ISTRC's GUIDEBOOK

to

YOUR GREENS

by

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I. INTRODUCTION

ISTRC was founded to serve and support the golf course superintendent, in particular, and the turf grass industry, in general. Our primary function is to provide useful information to the superintendent. That is, information which enables the superintendent to perform his/her job to the best of his or her ability.

The dissemination of useful information requires us to be more than a mere reporter of lab data. We believe that test results are meaningless without interpretation and education. Interpretation and education go hand-in-hand. For instance, if we test a root zone mix, interpretation merely tells the professional whether it is an appropriate material with which to build a green. Education tells the professional why it is an appropriate material.

With the introduction of the patented ISTRC SYSTEM™of undisturbed core testing, our education function becomes more complicated. We quickly discovered that the superintendents and turf grass professionals in the field were a treasure trove of knowledge gathered by experience and passed from generation to generation of professionals. This knowledge needed to be collected and shared. We also discovered a synergy between our testing of raw materials and our expanding knowledge with respect to how those materials reacted in the field. Finally, we discovered that undisturbed core testing was providing information which was not available from any other source.

This <u>Guidebook</u> was written for a very simple, yet fundamental, reason. Our reports were becoming too long and repetitive. As our knowledge expanded, the length of the reports expanded. In our opinion, the ever increasing length of the reports was becoming counterproductive.

This is a "primer" which was written for the superintendent, the turf grass professional, the crew, the greens committee, the supervisor, and the owner. It allows us to discuss the basics in greater detail than we were permitted in a report because of length constraints. The reports are more focused, but they reference sections which are pertinent to understanding the tested green. It is a partial compilation of the accumulated knowledge of our clients, academia, and ourselves -- to date.

II. SOIL PHYSICS vs. CHEMICAL TESTING

A golf green is a high stress environment. The turf is cut to minute tolerances and subjected to heavy traffic and abuse. We expect the turf to thrive irrespective of the weather conditions. Invariably, the signature holes on a golf course are those which constitute the poorest growing environment because the trees, shrubs and setting of the hole invariably shade the green and restrict air movement.

Grass, like all green plants, converts light energy, carbon dioxide & water into simple sugars through a process called photosynthesis. Water is transported from the roots to the leaves which gather carbon dioxide. In the presence of chlorophyll, light energy, water and carbon dioxide are converted into a carbon-based simple sugar [a carbohydrate] such as glucose [a compound composed solely of carbon, oxygen & hydrogen]. The "waste" from photosynthesis are water and oxygen.

The created simple sugars are stored in the roots for the future use of grass plant's cells. The sugars store light energy for future use by each cell to "power" its individual life processes. However, the actual storing and release of the energy in simple sugars is dependent on the creation of two additional compounds, using light energy captured by the chlorophyll. Those additional compounds require nitrogen and phosphorus.

The breakdown of the simple sugars [carbohydrates] by the individual cells into energy involve the nitrogen/phosphorus compounds and <u>oxygen</u>. The waste by-products are carbon dioxide and water.

Chemical testing determines the ability of the soil to deliver the nutrients and trace elements [micronutrients] required by healthy grass plants to thrive. Amino acids, which are called "the building blocks of life", always contain nitrogen, and some require sulphur. Amino acids and proteins are essential elements in the individual cells. Phosphorus is present in the nucleus of every cell. Potassium is required by the plants to help regulate the flow of elements between cells. Other elements, such as iron, boron, manganese, copper, zinc, sodium & chlorine, are required in minute amounts. Most of the trace elements are enzyme components. All of the nutrients and micronutrients are obtained by the roots.

Nutrients are present in the soil in several forms: (a) those which are dissolved in the soil water; (b) those which are bound by ions to soil particles [that is, "Cations"]; and (c) those which are locked in organic compounds. Nutrients which are dissolved in the soil water are readily available to the roots for absorption. They are also susceptible to being lost through leaching. Nutrients which are bound to soil particles are available to the roots through <u>Cation Exchange</u> and can be dependent on the pH balance of the soil. Nutrients which are locked in organic compounds are unavailable to the roots until they have been released by microbial activity.

One of the basic problems of plants, like animals, is the procurement of oxygen and the elimination of carbon dioxide. It is a common misconception that plants only take in carbon dioxide for photosynthesis and release oxygen to the atmosphere as a waste by-product. However, plants like animals must obtain oxygen to convert the simple sugars into cellular energy. Consequently plants, like animals, are constantly taking in oxygen and releasing carbon dioxide [waste product].

It is another common misconception that the leaves of a plant are the sole air-gatherers. In fact, the roots are an important gas-exchange medium. They are the primary source of a grass plant's oxygen.

The roots gather oxygen from the soil and release the carbon dioxide waste product into the soil. Carbon dioxide will gradually increase in the soil, and the oxygen content will decline, unless air circulation [permeability] permits the release of carbon dioxide-rich soil gases with the atmosphere and the replenishment of the oxygen supply.

Soil physical evaluation tests the ability of a root zone: (a) to maintain adequate oxygenation; (b) to supply the water requirements of the turf; and (c) to supply the nutrient needs of the turf. It is similar to chemical testing which is concerned with maintaining an appropriate balance of nutrients and micronutrients in a soil, in that physical testing is concerned with maintaining an appropriate balance between the air and water properties in conjunction with the nutrient delivery systems.

III. THE BIOLOGICAL & PHYSICAL FUNCTIONS OF THE ROOT ZONE

A. What is "Soil"?

By definition, soil is composed of three components, individually or in combination: (a) Sand, (b) Silt, & (c) Clay -- gravel is not considered as a soil component. A loam soil, for instance, is by definition composed of 5 to 10 percent clay, 25 to 50 percent silt, and 30 to 55 percent sand. Other soil classifications are based on the relative percentage distribution of the three components.

Sand, silt and gravel are defined solely by particle size. The chemical/mineralogical composition of the material is not considered. In contrast, clay consists of a family of secondary minerals created by decomposition or weathering.

Sand is, by definition, material between 0.05mm and 2.0mm in size. Material larger than 2.0mm is defined as gravel, or rock. Naturally formed sands are classified as either silica or calcareous. Silica sand is primarily silicon [quartz] in composition, whereas calcareous sands contain calcium compounds [calcium carbonate]. Calcareous sands are typically formed from limestone strata. A third less common sand is dolomite. Dolomite typically is a combination of calcium and magnesium carbonate compounds. Manufactured sands are materials typically created by rock crushing operations.

By definition, silt is any material between 0.002mm and 0.05mm in size. It appears similar to clay, but its chemical composition and physical characteristics are more similar to fine sand.

Clay consists of the smallest particles -- less than 0.002mm in size. The clay "family" consists of three major groups: (a) kaolinite -- the clay used for bricks and pottery, it is a material low in nutrient retention [fertility]; (b) montmorillonite -- a clay which is high in nutrient retention [that is, a high Cation Exchange Capacity ("CEC"); and (c) illite -- a clay which consists of degraded mica.

A property of clay particles is termed: "flocculation". Flocculation refers to the natural affinity of clay particles to each other. Small clay particles bond to other clay particles to form progressively larger clay particles. It is possible, however, for clay to "deflocculate". Deflocculation can be caused by chemical [for instance, high salts content water] action, or mechanical [for instance, heavy washing as in a flood] action. Deflocculating clay particles repel each other and bond to the larger sand and silt particles. The bonding properties can be so severe as to cause a sand to form a sandstone-like substance. Unlike sandstone, however, pressure is not required.

Clay particles tend to be relatively flat. Consequently, compaction can compress clay particles into a dense material.

