regional turfgrass authorities. These authorities could include neighboring golf course superintendents, university extension personnel, USGA Green Section staff, and other knowledgeable industry professionals.

With lists for each turfgrass candidate having been completed, a list of the pesticides required to control each pest can then be made. With this information in hand, it may quickly become evident that certain turfgrasses should not be selected because of a governmental restriction on the use of a particular product. For example, in some areas of the country, the application of certain fungicides for snow mold control is limited to their use on greens and tees. Under these circumstances, creeping bentgrass established on the fairways could be particularly susceptible to severe damage during the winter months.

This particular selection criterion can also be viewed from a different angle. Given the public's growing environmental awareness, it will become increasingly important for the turfgrass industry to respond, where possible, by establishing turfgrasses that require fewer pesticide and fertilizer applications.

Fertilization is another environmental factor worthy of consideration. When estimating total fertilizer requirements for each turfgrass candidate, remember that healthy turfgrass is more resistant to weed invasion and disease attack. With this in mind, do not underestimate fertilizer requirements. Reducing applications in the field could inadvertently increase the demand for herbicide and fungicide applications, nullifying the original intent of the turfgrass species or cultivar selection.

Golf Activity

Having considered agronomic limitations and the well-being of the environment, it is also necessary to take into account the amount of play anticipated on the course. This can be accomplished by estimating the maximum number of rounds expected and the anticipated maintenance budget. These estimates will provide a basis for determining (1) the possible need to select turfgrasses with maximum durability, and/or (2) limitations caused by the inability to complete the cultural requirements of a specific turfgrass due to heavy play or a low maintenance budget.

The *Los Angeles Times* recently reported that, at 135,000 rounds per year, Rancho Park Golf Course is the city's most heavily played course. This figure translates into 370 rounds per day, 365 days per year. Taking into account the short daylight period during the winter, daily play during the summer can exceed 450 rounds. To maintain dense turfgrass under such extraordinary circumstances requires working with only the most durable turfgrasses.

Interestingly, public facilities like Rancho Park Golf Course are large revenue producers; hence, you would think that the maintenance staff should have plenty of resources to maintain the course. To accommodate 450 rounds per day, though, requires scheduling foursomes off the first tee every seven to eight minutes from dawn until dusk. This heavy volume of play, unfortunately, makes it impossible to follow through with the cultural demands of some turfgrasses.

Alternatively, the maintenance of a golf course also can be limited by low play. While affluent memberships at private golf courses can raise membership dues to compensate for low play, golf courses that depend on income from green fees often must slash the maintenance budget to stay afloat.

Conclusion

In too many instances, the selection of turfgrasses for a site is based on an impulse rather than pertinent selection criteria. In reviewing criteria for selecting grasses for your site, be sure to include consideration of agronomic circumstances, environmental quality issues, and anticipated play. And don't be too disappointed if your favorite grass does not turn out to be the "best" selection.

A USGA/GCSAA-SPONSORED RESEARCH PROJECT

CULTIVATION HAS CHANGED

by DR. ROBERT N. CARROW
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FOR MANY YEARS golf course superintendents had relatively few choices for cultivation techniques: hollow-tine core aeration, slicing units, and pin spiking. Several versions of each cultivation technique were available, but all were confined to the surface 2 to 3 inches of soil. Though attempts at deeper cultivation were made, these units were too slow or heavy for commercial acceptance. Thus, cultivation programs could only deal with surface-related soil physical problems, including surface compaction, surface-located layers, and heavy (fine-textured) surface soil texture which limited infiltration of water. A second effect of limited equipment choices was that cultivation programs essentially were standardized. For example, on cool-season turf, core aeration was performed in spring and fall, slicing any time of the year, and pin spiking in the summer months.

Tremendous advances in turfgrass cultivation equipment have occurred during the past ten years. The most significant change has been the development of deep soil cultivation for turfgrass sites. Deep cultivation allows for alleviation of adverse soil physical problems that occur deeper in the profile, including soils with high silt or clay contents throughout the rootzone, compacted zones buried during construction, layers within the rootzone that impede water movement or rooting, and problems related to sodic soils.

