Precision Turfgrass Management and irrigation practices

Following the lead of Precision Agriculture, Precision Turfgrass Management makes it possible for superintendents to apply precise amounts of inputs exactly when and where they are needed.

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Precision Turfgrass Management is a term increasingly found in the turfgrass literature with respect to the potential for precise pest, fertilization, salinity or irrigation management (1,2,13,14). Many similarities exist between Precision Turfgrass Management and Precision Agriculture, a management concept in traditional agriculture that started about 20 years ago (11). To achieve input efficiency, both concepts promote greater attention to precise management at the subfield level in areas called *site-specific management units* (SSMUs). Site-specific management units are areas with similar soil, topography, microclimate and the same plant species/cultivar and plant growth conditions and, therefore, similar irrigation needs (5,10,15). For golf courses, site-specific management units are sub-areas within fairways, tees, greens and roughs (2).

As societal pressures intensify toward conservation for all water users, the golf industry must be on the cutting edge in efficiency (3,4). For irrigated turfgrass sites, the most important tools to achieve efficiency are an irrigation system designed for uniformity of application and flexibility, ideally down to a single head; and efficient irrigation scheduling. Greater site-specific management for irrigation will maximize water-use efficiency and conservation. This means making more-precise applications of water than are currently possible so that water is applied only where and when it is needed and in the amount needed by the plant. We must make more precise adjustments in irrigation design and scheduling on a much smaller area scale than we do currently. In this article, we explain how Precision Turf Management concepts can improve water-use efficiency and conservation.

Know your site

Site-specific management requires site-specific information, and the more complex the site, the more spatially detailed the information required across the landscape. For golf courses, spatial variability across a complex landscape influences fac-

During mapping, a truckster pulls the remote sensing device as it takes soil moisture readings about every 10 feet (3 meters). Mapping an average fairway takes about 30 to 45 minutes. **Photo by R. Carrow** tors affecting irrigation management, such as: soil factors (water-holding capacity, texture, organic matter content, slope, etc.), microclimate conditions (solar radiation, wind, humidity, temperature), irrigation system characteristics (uniformity of application, scheduling), and plant attributes (density, growth, color, plant species). Spatial differences in soil properties affecting turfgrass water relations also can be within a soil profile, such as layers (that is, a surface layer of high organic matter) in the soil, or a fine-textured B horizon on a fairway soil.

Precision Agriculture developed rapidly only when remote sensing of crop canopies or crop-yield mapping was coupled with detailed field information on soil properties and topography that was obtained with mobile field-monitoring units (5,11,12). Soil information is important because delineation of site-specific management units requires accurate determination of soil water content, which is highly correlated to soil texture and organic matter (5,6,12).

Sensors on the move

A primary factor hindering development of Precision Turfgrass Management has been the lack of mobile devices for detailed mapping of plant stress status *and* soil attributes affecting plant performance in large complex turfgrass landscapes. A review of considerable research involving optical sensing, especially by spectral reflectance, on turfgrasses showed that all the studies involving mobile units used on turfgrass sites obtained only plant data and not soil data (1).

Sensor technology and turfgrass applications have increased considerably in recent years; for example, coupling hand-held mobile sensor devices with geo-referenced data (GPS, global positioning system) that can be used in geographical information systems (GIS) to display maps. Devices that determine water-holding capacity (that is, volumetric water content) using time-domain reflectometry (7,9) also are available. However, the rapid mobile sensing platforms necessary to make spatial maps of large landscape areas where hundreds to thousands of measurements are necessary were not available until recently. In 2005, the first experimental unit was developed to obtain spatial and temporal soil and plant data over large turfgrass areas (some of the applications from this unit are discussed later in this article) (2).

The initial unit could

- determine water-holding capacity of soil to a depth of 4 inches (10 centimeters) while moving over the site
- map penetrometer resistance to spatially determine soil compaction
- provide a reasonable estimate of topography, especially degree of slope and aspect (direction the slope is facing) on sites without topographic maps
- determine current turfgrass performance spatially over the site based on the normalized difference vegetative index (NDVI) [NDVI is the most commonly used plant performance or stress indicator and correlates well with turfgrass quality, density and color (1)]
- provide GPS referencing for all data so that the data could be used in GIS systems for map development and analyses

Other researchers (13,14) also have reported on combining a spectral unit for measuring the NDVI with an electrical magnetic unit to estimate soil moisture in a system with GPS capability.