Organic material in various stages of decomposition is commonly found in native soils. The organic composition of a soil may not be considered in the classification of the soil, but it can have a significant impact on the soil's fertility. By definition, organic material is any carbon based compound. Like clay, most organic material is highly susceptible to compaction; that is, compaction can compress organic material into a relatively dense mass.

B. Porosity

Soil is not a dense, impervious mass of material. On the contrary, it is a matrix of sand, silt & clay particles with spaces ["pores"] between the individual particles. The size of the pores varies. As a general rule, larger particles create larger pores and smaller particles create smaller pores. In practice, the nature and composition of the pore spaces is dependent on the percentage distribution of particle sizes, the composition of the soil, the percentage of organic material, and the relative decomposition of that organic material.

The voids, or pores, are classified as one of two "types". The first type of voids are the very small "Capillary" pores. Percolating water infiltrates these pores and is held by "hydraulic tension". Capillary porosity measures the small water holding pores in a given area of a root zone. It reflects the amount of moisture retained in the root zone which is available to the roots.

The infiltration [or "percolation"] of water through a root zone is a function of the larger "Non-Capillary" pores as opposed to the small water-holding [Capillary] spaces. Non-Capillary pores are relatively large compared to the small water-holding pores. Like the small water-holding pores, percolating water infiltrates the large voids between the material comprising the root zone. The infiltrating water gradually fills the large pores until the weight of the water is sufficient to break the hydraulic tension holding the water in the large pore space. Once the hydraulic tension is broken, the water filling the space flows out of the pore. If the escaping water is not replaced by more water (for instance, during a rain storm or irrigation), it is replaced by air. Consequently, the Non-Capillary porosity reflects the potential air-holding capacity of the measured root zone, which we call <u>subsurface air capacity</u>.

The tested infiltration rate reflects the relative ability of the large Non-Capillary pores to drain. It is also an indirect measurement of the relative ease with which air can penetrate, and exit, the root zone. Consequently, we refer to the infiltration rate as a measurement of both <u>air & water permeability</u>. Air permeability is critical to healthy turf.

The positive benefits of well-aerated soil has been amply documented with field studies involving commercial crops. The positive effects of well-oxygenated golf greens was demonstrated by Mr. H. Leon Howard's USGA-funded research in the 1950's -- Mr. Howard's research data is the underlying support for the USGA's recommended sand-based greens specifications.

C. Compaction

When compaction is applied to a soil, the physical properties of the soil are altered. The severity of the effects is dependent on multiple factors; such as, percentage composition of sand/silt/clay, and the particle size distribution of the soil. The most direct effect of compaction is the physical restriction of root growth. roots grow in the pore spaces. Compaction increases the density of the solid material in a given area and reduces the size and amount of pore spaces. Field studies have found that the size of the pore spaces in a root zone is as important as the amount of pores to root growth. In other words, very small water holding pores are as effective an impediment to root growth as solid material.

The major indirect effect of compaction is its negative impact on subsurface air capacity and air/water permeability. Compaction reduces Non-Capillary pore space. Permeability is a function of: (a) the amount of Non-Capillary pore space in a given area, and (b) the relationship of the Non-Capillary pores to each other. Water infiltration, for instance, requires the flow of water from one Non-Capillary pore through successive Non-Capillary pores. The exchange of soil gases with the atmosphere is dependent on the same inter-relationship between Non-Capillary pores.

Compaction reduces air capacity and permeability. The most immediate effect is a reduction in the root zone's oxygen content. However, reduced permeability also impacts the release of excess moisture from the soil and the penetration of nutrients.

D. Layering & Saturation

It is possible to seal off a root zone at, or near, the surface. The effect is similar to placing a plastic bag over your face -- survival is dependent on the amount of oxygen retained in your lungs. Our work has found that organic material concentrated in a layer form is the most commonly occurring "sealant".

There are three primary sources of layering: (a) the roots themselves, (b) sod -- washed and unwashed, and (c) topically applied contamination such as "silty" irrigation water. The roots begin forming an organic layer from the moment of germination. The normal life processes of growth, die-back, and sloughing deposit organic material in the root zone. The root-created layering is the most common form and least recognized cause of deteriorating turf conditions.

The root-created layering is capable of completely sealing off an otherwise healthy root zone. Layering typically begins forming approximately 1/4th inch below the surface. The roots grow through the larger pore spaces; consequently, the organic material deposited by the roots is deposited in the same pore spaces. The result is a contamination of the Non-Capillary pores which reduces permeability and subsurface air capacity. Concomitantly, water retention is increased. Root-caused layering is not confined to sand-based root zones or a particular maintenance program. It is a condition which has been documented in root zones from the South Seas, to arid desert areas, to temperate Scotland.

It is also possible to seal off a root zone by a process we call, for lack of a better term, "saturation". If the percolating water contained in the air-holding pores cannot be released through the subgrade, the water will remain in the air-holding pores because it has no place else to go. The air, which may have been in the root zone, is replaced by water. When a human drowns, air in the lungs is replaced by water. Death comes from suffocation. A similar process can occur in a poorly drained upper root zone.

The response of the grass plant to either process (that is, sealing off the root zone at the surface, or saturation) is for the root mass and feeder roots to prune and lose density. The root mass will typically be confined to approximately 1/4th inch in depth. The feeder roots will prune to approximately 3 inches in depth. It is common to observe less than 5 feeder roots in an undisturbed, sealed off core sample.

E. Thatch

Thatch is raw undecomposed organic matter at the surface of the root zone. The development of a thatch layer can improve the playability of a golf green, it protects the sensitive crown areas of the grass plant, and it reintroduces nutrients and micronutrients into the upper root zone. The problems associated with thatch are as follows:

(a) Thatch can seal off a root zone. The best analogy is a thatched roof. Just like homes in England and South Africa are protected from the elements by a thatched roof, grass thatch can impede water percolation and limit air permeability. The root zone is rendered unusable by the roots because of poor nutrient migration, poor oxygenation, and poor water distribution.

(b) Using thatch to improve the playability of a golf green usually is attacking the symptoms of a more basic problem in the root zone. Too often, the root zone has developed a relatively high organic content near the surface. The thatch compensates for the "rock hard" qualities of dry high organic root zones by "softening" the playing surface. It does not, however, improve the "mushy" condition of a high organic root zone when it is wet.

(c) Thatch holds moisture and creates an excellent breeding ground for disease and other pests which prey on the grass plants.

(d) The decomposition of the thatch, and the release of the locked nutrients, is dependent on the existence of microbial populations capable of consuming the organic material. Certain chemicals in common usage kill the microbes which breakdown raw organic material.

Healthy turf systems need a thatch layer, but too much thatch can create problems which outweigh the benefits. It is incumbent on the turf professional to maintain a balance. Some of the new varieties of creeping bentgrass are noted for their heavy thatch production. It is ironic that the new varieties are capable of quickly destroying the very environment which initially allows them to thrive.

F. Oxygen, Organic & Microbes

The role of organic material in a root zone is widely misunderstood. High quality peats and composts are used in new root zone mixes to (a) improve moisture retention, (b) slow water infiltration, (c) introduce nutrients and micronutrients into the root zone needed to support plant life, and (d) improve the root zone's nutrient retention capacity [CEC]. Root-created organic material similarly retains moisture, reduces permeability, and contains needed nutrients and minerals. It is a common misunderstanding that organic material is "food" for the turf. Rather, organic material is "food" for microbes -- such as aerobic bacteria.

