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Title: Encouraging adoption of precision irrigation technology through on-course application and demonstration of water savings

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Objectives:

1. Quantify response of turf and course conditions to changes in plant available water.
2. Quantify changes in water consumption, relative to typical practices, due to implementation of ET-based and soil moisture sensor-based irrigation scheduling.

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Projects Duration: Three years
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Introduction

The golf industry is under increasing pressure to improve environmental impacts and operate with smaller budgets and fewer resources. As such, it seems natural that turf managers should find benefit in adopting precision management practices and tools. Indeed, precision management, sometimes referred to as site-specific management, has become increasingly studied for turfgrass applications and has been adapted from concepts in precision agriculture (Krum et al., 2010). A wide variety of tools exist to implement precision irrigation including soil moisture sensors (SMS), optical sensors, spectrometers, electrical conductivity sensors, electromagnetic sensors, multi-sensor platforms, and many others. Use of in-ground soil moisture sensors to schedule irrigation has been shown to reduce water use by up to 74 percent (McCready et al., 2009) and, despite common misconceptions, greater benefits are typically found in wetter climates (Dukes, 2012). Evapotranspiration (ET)-based irrigation scheduling has also been identified as a potential means of reducing water use; however, changes in water consumption have been more variable ranging from 62 percent decrease (McCready et al., 2009) to 68 percent increase (Devitt et al., 2008).Increases in water consumption are often due to the use of off-site reference ET values, which may overestimate ET relative to actual on-site values and lead to overapplication of water (Vasanth, 2008).

Although the majority of work in this area has been conducted on home lawns with residential-type sensors and control systems, irrigated fairways occupy an average of 28 acres on golf courses in the United States and represent significant potential for water savings. Still, our experience and data to date suggests that adoption rates of precision management technologies by the golf industry has been slow with just 33 percent and 4 percent of courses using hand-held and in-ground soil moisture sensors, respectively, and 18 percent using on-site weather stations to inform irrigation scheduling (Golf Course Superintendents Association of America, 2015). The lack of adoption of precision management technologies on golf courses is likely due to a combination of factors, including perceived technical barriers and difficulty of use, up-front equipment costs, and logistical issues such as uncertainty around sensors. As a result, precision management has not, in practice, achieved the level of results that theory would indicate are possible. Therefore, the long-term goals of this research are to encourage increased adoption, acceptance, and regular application of precision management tools and practices for golf course irrigation thereby reducing material, time, and labor inputs, and minimizing economic costs of management.

We propose to conduct applied research on precision management technologies and practices for golf course irrigation. Our intent is conduct an on-course case study to demonstrate that adoption of currently available technologies can provide golf course superintendents with appropriate, actionable information and can result in significant water and cost savings as compared to traditional irrigation scheduling methods. We will show that, given the diversity of technology currently available, golf courses of varying sizes, types, and budgets have multiple options to adopt data-driven irrigation practices and create meaningful change. We propose to study this by comparing frequency-, ET-, and soil moisture sensor-based irrigation scheduling methods for golf course fairways. We hypothesize that ET-based irrigation scheduling can provide a low-cost means of implementing site-specific irrigation practices and generate positive water and cost savings on a golf course. Further, we hypothesize that by implementing mobile sensor and geographic information system (GIS) technology to properly place in-ground soil moisture sensors, golf courses can realize even greater savings.

Research Methods

Experimental Setup

This research will be conducted at Brackets Crossing Country Club in Lakeville, MN (20 miles south of the Twin Cities). Initial surveys using the Precision Sense™ 6000 will be conducted in fall 2017 to gain a fundamental understanding of spatial variability at the research site and aid in experimental design. In spring 2018, georeferenced data including soil moisture and salinity, penetration resistance, and NDVI will be collected across the entire golf course using the Toro Precision Sense 6000 mobile sensor platform. Data will be collected and analyzed under a variety of conditions including immediately following a saturating rainfall, 1 to 2 d after that rainfall, and after an irrigation cycle. Remotely sensed multispectral imagery will also be collected using a UAS-mounted camera at the same time as each Precision Sense survey. Precision Sense data will be spatially analyzed using ordinary kriging as implemented in a combination of existing scripts for ArcGIS and R. The results of each analysis will be a spatially interpolated map of each response variable.