Mapping Fairway 10

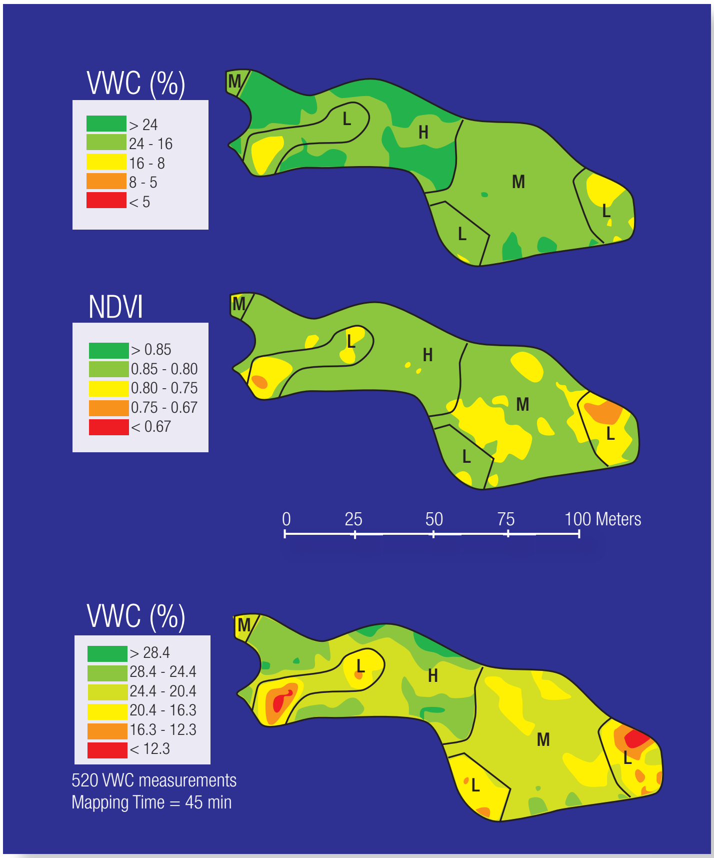

Figure 1. Defining site-specific management units. VWC (volumetric water content) data is the primary factor and the legend scale is based on estimated soil types. Secondary factors used to adjust SSMU boundaries are NDVI responses (measure of plant stress, where NDVI = 1 is ideal turf) and the VWC standard deviation data. Information on L (low), M (moderate) and H (high VWC) site-specific management units is presented in Table 1.

VWC uniformity: Fairway 10

SSMU	VWC_{tot}	VWC_{lq}	DU_{lq}	DU_{lh}
	%			
Fairway	**22.1**	**15.2**	**69**	**81**
High VWC	25.2	19.5	77	86
Moderate VWC	21.8	17.0	78	86
Low VWC	17.5	10.3	59	75

SSMU, site-specific management units; VWC, soil volumetric water content; VWC_{tot} = average of all soil volumetric water content (VWC) measurements; VWC_{lq} = average of the lowest one-fourth of VWC measurements; DU_{lq}, lower-quartile distribution uniformity, $DU_{lq} = (VWC_{lq}/VWC_{tot}) \times 100$; DU_{lh}, lower-half distribution uniformity, $DU_{lh} = [0.386 + (0.614 \times DU_{lq})]$ is the equation used for irrigation scheduling.

Table 1. Characterizing site-specific management units. See Figure 1 for the SSMU locations on Fairway 10. Data relates to the top map in the figure.

Field applications for irrigation

Along with Van Cline, Ph.D., of The Toro Co., we have defined four primary field applications using Precision Turf Management principles for enhancing water-use efficiency through improvements in irrigation design and scheduling on complex turfgrass sites (2).

Irrigation application No. 1

The first field application for irrigation is mapping after a rain that has brought all areas to field capacity (a measure of the soil water-holding capacity). Mapping under these circumstances determines baselines for defining site-specific management units because field-capacity values are highly correlated to soil texture and organic matter. Figure 1 illustrates this application and site-specific management unit boundaries. Mapping after adequate rainfall removes irrigation non-uniformity and slope runoff that would influence soil water status. However, NDVI values may reflect previous plant stresses and, therefore, reflect the effects of water relations on plant performance.