The roots cannot directly access the minerals and nutrients locked in the organic material. The minerals and nutrients are unavailable to the root systems without synergistic microbes. The microbes consume and break down the organic material utilizing the minerals and nutrients to support their own life processes. Nitrogen compounds which are in a useable form to the roots are a by-product of the synergistic microbes. Similarly, the nutrients and minerals which are consumed by the microbes become available to the roots when the consuming microbe dies -- fortunately, their life-span is very short.

Neither healthy roots nor synergistic microbes are able to thrive in an oxygen-poor, anaerobic, environment. So-long-as the root zone has adequate subsurface air capacity and the ability to replenish the oxygen supply by exchanging gases with the atmosphere (air permeability), vigorous synergistic microbial populations can exist in concert with healthy root systems. The problem is that organic material is: (1) highly susceptible to compaction, and (2) is capable of contaminating a root zone's air pores. The two properties are capable of independently sealing off a root zone thereby denying the synergistic microbes and root systems of the oxygen which they require to thrive. In a golf green, however, compaction and contamination are usually found in tandem -- a combination which can be lethal.

A root zone needs organic material, but too much organic can create a root zone environment which makes the organic material unusable. In other words, too much organic material can seal off the root zone thereby denying the synergistic microbes of the oxygen they need to live. Without the microbes, the organic material cannot be broken down and used by the roots.

G. Cation Exchange Capacity [CEC] & Plant Nutrition

We have previously discussed the grass plant's need for food [nutrients], water & oxygen in its root zone. We have also alluded to field studies which found that the depth and density of root systems are directly related to the ability of the root zone to supply oxygen. Cation Exchange Capacity, known as "CEC", is a measurement of the nutrient holding capacity of a root zone. It directly affects the root zone's ability to support the turf's nutrition requirements.

Sand and kaolinitic clays are exceptionally low in CEC; consequently, they are considered "infertile" soils. In contrast montmorillonitic clays, high quality peats & composts, diatomaceous earth, certain lava deposits such as clinoptilolite zeolite & rhyolite tufts, and others are relatively high in CEC. [The existence of CEC, by itself, does not render a material suitable for growing healthy turf; however, the existence of CEC may be a reason to prefer one material over another otherwise equal material.]

Roots are "passive" feeders in that a nutrient must be in close proximity to a root hair to be absorbed by the plant. Nutrients can be available in the soil in the following forms: (a) nutrients in solution with the soil water, (b) nutrients attached to cation exchange points, (c) nutrients which are "locked" in organic material, and (d) nutrients created by synergistic microbes, primarily useable nitrogen compounds, either in humus or the decomposed residue of dead microbes.

As we discussed in the previous section, the desirable synergistic microbes are aerobes. Like the grass plants, they need oxygen to live and release carbon dioxide into the soil as a waste by-product. They are in competition with the roots for soil's oxygen and cannot survive in appreciable numbers in a low-oxygen environment. A root zone which cannot efficiently release its carbon dioxide soil gas and replace it with oxygen-rich air from the atmosphere is incapable of supporting deep root systems or the microbial populations which benefit the turf.

Nutrients suspended in the soil water typically enter the root zone from topically applied fertilizers. These nutrients are highly susceptible to leaching. The nutrients are available to the roots as the roots are "bathed" in nutrient rich water, or a root hair penetrates a water-holding pore which contains water-suspended nutrients. Straight sand greens rely exclusively on this system to feed the turf until sufficient organic material has been deposited by the roots in the soil to provide CEC and organic-locked nutrients.

CEC is a chemical property of organic and some inorganic materials. In simple terms, cation exchange points hold nutrient molecules and prevent them from leaching out of the root zone. The root hair "trades" a hydrogen ion for the nutrient ion. CEC improves the efficiency of fertilization. In rough terms, turf on a straight sand green may be able to use only 25% of the topically applied fertilizer before the remainder is lost to leaching. CEC is capable of increasing that usage to above 70%.

The CEC of organic matter is pH-dependent. The soil pH must be at least 5.5 before organic CEC becomes effective. In contrast, the CEC provided by inorganic material such as clinoptilolite, diatomaceous earth, certain ceramics, and certain rhyolite tufts [a lava created substance] is not pH dependent.

Theoretically, it is not possible to have too much CEC in a root zone. From a management perspective, however, inordinately high CEC can cause the professional to lose control of his turf. For instance, it is a common practice for superintendents to prepare their greens for a tournament by "starving" the grass for a few days. If the soil has too much CEC, the professional must lengthen the starvation period and run the risk that areas, and greens, may respond differently. As a rule of thumb, a CEC of 8 to 12 meq./100g is an appropriate range which balances efficient fertilizer use with the need to control feeding.

IV. ROOT ZONES & THEIR ENVIRONMENT

A. USGA Sand Based Greens

In the 1940's, the USGA began funding a series of research projects at Texas A&M which culminated in the publishing of Mr. H. Leon Howard's Master's Thesis in May, 1959. The purpose may be best stated by Mr. Howard's introduction to the Thesis:

> Soil compaction is recognized as one of the major problems to be overcome in the production of crops and particularly in producing good turf. This is especially true on golf courses where player traffic and the use of high speed maintenance equipment subjects the soil to constant packing. The fact that golfers demand that the grasses be kept moist enough to hold a golf shot serves to intensify the compaction problem.
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> ....
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> Soil compaction under turf develops slowly and builds up over a period of time. If compaction is detected before it becomes too serious, steps may be taken to alleviate the condition. In too many instances, however, complete deterioration of turf occurs before the basic cause is realized. Compaction has been considered by some specialists to be the major factor contributing to the loss of turf on putting greens. Because the effects of this condition are not readily identifiable in the early stages, it is well to take precautionary measures in building greens to assure a soil mixture which will retain desirable characteristics after continuous heavy traffic.
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> **A desirable putting green soil is one in which the chemical and physical properties will favor the growth of turf and retain a good playing surface. The chemical properties are readily controlled with fertilizers and amendments, but the physical properties of a green are not easily altered after construction.** [emphasis added]

Mr. Howard's test green consisted of 135 test plots of different sand-soil-organic mixes with subsurface drains. The construction techniques used to build the green became the prototype for the USGA's recommended construction specifications for sand-based greens with subsurface drainage. The data collected from the study was used by Dr. Marvin Ferguson and Mr. Howard to create the USGA's initial recommended specifications for physical properties and particle size distribution of the sand/soil.

The fundamental problem with maintaining golf greens and athletic fields is the effects of compaction. A farmer is able to remove compaction and aerate the soil by plowing, tilling & cultivating. A golf course superintendent cannot till the greens each year; consequently, compaction continues to increase.

Sand resists compaction. A properly distributed sand is able to maintain an appropriate balance of critical properties when compacted. In contrast, soils with even moderate percentages of silt & clay sized particles are highly susceptible to compaction. [The effects of compaction are more fully discussed in the <u>Compaction</u> section <u>supra</u> at p. 5.]

The USGA recommended particle size specifications are not a guarantee that a sand/soil which meets the recommended criteria will produce an appropriate root zone [as defined by the physical property recommended specifications] when compacted. The original intent of the recommendations was that a sand/soil which meets the criteria <u>is more likely than not</u> to maintain an appropriate balance of physical properties when compacted. Similarly, the recommended specifications are not a guarantee that a sand/soil which does not meet the specifications will not produce an appropriate balance of physical properties when compacted. The USGA's recommended particle size distribution specifications remain virtually identical to Dr. Ferguson's and Mr. Howard's original specifications.

At ISTRC we have developed a set of Guidelines which are a refinement of the USGA's recommended specifications. In our research we have found that stable sands with good air porosity are built on the interrelationship of the particles which are retained on the #35, #60 & #80 mesh screens. The key to stability is the #60 mesh screen. We include our ISTRC Guidelines at the bottom of each Textural/Particle Size Distribution data report.

