A PRACTICAL RESEARCH DIGEST FOR TURF MANAGERS

TURFGRASS TRENDS

Volume 9, Issue 5 • May 2000

BACK-TO-BASICS

Understanding the Turfgrass Crown

By Richard J. Hull

This is the first of a three-part series on turfgrass morphology, function, physiology and management implications. This series will feature crowns, leaves and roots, all vitally important parts of turfgrass plants. Today we will concentrate on turfgrass crowns.

In his recent textbook on turfgrass management (1998), Nick Christians states, "The crown is the center of activity for the turfgrass plant, and as long as it is alive the plant is alive."

If anything, this is an understatement. The crown literally is the turfgrass plant, or at least that which makes a turfgrass a perennial plant. The primary growing points (meristems) are located in the crown which means all grass organs originate from the crown. Most of the energy reserves of a turfgrass plant are stored in its crown.

During the winter and even during drought-induced summer dormancy, the crown may be the only part of a grass plant that survives. Considering all this, it may appear strange that most turf folks rarely think about the well-being of grass crowns when developing a turf management program.

Leaves are certainly considered when deciding on a height of cut and the impor-

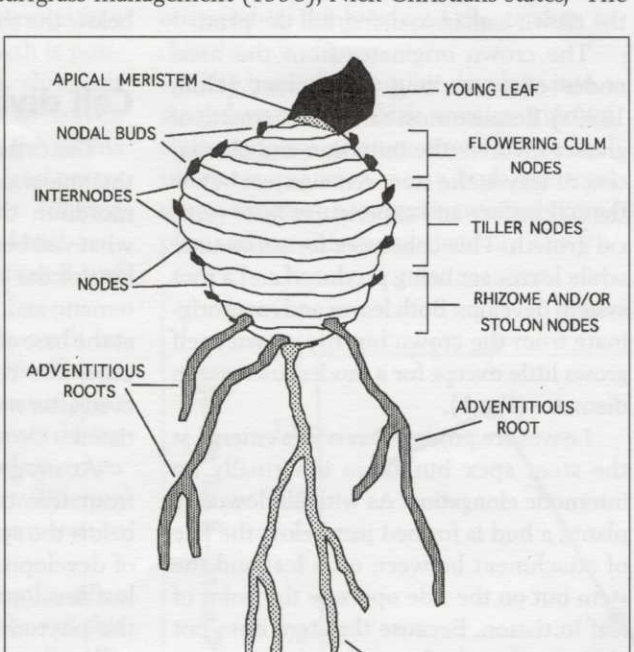

Figure 1. Stylized image of a turfgrass crown with nodes identified that will contribute to a flowering culm, produce tillers, and give rise to rhizomes or stolons. Only the flowering culm internodes will elongate. Roots are much reduced for a crown old enough to have so many nodes. All but the youngest leaf are removed.

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tance of roots is generally acknowledged when scheduling fertilizer applications or aerification. Crowns are down there where the leaves meet the roots and you do not want to scalp them by mowing too close, but otherwise they are not worth much attention. Today, I hope to change that attitude.

The mother of a turfgrass

The crown is a stem from which all other stems, leaves and most roots originate. It is literally the mother of a grass plant. As long as the crown is alive and healthy, the plant can survive even when all other organs have been killed. Insects and diseases that spare the crown, even if they ravage leaves and roots, rarely cause turfgrass death. Diseases such as Pythium blight and severe infections of stripe smut will attack the crown and, in so doing, kill the plant.

The crown originates from the basal nodes of a seedling grass plant (Hull, 1999a). Because most early shoot growth of grasses involves the initiation and elongation of leaves, the stem remains just below the soil surface and experiences little vertical growth. This continues for some time while leaves are being produced and a root system develops. Both leaves and roots originate from the crown but the crown itself grows little except for a modest increase in diameter (Fig. 1).

Leaves are produced as nodes emerge at the stem apex but there is virtually no internode elongation. As with all flowering plants, a bud is formed just below the line of attachment between each leaf and the stem but on the side opposite the point of leaf initiation. Because the stem does not elongate, these buds are clustered on alternating sides of the crown. Such buds do not resume growth into basal shoots until the plant achieves the appropriate developmental state.

