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Title: Development of Irrigation Scheduling Techniques that Conserve Water using Soil Moisture Sensors, Reference Evapotranspiration, and Turfgrass Quality Data

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Objectives:

1. Determine quantitative turf canopy responses to plant available water from in-situ soil moisture sensors.
2. Compare SMS-based irrigation scheduling to traditional irrigation and ET-based irrigation scheduling.
3. Prototype a simple turfgrass irrigation forecasting tool.

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Project Duration: Four years
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Introduction

Turfgrass irrigation water management is critical to ensure turf playability, landscape aesthetics, and protect local water resources. Efficient application of water to match but not exceed requirements of high quality turfgrass is crucial. In the United States there are an estimated 1.5 million acres of maintained turfgrass in golf courses that used approximately 1.859 million acre- feet of water per year (EIFG, 2007, 2015). The use of soil moisture sensors to control irrigation has resulted in up to 70% water savings in lawn-or rough-height turfgrass, with greater savings in wet than dry climatic conditions (Chabon et al., 2017; Dukes, 2012).

Fairways represent about 30% of the turfgrass on a typical 18-hole golf course (EIFG, 2007). Although fairways are usually irrigated, to our knowledge there are no data available in the scientific literature regarding potential water savings on fairway height turfgrass of using soil moisture sensors to control irrigation. Sensors Magazine reported the Desert Mountain Golf Course had 15-20% water savings by using soil moisture sensors to control irrigation on their fairways and greens (Kevan, 2006). However, golf courses have not taken full advantage of soil moisture technology in fairways, possibly because of cost but also because of a lack of research into fundamental questions such as sensor placement, soil moisture thresholds for initiating irrigation, effects of soil type on irrigation thresholds, and unknown quantitative relationships between soil moisture and turfgrass quality.

We propose to conduct fundamental research on how to improve irrigation by using soil moisture sensors to control irrigation. This will involve addressing several questions. What are the plant available water thresholds for initiating irrigation based on turfgrass visual quality and the onset of stress symptoms, and how do different soil properties affect those thresholds? Can current and forecasted reference evapotranspiration (FRET) data be used to potentially delay irrigation in order to conserve water while not risking unacceptable damage to turfgrass? Can we use historical and FRET data to predict soil moisture deficits? How well does the increase or decrease in soil moisture correspond to ET and irrigation inputs? Essentially, we propose to use a controlled study to investigate the underlying factors governing irrigation scheduling using soil moisture sensors in golf turf. We will utilize research that has been conducted in other agricultural crops and in residential irrigation of turfgrass and leverage it into golf where there are little data available addressing these questions.

We also propose to use remote sensing to evaluate the turf canopy in the different areas. This will include using handheld as well as UAS-mounted NDVI and thermal cameras.

We hypothesize that when used properly, the integration of soil moisture, reference ET, and turfgrass quality data can be used to improve irrigation scheduling and reduce total water use in turfgrass. By extension, the goal is to encourage golf facility adoption of these new irrigation scheduling techniques for water and cost savings.

Research Methods
This research will be conducted on 12 plots (30 x 30 ft.), each representing a separate irrigation zone, of perennial ryegrass (Lolium perenne L.) at the Rocky Ford Turfgrass Research Center near Manhattan, Kansas; perennial ryegrass will be established in fall 2017. Ryegrass plots will be maintained at 5/8 inch height and will be fertilized with 3 lbs N per 1000 ft2 annually.

Objective 1: Determine quantitative turf canopy responses to plant available water from in-situ soil moisture sensors (Phase I).
Recognizing the need for site-specific irrigation thresholds based on plant available water (PAW), the first objective of this proposed research will be to better understand turf canopy responses to soil moisture deficits. We will quantify canopy responses of perennial ryegrass using green canopy cover and NDVI during multiple soil drydown cycles during the first year of the project. Our approach will include both field and laboratory determination of soil physical properties.