There are always exceptions to any set of guidelines. A heavy mica or deflocculating clay sand can satisfy the USGA's recommended specifications and our Guidelines but prove to be unsuitable in the field. We have found that a particle size analysis is merely a guide. The physical properties of a sand, or root zone mix, are the final arbiter of a sand's suitability. Consequently, we strongly recommend a physical evaluation for topdressing sands.

The primary benefits derived from USGA-profile greens [that is, greens built to USGA recommended specifications] are as follows:

(a) **Compaction Resistance.** The high sand component of the greens, when properly distributed and blended, is able to maintain air/water permeability balanced with sufficient water retention to provide sufficient oxygen and water to sustain healthy turf when compacted.

(b) **Good Drainage.** Good water permeability is ineffective unless it can be removed from the root zone. The combination of drains and good water permeability removes the moisture which otherwise would fill the Non-Capillary [air-holding] pores. The release of the percolating water through the drains permits oxygen-rich air to fill the Non-Capillary pores in the root zone thereby aerating the soil.

(c) **Perched Water Table.** The unsaturated conductivity of a properly constructed gravel bed is less than the root zone. The net effect is that moisture is not drawn out of the root zone by the drainage bed leaving a reservoir of water perched above the gravel & drains which is accessible to the roots.

We have had the privilege of documenting the dynamic nature of golf greens around the world. They are constantly changing environments which require management. The primary catalysts of change are the roots. The roots are constantly depositing organic material into the upper root zone. The organic material changes the balance between the physical properties by increasing the water retention of the root zone, reducing air & water permeability, and reducing subsurface air capacity. If allowed to develop, organic layering will seal off the root zone at, or near, the surface. The lower root zone may contain an excellent environment for growing grass, but the layering has confined the turf to growing at the surface.

Healthy turf deposits more organic material into a root zone than weak turf. The irony is that healthy turf is actually expediting its demise.

The tools are available to today's professional to manage the root zone. The key to any successful management program is information about the condition of the root zone.

B. Push-up [Native Soil] Greens

The term "push-up" refers to the traditional method of constructing greens. Prior to the advent of USGA-profile greens, earth moving equipment would typically cut out and shape the fairways. The greens were constructed by "pushing up" the soil -- usually saved topsoil -- into a mound and shaping the green. Hence the term "push-up" to describe native soil greens.

Native soils are typically high in silt, clay and fine sand. Some may even be relatively high in organic material. The basic problem is that most soils are susceptible to compaction. The observed result was that turf would thin and stress out each season. However, it is important to recognize that push-up greens are capable of supporting excellent turf. It is also important to recognize that push-up greens are capable of providing excellent playing surfaces. If compaction and saturation can be managed, push-up greens will support excellent turf.

Most native soil greens have been modified in the top 2 to 4 inches with sand. These greens are sometimes referred to as "modified push-ups". Sometimes the modifications have been achieved by stripping the top inches of a push-up green and replacing the material with a sand root zone mix. In most instances, the modification was achieved over a period of many years with sand topdressing mixes and aerification.

Most push-up greens do not drain -- there are areas where the native subgrade drains relatively well. We have found that water management is critical to maintaining healthy turf on poorly drained push-up greens.

Water from rainfall and irrigation <u>fills all the pore spaces</u> between the sand/soil particles in a root zone, including the air holding (Non-Capillary) pores. Unless the excess moisture is released from the air pores, the roots will suffocate. USGA-profile greens use gravel beds and subsurface drains to remove the excess moisture. Native soil subgrades, however, typically do not provide adequate drainage. Consequently, excess moisture must be released through the surface by evaporation and transpiration.

Most modified push-up greens are like large bowls which hold water. If the excess moisture cannot be released through evaporation and transpiration, there is a high probability that an anaerobic condition (that is, the absence of useable oxygen) will be created. The root mass will prune to the surface looking for oxygen with an observable reduction in density, and the feeder roots will similarly prune to shallower depths and become sparse. These changes reflect a loss of stress tolerance and an increased susceptibility to disease. The moist conditions in the root zone, unfortunately, create an ideal home for harmful bacteria, mold, algae, and other pests which prey on the weakened grass plants.

In our work, we have found that the key to maintaining healthy, stress tolerant push-up greens is directly related to managing the saturation of the air (Non-Capillary) pores. A balance must be struck between the need for air permeability (which is essential for evaporation and transpiration) and the need to control saturation of the root zone. The balance is predicated on the following:

(1) Surface drainage is essential to quickly move water off of the green before it has an opportunity to infiltrate the root zone. It is essential to fill in any low areas which allow water to "puddle".

(2) Our infiltration rate target range is a balance between the root zone's need to breathe and the superintendent's need to control over-saturation from rainfall. The target range is 2 to 6 inches of water per hour. It is impossible to prevent a green from becoming over-saturated during periods of extended rainfall; however, an infiltration rate in the target range coupled with good surface drainage can prevent over-saturation from "normal" showers and short heavy downpours.

Greens which are open to good air movement and sunshine, in general, are able to support healthy turf systems at the lower end of the target range. The sunshine promotes the change of water to its gaseous state, and the air movement removes the moisture from the surface. The result is effective evaporation <u>and</u> a cooling of the root. In contrast, sheltered greens must compensate for their sheltered conditions with: (a) increased attention to the moisture content in their root zones (allowing the green to dry out is very important), and (b) promoting evaporation with an infiltration rate (air permeability) at the upper end of the target range.

(3) Many superintendents have success with a practice which we call "stress management". Stress management is designed to force the roots down by drying out an initially saturated root zone. In our opinion, this practice should be used following a heavy rain. It is important to allow the root zone to dry out (that is, allow the excess moisture to release through evaporation and transpiration). We recommend constantly checking the root zone with a hand probe. A periodic syringing may be necessary to prevent the surface from becoming too dry, but the practice should be used to merely moisten the surface --- the root zone does not need more water.

(4) It is important to maintain an upper root zone with sufficient depth to accommodate deep and dense root systems -- which is critical for stress resistance -- but not so deep as to prevent the effective release of excess moisture through evaporation & transpiration. Excess moisture saturates <u>both</u> the air holding pores as-well-as the water holding pores. It forces the useable air, which the roots and synergistic microbes need to live, out of the root zone. The experience of superintendents in the field indicates that evaporation and transpiration are effective in a 3 to 4 inch root zone in the temperate areas of the country.

C. Other Types of Greens

It is possible to build greens over areas which have excellent naturally occurring drainage. A course near Austin, Texas, for instance, is built on the aquifer's recharge area. If a heavy rain leaves standing water on the course, post hole diggers are used to remove a few inches of topsoil to reach the aquifer. The water drains into the aquifer just like water draining out of a giant bathtub.

There are many areas which have excellent naturally occurring drainage. It is not necessary to have a rapid movement of water for the drainage to be effective. It is a common practice, where the drainage characteristics are understood, to build greens without subsurface drains. "California System" greens refer to sand based greens without subsurface drains. The greens need not be located over an area with good naturally occurring drainage. The management of the greens is predicated on the perceived effectiveness of the subsurface drainage.

It is not necessary to have subsurface drains to grow healthy turf. It is important, however, for the superintendent to be able to control root zone saturation.

D. The Green's Micro-Environment

A green's environment has a profound effect on turf quality. An open environment is capable of compensating for poor physical properties in the root zone. In contrast, grass on heavily shaded greens with low air movement demand ideal physical conditions to produce an acceptable turf.