The basal nodes of a developing crown give rise to the adventitious roots that will become the principal root system of the plant. The primary roots emerge from the germinating seed but they are replaced by the adventitious roots which emerge from crown nodes. The primary roots can survive for several weeks or more than a month and make a modest contribution to the plant's nutrition and supply of water. Eventually, they are shed and the adventitious roots assume the task of establishing and maintaining an intimate relationship with the soil. Root structure and function will be the subject of a future report.

For the turf manager, the most important and obvious function of turfgrass crowns is their role in initiating leaf and stem development. The apical meristem is positioned at the apex of the crown where it undergoes cell divisions, producing new cells for leaf and nodal bud development. Unlike apical meristems of broad-leaved plants (dicotyledons), the apical meristem in grasses produces leaf primordia that retain meristematic activity at their base, below the shoot apex.

Cell divisions

The cell divisions occur in a line around the apical dome, giving rise to a leaf primordium that forms a ridge just above what will become a stem node. Cells at the base of the leaf primordium remain meristematic and form the intercalary meristem at the base of each developing leaf that supports the continued growth of that leaf even after more apical leaves have been initiated.

At any given time, most turfgrasses have from five to 10 leaf primordia present, below the apical meristem at various stages of development (Turgeon, 1999). Further leaf development from its primordium and the phytomer concept of grass structure will be discussed in a future article devoted to turfgrass leaves.

A nodal bud is initiated at the time when the ring of dividing cells that will become a leaf primordium completely encircles the shoot apex. A small group of surface cells just below the developing leaf primordium and on the side opposite leaf initiation, begin to divide and form a new meristem.

This meristem develops into a nodal bud and has the potential of becoming a secondary apical meristem capable of producing a secondary shoot: tiller, rhizome or stolon (Fig. 1).

Nodal buds are formed opposite most grass leaves; exceptions being the seed leaf (coleoptile), the bud scale (prophyll) and the flower scale (palea). These are all first leaves produced by an apical meristem of a new shoot (Madison, 1971) and generally arise from a node that fails to initiate a bud.

Stems emerging from the crown

Secondary stems can emerge from nodal buds on the crown and contribute enormously to the ability of a grass plant to produce a thick stand and spread vegetatively. These secondary stems include tillers, rhizomes and stolons.

Tillers emerge from nodal buds near the midregion of a grass crown. The buds normally resume growth while surrounding leaves are still functional. Growth is positively geotropic so the tiller elongates upward between the sheaths of leaves. Tillers are said to be intravaginal shoots reflecting their growth among and emergence from encircling leaf sheaths. Tillering adds shoots to a turfgrass stand and contributes in a major way to increased turf density.

Crown buds commence growth as tillers when the plant reaches a specific age or more likely a suitable energy status. Most tillering occurs in cool-season grasses during the autumn and is most abundant when temperatures are moderate to low. Tillering also occurs in the spring when temperature appears to be less of a factor.

During the hot summer months, tiller emergence is much reduced although this can be influenced by management. In general, mowing promotes tiller production and this is also influenced by leaf length. Long leaf blades are correlated with few tillers while shorter leaves are associated with more frequent tillering (Etter in Madison, 1971). Very close mowing reduces the photosynthetic leaf surface so much that the plant's energy status is lowered and tillering declines. Modest fertilization will promote tillering. Excessive nitrogen promotes leaf growth but depresses tiller production.

Tiller production is not unlimited. There can be no more tillers than there are crown buds that can develop into tillers. With one bud per node, the number of nodes in a grass crown sets the upper limit for tillers that can be produced.

Of course, as each leaf is initiated from the crown apex, a new bud is formed and thus another potential tiller. Most grasses can produce no more than 14 to 20 leaves per stem (Madison, 1971).

Most tillering occurs in cool-season grasses during the autumn and is most abundant when temperatures are moderate to low.

Not all crown buds develop into secondary shoots — some remain dormant and never resume growth. Stand density influences the degree of grass tillering. More tillers per plant are observed in thinly spaced plants than in dense stands of grass.