Currently, several units can penetrate to a depth of 6 to 16 inches, including the Aerway slicer, Deep-Drill aerofier, Turf Conditioner, HydroJect, contain

The Verti-Drain uses solid or hollow tines to penetrate the soil 2 to 16 inches for deep soil cultivation of turfgrass sites.

straight-line slicer units, and the Verti-Drain. While previous equipment helped alleviate soil physical problems in the surface 3 inches, the newer devices can aid in correction of problems observed in the 6- to 16-inch zone. Of these new techniques, the Verti-Drain has become the most frequently used deep cultivation unit to date.

Though these new pieces of equipment are welcomed, they have made the formulation of a good cultivation program more complex. Each site must be evaluated for surface and subsurface soil physical problems. Then, appropriate choices must be made for equipment to be used, cultivation timing, procedure frequency, and correct soil moisture conditions at the time of treatment. This requires a good working knowledge of each technique and the underlying soil physical problems. The purpose of this article is to detail the characteristics of Verti-Drain cultivation and its role in cultivation programs.

The Verti-Drain

Introduced in the mid-1980s from the Netherlands, the Verti-Drain is a power-driven unit using solid or hollow tines to penetrate into soil to a depth of 2 to 16 inches, with tine spacings of 2 to 8 inches forward, and with 2½ to 7 inches between tines on the tine holders. Solid tines are available in diameters of ½, ¾, and 1 inch and lengths of 12 to 16 inches. Hollow tines have ¾- to 1-inch diameters and are 12 inches long.

A unique tine action allows for loosening of the soil to improve structure. The tine penetrates straight into the soil, rapidly rotates to the rear by 10 to 15 degrees with the fulcrum point at the soil surface, and is withdrawn at the angled position. This allows for greater loosening action deeper in the profile with very little turf or soil surface disruption. The latter aspect has resulted in the Verti-Drain being used even on closely cut golf greens.

Uses

The Verti-Drain can be effectively used to improve any subsurface (i.e., 6 to 16 inches deep) problems listed in Table 1 for fine-textured soils, except for poor contouring or a naturally occurring high water table. The channels created by the Verti-Drain tines and fracturing of soil between tines would be expected to improve water movement, air exchange, and rooting within the treated zone. In coarse-textured soils, disruption of layers impeding root, water, and air movement would be beneficial.

There are situations where other methods may be preferred or where the Verti-Drain could actually be detrimental. For example: (a) On a properly constructed USGA golf green, the coarse sand layer and pea gravel interface forms a desirable perched water table. Verti-Drain tines do not judge between good and bad layers; they disrupt both equally as well. (b) In areas with shallow irrigation lines. (c) If the soil physical problem is confined to the surface 3 inches, other techniques may be as effective or more effective. For instance, a high-sand-based site without any subsurface layers that impede drainage may receive no benefit from deep cultivation. (d) As with most techniques, Verti-Drain cultivation when the turf has very shallow roots may cause severe turf disruption.

Soil Responses

As part of the USGA/GCSAA Turfgrass Research Program, the Research

Committee is funding a series of projects to evaluate different cultivation techniques at the University of Georgia. The studies are being conducted on an Appling sandy clay loam soil (55% sand, 22% silt, 23% clay, 1.74% organic matter) using common bermudagrass. The soil was subject to periodic compaction with a smooth power roller. Verti-Drain treatments were applied in mid-spring and late July of each year using 12-inch, ½-inch-diameter solid tines.

The Verti-Drain consistently loosened the soil to a depth of 4 inches and at times to a 10-inch depth as evidenced by reduced penetration resistance readings. Penetration resistance decreased by about 25% at all depths relative to the compacted control. Most measurements were made 20 to 27 days after treatment, but in one instance, significantly lower penetration resistance was apparent to a depth of 10 inches 7 months after the late-July cultivation.

At Michigan State University, Drs. James Murphy and Paul Rieke reported decreased penetration resistance to below 8 inches on an intramural field 2 weeks after Verti-Drain treatment. They used both hollow and solid tines and obtained better results with the hollow tines.