Direct sunlight is important to a green for two reasons: (a) it is essential for the life processes of the grass plant, and (b) it is a key element in removing excess moisture from the root zone. As discussed in the Soil Physics vs. Chemical Testing section [supra at p. 2], sunlight is required for the creation of the simple sugars which supply energy to the individual cells. It is also required to create the nitrogen/phosphorus compounds which convert the simple sugars into energy. Direct sunlight also stimulates plant growth.

It is important to recognize that today's turf is cut very close to the surface. The grass plants have very little leaf surface to gather sunlight. Bentgrasses, in general, do not perform well in shaded environments -- they are not "shade tolerant" -- irrespective of the length of their leaves. In contrast, the *poa* pests -- *poa annua* and *poa trivialis* -- grow reasonably well in shaded conditions. A shaded environment weakens the preferred bent, bermuda & rye grass varieties and favors *poa*. The stronger *poa* has an advantage which enables it to crowd out the preferred turf varieties.

Sunlight warms the surface of the green converting water into vapor. Air movement removes the water vapor from the green thereby drying the surface. If the root zone has adequate air permeability, the whisking of the surface vapor from the green draws additional water up to the surface through the Non-Capillary pores where the moisture is converted to vapor and whisked away. The described process is called "evaporation"; this simplistic explanation demonstrates how the drying process, if unimpeded by layering or other soil conditions, moves progressively deeper into the root zone.

There is another release mechanism called "transpiration". Transpiration is, by definition, the loss of water vapor from living plant tissue. The concept incorporates the water created and released by respiration [by definition, respiration is the process of converting simple sugars into cellular energy]. Transpiration is the removal of moisture from the leaf tissue. The water is replaced by water gathered by the roots. Consequently, root depth has an effect on the effective depth with which water can be released from a root zone.

Sunlight increases the respiration process and warms the grass plant thereby improving the vaporization of moisture within the plant. Consequently, sunlight also expedites the release of moisture from a root zone by its effects on transpiration.

It is well-known that heat will stress a grass plant. Cool-season bentgrasses, in particular, are vulnerable to heat stress even though new varieties exhibit increased tolerance. Evaporation and transpiration [termed "evapotranspiration"] are cooling mechanisms. The release of moisture from the root zone and grass plants cools the plants and the surface of the green. On a hot day, a gentle breeze can reduce the ambient temperature of the surface by at least 10 degrees.

The evaporating and transpiring water vacates pore space in the root zone. Air from the atmosphere replaces the water and in the process supplies needed oxygen to the soil. Some of the vacated pores are small enough to be classified as Capillary [water-holding] pores. In essence, the effective evapotranspiration associated with open-environment greens compensates for poor subsurface air capacity by converting water-holding pores to air-holding pores. The moisture "draw" created by good air flow also compensates for poor air permeability by increasing the flow of air into the moisture-vacated pores.

There are limits to the ability of good sunlight and air flow to compensate for poor root zone properties. Relatively high concentrations of compacted organic material and/or silt & clay are capable of holding moisture so tightly that they effectively resist efficient evapotranspiration. The tested infiltration rate of such greens is typically very low.

It is possible for evapotranspiration in a heavily compacted layered green to be confined to an area less than a half inch below the surface. Consequently, the affected green may require periodic syringing to prevent the roots from drying out; nonetheless, we have tested greens which have supported excellent turf systems with periodic syringing.

It is reasonably well established, and confirmed by our research, that stress tolerance is directly related to the depth of the grasses' roots. Our research has also shown that stress tolerance is also affected by the green's micro-environment and the maintenance program. For instance, we have tested excellent *poa annua* greens which are maintained through periods of high-heat stress during the summer. The greens enjoy open environments, and the turf is maintained by hand syringing during the day. The root zones are high in organic, retain excessive amounts of water, and have poor air permeability/subsurface air capacity.

Poa annua is a shallow rooting grass which is noted for its low tolerance of heat stress. The *poa's* ability to be maintained through periods of high-heat demonstrates that the grass is not easily stressed by the heat *per se*, rather, the observed stress is from the <u>effects</u> of the heat on its root zone environment.

The heat and wind dry out the soil around the roots [evaporation]. The heat and the wind also draw water out of the grass plants [transpiration]. As the surface dries out, the physical properties of the root zone continue to hold the water, however, very little moisture becomes available to the grass through hydraulic conductivity. As the soil surrounding the roots dries out, continued transpiration will eventually kill the grass by desiccation [the loss of needed plant fluids]. The syringing provides moisture to the roots which prevents desiccation; and, the evaporation of the water provides additional relief with its cooling effect.

This discussion should not be misconstrued as a recommendation that open environment greens do not need an appropriate balance of the root zone's physical properties. Heretofore, we have discussed the performance of turf during a normal summer. If the summer is cool and wet -- such as New England's summer of 1996 -- high water content/high organic greens will be difficult to maintain even in open environments. The greens do not dry out properly under cool wet conditions, turf is stressed by extended periods of oversaturation, pathogens and pests flourish, and the surface of the greens tends to be "mushy". All greens need an appropriate balance of their physical properties. An open environment merely gives the superintendent more flexibility.

Shaded greens are usually associated with low air movement. Shading limits a grass plant's access to sunlight. Reduced sunlight reduces the growth activity of most preferred turf grasses. As a consequence, the turf is more susceptible to disease and slower to recover from stress. The choices available to the superintendent are limited; either introduce a low-light tolerant turf, or trim trees. Tree trimming is the most frequently chosen option. Even if a suitable low-light tolerant turf is found, a successful introduction usually entails stripping and reseeding the green. Overseeding as an option takes years and usually produces mixed results.

Most courses have at least one problem green. Invariably, that problem green is in a restricted air environment. Frequently, the setting which creates the low air movement is picturesque and the green is a signature hole on the course. In the majority of best green/worst green tests we have conducted, the physical properties of the worst green are as good as, if not better than, the best green. The difference is the micro-environment; the accumulated test data emphasizes the impact of poor air circulation.

We have found in our work that the condition of the turf on restricted air greens is directly attributable to: (a) an overabundance of moisture in the root zone, and (b) an overabundance of moisture in the air immediately above the surface of the green. As the sun warms the green, water is converted into vapor which raises the humidity of the ambient air at the surface of the green. In an open environment setting, the water-rich air is quickly removed by good air circulation thereby drying the root zone and cooling the turf. The oxygen content of the soil is increased as the water vacates the pore spaces and is replaced with oxygen-rich air from the atmosphere.

In the restricted air movement green, the moisture ladened air sits. The increase in humidity reduces the moisture "draw" on the root zone and grass plants which results in a reduction in evaporation and transpiration. Pore spaces which would otherwise fill with oxygen-rich air remain water-logged. The balance between air and water in the root zone is skewed in favor of water retention. The poor turf, on every restricted air movement green we have tested, reflected the effects of an over-saturated root zone.

In addition to the propensity for the root zone to remain over-saturated, restricted air movement greens do not benefit from the cooling aspects of good air movement. In fact, the ambient temperature at the surface actually increases.

As sunlight strikes the moisture-ladened air at the surface of the green, each tiny droplet of water becomes a miniature magnifying glass. The droplets intensify the sun's rays and reflect them back to the surface which intensifies their effect. The result is a significant increase in temperature. On hot still days, the turf can be virtually steam cooked.

A third factor which can have a significant impact on turf quality we call: "disease & pests". The hot, humid & moist conditions are an ideal environment for culturing pathogens and pests. The pathogens may be algae, mold, mildew, fungus, harmful bacteria and viruses. Many harmful insects also thrive in the environment. Disease and pests increase the stress on the turf.