The base of each tiller develops into a secondary crown, which remains attached to the original primary crown. As several tillers emerge from crown buds, the total crown structure becomes increasingly complex and can enlarge substantially. The fre-

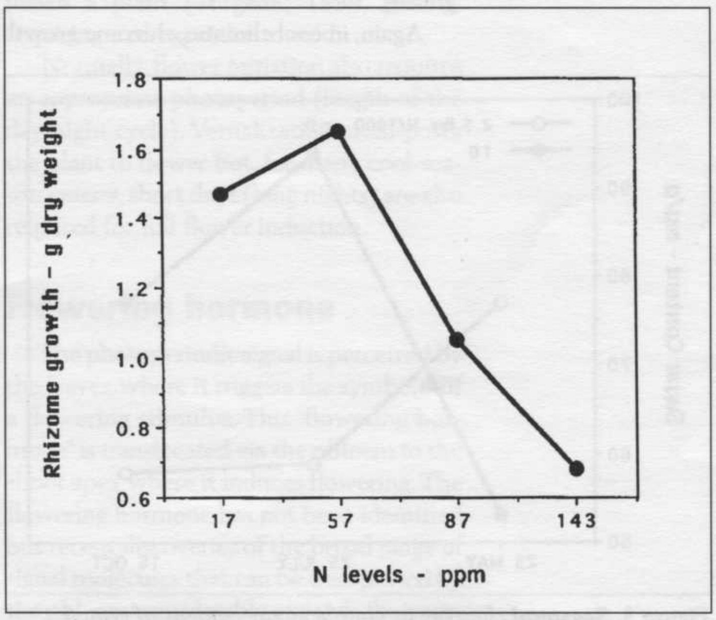

Figure 2. Impact of nitrogen supply on rhizome growth of Kentucky bluegrass (Madison (1971).

quent and close mowing associated with turfgrass management limits secondary crown development to levels well below that observed in unmowed or infrequently cut perennial grasses.

Rhizome growth

A rhizome is a stem distinctly different from the crown in that internodes elongate by as much as an inch or more.

Rhizomes are horizontal shoots that also emerge from basal crown buds in some grasses. Rhizome initiation occurs in a seedling plant, tiller or plant originating from a rhizome or stolon bud at about the five-leaf stage. The trigger for rhizome initiation appears to be carbohydrate or energy status (Madison, 1971) but we cannot exclude a possible role for day-length or temperature.

Little rhizome growth occurs during the winter in cool climates but increases markedly from March through June. The high temperatures of summer depress rhizome growth in cool-season grasses but can stimulate their growth in warm-season grasses.

Again, in cool climates, rhizome growth is favored during September through November, declining again with the onset of cold weather. Managing grass as turf appears not to inhibit rhizome initiation and growth although the length of rhizomes is normally much reduced. This is likely a restriction imposed by stand density rather than by insufficient energy.

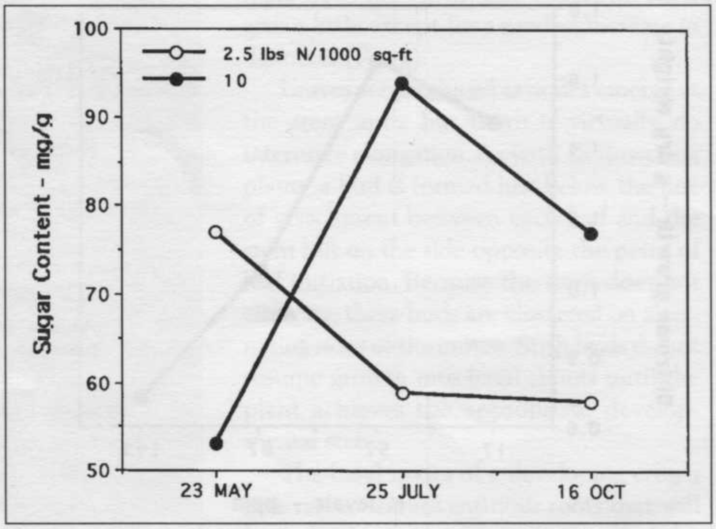

Figure 3. Seasonal changes in simple sugar content of crown tissue from Kentucky bluegrass grown at two N levels (Hull & Smith 1974).

Rhizome growth progresses through three phases. The initial primary growth occurs in a downward direction that places the apex well below the soil surface. Soon, this is followed by horizontally oriented secondary growth that is the major growth phase of most rhizomes. Unless stand crowding is limiting, the secondary phase can consist of 20 nodes being produced over a distance of several feet.