Saturated hydraulic conductivity measurements were conducted to determine effects on water infiltration plus percolation under saturated soil conditions. In saturated water flow, impedance to drainage anywhere within the soil profile will reduce water flow. On two out of three measurement dates, Verti-Drain-treated plots exhibited greater saturated water flow. At 30 days after cultivation, saturated hydraulic conductivity of the Verti-Drain plots was increased 7.7 fold over the control, and in the second instance at 21 days after cultivation, improvement was 1.6 fold.

Verti-Drain effects on the physical properties of the surface 2 inches of soil were determined on two dates at 41 and 107 days after the most recent cultivation in the second year of the study. No influence on bulk density, total pore space or aeration porosity (pore space after initial drainage) was observed. However, as noted, penetration resistance was lower than the compacted control in the surface 2 inches, and the saturated hydraulic conductivity data implies that infiltration was at least as good as the control (and probably significantly better since the most likely impedance to saturated water flow would be soil surface compaction).

Plant Responses

Injury to the turf that would detract from visual quality, especially immediately after cultivation, was not observed. Visual quality and shoot density were as good or better than the control. Improved quality was most apparent at the mid-fall and mid- to late-spring periods.

A 79% increase in roots within the 12- to 24-inch zone was observed in Verti-Drain-treated turf in late summer of the first year relative to the control. In the second year, rooting in July and September within this zone was numerically better by 25% to 38%, but not significantly different based on normal statistical procedures.

Timing

Verti-Drain cultivation can be done at any time of the year that the turf has sufficient roots to prevent sod tearing. Sometimes the question arises as to whether the vigorous action of the tines would injure roots. This is a possibility within the treated zone. In our study, rooting was less (not significantly) in the 0- to 12-inch zone in late summer after the late-July cultivation compared to the control, but greater within the 12- to 24-inch zone as noted previously. The magnitude was 15% to 25% less. However, soil compaction via low soil oxygen often enhances surface root development by stimulating adventitious rooting in the surface 1-2 inches of

The unique tine action of the Verti-Drain allows for greater loosening deeper in the soil profile with very little surface disruption.

TABLE 1
Primary Soil Physical Problems on Golf Courses

PROBLEM	Frequency of the problem by soil depth[1] 0-3 in.	4-16 in.	Will cultivation help alleviate this problem?
Fine-Textured Soils (high clay/silt content)	1 = most /	5 = least	
1. Excessive silt/clay content. Some soils contain high clay and/or silt that impedes infiltration, percolation, air exchange, and rooting. These problems are enhanced with traffic.	1	1	Yes
2. High water table or waterlogged soil either naturally or from a perched water table formed by a layer of fine-textured soil with limited percolation.	5[2]	3	Sometimes
3. Improper surface contouring that channels water to low areas that become excessively moist. This is more serious on fine-textured soils with limited internal drainage.	—	—	No
4. Presence of layers that impede water, air, or root movement. Layers may be a distinct textural change or buried organic layer.	2	3	Yes
5. Salt-affected soils, especially sodic soils. The high sodium causes soil structure to deteriorate.	2	2	Yes
6. Soil compaction, whether within the surface as a thin zone of 1 to 2 inches depth, a surface zone several inches deep, or a compacted layer below the surface.	1	3	Yes
Coarse-Textured Soils (high sand content)			
1. Excessive sand content, which leads to low water retention and droughty conditions.	1	1	No
2. Hydrophobic condition due to water-repellent organic coatings on sands.	2	5	Not alone[3]
3. High water table or waterlogged soil, either naturally or from a subsurface drainage barrier such as a clay lens or a fine-textured zone.	5[2]	3	Sometimes
4. Improper contouring that leads to excessive water accumulation in low areas.	—	—	No
5. Presence of layers that inhibit roots, water movement, or gas exchange. Layers may be from sod, topdressing, wind deposited, etc.	1	3	Yes
6. Salt-affected sands that interfere with water uptake but generally do not affect structure in a sand unless it disperses silt/clay and plug pores.	2	3	Sometimes
7. "Hard" sands with little resiliency due to wide particle size range, too many fines, or angular-shaped sand particles.	4	4	Sometimes
8. "Soft" sands with poor traction due to a very narrow particle size and rounded particle shape.	4	4	No

[1]Frequency of soil physical problems within the soil zones of 0 to 3 and 4 to 16 inches: 1 = very common problem, 5 = very rare problem within the zone.

