Irrigation scheduling by soil water potential

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Abstract. One of the fundamental ways to schedule irrigation is through the monitoring and management of soil water potential (SWP). Soil water tension (SWT) is the force necessary for roots to extract water from the soil and growers find it easier to deal with the positive units of SWT rather than the negative units of SWP. With the invention of tensiometers, SWT measurements have been used to schedule irrigation. There are seven different types of field instruments used to measure SWT, either directly or indirectly. Specific SWT criteria for irrigation scheduling have been developed for the production of individual vegetable crops, field crops, trees, shrubs, and nursery crops and for the management of landscape plants. A review of the known SWT criteria for irrigation scheduling will be presented.

Keywords. Soil water tension, Tensiometer, Granular matrix sensor

Why Measure Soil Water Tension

The lack of water in plant-top tissues is transmitted through the plant, down into the roots, and into the soil. The measurement of soil water tension can be closely related to the stress experienced by the plant tissues, and in these conditions irrigation scheduling based on soil water tension can be directly related to plant performance. The use of a soil water tension measuring device provides a continuous measurement analogous to the force (suction) necessary to extract water from the soil.

When growers irrigate too infrequently and with too much water, product yield and quality is lost (Tjosvold and Schulbach 1991) and water and nutrients are lost, with the potential of environmental harm. Since SWT is closely related to plant stress, crop yield and quality is closely related to SWT irrigation criteria (Shock et al. 2007b). Careful irrigation scheduling by SWT simultaneously provides the grower with a tool to optimize income and minimize negative off site effects of irrigation.

Instruments to Measure Soil Water Tension

Soil water tension has been measured directly with tensiometers and through indirect methods such as with gypsum blocks, granular matrix sensors (GMS, Watermarks), porcelain resistance to air movement (Irrigas), psychrometers, pressure plates, and dielectric sensors coupled with porous media (MPS-1).

The Response of Specific Crops to SWT Irrigation Scheduling

The specific SWT irrigation criteria chosen for each crop should be based on experience with the crop in a given region. The climate, soil type, irrigation system, and sensor placement can affect the optimal irrigation criteria.

Response of Onion

Onion is a shallow rooted crop requiring relatively wet soil (Table 1). The response of vegetable crops to SWT has been reviewed (Shock et al. 2007b). For short-day onion, the irrigation criterion has varied from 8.5 to 45 cbar depending on the climate, soil, and irrigation system. Sandy soil and drip irrigation systems necessitate wetter irrigation criteria. When and where rainfall is significant, onion production is favored by slightly drier irrigation criteria. The irrigation criterion for long-day onions on silt loam has varied from 10 to 27 cbar. When rainfall is absent, wetter criteria are favored. Furrow irrigation requires drier criteria due to the risk of bulb decomposition in excessively wet parts of fields. Increasing water stress (increased SWT) in the later part season in an attempt to reduce onion bulb decomposition reduced bulb yield and grade (Shock et al. 2000b). Onions are particularly sensitive to losses in yield and grade from small amounts of water stress when infected by iris yellow spot virus (Shock et al. 2009).

Table 1. Soil water tension (SWT) as irrigation criteria for onion bulbs.

SWT, cbar	Location	Soil type	Irrigation system	Soil moisture sensors, depth	Citation
8.5	Piaui, Brazil	sandy	micro sprinkler	tensiometer	Coelho et al., 1996
10	Pernambuco, Brazil		flood	tensiometer, gravimetric	Abreu et al., 1980
15	Sao Paulo, Brazil	sandy and clay	furrow	gravimetric	Klar et al., 1976
10 to 15	Oregon	silt loam	drip	GMS	Shock et al., 2009
17 to 21	Oregon	silt loam	drip	GMS	Shock et al., 2000a
27	Oregon	silt loam	furrow	GMS	Shock et al., 1998a
45	Karnataka, India	sandy clay loam		tensiometer, gravimetric	Hegde, 1986

Response of Potato

Potato is also shallow rooted requiring relatively wet soil (Table 2). Precise irrigation of potato has been closely related to many tuber quality attributes (Shock et al, 2007a). Wetter irrigation criteria are needed on sandy soils. Silt loam soils should be maintained slightly drier. Where drip irrigation is applied frequently, the irrigation criteria for silt loam is wetter (25-30 cbar) than where sprinkler or furrow irrigations systems are used (50-60 cbar).

Table 2. Soil water tension (SWT) as irrigation criteria for potato.

SWT, cbar	Location	Soil type	Irrigation system	Soil moisture sensors, depth	Citation
20	Western Australia	sandy loam	sprinkler	tensiometer	Hegney and Hoffman, 1997
25	Maine	silt loam	sprinkler	tensiometer, gravimetric	Epstein and Grant, 1973
25	Northern China		drip	Tensiometer	Wang et al. 2007
30	Oregon	silt loam	drip	GMS	Shock et al., 2002b
50	California	loam	furrow	tensiometer	Timm and Flockner, 1966
50 to 60	Oregon	silt loam	sprinkler	GMS	Eldredge et al., 1992, 1996; Shock et al. 1998b, 2003
60	Oregon	silt loam	furrow	GMS	Shock et al., 1993

Response of Cole Crops

Cole crops are among the species most sensitive to soil water tension (Table 3). Irrigation criteria as wet as 6 to 10 cbar are recommended in Arizona.