Initial site-specific management unit areas based on water-holding capacity at field capacity can be further refined by considering topographic slope and aspect. Sloped areas may require different irrigation programs (that is, pulse irrigation cycles) to allow water to infiltrate.

Soil sampling protocols are necessary to validate the site-specific management unit areas and to determine the soil chemical and physical characteristics of the site-specific management unit (5). To obtain the best estimate of soil chemical and physical properties within the site-specific management unit, superintendents can use statistical programs that indicate the least number of soil samples required and where they are located within the unit. Thus, information on each site-specific management unit obtained after the initial mapping data can be useful for other site-specific management decisions such as lime applications or fertilization.

Appropriate statistical tests provide a quantitative means to describe spatial data within a site-specific management unit compared to the whole area or to other site-specific management units. A useful means of characterizing the spatial variability of soil water content at field capacity across a whole fairway or within a site-specific management unit is the distribution uniformity (DU) approach, which uses volumetric soil water-content values instead of catch-can values to assess uniformity (Table 1) (7,8,9). This approach is valuable for several reasons.

- Whole fairways or greens can be evaluated. The catch-can method used in traditional water audits covers more-limited areas.
- The distribution uniformity analysis based on soil water status at field capacity would not reflect the influence of irrigation system distribution, but it would determine the natural variation of soil moisture at field capacity (100% field capacity is the fill point for irrigation). The lower-quartile distribution uniformity (DU_{lq}) can be calculated to quantify the variability within a site-specific management unit. A high DU_{lq} indicates good uniformity of soil moisture status within a site-specific management unit, which is the goal.
- Calculation of the DU_{lh} (lower-half distribution uniformity) is used as a run-time modifier for irrigation scheduling. This could be applied to a site-specific management unit to schedule irrigation on a more site-specific basis (8).

Irrigation application No. 2

A second irrigation application (illustrated in Figure 2) is to identify problem areas within a site-specific management unit. Problem areas are often related to irrigation heads, scheduling or other management issues that are relatively easy to correct, such as: head arc alignment, head not operating, wrong nozzles, incipient localized dry spot that is not yet visible, incorrect scheduling (too much or too little), spray blockage caused by a head that is too low or not level, disease causing turf decline, or other issues. Some of these problems may be obvious, but others are less apparent

Identifying problem areas

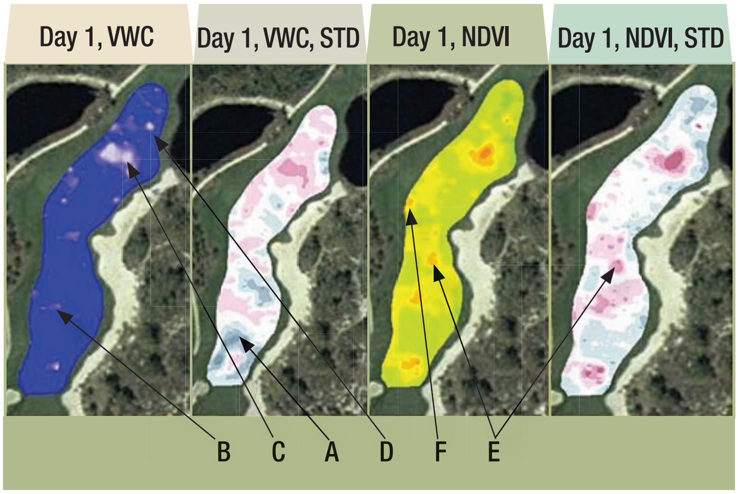

Figure 2. The normalized difference vegetative index (NDVI) and soil volumetric water content — standard deviation (SD) maps are useful for identifying problem areas. Spatial mapping of actual soil volumetric water content (VWC, blue = highest) and normalized difference vegetative index (NDVI, light green = highest); and the same maps displayed in a standard deviation format (white = average; pink = lowest values; aqua = highest values). Information on the maps can be used to identify easily correctable problems. The superintendent went to each location to determine the cause of each problem and found: A, too much overlap of irrigation, some scalping; B, low irrigation head; C, incipient localized dry spot; D, insufficient coverage or scheduled time from the three irrigation heads covering the area; E and F, irrigation head recessed and tilted.

and show up in the maps. Once possible problems are identified on maps — usually by using both soil water content and plant stress (NDVI) maps — the superintendent can systematically go to each area and determine the specific problem, as was done in the example in Figure 2.