[2]Excessive water may appear at the surface but the cause is normally deeper in the profile.

[3]Cultivation plus a wetting agent, but the wetting agent is more important than cultivation.

soil. If this occurred in our study, then Verti-Drain may have simply decreased the adventitious rooting by improving oxygen relations in the very surface 1-2 inches, which would not be detrimental since these roots are not important in drought. Thus, the questions remain unanswered.

Precautions can be taken to avoid potential injury to existing roots. For cool-season grasses, vigorous cultivation would be best in early spring and mid-fall just prior to the times of maximum root growth. The most intensive cultivation for warm-season grasses to promote rooting should be in mid- to late spring. If a mid-summer cultivation is intensive enough to cause some injury to warm-season grasses, they can still continue root development, whereas cool-season grasses cannot resume root growth until mid-fall.

All Verti-Drain operations are not of the same vigor. Obviously, more intensive operations are likely to cause some root damage. Therefore, if Verti-Drain cultivation is needed for better water and oxygen relations but the turf manager is concerned about effects on existing roots, cultivation intensity can be reduced by using smaller-diameter tines, 12-inch versus 16-inch tines, and greater distance between holes.

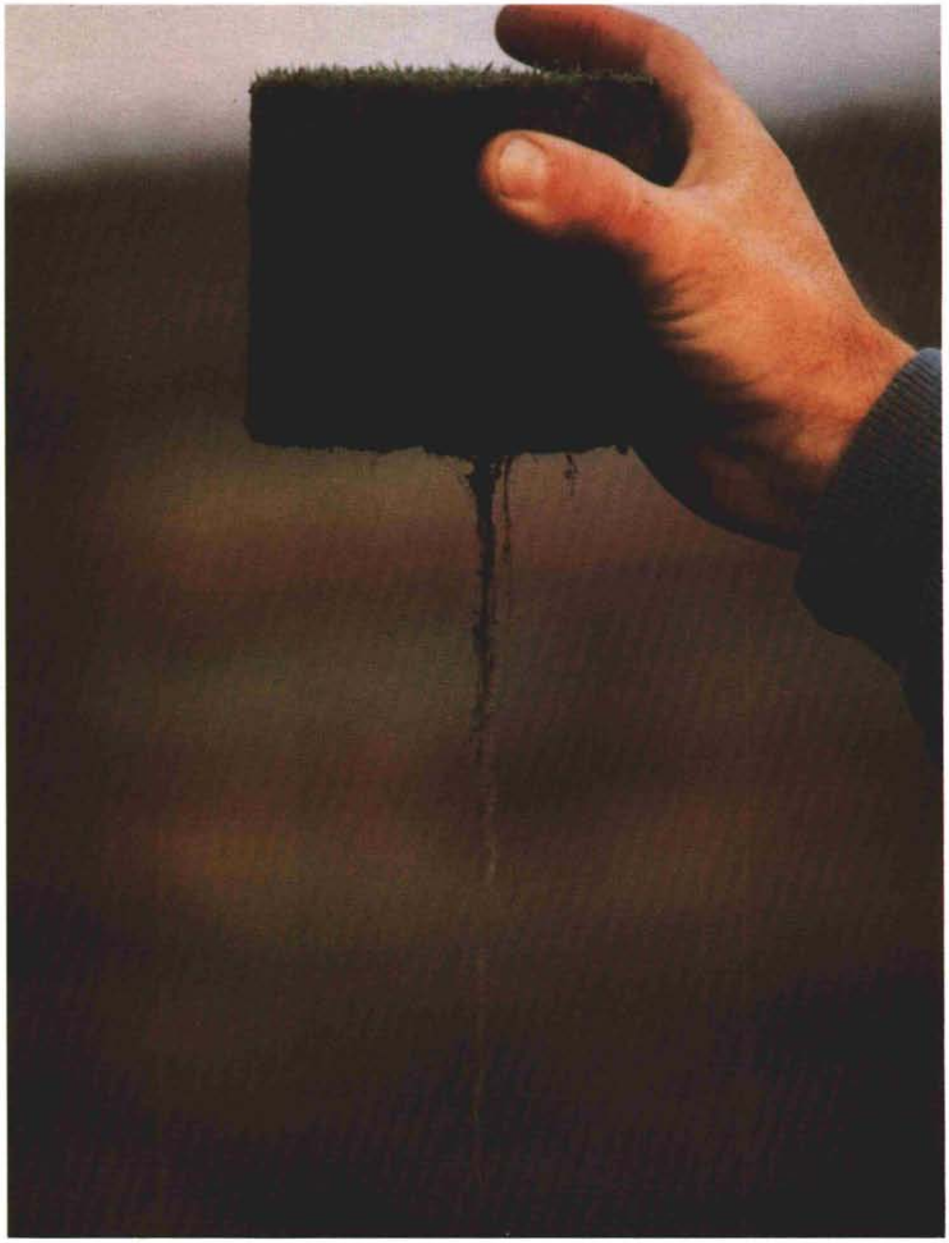
Frequency of Verti-Drain Cultivation

Frequency of an operation depends upon the severity of the problem and whether it recurs. An excessively fine-textured soil with poor physical properties throughout the profile will exhibit improvement after Verti-Drain cultivation. However, the structure formed by tine action will eventually deteriorate and require another cultivation.

Initially the surface portion of the core hole may collapse from foot and vehicle traffic. A good cultivation program with devices that penetrate to 3 inches will help delay this action. Once the surface core hole becomes closed, then certain benefits are lost; namely, better water infiltration and percolation (since water movement rate is controlled by the rate of water entry — i.e., infiltration rate) and gas exchange to some extent. However, the lower portion of the tine channel can still allow for better root growth, and gases can move within these channels.