The most important thing a superintendent can do for a restricted air movement green is reduce the moisture content of the root zone. In a poorly drained green, it may entail a three-pronged approach consisting of the installation of a drainage systems [such as Cambridge drains], modifying the upper root zone with intensive aerification, and limiting the amount and frequency of irrigation. In a well-drained green, reducing the root zone's moisture content usually entails a two-pronged approach of modifying the upper root zone with intensive aerification and closely monitoring the irrigation. Obviously, the drainage system's effectiveness should also be monitored. In both instances, it is important to develop deep and dense root systems.

E. Disease & Pests

In the preceding Section D, we briefly discussed the impact the environment can have on populations of pathogens and pests. For our purposes, pathogens may be algae, mold, mildew, fungus, harmful bacteria and viruses. Pests are generally considered to be harmful insects, but there are other organisms living in the soil which are properly termed "pests" -- with some, the size of their population determines whether they are harmful. *Poa*, for instance, can be considered a pest on many greens.

Pathogens and pests such as algae, mold, mildew, fungus, harmful bacterial, viruses, and *poa* have two common denominators: (a) they require moisture at, or relatively near, the surface; and (b) they require nutrients at, or relatively near, the surface. Organic layering, topically applied contaminants [such as silt in the irrigation water], and poorly distributed sand/soil -- to name the most common examples -- increase the water retention of the root zone at, or near, the surface. Each example is typically associated with poor water infiltration which confines the topically applied nutrients to the surface. Fairy Ring, for instance, is a fungus which "sucks" the nutrients out of the soil. The telltale brown grass represents turf which has died because of starvation. Fungi require a moist environment to thrive.

Proper attention to the root zone's physical properties may not eradicate the pathogens and pests; however, it should improve your efforts to control a problem. Furthermore, the root zone's physical properties directly impact the ability of the turf to resist the stresses associated with pathogens and pests.

V. MAINTENANCE PRACTICES

A. Nutrients & Chemical Testing

Our physical evaluation does not replace the need for regular chemical testing during the course of the year. A grass plant requires food, water and oxygen in its root zone to thrive. Nutrient & chemical testing is another necessary aspect of the total picture.

Root zones which have poor air & water permeability, as measured by the infiltration rate, also have poor nutrient permeability. If moisture is unable to percolate into the soil, the barrier to the water is also a barrier to the percolation of nutrients with the water. Consequently, topically applied nutrients, whether dry, organic based, or in solute form, will tend to be retained near the surface where they are subject to surface leaching.

Roots will prune to the surface because the lower root zone is incapable of supplying their needs. It is rare that a lack of moisture is the problem. The most prevalent cause of pruning is poor aeration. The roots prune to the surface to obtain an adequate supply of oxygen. Poor nutrition in the lower root zone can also cause pruning. We have tested root zones where the roots pruned because of apparent starvation. It is also possible to cause a loss of root density and depth with a chemical imbalance. Some needed micronutrients, in particular, can be toxic to the grass at threshold concentrations.

I.S.T.R.C. is not in business to provide nutrient & chemical testing. There are other labs which are far more qualified than us to service the turf professional. We strongly support and recommend regular chemical testing during the course of the year.

B. Dethatching

Thatch can seal off a green and inhibit the ability of a root zone to breathe. A heavy thatch layer is also an excellent breeding ground for disease and pests. Consequently, the success of any maintenance program is dependent on effective thatch control. Some of the newer bent grass varieties, in particular, are noted thatch producers. There is no substitute for regular visual monitoring of the thatch layer.

If you identify a heavy thatch layer, we recommend lightly verti-cutting an affected green once a week until the excess thatch has been removed from the affected root zone. A light fertilization a few days prior to verti-cutting can help expedite the recovery of the turf system. The use of the fertilizer helps to alleviate the stress associated with the verti-cutting.

Chemical dethatchers can also help control the development of excessive thatch, but we have found in our testing that their effectiveness can vary. On one high profile course we tested, for instance, chemical dethatchers were effective on the heavily traveled areas of the greens. Areas which received minimal traffic, however, exhibited heavy thatch development. The heavy thatch areas could best be described as "water sponges". Plastic was placed over the areas during irrigation to encourage the areas to dry out.

The solution to the described problem was simple: merely verti-cut the lightly traveled areas. The example highlights the need to closely monitor the thatch condition over multiple areas. Furthermore, close monitoring should be employed whether you dethatch mechanically or chemically.   Different areas within a green may require slight modifications to the dethatching program to meet their needs.

An effective dethatching program will promote a green's air and water permeability without aerification. However, a dethatching program will not increase a root zone's subsurface air capacity [Non-Capillary porosity], nor will it materially change the water retention properties or reduce the organic content <u>within the root zone</u>. Dethatching can have, however, a significant impact on the thatch's water retention and dethatching will clearly remove organic material [thatch is, by definition, organic in composition] from the surface area. Permanent changes to the subsurface air capacity, water retention, and organic content within a root zone require rebuilding [either by reconstruction, partial rebuilding, or hollow core aerification].

C. Aerification

1. The Equipment

We have found that effective maintenance programs utilize multiple aerification tools. Hollow tine & drilling equipment [generically termed "hollow coring"] are used to relieve compaction and modify the composition of a root zone by removing material and replacing it with topdressing. Hollow coring can be used to rebuild a root zone. Quadra-tines, solid tine spikers, slicers & hydrojects are excellent tools to provide temporary aerification and relief from compaction with minimal disruption to the surface of a green. Deep verti-draining with large solid tines which "waggle" in the soil is an excellent tool to loosen the lower root zone and promote drainage.

We recommend the use of aerification tools which remove material [such as hollow tines or "drill & fill"]. Our research has found that upper root zones are not static environments. The physical properties of a golf green's root zone are constantly changing -- deteriorating in most instances -- because organic material is constantly being deposited in the upper root zone by the root systems. Healthy turf is typically associated with deeper and denser root systems than weak turf. The increased root mass deposits more organic material in the root zone. The irony is that healthy turf usually requires a more aggressive aerification program to maintain its conditon than weak turf.

Spiking, slicing and hydrojecting are excellent tools to use during peak-play periods. Each type of aerification opens up the upper root zone while causing minimal, to no, surface disruption. It is common to spike or slice a green in conjunction with a topdressing application to help work the sand into the turf. However, it is not necessary to topdress each time a green is aerified by spiking, slicing or hydrojecting. The goal is to open up the root zone <u>without disrupting play</u>.

Deep verti-draining is an excellent tool to break up hardpan and areas which impede the percolation of water through the lower root zone. Deep hollow coring is an excellent tool for modifying the soil composition in the lower root zone. Solid tines are normally used when verti-drain equipment is set to "waggle" in the lower root zone. Filling the cavities with sand is recommended to keep the holes open. The solid tines do not remove material; consequently, verti-draining is not as effective as hollow core aerification in rebuilding a root zone. Deep verti-draining with solid tines causes less disruption to the playing surface than hollow coring. Turf recovery is faster. Consequently, many superintendents will use deep verti-draining to supplement their hollow core program.

It is possible to reinvigorate sealed off sand-filled hollow core and deep verti-drain cavities with spiking, slicing, and hydrojecting. If the spikes [we use the term "spiking" to refer to any shallow solid tine equipment] or water jets bisect the organic material which is sealing off a sand-filled cavity, the cavity is temporarily re-opened and aerated. As long as the spike or water jet hole remains open, the sand-filled cavity is available for the release of soil gases and the reintroduction of oxygen into the root zone.

It is a prudent practice to prepare the turf for the stress associated with hollow core aerification and verti-draining. We recommend a light fertilization a few days prior to an aerification application followed by another light fertilization a week later. Fertilizers which promote root growth and stress tolerance are preferred.