First, we will fully characterize the existing soils on site for texture, organic matter content, pore size distribution, and soil water retention curves. This will ensure we have a full description of the site for which we are developing the threshold recommendations and will provide a point of reference for future work under different site conditions. Root depth will be measured and in- ground SMS will be installed with the sensing element at the mean root depth. Following a settling-in period of at least 30 days during which typical irrigation practices will be followed, the plots will be irrigated to near saturation and a drydown will be initiated. This cycle will be repeated multiple times during the summer in order to acquire sufficient information relating turfgrass quality and soil moisture. Volumetric water content and soil matric potential during the drydown events will be recorded using the SMS system, visual ratings for turf quality will be collected every 1 to 2 d, and handheld NDVI imagery and surface hardness will be measured every 2 d. Measurements with UAS-mounted NDVI and thermal cameras will be conducted every 4-7 d; the frequency of UAS measurements will be influenced by the pace of change in turf quality and weather conditions conducive for flying and obtaining viable data. Hourly reference ET will be recorded during the drydown events using local data from the Kansas Mesonet environmental monitoring network. Using recorded VWC, turfgrass quality ratings, and NDVI values, field capacity (FC) and permanent wilt point (PWP) VWC values from each sensor will be determined. Field capacity will be determined as the stable VWC value following the initial saturating irrigation event, but before significant ET-driven decline. Wilt point will be determined as the VWC value at which visible wilt becomes evident and/or NDVI values begin to decline significantly. The difference between FC and PWP will determine the PAW value for each plot.

Objective 2: Compare SMS-based irrigation scheduling to traditional irrigation and ET-based irrigation scheduling (Phase II).
In this objective we compare the SMS-based irrigation approach against a historical ET-based deficit irrigation treatment and a traditional calendar-based irrigation scheduling treatment (Table 1). For these treatments, we will consult with current and former superintendents on perennial ryegrass golf courses

in Kansas to ensure our selections for percent deficit and timing are representative of typical practices in that area. Weather and current ET data will be obtained from an on-site weather station, which is an official station of Kansas Mesonet (mesonet.k- state.edu). The exact irrigation thresholds based on plant available water will be determined based on the results from phase I.

Treatments will be assigned to plots in a randomized complete block design. Irrigation decisions will be made periodically as determined by data collected from the in-situ SMS system and historical ET. Prior to initiation of treatment applications, irrigation application rates will be calibrated for each plot and distribution uniformity will be characterized using catch cans and handheld soil moisture sensor measurements. Where necessary, irrigation depths will be adjusted to account for differences in real application rates due to plot-to-plot inconsistencies.

Upon initiation of treatments, total irrigation applied and number of irrigation events will be recorded for each plot. For all plots, soil moisture will be measured continuously using Campbell Scientific CS655 sensors and Toro Wireless TurfGuard sensors. Soil matric potential will be recorded using Decagon MP6 sensors, which will be used in tandem with CS655 sensors to create in-situ soil moisture release curves. Multi-spectral cameras (e.g. visible, near-infrared, thermal) will be used to collect periodic digital images and monitor turfgrass canopy using standard indices such as NDVI and percent green turf cover. Multispectral data will be collected to assess spectral reflectance characteristics. Canopy NDVI and canopy thermal images will be collected biweekly to monthly with UAS (Bremer and van der Merwe, 2016) during phase III. Across each irrigation zone, NDVI images provide maps of the relative quality and stress level of the turfgrass (Bremer et al., 2011), while thermal images provide maps of canopy temperatures; the latter is also an indicator of relative ET rates. Both NDVI and thermal images indicate areas where the turfgrass may be stressed.

The results of phases I and II will produce a thorough understanding of the relationships between soil moisture, plant available water, and turf health.

Objective 3: Prototype a simple turfgrass irrigation forecasting tool (Phase III).
Our hypothesis for this phase of research is that turfgrass managers can successfully conserve water by incorporating multiple sources of information into a simple irrigation decision-support tool.

The tool will generate 7-day forecasts of plant available water (Figure 1) based on site-specific soil texture, information of plant available water obtained from the soil moisture sensors at the time of deciding a possible irrigation event, and short-term forecasts of reference ET and precipitation obtained from the National Weather Service (digital.weather.gov). The tool will generate an ensemble of possible scenarios with the aim of assisting golf course with irrigation decisions. The tool will provide the most probable number of days until stress and the required amount of irrigation to be applied. Because this tool will be based on stochastic forecasts, managers can test multiple alternatives and make decisions according to the risk that each golf course is willing to accept.

Finally, actual reference ET from the on-site weather station will be compared with FRET values from the NWS to evaluate the accuracy of FRET values by the NWS.

Expected Results
From this work, we expect to gain a more thorough understanding of how to best select PAW thresholds for implementing SMS-based irrigation scheduling. The information gained from this project will begin to provide turfgrass managers a more meaningful way of interpreting SMS data and enable them to make a

meaningful changes in their irrigation practices. In addition, a quantification of water savings generated through the use of data-directed irrigation scheduling will be achieved and can give increased motivation for turf managers to invest in new technology that allows them to be better water managers.

The knowledge gained through this research will be disseminated in peer-reviewed articles, extension activities, and presentations at conferences. New knowledge on how to use soil moisture sensors for turfgrass irrigation management can be provided to sales and support personnel of SMS manufacturers so that customers are able to better understand how to implement these technologies.