A rhizome is a stem distinctly different from the crown in that internodes elongate by as much as an inch or more. The rhizome apical meristem is covered by scale leaves called cataphylls, one produced at each node.

As internodes elongate, the nodes and their cataphylls are arrayed in regular intervals along the rhizome length. At each node, opposite the cataphyll, is a bud which normally remains dormant until induced to resume growth and produce a new plant.

Eventually, the rhizome enters its tertiary growth stage when the tip grows upward and the cataphylls, that until now have consisted only of a leaf sheath, develop a collar and form a rudimentary blade. When the cataphylls covering the rhizome apex break through the soil and are exposed to light, internode elongation stops and a new crown develops.

The former rhizome, now crown apex, continues producing leaf primordia that develop into full grass leaves. The crown functions much as did that of the parent plant from which the rhizome originated.

Low rates of nitrogen fertilization will stimulate rhizome growth but even moderate rates will retard growth (Fig. 2). Nitrogen also will exacerbate the inhibitory effect of high temperatures on rhizome growth. At 90-100°F, nitrogen applications can cause rhizome death in cool-season grasses. Reduced rhizome growth in response to nitrogen application results from fewer nodes being initiated rather than shortened internode elongation.

Nitrogen can promote rhizome growth under some circumstances. While only low nitrogen plants will initiate many rhizomes during the fall, autumn fertilized plants have been observed to produce more rhizomes during the following spring.

Again, much of this nitrogen effect can be attributed, at least in part, to plant energy status. This nitrogen inhibition on rhizome initiation and growth is more characteristic of mature turf and much less evident in young turfgrass stands.

Stolons' horizontal growth

Stolons are similar to rhizomes in that they, too, arise from basal buds on the turfgrass crown. They differ in not undergoing a downward primary growth phase but rather growing horizontally right from the beginning.

As a result, stolons grow along the soil surface and their cataphylls are more likely to consist of both a leaf sheath and small blade. Also, the nodal buds of stolons are more likely to initiate new plants quickly than are the buds of rhizomes. If stand density is not too great, stolons can grow for several feet before their apex turns upward and initiates a terminal shoot from which a new crown will develop.

Vegetative spread via stolons is characteristic of many warm-season turfgrasses including bermudagrass, buffalograss, zoysiagrass, carpetgrass, centipedegrass and St. Augustinegrass. Many of these grasses are commercially propagated and established by planting stolons.

Among cool-season grasses, creeping bentgrass, velvet bentgrass and rough bluegrass are the only ones that spread primarily by stolons. Cool-season grasses that spread vegetatively are more likely to do so via rhizomes.

Both rhizomes and stolons arise from buds at the base of a grass crown (Fig. 1). If leaf sheaths are still present when a basal bud resumes growth, the rhizome or stolon breaks through the sheath forming what is termed an extravaginal shoot. Once rhizome or stolon growth begins, several normally are initiated within a short time from basal crown buds, allowing the plant to spread in all directions.

In a dense sod situation, rhizome and stolon growth is usually restricted but has great potential to fill-in open areas caused by disease or mechanical injury. Early rhizome and stolon growth knits a turfgrass sod together, making it possible to harvest sod within 8 to 12 months after seeding.

If stand density is not too great, stolons can grow for several feet before their apex turns upward and initiates a terminal shoot from which a new crown will develop.

A turfgrass crown will be induced to flower when conditions are favorable. In cool-season grasses, flower induction frequently involves exposure to cold temperatures for a period of several weeks or longer. This vernalization response is centered in the crown's apical meristem but does not elicit an immediate response, probably because it occurs during late fall and early winter. Temperatures of between 32°F and 45°F are sufficiently cold for vernalization, although the process is more rapid and complete at lower temperatures. A period of warm temperatures can devernalize a plant (Turgeon, 1999, p. 36), requiring a re-exposure to cold.

Normally, flower initiation also requires an appropriate photoperiod (length of the day-night cycle). Vernalization predisposes the plant to flower but, for many cool-season grasses, short days (long nights) are also required for full flower induction.

