeping alkaligrass (*Puccinellia distans*) and perhaps the salt-gland equipped grasses mentioned above can be considered truly halophytic. Some cultivars of seashore paspalum are sufficiently salt-tolerant that they can be irrigated with seawater.

The relative salt tolerance of cool- and warm-season turfgrasses are presented in Table 2. It is evident that both grass types vary greatly in their tolerance to salinity, although warm-season grasses appear to be generally more tolerant. Among the most commonly used cool-season grasses, most have good tolerance except for Kentucky bluegrass, which rates poorly. The more commonly used warm-season turfgrasses exhibit excellent or good salt tolerance except for bahiagrass (which rates medium) and carpetgrass (which rates fair).

The adverse effects of Na^+ on turfgrass growth as a component of salinity were enumerated by Carrow et al. (2001) as follows:

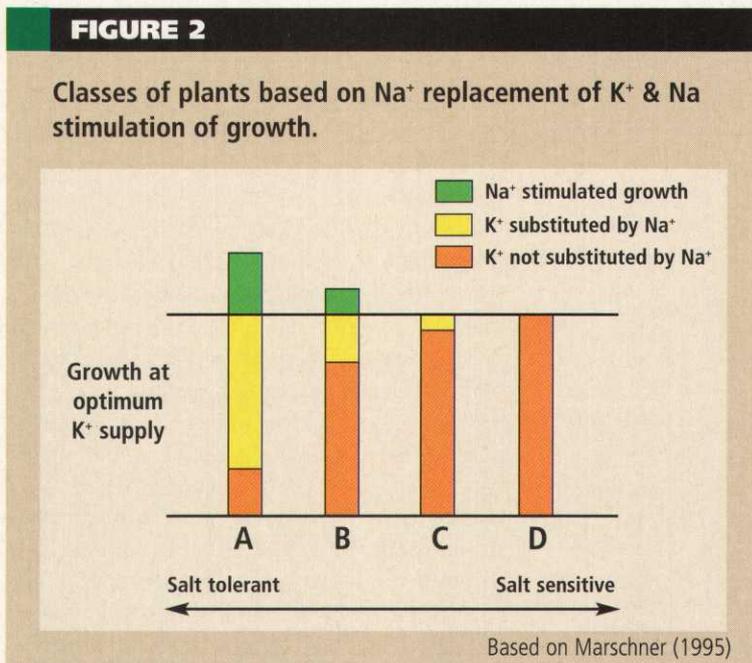
- ion toxicity of high Na^+ levels in plant tissues;
- ion imbalance where Na^+ may inhibit K^+ , calcium (Ca^{+2}), magnesium (Mg^{+2}) and manganese (Mn^{+2}) uptake;
- Na^+ influence on soil structural deterioration (deflocculation of clays); and
- Na^+ contributing to total salinity – osmotic stresses.

The principal problem of high Na^+ levels in the soil solution is its ability to displace Ca^{+2} from the outer surface of the plasma membranes of root cells. Calcium is essential for stabilizing the structure and association of integral

proteins in the plasma membrane. Without Ca^{+2} , the proper structure of ion transporters can't be maintained, and cells become leaky and are unable to absorb nutrient ions properly or discriminate against toxic ions (such as Al^{+3} , Mn^{+2} , Se^{+2}).

Functions of Na^+

Even though salinity and Na in particular are considered abiotic stresses to most turfgrasses, small amounts of Na can be beneficial and even essential in some instances. Marschner cites three aspects of Na nutrition that should be considered:



- Na is essential for some plant species.
- Na can fulfill some of the functions ascribed to K.
- Na often exhibits a growth enhancement effect.