2. Hollow Coring

We have not found a maintenance "tool" to replace regular hollow core aerification [the term includes "drill & fill" and hollow tining]. Hollow core aerification relieves compaction, aerifies, and removes material. Refilling the cavities with new material can be used to gradually change the texture and particle size distribution of the soil. A program designed around the removal/replacement process is capable of completely rebuilding the area of the root zone serviced by the hollow coring. As a rule of thumb, the sand/soil structure of a green's upper root zone -- the top 3 to 4 inches -- can be completely rebuilt with approximately 16 hollow core aerification applications using 5/8ths inch hollow tines, or similar equipment.

Historically, aerification has been used to relieve compaction and permit air to permeate into the root zone. With the introduction of the ISTRC SYSTEM™, hollow core aerification has been found to control the build-up of organic material. It is excellent at managing the tendency of the organic material to concentrate into layers.

Organic material is removed with cored plugs. Removing organic material and filling the cavities with straight sand reduces the amount of organic material in the upper root zone. In addition, organic material migrates through sand-filled aerification cavities and dissipates into the lower root zone.

We have found that high organic concentrations -- 2.5% and above -- will contaminate the air pores and seal off the sand-filled cavities. It is common for the organic material to appear as a plug or "cap" near the top of the sand-filled cavity. Organic concentrations less than 2.5% do not appear to seal off the cavities. Organic material continues to migrate through the sand with the percolating water, but the lesser amount of migrating organic material does not materially inhibit the cavity's air permeability.

It is a common phenomena of hollow coring that the turf initially responds positively to the aerification. Unfortunately, the turf eventually returns to its original condition. On some greens the decline is rapid while slower on other greens. We believe the phenomena is explained by the organic sealing off the sand-filled cavities. The differences observed between turf systems is primarily attributable differences in the upper root zones' organic contents. While the cavities remain open, the turf thrives. Once the cavities are sealed off, the grass reverts to its former condition. As a rule of thumb, it takes 4 to 6 hollow core aerification applications [with the 5/8ths tines] before the observed positive changes to the turf will appear permanent. Some root zones require less applications, many root zones require more applications.

The ISTRC SYSTEM™ acts like a window which permits the superintendent to view the condition of his root zones. The information provided in the reports is instrumental in deciding: (1) how often to aerify, (2) how deep to aerify, (3) what size of tines, and (4) what fill/topdressing material to use. Prior to the introduction of the ISTRC SYSTEM™, the answers to each of the 4 questions were based on what appeared to work.

We have found that 1/2 inch or 5/8ths inch hollow tines, or similar equipment, produce the desired results -- our preference is the 5/8ths inch tines. It is possible to use larger, or smaller tines to achieve the same ends if the program is adjusted to account for the difference in size -- such as, by modifying the spacing between the tines and/or the frequency of aerification.

We have also found that golf greens require, on average, twice-annual aerification to merely <u>maintain</u> their physical condition. That is, twice-annual aerification is needed to merely remove the organic material deposited by the roots. This general rule, however, has its exceptions.

If twice-annual hollow core aerification applications are required with 5/8ths tines or similar equipment to maintain a root system, an accelerated program is required to <u>reduce</u> the organic concentration. Our normal recommendation is an accelerated aerification program consisting of <u>at least</u> 4 aerification applications per year. On occasion, a turf system is not strong enough to withstand the stress and the program must be scaled back.

It is important to allow a turf system time to recover after each aerification application. The recovery period is usually 4 to 6 weeks. Field reports indicate excellent recovery results when the greens are lightly fertilized a few days before an aerification application followed by a light fertilization a week later.

An accelerated aerification program is not intended to be permanent. In time, the greens will achieve optimal visual properties which are capable of being maintained, due to the changes in the root zones' physical properties, during periods of stress. It is possible to over-aerify a green; however, the more common mistake is to reduce the number of annual applications too soon. Regular monitoring, consisting of at least annual testing, is essential to ensure the success of the program year after year. Eventually, the program will be modified to <u>maintain</u> the physical properties which you have achieved.

3. Spiking, Slicing & Hydrojecting

We use the term "spiking" to refer to any shallow solid tine aerification equipment. Slicing is used primarily along the Southern Eastern Seaboard. Slicers slit the root zone 6 to 8 inches in depth with virtually no disruption to the playing surface. We use term "hydrojecting" to refer to any equipment which aerifies using streams of water under high pressure.

The holes and slits created by spiking, slicing and hydrojecting are effective whether topdressed with sand or left open. It is important for the holes or slits to penetrate through any layering which may exist near the surface. The open cavities permit the release of soil gases from the lower root zone and the oxygenation of the soil. So-long-as the cavities remain open, the cavities provide a highway for gas exchange, water percolation, and root development. We have time lapse photos of roots using spike holes to bypass dense layers.

The holes and slices created by the recommended equipment collapse within a relatively short period of time. The rate of collapse is a function of foot traffic, organic content near the surface, weather and soil composition. During peak playing periods, a good rule of thumb is that the holes and slices will lose their effectiveness within a week. Heavily traveled areas, such as paths on & off a green, can seal off even sooner.

Our recommendation is to spike, slice or hydroject at least once a week during the peak-play periods. It is appropriate, and recommended, that the superintendent modify our recommended frequency with information gathered by on-site inspections. Some turf may not require weekly aerification, while heavily traveled areas and low air movement greens may benefit from more frequent aerification.

Spiking, slicing & hydrojecting are excellent tools to use in conjunction with hollow core and deep tine aerification. In addition to the direct benefits derived from their use, they can reinvigorate older sand-filled hollow core and deep tine aerification holes by bisecting the organic material which typically seals off the sand-filled aerification holes with an impervious organic "cap". These tools, when used frequently on a root zone, are capable of maintaining relatively deep and dense root growth.

We have found the hydroject to be an excellent tool for aerifying a green at least once a week during the heavy play months. The machine opens up the root zone with virtually no disruption to the playing surface. Two of our local high-profile courses chose the hydroject because it permitted daily applications, if necessary, with virtually no disruption to the playing surface. Both courses' programs have been very successful.

Hydrojecting has proven to be an effective substitute for solid tine aerification. There are advantages to using a hydroject. For instance, solid tines can leave "tufts" which are disruptive to the putting surface. The superintendent is usually faced with the prospect of rolling the green to repair the surface, but the rolling counteracts the compaction relief achieved by the solid tine application. Hydrojecting has been found to cause very little, to no, disruption of the playing surface. In addition, we have monitored heavy-organic greens which have been kept "open" during periods of heat stress with daily hydrojecting applications --- an option which is not available with solid tines. It is our understanding that slicer aerofiers, like the hydroject, do not require rolling to prepare the surface and are easier to use than solid tines.

Spiking, slicing, and hydrojecting <u>are not</u> substitutes for a hollow core aerification program, but we have seen each effectively used <u>in conjunction with</u> hollow core aerification programs. Temporary aerification "buys time" while hollow core and deep tine aerification gradually restructures the composition of the root zone.

The goal is to keep the root zone "breathing". If the superintendent is able to maintain an adequate oxygen supply in the lower root zone, the turf has an excellent opportunity to maintain reasonably deep and dense root systems which are directly related to the stress tolerance of the turf. Consequently, a spiking, slicing and/or hydrojecting program is an essential element in ensuring the success of the greens.

4. Verti-Draining & Deep Coring

Deep verti-draining is an excellent tool for relieving compaction and aerifying a root zone. The "waggle" in the lower root zone shatters hard pan and deep layers. It is common to observe deep root growth following verti-drain applications.