Flowering hormone

The photoperiodic signal is perceived by the leaves, where it triggers the synthesis of a flowering stimulus. This 'flowering hormone' is translocated via the phloem to the shoot apex where it induces flowering. The flowering hormone has not been identified but recent discoveries of the broad range of signal molecules that can be transported by the phloem considerably expands the number of possible candidates (Hull, 1999b).

While most cool-season grasses are

induced to flower during the short days of late fall, flowering is delayed until the long days and warm temperatures of spring. For this reason, tillers initiated during the spring often will not flower until the following spring while tillers produced during the fall will flower that spring. While December tillers might flower, tillers maturing in late January or February did not flower (Madison, 1971, p. 32).

The grass crown is the only truly perennial organ of a grass plant.

When a crown apex is induced and initiated to flower, the apical meristem elongates and produces many buds that will develop into spikelets (flower clusters). At the same time, or soon thereafter, the upper internodes of the crown begin elongating and lift the developing inflorescence through the tube formed by encircling leaf sheaths.

During this elongation process, the youngest leaves emerge as culm (stem) leaves and the maturing inflorescence is lifted above the flag leaf into the atmosphere. This is the only time a grass crown apex is visible as a true stem. Flower induction is terminal for the flowering culm — it will die once flowering and seed set are completed.

However, the nodes lower on the crown that did not experience internode elongation continue to produce tillers from their buds, and these do not die because the crown apex has flowered. In this way, the crown enlarges as more secondary crowns are added to it, which, in turn, will produce tertiary tillers and crowns.

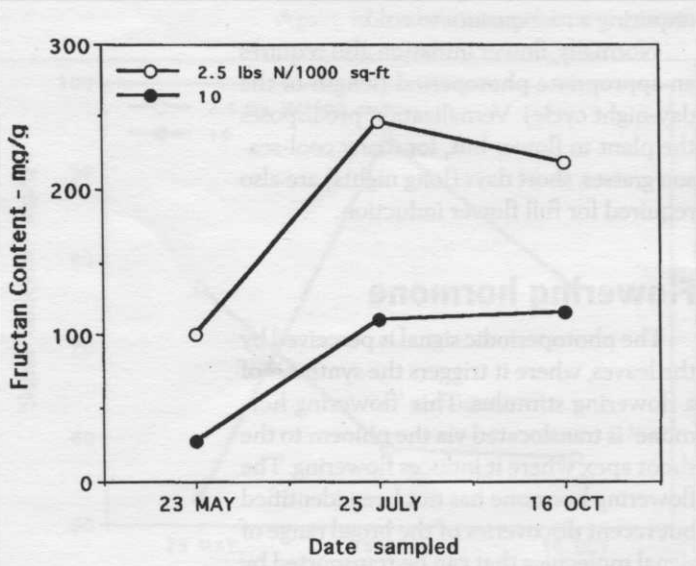

Figure 4. Seasonal changes in fructan content of crown tissue from Kentucky bluegrass grown at two N levels (Hull & Smith 1974).

Crowns as storage organs

The grass crown is the only truly perennial organ of a grass plant. Roots and leaves normally live for less than a year. Rhizomes and stolons are regenerated each year, which leaves only the parent crown with any permanency.

Consequently, only the crown is able to maintain energy reserves to power new growth and replace injured organs. Rhizomes, stolons and leaf sheaths do serve as temporary storage organs but their energy reserves are pretty much directed toward local needs. Rhizomes and stolons support new shoot and nodal root growth and rhizome extension. Leaf sheaths support the emerging inflorescence while roots actually serve a minor storage role in grasses.

When you read about carbohydrate reserves accumulating or being used in response to a turf management practice, it is crown reserves that are most involved. Crown reserves undergo seasonal cycles being drawn down during spring and fall regrowth and replenished during the late spring and fall-winter periods.

Yes, even during the winter, cool-season turfgrasses carry on photosynthesis that powers root growth and replenishes carbohydrate reserves in the crown (Hull, 1996). The turf may appear brown and nonfunctional but many green leaves lie just below the dead surface leaves and they are photosynthetically active whenever temperatures are above freezing.

Cool-season grasses store mostly simple sugars and fructans (Hull and Smith, 1974). Some temporary starch accumulation can occur in leaves, but the primary storage carbohydrates are fructans, which are polymers of fructose built on a sucrose molecule.