These results also have the potential to drive changes in other industries. Residential, commercial, and agricultural irrigation all have the potential to benefit from the methods and knowledge developed in this proposed work. The golf industry will likely be acknowledged for contributing valuable knowledge to the general field of data-driven landscape irrigation.

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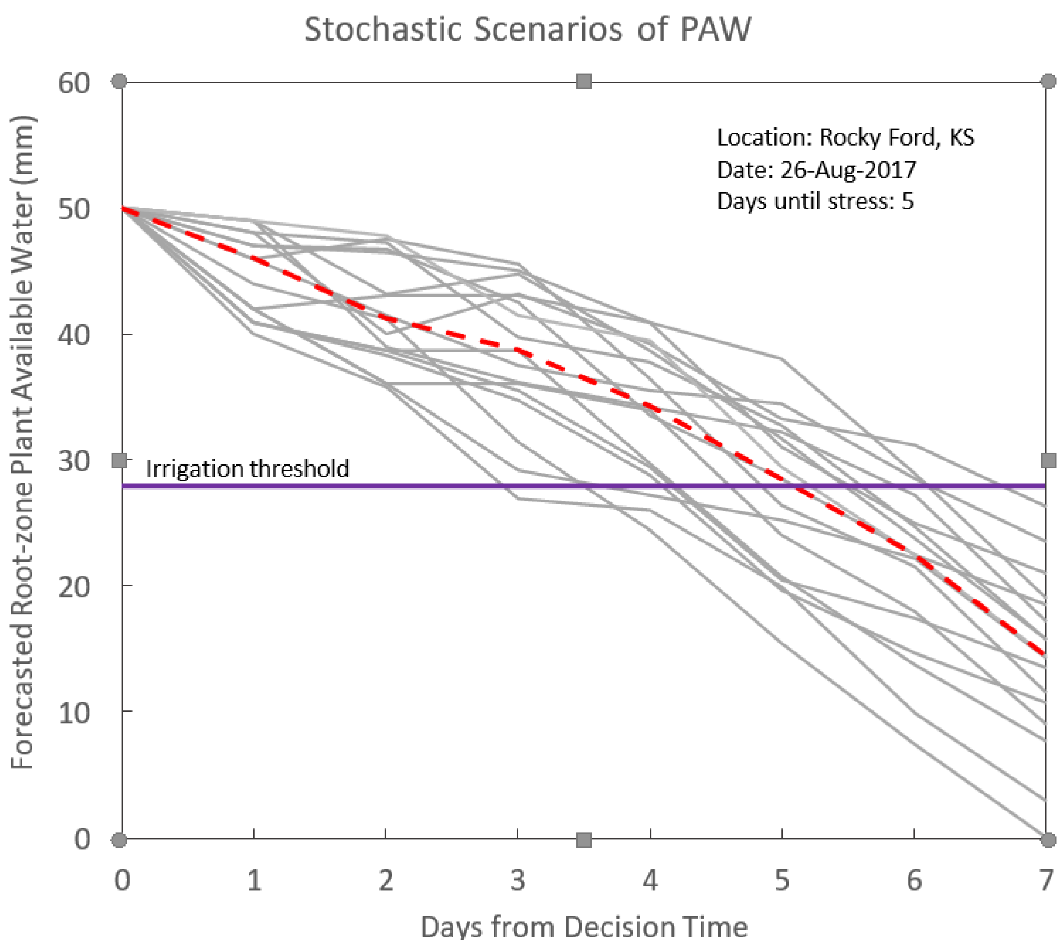

Figure 1. Example of stochastic forecasts of plant available water. Gray lines indicate each scenario using a 20-yr database of reference evapotranspiration. Dashed red line indicates the post probable scenario. The forecasts include a 25 mm (about 1 inch) of rainfall with 20% chance of occurrence 48 hours after decision time.

Table 1. Project treatments showing tentative treatment values.

Treatment ID	Description
1 (Traditional)	Traditional management based on a fixed irrigation schedule. No or little soil water stress. Usually leads to over-application irrigation. Three irrigation events per week totaling 1 inch per week.
2 (60% ETo)	Deficit irrigation. Irrigation represents a fixed portion of the reference ET. Arbitrary percentages are often hard to estimate accurately and vary across locations. We will start with 70% ET_O and adjust as necessary.
3 (SMS-based)	Irrigation based on plant available water. The concept of plant available water links the soil moisture condition with plant water stress, improving the timing and amount of the irrigation event. The irrigation threshold will be determined from phase 1 of the project.