The essentiality of Na for the halophyte *Atriplex vesicaria* was reported by Brownell in 1965. After eliminating virtually all Na contamination from nutrient solutions, plants became chlorotic and necrotic, followed by a cessation of growth. Supplying increased amounts of K failed to repair the injury caused by the lack of Na but providing micronutrient quantities of Na (20 micromoles (μM) to 100 μM) restored normal growth. In the early 1970s, the same authors (Brownell & Crossland, 1972) reported

Continued on page 66

Continued from page 65

that a number of C⁴ species (warm-season plants) showed deficiency symptoms when deprived of Na and failed to flower in some cases.

All C³ (cool-season plants) that were studied grew well in the absence of Na. These findings prompted the conclusion that Na was indeed an essential nutrient to C⁴ species but not C³ plants. This interpretation of these data proved to be premature.

In these initial studies, glycophytic C⁴ species (plants intolerant of high salt like corn and sugarcane) were not considered. When these plants were tested for their Na requirement, they were found to grow equally well with or without Na. It now appears that most salt-sensitive plants (C³ and C⁴) have no requirement for Na, but those adapted to high salinity do require Na at low micronutrient concentrations.

In C⁴ plants, carbon dioxide (CO₂) is assimilated initially by bonding to a 3-carbon acid, phosphoenolpyruvate (PEP) in leaf mesophyll cells. PEP is reduced to the 4-carbon acid malate and transported to bundle sheath cells that surround the vascular bundles. There malate is decarboxylated releasing CO₂ that accumulates to levels several times that of the atmosphere. Under this elevated concentration, CO₂ is efficiently fixed to the 5-carbon sugar ribulosebiphosphate (RuBP) and the 6-carbon product spontaneously splits to form two molecules of the 3-carbon acid phosphoglyceric acid (PGA). The 3-carbon product remaining after decarboxylation pyruvate is returned to a mesophyll cell, where it enters a chloroplast and is phosphorylated to PEP and is ready to start the C⁴ cycle all over again.

This ability to concentrate CO₂ in bundle sheath cells, where photosynthesis really occurs, makes C⁴ plants much more efficient than C³ plants that must fix CO₂ directly from the low atmospheric concentrations.

In glycophytic C⁴ plants, pyruvate re-enters mesophyll chloroplasts through a cotransport process with a positive hydrogen ion (H⁺). Apparently, in C⁴ halophytic species, pyruvate enters chloroplasts through cotransport with a Na⁺. This role for Na in some C⁴ species was suggested when plants growing in a solution lacking Na were found to accumulate pyruvate in their leaves while PEP and malate declined to

very low concentrations. The flow of pyruvate toward the regeneration of PEP was obviously disrupted, and pyruvate entry into mesophyll chloroplasts was a likely site for this disruption. Further studies by Ohnishi et al. (1990) involving mesophyll chloroplasts isolated from salt tolerant C⁴ plants showed that pyruvate was absorbed readily, but only when Na⁺ was present in 1 mM to 2 mM concentration. The Na⁺ was also absorbed along with the pyruvate. When chloroplasts from salt-sensitive C⁴ plants were studied, pyruvate absorption occurred in the total absence of Na⁺. Thus, it appears that C⁴ plants adapted to growth under saline conditions have evolved the use of Na⁺ rather than H⁺ to power the cotransport of pyruvate into mesophyll chloroplasts. This function is sufficiently limited that only micronutrient quantities of Na are required.

Without specifically determining their need for Na, one cannot predict with certainty which warm-season turfgrasses have essential Na requirements. Based on the above discussion, it appears that Na is essential only for warm-season grasses that have substantial tolerance to saline conditions. Thus, seashore paspalum, St. Augustinegrass, zoysiagrass and bermudagrass all likely require small amounts of Na for proper growth.

Substitution for K by Na

Because of their close chemical similarity, Na can substitute for several K functions in a number of plants. Marschner (1995) classified plants into four groups according to their growth response to Na:

- Group A — Na can substitute for a large proportion of the K needed by these plants, and the presence of Na stimulates additional growth that K cannot match (highly salt tolerant).
- Group B — A much smaller proportion of K can be replaced by Na, and growth responses to Na are less distinct.
- Group C — Na has no specific effect on plant growth, and it can substitute for only a small amount of K.
- Group D — Na does not substitute for K in any way and has no effect on plant growth (highly salt sensitive).