Using the data collected following a saturating rain, nine fairways will be selected that have similar mean and spatial variability of soil moisture. Those nine will be placed into groups of three that will be used as replications for treatments in Objective 3. One fairway from each replicate block will be assigned a SMS-based irrigation scheduling treatment. Georeferenced data from the Precision Sense survey will be used to create irrigation management zones around each sprinkler head and each management zone will be assigned to one of three or four soil moisture classes based on mean soil moisture value (Fig. 1). We will ensure that each fairway chosen contains zones representing each of the defined moisture classes. Results of the zoning process will be used to direct soil moisture sensor positioning. We will select representative location for each moisture class on each fairway at which Toro TurfGuard in-ground soil moisture sensors will be installed with the top tines at a depth of 2.5 inches. The sensors will be set to collect data every 5-10 min and monitored over time. At least one and no more than three sensors for each moisture class will be installed on each of the three fairways receiving the SMS-based treatment. Although only one sensor per moisture class will be used for scheduling irrigation cycles, the additional sensors will be used to verify that other areas representing the same moisture class exhibit similar trends in volumetric water content over time.

Soil core samples will be collected from the location of each sensor to be used in irrigation scheduling decisions for each moisture class on each fairway and fully characterized for particle size distribution, bulk density, organic matter, and soil water retention characteristics using standard lab methods. In addition, results of the initial mapping process will be used to direct soil sampling in order to fully characterize the contributions of soil physical properties, organic matter, and irrigation system distribution and performance to observed soil moisture distributions. Hourly precipitation and ET will be recorded using an on-site weather station and any changes in the relationship between ET, precipitation, and changes in VWC will be analyzed over time.

Objective 1: Quantify response of turf and course conditions to changes in plant available water.
Following a settling-in period of at least 30 d during which typical irrigation practices will be followed, fairways with soil moisture sensors installed will be irrigated to near saturation and a dry down will be initiated. Volumetric water content during the initial irrigation and dry down will be recorded using the installed soil moisture sensors. Aerial imagery (RGB and NDVI) and visual assessments of the turf canopy will be collected once per week. The Precision Sense mobile sensor platform will be used to collect georeferenced NDVI as well as soil moisture, salinity, and penetration resistance on those three fairways three times per week during the dry down. Hourly reference ET and precipitation will also be recorded during the dry down event using local weather station data. Using recorded VWC, aerial imagery, and NDVI data, VWC values corresponding to field capacity (FC) and permanent wilt point (PWP) will be determined for each installed soil moisture sensor. Field capacity will be determined as the stable VWC value following the initial saturating irrigation or precipitation event, but before significant ET-driven decline. Wilt point will be determined as the VWC value at which 50 percent of the irrigation management zones associated with a given sensor exhibit visible wilt, NDVI values begin to decline significantly, or the superintendent feels that we have reached the limit of his or her comfort. The difference between FC and PWP will determine the plant available water (PAW) value for each plot. This process will be repeated multiple times throughout the 2018 growing season to ensure representative values for FC, PWP, and PAW are achieved.

Objective 2: Quantify changes in water consumption, relative to typical practices, due to implementation of ET-based and SMS-based irrigation scheduling
Beginning in spring 2019, we will apply the knowledge gained from Objectives 1 to compare soil moisture sensor-based irrigation scheduling with ET-based and traditional approaches. First, we will conduct an irrigation audit of the nine fairways identified in Objective 1 and quantitatively define the relationship between the programmed water application and the true depth of irrigation applied. This information will be used when applying the prescribed irrigation treatment to adjust the command as necessary. Of the nine fairways identified in Objective 1, one fairway from each replicate block will be assigned a treatment corresponding to each of the irrigation scheduling techniques (Table 1).

For the soil moisture sensor-based treatment, we will make use of valve-in-head sprinkler control and schedule the head in each irrigation management zone to be run together with all other heads in the same corresponding soil moisture class. Irrigation will only be allowed once the PAW has been reduced by 50% as measured by the soil moisture sensor associated with that soil moisture class. When irrigation is allowed, the applied depth will be the lesser of: 1) the total forecasted ET before the next forecasted rain event or 2) the amount required to return the soil water content to 75% of total PAW. These upper and lower PAW limits will be adjusted as necessary. Forecasted reference ET (FRET) will be obtained from the national weather service’s Forecasted Reference Evapotranspiration service (digital.weather.gov). For the ET-based scheduling treatment we will take a deficit irrigation approach and apply 70% of reference ET every three days. We will consult with local superintendents to ensure that our timing and percent deficit are representative of what would typically be used by a golf course in Minnesota and adjust as necessary. Finally, for the remaining treatment, we will ask the superintendent to irrigate the remaining three fairways as he or she typically would, taking into account any information that would typically be used. During the course of the growing season, total depth of irrigation applied will be recorded for each irrigation event and totals will be quantified on an area basis. We will also track and analyze relationships between precipitation, FRET, and actual on-site ET throughout the course of the study.