Deep verti-draining is typically performed with solid tines. It is possible to use hollow tines, but the tines have a tendency to break when accompanied with the "waggle". The preferred practice is to topdress the greens and work the topdressing as deep as possible into the cavities.

Deep verti-draining [with solid tines] is more effective than hollow coring in relieving compaction, but less effective in rebuilding the root zone because the solid tines do not remove material. Like sand-filled hollow core cavities, organic material migrates through the sand-filled verti-drain cavities. The propensity for organic material to seal off the verti-drain sand-filled cavities is the same as hollow coring.

Turf usually responds positively to deep verti-draining. The deep root growth is symptomatic of the positive response and reflects the excellent aeration achieved with deep verti-draining. Like hollow core aerification, the positive results remain only so-long-as the sand-filled cavities remain open and breathing. Once the migration of organic material has sealed off the cavities, the roots prune and lose density -- the same process observed in hollow coring.

Field reports indicate that the turf recovers quicker after verti-draining than hollow coring. A few reports also suggest that there may be less surface disruption associated with verti-draining.

Deep coring is used to attack specific problems in the lower root zone. 95% of compaction is confined to the top 3 inches of a root zone, and 99% of compaction is confined to the top 4 inches. Shallow coring and verti-draining are the preferred tools to alleviate the effects of traffic compaction. Deep coring is used to change the soil profile below the 3 to 4 inch depth. A common use is to promote improved water percolation to the subsurface drainage field.

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5. Managing Organic Fertilizers

The use of organic fertilizers appears to be growing. The two benefits most frequently discussed are the slow release nature of organic fertilizers, and reduced leaching of nitrogen compounds into the environment [when compared to synthetic fertilizers]. Organic fertilizers rely on microbes to break down the organic material and unlock the nutrients. Consequently, it is important to maintain good aeration of the upper root zone to ensure the vitality of the microbial populations. We recommend spiking, slicing, and/or hydrojecting in conjunction with the use of organic fertilizers to promote continued aeration of the material.

The organic compounds in the fertilizers are providing the "food" for the microbes, but the nutrients remain "locked" in the organic material until the organic compounds have been decomposed by microbial activity. Aeration ensures that there is sufficient oxygen to support the microbial populations. Soil temperature influences the vitality of the microbes. The efficiency with which the nutrients are released to the roots is dependent on adequate levels of oxygen and soil temperature.

Synergistic microbial populations are considered to be dormant when soil temperatures fall below 55 degrees Fahrenheit. They become progressively more active as the soil temperatures rise. During the hot summer months, the fertilizer release rates are higher with organic fertilizers than in the Spring & Fall because of the attendant increase in microbial activity. If an organic fertilizer is applied when the synergistic microbes are dormant, the material is not broken down and the nutrients remain unavailable to the roots. Consequently, synthetic fertilizers may be a more appropriate choice in the Spring & Fall months with organic fertilizers remaining the choice during the summer.

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D. Inorganic Amendments

Inorganic amendments can be used in new construction mixes, topdressing mixes, and as aerification fill material. In our work of testing inorganic amendments in the lab and monitoring their performance in the field, we have found that inorganic amendments are useful in attacking specific problems.

The commercially available inorganic amendments which we have worked with are:

(a) **Isolite**,

(b) **AXIS**,

(c) **PSA**,

(d) **Profile**,

(e) **Soilmaster Plus**,

(f) **Ecolite**,

(g) **Clino-Lite**, and

(g) **Sand Aggregate's Rhyolite Tufts sand**.

Isolite, AXIS, Profile, Soilmaster Plus, Ecolite, Clino-Lite, and Sand Aggregate's rhyolite tufts sand can improve a root zone's permeability and subsurface air capacity while maintaining good water holding. They are useful in opening up root zones which periodically require flushing without sacrificing water retention. PSA holds water longer in the root zone and can supplement the water holding properties of straight sand greens and has been successfully used as an amendment for poorly drained greens and attacking dry areas in a root zone. AXIS, Profile, Soilmaster Plus, Ecolite, Clino-Lite, Sand Aggregate's tufts sand, and PSA are useful in improving a root zone's nutrient retention properties. Profile, Soilmaster Plus, AXIS, PSA, Ecolite, Clino-Lite, and Sand Aggregate's rhyolite tufts sand supplement a root zone's nutrient retention [CEC]. The rhyolite tufts sand can be used as a sand in root zone construction.

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VI. The ISTRC SYSTEM™

ISTRC was founded in 1991. At that time, lab testing consisted of evaluating raw materials. Root zone components would be sent to the lab for analysis. Mixes would be created and lab cores prepared using USGA recommended protocols established by Mr. H. Leon Howard in the late 1950's to simulate the effects of compaction experienced by a mature green. The labs were not serving the superintendents because they were not able to help the superintendent with his or her problems after the greens were built. If we were in existence to serve the superintendent, we needed to develop a tool which provided information which was reliable and useful to the superintendent.

Historically, core testing has consisted of the superintendent driving a PVC pipe into a green, capping the cored material, and shipping the material to a lab for physical evaluation. In the lab, the PVC would be cut open and the contents visually inspected. The material constituting the upper root zone would be removed, and reconstituted into lab cylinders for testing. Frequently, the report would state that there was nothing wrong, physically, with the green when the superintendent knew better -- for instance, the testing reflected an adequate infiltration rate on a green with standing water after a minor shower.

In our patent application we were asked to demonstrate the difference between the ISTRC SYSTEM™ and the traditional method of core testing. We took side-by-side samples from a layered green. With one sample we removed the material and constructed a lab core following established USGA recommended protocols. The other core was tested in its undisturbed condition. The reconstituted core had an infiltration rate of 8.61 inches of water per hour vs. 0.11 in./hr. for the undisturbed sample. The two cores contained virtually identical material, but the undisturbed core retained the organic layer as it existed in the field. The organic layer had sealed off the root zone.

The poor condition of the turf was consistent with the undisturbed core data, but totally inconsistent with the reconstituted core. When the undisturbed core was broken down and analyzed by strata, the root mass was confined to the quarter inch above the layer and differences in the textural/particle size distribution of the material were identified. The ISTRC SYSTEM™ is a tool which opens a window on the root zone by providing accurate and reliable information.

The key to successfully managing a golf green contains two elements:

(a) A correct evaluation of a root zone's condition which is predicated on accurate and reliable data. As we demonstrated with the "Old Method" comparison, inaccurate data results in an incorrect evaluation.

(b) A working knowledge of the effects of air, water & nutrients on turf grass and a working knowledge of the ability of the root zone to supply those elements under various conditions. This knowledge places the undisturbed sample's evaluation into context. In essence, there are two evaluations; namely, an evaluation of the condition of the root zone, and an evaluation as to how that root zone reacts in its micro-environment.

Armed with an understanding of the root zone's dynamics and how those properties are affected by the environment, the superintendent is able to design a maintenance program which meets the needs of the green.

What we have discovered in the process of working with superintendents and turf professionals around the world is that the information provided by our undisturbed core testing permits flexibility in the use of different materials. For instance, it is possible to use non-USGA recommended materials to build a root zone <u>if</u>, through regular testing, deficiencies are timely identified and corrected through the maintenance program. We cannot over-emphasize the need to monitor the condition of the greens with regular testing irrespective of the material used in the root zone.

As a final note, it is important to test all materials intended for the greens prior to use -- including your topdressing sand. Many sand companies, for instance, regularly test the products they sell to golf courses as a quality control check. We recommend that the superintendent obtain a copy of the test results for the files. If a supplier does not have a current report, it is our opinion that the supplier should have the material tested as a prerequisite to making the sale.