Those plants in groups A and B tend to be halophytic, while those in groups C and D are more glycophytic. In group A halophytes, Na not only can substitute for K in several func-



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tions but it can perform those functions better, resulting in greater growth than can be supported by K alone. This does not make Na essential for group A plants because such plants can grow well in the absence of Na in most cases. The capacity of Na to replace K should not imply that K is of minor importance in these plants, however. Group A and B plants permit the transport of Na⁺ through the roots and into the xylem, where it's carried to the leaves with the transpiration stream.

There, most of it is loaded into vacuoles where it contributes in a major way to maintain proper osmotic relations within leaf tissues. In the cytoplasm and subcellular organelles, the Na⁺ level is maintained well below that of K⁺. Since the bulk of mature cell volume is vacuole, however, its high Na⁺ content imparts a high Na concentration to leaf tissues. Young leaves of halophytic plants, having smaller, less vacuolated cells, invariably have a much lower Na content than older leaves.

Na stimulation of plant growth

It has been observed that the presence of Na⁺ in the culture solution increases the growth of many natrophilic species (Marschner, 1995). Here, the major factor appears to be a stimulation of cell and therefore leaf expansion. This is attributed to Na⁺ working more efficiently than K⁺, as an osmoticum, thereby allowing greater turgor pressure to develop in cells causing enhanced expansion and growth.

Sodium ions enter vacuoles more readily than K⁺ probably because of their slighter weaker positive charge. Sodium ions also have a depressing effect on starch synthesis but stimulate simple sugar (especially sucrose) accumulation. These small organic molecules lower water potential further, thereby promoting even more water influx and greater cell turgor.

When Na⁺ contributes to the osmotic regulation of guard cells, stomates close more rapidly under drought stress and open more slowly when the stress is relieved. This maintains a more favorable leaf water status during periods of changing water availability and allows uninterrupted photosynthetic activity and greater growth. It should be remembered that these positive effects of Na⁺ availability operate mostly in halophytic plants and have not been observed in glycophytes.

The beneficial aspects of Na⁺ availability to plants have prompted the practice of applying Na salts as fertilizer to crop plants. This appears to have some benefit when:

- the crop is a natrophilic species;
- soil levels of K or Na are low; or
- when rainfall is irregular, causing transient drought during the growing season.

As a general rule, Na is not added as a fertilizer nutrient because natural sources are usually adequate to meet any beneficial effects on most turfgrasses. Various considerations in applying Na or irrigation water containing Na⁺ and other salt ions are discussed in detail by Harivandi (1992). The total salt content as measured by electrical conductivity is generally more important than the amount of Na⁺ present. Often, the potential injury caused by applying irrigation water containing salts can be partially reduced by including a calcium salt.

The Ca²⁺ has a protective effect on root-cell membranes and helps them exhibit maximum selectivity in ion absorption. However, saline irrigation water must be managed carefully so as to avoid salt accumulation in the soil. This normally involves leaching salts from the soil with pure water once or twice each year. Rainfall can accomplish this, but another water source must be found if rain does not occur. Thus, a decision to use saline water for irrigation should be made carefully.

Since turfgrasses, especially warm-season grasses, differ dramatically in their tolerance to salt, planting resistant grasses is an excellent first step to avoiding salinity problems. Because salt tolerant warm-season grasses actually require small amounts of Na and often grow best when Na is present, including a Na-salt in the fertilizer mix is reasonable.

Also, irrigating such grasses with effluent water that contains low levels of Na⁺ might be recommended. In many areas, effluent water from municipal or industrial sources is available when normal potable water is not, so there may be political or economic incentives for using it. If a turf is composed of salt-sensitive cool- or warm-grasses, Na⁺ applications should be avoided especially if provided through irrigation water.

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