Expected Results

From this work we expect to gain a deeper understanding of the importance of spatial variability in golf course management. Further, methodologies developed for mapping, sensor placement, and monitoring via remote sensing can be of great value to the industry. Together, those technologies will help us develop a meaningful relationship between course conditions and soil water status as measured by the physiological response of the turf canopy. By doing so, we can demonstrate how information from these types of technologies can provide meaningful data for a superintendent to use in course management.

Most importantly, our on-course comparison of various irrigation scheduling technologies can provide easy to follow examples of how to effectively use information from available technologies to make meaningful changes in management practices. This will help superintendents understand which technologies can work for them and what the potential benefits are and it can help industry manufacturers understand how to provide data that is both meaningful and actionable.

Results of this work will be disseminated in peer-reviewed journal and trade articles and in presentations at conferences and seminars. Device manufacturers can also be industry advocates and help distribute information and results of this work at customer workshops, trainings, and on-course installations through training, sales, and service groups. This type of spatial data is also ideal for future addition to dashboard and management tools such as the USGA Resource Management Tool and irrigation controller interfaces.

Recent Activity

We have tentatively settled on performing the project at Brackett's Crossing Country Club in Lakeville, MN (Fig 3A). A full course Precision Sense survey was previously conducted in 2012 (Fig. 3B), which gives us some sense of the variability we can expect when we conduct an updated survey in spring 2018. The course currently has a TurfGuard wireless soil moisture sensor system installed. This eliminates the cost, time, and labor associated with installing a new system.

In January, the project team will meet to define a 2018 schedule. We will work on obtaining and interpreting the irrigation database records from Brackett's Crossing to evaluate current water use practices and begin preparation for the subsequent irrigation calibration and audit in spring 2018. The Precision Sense machine has been transported to the course and is ready to use as soon as the ground has thawed. A baseline survey will be conducted in spring 2018, which will be used to determine the fairways for our research.

Literature Cited

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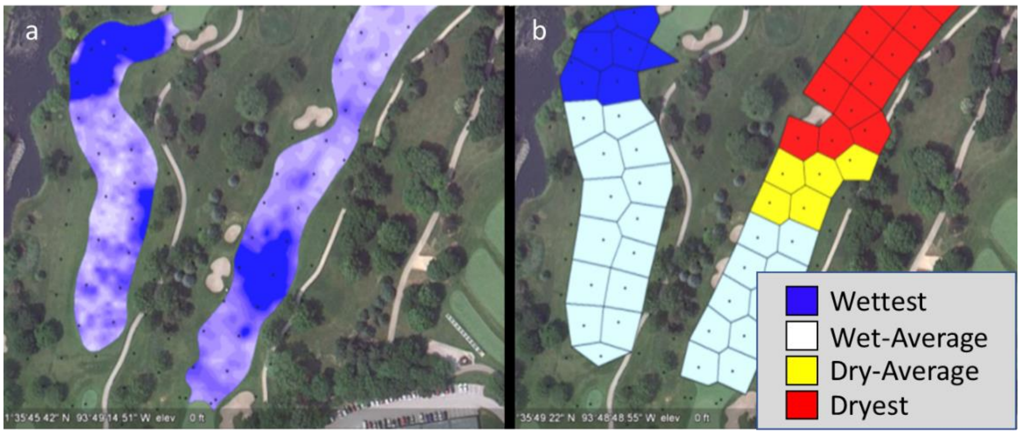

Figure 1. (a) Example of kriged soil moisture data and (b) corresponding irrigation management zone assignments for each sprinkler head.

	2018			2019			2020		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
Objective 1									
Sensor Install									
System Training									
Objective 2									
Irrigation Audit									
Data Collection									

Figure 2. Estimated schedule of work for major tasks in the irrigation scheduling comparison study.

Figure 3. (A) Location of Brackett's Crossing CC and (B) 2012 Precision Sense survey of Brackett's Crossing Country Club showing wet (dark blue) to dry (white) soil moisture on a stretched scale.

Table 1. Summary of treatments to be applied in the comparison of irrigation scheduling techniques

Treatment	Description
SMS-based	Irrigation allowed at ≥50% PAW reduction. Applied depth determined by FRET or sufficient to achieve 75% PAW level. PAW thresholds to be adjusted as necessary.
ET-based	70% ETo to be applied every three days. Percent deficit and frequency to be adjusted as necessary.
Traditional	As typically applied by course superintendent using any typically available information.