Triggering drip irrigation onset by soil water tension

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Sustainable irrigated agricultural production depends on high and stable productivity using limited inputs of water and nutrients. When irrigation events are triggered by soil water tension (SWT) criteria, the criteria should be adjusted to precisely meet plant needs and provide increments of applied water consistent with soil properties. Drip irrigation systems are often used for triggered irrigation due to the potential to precisely control the irrigation system. Here we review the processes of collecting, filtering, and using SWT data for irrigation onset. A compilation of the successful triggering of irrigation onset using SWT criteria for many crops is discussed.

Introduction

Precise irrigation is becoming extremely important due to the shortages of water, competition for water, increase in population, consumer preferences for consumption of meat in the developing countries, and environmental pollution resulting from the excessive application of irrigation water. There are several irrigation scheduling techniques that can be used to obtain excellent irrigation scheduling. These include the use of estimates of crop evapotranspiration, SWT, soil water content, or plant stress. In the following paragraphs we will discuss applications of the use of SWT for precise irrigation scheduling.

Six years ago two of us (Shock and Wang, 2011) summarized the literature on the use of SWT as an irrigation onset criteria. Since that time additional research has fine-tuned irrigation criteria for several other crops. Also we have become aware of parallel research in agricultural engineering where the emphasis has been on triggering irrigation rather than the emphasis on optimal plant responses. Consequently in this brief summary we seek to combine the literature that emphasizes the idea of water tension to trigger irrigation with the literature that emphasizes the idea of water tension criteria for the ideal plant response.

The units of SWT in bars or kilopascals are the force necessary for plant roots to extract water from the soil. The higher the SWT number the dryer the soil. Different plant species have different ranges of ideal SWT irrigation onset criteria. Also the onset criteria to trigger irrigation can vary with the soil type and climate as we have shown previously (Shock and Wang, 2011; see tables 1 and 2 below). Tables 1 through 4 are from Shock et al. (2013). For the detailed references of the research results in tables 1-4 see Shock and Wang (2011).

There are a variety of different instruments that can be used to measure SWT that vary in price and in the range of SWT where they are most accurate. Soil moisture sensors for SWT can be read manually, integrated into an automated reading system, or be integrated into a totally automated system where the SWT feedback information controls the irrigation (Shock et al. 2002).

Soil water tension information can only lead to precise irrigation if plant responses are known and the soil properties are well defined. Critical for precise irrigation is the application of the correct amount of water to refill the root zone without creating undue water percolation. In both manual and automated systems, knowledge of soil properties and characteristics of the irrigation system govern the duration of the irrigation following the crop reaching its irrigation onset criteria. In this way nutrients that are in the soil are retained in the root zone as well as fertilizer inputs supplied by fertigation.

Sensor placement

In any irrigation decision system, the location used to determine whether or not irrigation of a particular block of crops is necessary is a subjective decision. With the use of sensors subjective decisions need to be made as to what part of the field or subpart of the field is appropriate for governing the entire irrigated block within the field. Knowledge needs to be applied as to the number of sensors required to provide an accurate estimate since the soil moisture always varies from spot to spot (Stieber and Shock, 1995). Sensor readings can vary tremendously by sensor position in the soil, positioning of plants in the field, and the relationship between sensor placement and water application. These placements are extremely critical in the case of drip irrigation where the soil more distant from the drip tape or emitters receives less water.

Automated systems

In automated systems not only is there a need for appropriate sensor placement and sensor number, but there is also the need to filter sensor data before each set of sensor readings is averaged and used for automated irrigation. Suppose there are sets of six sensors installed to provide information for the irrigation of a particular zone of a field. The technique that one of us (Shock) developed in 1995 to reduce automated irrigation errors was to sort the data so that errant sensor readings would not cause errors in automated irrigation. Many things can go wrong with wiring or electronics. Reasonable ranges of device readings can be determined and if the readings for a particular sensor are outside of the reasonable range that sensor needs to be flagged and not used in calculations until the operator can check the device for proper operation. The readings from the other devices that are within that zone can be used to provide automated irrigation.

The automated system must make readings of the field sufficiently frequently to catch the moment when the SWT in the field reaches the onset criteria to trigger irrigation. Then the automated program runs the irrigation system in that zone for the time needed to replace the water in the soil according to the irrigation system’s properties and the soil water retention characteristics of the soil. As a matter of brief review, the units of SWT (kPa = cb) are the force necessary for plant roots to extract water from the soil and send the water up into the plant. The higher the SWT number the dryer the soil. Different plant species have different ranges of ideal SWT irrigation onset criteria (Tables 3 and 4). For the detailed references of the research results tabulated here see Shock and Wang (2011).