Both simple sugar and fructan concentrations undergo substantial seasonal variation, and this variation is strongly influenced by nitrogen nutrition (Figs. 3 & 4).

Nitrogen stimulates shoot growth during the spring and this draws down all carbohydrate reserves to very low levels. Less heavily fertilized turf also experiences a spring carbohydrate decline but it is much less dramatic. During the summer and into the fall, fructan levels gradually increase but they are always more abundant in low fertility turf (Fig. 4).

Simple sugars are present in lesser amounts and they increase when metabolic activity is high (rapid growth or stress induced respiration). For that reason, heavily fertilized grass that is growing more rapidly normally has higher simple sugar levels, except during the spring when energy levels are generally diminished (Fig. 3). During the winter months, reserve carbohydrates slowly increase unless conditions are such that photosynthesis is inhibited.

Warm-season grasses store starch in their crown and stem tissues along with variable amounts of sucrose. They also experience seasonal variations with a spring-time low and a progressive increase throughout the summer and early fall. These grasses generally experience winter dormancy and carry on little photosynthesis at that time.

Consequently, carbohydrate reserves are highest in mid-autumn and slowly decline during the winter and early spring. In mild climates, where winter dormancy is not induced, warm-season grasses will grow all year and their carbohydrate reserves normally experience less seasonal variation.

For all grasses, low carbohydrate concentrations in crown tissues indicate vulnerability to adverse environmental conditions and damaging management practices. At such times, the grass simply lacks the energy to respond aggressively to stresses or injury. Recognizing this fact may assist in altering management practices so as to minimize grass injury.

Turf management and crown functions

The turf manager is confronted with an interesting problem in that the management program should be geared to preserving the integrity of a grass organ that is largely invisible.

Crowns must be preserved because all other organs can be replaced except for them. Simply knowing the crown is present and is important represents a good first step to sound turf management. With this realization, several management variables can be analyzed for their impact on the vitality of grass crowns.

Mowing. Since all new leaves emerge from the grass crown, any mechanical injury to the crown should be avoided. If grass appears to have heaved during the winter or in any way appears excessively exposed, consider rolling or topdressing before the first mowing. Raising the height of cut for the first mowings in the spring may reduce crown injury when the cutting height is lowered later.

The turf may appear brown and nonfunctional but many green leaves lie just below the dead surface leaves and are photosynthetically active whenever temperatures are above freezing.

Flowering is not a problem for most grasses maintained as a turf. However, Poa annua and some Kentucky bluegrass cultivars can flower heavily in the spring and early summer. The flowering culms will die, but that is no reason to lower cutting height to remove as much dead stem tissue as possible.

The crown below each flowering culm is not dead and will produce tillers from its buds that will rapidly replace the lost grass. Close mowing may scalp the crowns, causing their death, and it will surely reduce the leaf surface feeding the crowns, thereby limiting their ability to generate new tillers. Remember, crown reserves may be low during early to mid-spring.

Fall is a good time to raise the cutting height. Photosynthetic leaf surface is the greatest resource a grass plant has to replenish depleted carbohydrate reserves. Replacing roots and generating tillers in the fall can lower energy reserves in the grass crowns. These need to be replaced, and promoting photosynthesis is the only way to do it.

A higher cutting height will maintain a larger leaf surface area which will make more carbohydrates available to the crowns. During the winter, surface leaves will desiccate and die but the health of your turf depends on the photosynthetic activity of lower leaves. If grass is mowed too close, there will be no lower leaves, the stand will be weakened and the turf will be ill prepared to resume spring shoot growth.

During the winter, surface leaves will desiccate and die but the health of your turf depends on the photosynthetic activity of lower leaves.

Fertilizer management. Carbohydrate reserves in grass crowns will be reduced during the spring, and nitrogen fertilizer increases this problem. Consequently, mid-spring fertilization that will stimulate excessive leaf growth should be avoided. Some of that growth is occurring at the expense of reserves in the crowns.

This is more than a problem of having to mow more frequently or disposing of additional clippings. Crown starvation can be occurring, and that could result in stand collapse should disease or other stress conditions develop. Assimilating nitrogen is an energy demanding process, and if all it accomplishes is more rapid leaf growth that is soon removed by mowing, the grass plants suffer a net energy drain.