Once problems are solved within a site-specific management unit, future mapping should show more uniformity of the site. The maps in Figure 2 show both actual volumetric water content and NDVI values. These maps were developed by a method incorporating the standard deviation, which maps the lowest and highest values for soil moisture and makes plant stress easier to identify. How data are mapped and analyzed is important in order to gain the optimal information for the specific field application.

Irrigation application No. 3

A third application is evaluation of spatial uniformity of soil water status when the irrigation system is being operated under normal use conditions. This evaluation shows how spatial uniformity of soil water is influenced by irrigation system design (for example, incorrect head spacing); scheduling parameters; wind; effect of slope on infiltration of irrigation and precipitation; and other factors that result in non-uniformity of soil water status across a landscape. Mapping for this field application should occur within a few hours of a typical irrigation application and not after a rainfall.

The distribution uniformity approach also can be used in this situation, but it would be a measure of non-uniformity of soil water status from all contributing factors integrated together, in particular, natural soil variation in water-holding capacity, irrigation system distribution uniformity, irrigation scheduling differences and slope. Distribution uniformity is a well-understood and frequently used approach for assessing irrigation system uniformity and for scheduling irrigation. Therefore, including DU_{lq} and DU_{lh} values for whole fairways and then for individual site-specific management units would appear to be beneficial for the same purposes (7,8,9).

Irrigation application No. 4

The fourth application related to more efficient irrigation is determining the best placement of in-situ sensor arrays. On complex sites, questions arise as to how many sensor placements are needed and where they should be located. Site-specific management units offer a common-sense science-based means to address these issues. Because complex landscapes may have a particular site-specific management unit type at several locations across the broad landscape, careful placement within a single site-specific management unit could be used to represent other site-specific management units of the same type (2). A typical golf course may contain four to six site-specific management unit types per 18 holes. A sensor array within a site-specific management unit could provide real-time, multiple-depth "indicator" information on water status and rooting depth (which can be determined by dry-down patterns) for the other sites with the same site-specific management unit type. Soil water-content set points can be used to help schedule irrigation or act as "red flag" values for closer inspection of irrigation programs.

Challenges

With companies and university scientists focusing on developing the mobile sensor devices necessary for large complex sites, precision turfgrass management can rapidly progress as a means for improved efficiency in irrigation as well as other inputs. However, the same restraints hindering more rapid advance of Precision Agriculture will require attention (5,10,15). Important challenges include:

- careful definition of mapping goals
- detailed, uniform protocols for each specific goal or field application
- data analysis and description
- presentation of maps in the appropriate formats
- information transfer and interpretation for the end user

Increasingly, the face of turfgrass management will reflect Precision Turfgrass Management concepts and tools.

Mapping frequency

Mapping frequency depends on the specific field application. For example, determining the site-specific management units and using them to locate in-situ sensors would be a one-time mapping event, assuming the right conditions were present. Spatial mapping with a device that could determine both volumetric soil-moisture content and plant performance by NDVI during a drier period would be used primarily to evaluate irrigation design and scheduling issues. This type of mapping would be a new means of water auditing and could be done every two to four years. Mapping with routine maintenance equipment would normally involve only spectral devices for NDVI or other stress indices and could be done on a routine basis, such as at each mowing or once per week or month. Regardless of the frequency, presenting, analyzing and interpreting the information in a practical fashion is a significant challenge.

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The research says

→ Precision Turfgrass Management, like Precision Agriculture, can improve irrigation efficiency by providing more-precise information about where and when to irrigate and how much water to apply.

→ Detailed spatial mapping of soil-moisture status, topography and plant performance on large complex landscapes (for example, fairways) is important for Precision Turfgrass Management.

→ Specific field applications related to improving irrigation depend on obtaining site mapping information, namely: identify sub-fairway site-specific management units; identify problem areas that can be easily corrected; assess the uniformity of volumetric soil water content within a site-specific management unit and use that information for irrigation scheduling; and determine the number and location of soil moisture sensors.