Recent advances

Progress has continued at a rapid pace. One example is the work by Paris et al. (2017) where *Stevia rebaudiana* (stevia) leaf quantity and stevia leaf quality as measured by the natural non-caloric sweet steviol glycosides were closely related to the SWT criteria triggering irrigation. Stevia leaf yield was highest at relatively wet SWT (10 to 20 kPa) and several sweet leaf constituents were also closely related to similar wet irrigation criteria. Contreras et al. (2017) showed that zuchinni was best irrigated at 25 kPa. Seidel et al. (2017) report that cabbage was best irrigated at 25 kPa. Muller et al. 2016 showed that eggplant growth could be divided into two stages, where early plant development would be irrigated at 15 kPa and then fruit development would be best irrigated at 40 kPa. Kumar et al. (2016) examined flooded rice and recommended and irrigation criteria of 30 kPa, considerably drier than flooded conditions. Felix et al. (2015) studied sweet potato irrigation criteria and found that the best irrigation criteria was 25. In the first year of the study of the sweet potatoes the wettest treatment tested was (40) kPa, which was better than the drier treatments. Létourneau et al. (2015) examined, strawberry irrigation and recommended a triggering irrigation onset criteria of 10 kPa. Xi et al. (2014) studied the irrigation of the popular specie *Populus tomentosa*, and recommended a triggering onset criteria of 50 to 75 kPa. Rekika et al. (2014) worked on a series of vegetable species and recommended triggering irrigation onset criteria of 20, 15 to 30, and 10 kPa for onion, celery, and spinach, respectively. Evangelista et al. (2013) studied coffee and found ideal irrigation onset criteria of 32 kPa during flowering and fruit formation and 38 kPa during fruit maturation.

We are currently examining the drip irrigation of vineyards by and are studying the use of SWT criteria for triggering irrigations in widely different environmental circumstances.

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Table 1. Soil water tension (SWT) as irrigation criteria for onion bulbs as reviewed by Shock and Wang, 2011.

SWT (cb)	Location	Soil type	Irrigation system	Soil moisture sensor depth (inches)
8.5	Piauí, Brazil	Sandy	Microsprinkler	—
10	Pernambuco, Brazil	—	Flood	—
15	São Paulo, Brazil	—	Furrow	—
10–15	Malheur County, Oregon	Silt loam	Drip	8
17–21	Malheur County, Oregon	Silt loam	Drip	8
27	Malheur County, Oregon	Silt loam	Furrow	8
30	Texas	Sandy clay loam	Drip	8
45	Karnataka, India	Sandy clay loam	—	—

Table 2. Soil water tension (SWT) as irrigation criteria for potato as reviewed by Shock and Wang, 2011.

SWT (cb)	Location	Soil type	Irrigation system	Soil moisture sensor depth (inches)
20	Western Australia	Sandy loam	Sprinkler	—
25	Maine	Silt loam	Sprinkler	—
25	Luancheng, Hebei Province, China	Silt loam	Drip	8
30	Lethbridge, Alberta, Canada	Sandy loam	Sprinkler	—
30	Malheur County, Oregon	Silt loam	Drip	8
50	California	Loam	Furrow	—
50–60	Malheur County, Oregon	Silt loam	Sprinkler	8
60	Malheur County, Oregon	Silt loam	Furrow	8

Table 3. Soil water tension (SWT) as irrigation criteria for cole crops as reviewed by Shock and Wang, 2011.

Common name	**SWT (cb)**	**Soil type**	**Irrigation system or measurement equipment**	**Soil moisture sensor depth (inches)**	**Location, season**
Broccoli (*Brassica oleracea* var. *italica*)	10–12	Sandy loam	Subsurface drip	12	Maricopa, AZ; fall–winter
Broccoli	50, 20[1]	Silt loam	Lysimeters in rain shelter	4	Agassiz, British Columbia, Canada; spring
Cabbage (*Brassica oleracea* var. *capitata*)	25	Loamy sand and sand	Lysimeters in rain shelter	4	Tifton, GA; spring and fall
Cauliflower (*Brassica oleracea* var. *botrytis*)	10–12	Sandy loam	Subsurface drip	4	Maricopa, AZ; fall–winter
Cauliflower	25[2]	Sandy loam	Furrow and flood	7	Bangalore, India; winter
Cauliflower	20–40	Sandy loam	—	—	Skierniewice, Poland; spring–summer
Collard	9	Sandy loam	Subsurface drip	12	Maricopa, AZ; fall–winter
Mustard, greens	6–10	Sandy loam	Subsurface drip	12	Maricopa, AZ; fall–winter
Mustard, greens	25[2]	Loamy sand and sand	Lysimeters in rain shelter	4	Tifton, GA; spring and fall

[1] SWT of 50 cb during plant development, then 20 cb during head development.