Ultimately, the lower portion of the Verti-Drain tine channel and any soil fractures created between tines may close. How rapidly this occurs depends upon (a) initial size of the channel. Larger-diameter tines or hollow tines will create holes that will last longer. Another factor is (b) type of clay. Expanding clays (montmorillonite, vermiculite) when moistened can easily expand and seal the channels, especially since water entry is primarily in these channels. In contrast, one would expect greater longevity within a kaolinite or non-expanding clay, (c) reduced degree of traffic pressure, and (d) when sand is backfilled into the holes to keep them open. Sand-filled holes may not remain open to the surface unless sufficient topdressing is periodically added. Some turf managers have back-filled Verti-Drain holes with sand, usually by washing it into holes with water or tediously brushing it into the holes, but there is not any easy way to accomplish this task.

In the previous paragraph, the emphasis was on excessively fine-textured soil profiles. If the subsurface problem is a distinct layer, then one or two Verti-Drain treatments may be sufficient for a permanent solution. However, layers that are relatively thick (2 to 4 inches) or contain expanding clays can reseal. Soil profiles that require deep cultivation as part of a sodium removal program, especially sodic soils, may require frequent Verti-Drain treatment initially to maintain adequate water infiltration and percolation. In a sodic soil, the sodium ion would promote deterioration of the core hole until the sodium is leached out.



The channels created by the Verti-Drain tine action improve water movement and air exchange. The turf plant responds to the cultivation with increased rooting.

Soil Moisture for Application

Verti-Drain, as with all the methods that have a loosening action between tines, should be applied when soil moisture is somewhat drier than field capacity. Field capacity would be the natural soil moisture content after a rainfall or irrigation event, normally 8 to 24 hours afterwards. A somewhat drier soil will be prone to more fracturing action.

It is not unusual for the initial cultivations to be made at field capacity in order to obtain deep-tine penetration. After one or two operations, the soil may loosen sufficiently to allow a somewhat drier moisture level. Drier would mean allowing the soil to dry 1 to 3 days after reaching field capacity.

In conclusion, effective use of the Verti-Drain depends upon correct identification of the soil physical problems and their location in the soil, selecting the Verti-Drain procedure if it is the best for the observed problems, determining the time of year to cultivate, using the right frequency of Verti-Drain treatment plus any other cultivation being done, and treating at the correct soil moisture. Disregarding any potential adverse responses, effectiveness can be enhanced by: longer tines, larger-diameter tines, hollow tines, repeated treatment over a site, closer spacing of tines, adding sand to keep holes open, treating at the correct soil moisture, and more frequent treatment.