Because nitrogen fertilization promotes leaf growth, it should be avoided whenever tillers, rhizomes or stolons are being initiated. A light application of nitrogen in early fall will probably stimulate tillering, and late fall fertilization after most tillering has occurred also will be beneficial.

Inappropriate nitrogen applications can divert so much energy from rhizomes and stolons that they succumb to disease or are killed by other stresses. Poorly timed fertilizer applications can seriously retard rhizome and stolon growth and thereby limit the ability of grass to spread, repair damage and increase density. This is most likely to result from heavy nitrogen applications during mid-fall and mid-spring.

Fertilizer applied during early spring will generally be beneficial. If shoot growth has not yet commenced, nitrogen will not stimulate excessive growth but will be absorbed, reduced and assimilated and then be available to support all growth when it is initiated.

Other plant nutrients are less sensitive with respect to growth stimulation and the maintenance of adequate energy reserves in crowns and other stems. Following a period of rapid shoot growth and heavy clipping production, whether stimulated by nitrogen or not, a light application of phosphorus, potassium and even micronutrients is often beneficial.

Nutrients are lost from turfgrasses when clipping removal is heavy. These nutrients should be replaced before the plants are asked to tolerate stress conditions and recover from wear or other injuries. A major advantage of providing nutrients following heavy growth is that they will increase the efficiency of metabolic processes, making more energy available for crown replenishment and appropriate responses to stress conditions.

Water management. Crowns are at or just below the soil surface and, as such, have little insulation from rapid changes in temperature, moisture status and other environmental variables. Crowns are also living stems that require oxygen for normal functioning.

Consequently, they should not be subjected to prolonged flooding or ice cover. Other plant organs are no less sensitive but can be replaced; crowns cannot.

Heavy irrigation that promotes standing water or poor drainage that allows water to pond for extended periods should be avoided. This is important during the warm months because metabolism is rapid and oxygen supplies can quickly become exhausted.

It is no less important during the cold season because crown activity continues.

Prolonged periods of flooding can cause significant injury due to anaerobic conditions and disturbed metabolism.

Disease and other secondary stresses can be especially damaging to grass weakened by periods of anoxia. Soils are generally wetter during the cold season and surface flooding can easily occur without notice. This can even occur under a snow cover where it is especially difficult to monitor.

Being conscious of good drainage is obviously an important part of sound turfgrass management. However, the sensitivity of perennial grass crowns to anoxic conditions is another critical reason to take drainage problems seriously. It is not uncommon for winter-spring disease problems to be aggravated by a weakened turf resulting from periods of surface flooding and anoxic stress.

Hopefully this discussion has made you more conscious of the need for managing turfgrasses with crown well-being in mind. Crowns may not be visible but maintaining their health is an essential objective of effective turfgrass management.

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REFERENCES CITED

Christians, N. E. 1998. Fundamentals of Turfgrass Management; Chapter 2. Introduction to the grasses. p. 9-31. Ann Arbor Press, Chelsea, MI. 301 pages.

Hull, R.J. 1996. Turfgrasses. Chapter 33:781-796 IN E. Zamski and A.A. Schaffer (eds.). Photoassimilate Distribution in Plants and Crops: Source-Sink Relationships. Marcel Dekker, Inc., New York.

Hull, R.J. 1999a. Back to basics: How turfgrasses grow. TurfGrass Trends 8(5):7-12.

Hull, R.J. 1999b. How does turfgrass allocate energy? Golf Course Management 67(8):60-63.

Hull, R.J. and L.M. Smith. 1974. Photosynthate translocation and metabolism in Kentucky bluegrass turf as a function of fertility. p. 186-195 IN E.C. Roberts (Ed.) Proceedings 2nd International Turfgrass Res. Conf., Amer. Soc. Agron., Madison, WI.

Madison, J.H. 1971. Principles of Turfgrass Culture; Chapter 1. Anatomy and morphology of the turfgrass plant. p. 1-48. Van Nostrand Reinhold Co., New York. 420 pages.

Turgeon, A.J. 1999. Turfgrass Management, Fifth Edition.; Chapter 2. Growth and development. p. 15-47. Prentice Hall, Upper Saddle River, NJ. 392 pages.