[2] Twenty-five cb was the wettest irrigation criterion tested.

Table 4. Soil water tension (SWT) as irrigation criteria for other field and vegetable crops as reviewed by Shock and Wang, 2011.

Common name	**SWT (cb)**	**Soil type**	**Irrigation system or measurement equipment**	**Soil moisture sensor depth (inches)**	**Location, season**
Alfalfa grown for seed	200–800	Fine sandy loam, loam, silt loam	Sprinkler and surface flood	4–72	Logan, UT; summer season of the perennial crop
Beans, snap (*Phaseolus vulgaris*)	25[z]	Loamy sand	Lysimeters in rain shelter	4	Tifton, GA; spring and fall
Beans, snap	45	Sandy clay loam	—	6	Bangalore, India; fall–winter
Beans, snap	50	Clay loam	Furrow and drip	12	Griffin, NSW, Australia; summer
Carrot	30–50	—	Sprinkler	—	Nova Scotia, Canada; spring–summer
Carrot	40–50	—	Microsprinkler	6	Nova Scotia, Canada; spring–summer
Celery	10	Sandy loam	Drip	8	Santa Ana, CA; fall–winter
Corn for sweet corn	10–40	Sand	Drip	6	—
Corn for sweet corn	30	Carstic soils	Drip	12	Champotón, Campeche, Mexico; spring–summer
Corn for sweet corn	50	—	—	—	Utah; spring–summer
Corn for grain	30	Loamy fine sand	Sprinkler	6	Quincy, FL; spring–summer

Table 4 continues

continued—*Table 4. Soil water tension (SWT) as irrigation criteria for other field and vegetable crops as reviewed by Shock and Wang, 2011.*

Common name	SWT (cb)	Soil type	Irrigation system or measurement equipment	Soil moisture sensor depth (inches)	Location, season
Corn for grain	50	—	—	—	Utah[5]
Cucumber	15–30	Fine sand and sandy clay	Drip	8	Piikkio, Finland; spring–summer
Lettuce, romaine	<6.5	Sandy loam	Subsurface drip	12	Maricopa, AZ; fall–winter
Lettuce, leaf	6–7	Sandy loam	Subsurface drip	12	Maricopa, AZ; fall–winter
Lettuce	<10	Red earth	Drip	12	NSW, Australia
Lettuce	20	Clay loam, sandy loam	Sprinkler, drip	6	Las Cruces, NM; summer-fall
Lettuce, romaine	30[1]	Clay loam	Surface	12	—
Lettuce, crisphead and romaine	50	Sandy loam	Sprinkler	6	Salinas, CA; spring–summer
Radish	35	Silt loam	Drip	8	Luancheng, Hebei Province, China; summer–fall
Radish	20	Sandy clay loam	Control basin and furrow	7	Bangalore, India; winter
Rice	16	Sandy loam	Flood	6–8	Punjab, India; summer–fall
Spinach	9	Sandy loam	Drip	—	Maricopa, AZ
Squash, summer	25[1]	Loamy sand and sand	Lysimeter	—	Tifton, GA; spring, summer, and fall
Sweet potato	25, then 100[2]	Loamy sand and sand	Lysimeters in rain shelter	9	Tifton, GA; summer
Sweet potato	25–40	Silt loam	Drip	8	Ontario, OR; summer
Tomato	10	Fine sand	Drip	6	Gainesville, FL; spring
Tomato	20	Sand	Drip	6	Coruche, Portugal; spring–summer
Tomato	12–35[3]	Clay	Drip	4–8[4]	Federal District, Brazil; fall–winter
Tomato	50	Silt loam	Drip	8	Yougledian, Tongzhou, Beijing, China; summer
Watermelon	7–12.6	Sandy loam	Drip	12	Maricopa, AZ; spring–summer

[1] Twenty-five cb or 30 cb was the wettest irrigation criterion tested.

[2] SWT of 25 cb during plant development, then 100 cb during root enlargement.

[3] Thirty-five, 12, and 15 cb during vegetative, fruit development, and maturation growth stages, respectively.

[4] Tensiometer depth was 4" during the vegetative growth stage, 6" in the beginning of the fruit development stage, and 8" from thereon until the irrigations were stopped.

[5] Taylor, S.A., D.D. Evans, and W.D. Kemper. 1961. *Evaluating Soil Water*. Utah Agricultural Experiment Station Bulletin 426.