Table 3. Soil water tension (SWT) as irrigation criteria for cole crops.

Common name	SWT, cbar	Soil type	Irrigation system	Soil moisture sensors, depth	Citation
Broccoli	10 to 12	sandy loam	drip	tensiometer	Thompson et al., 2002a, b
Broccoli	50, 20[b]	silt loam	lysimeters	gypsum blocks	Maurer, 1976.
Cabbage	25	loamy sand and sand	lysimeter	gypsum blocks	Smittle et al., 1994
Cauliflower	10 to 12	sandy loam	drip	tensiometer	Thompson et al., 2000 a, b
Cauliflower	25[a]		furrow and flood		Prabhakar and Srinivas, 1995.
Cauliflower	20 to 40	various			Kaniszewski and Rumpel, 1998
Collard	9	sandy loam	drip	tensiometer	Thompson and Doerge, 1995
Mustard, greens	6 to 10	sandy loam	drip	tensiometer	Thompson and Doerge, 1995
Mustard, greens	25[a]	loam sand and sand	lysimeter	gypsum blocks	Smittle et al., 1992

[a]25 kPa was the wettest irrigation criterion tested.
[b]SWT of 50 during plant development, then 20 during head development.

Response of Other Field and Vegetable Crops

The published SWT irrigation criterion for other crops is listed in table 4. In the case of sweet potatoes, the recommendation is to irrigate at 25 cbar during early plant development, then switch to a much drier criteria for potato development. These recommendations contrast with potato, where the soil is maintained a more constant SWT throughout development, and where some limited stress on early vegetative plant growth favors potato vine health and tuber quality (Cappaert et al. 1994; Shock et al. 1992).

Thomson and Fisher (2006) used SWT irrigation criteria of 60 cbar for developing ET irrigation scheduling for cotton in Mississippi.

Table 4. Soil water tension (SWT) as irrigation criteria for Other Field and Vegetable Crops

Common name	SWT, cbar	Soil type	Irrigation system	Soil moisture sensors, depth	Citation
Beans, snap	25[a]	loamy sand	lysimeter	gypsum blocks	Stansell and Smittle, 1980
Carrot	30 to 50		sprinkler	TDR[b]	Lada, 2002
Carrot	40 to 50		micro sprinkler	GMS	Lada and Stiles, 2004
Lettuce, romaine	<6.5	sandy loam	drip	tensiometer, 30, cm	Thompson and Doerge, 1995
Lettuce, leaf	6-7	sandy loam	drip	tensiometer, 30 cm	Thompson and Doerge, 1996a, b
Lettuce	<10	red earth	drip	tensiometer, 30 cm	Sutton and Merit, 1993
Lettuce	20	clay loam	sprinkler, drip	tensiometer, 15 cm	Sammis, 1980

Lettuce, romaine	30	clay loam	n.a.	tensiometer and gypsum blocks, 30 cm	Aggelides et al., 1999
Lettuce, crisphead and romaine	50	sandy loam	sprinkler	tensiometer, 15 cm	Gallardo et al., 1996
Spinach	9	sandy loam	drip	tensiometer	Thompson and Doerge, 1995
Squash, summer	25[a]	loamy sand and sand	lysimeter	gypsum blocks	Stansell and Smittle, 1989
Sweet corn	20		drip		Phene and Beale, 1976
Sweet potato	25, then 100[c]	loamy sand and sand	lysimeter	gypsum blocks	Smittle et al., 1990
Tomato	10	fine sand	drip	tensiometer	Smajstrla and Locasio, 1996
Tomato	20	sand	drip	tensiometer	Oliveira and Calado, 1992
Watermelon	7 to 12.6	sandy loam	drip	tensiometer	Pier and Doerge, 1995a, b

[a]25 kPa was the wettest irrigation criterion tested.
[b]TDR, time domain reflectrometry.
[c]SWT of 25 during plant development, then 100 during root enlargement.

Response of Poplar Trees

Poplar tree growth is favored by an irrigation criterion of 25 cbar and drier criteria lead to reduced tree and biomass production (Shock et.al. 2002).

Response of Wine Grapes

Recently the viticulturist of Camalie Vineyards, Napa, California, has demonstrated potential usefulness of SWT data for the production of quality grapes (Holler 2008). Wine grapes are a case where controlled and managed water stress is related to crop quality.

Response of Cranberries

Jeranyama (2009) reports that cranberries require SWT in the range of 2 to 6 cbar in the morning and 2 to 10 cbar in the afternoon. Surprisingly soil consistently wetter than 2 cbar is too wet.

Response of Strawberries

Strawberries are extremely sensitive to water stress. A SWT irrigation criterion of 10 cbar has been recommended (Serrano et al. 1992).

Response of Flower Production and Ornamental Plants

The production of nursery plants and flowers grown in artificial medium is particularly vulnerable to loss of water and nutrients from excessive amounts of irrigation (Tjosvold and Schulbach 1991; Oki et al. 1995). Soil often needs to be maintained in the range of 1 to 6 cbar (Kiehl et al. 1992; Plaut et al. 1976). Plaut et al. showed that the medium needs to be maintained wetter than 6 cbar for cut roses. Oki et al. demonstrated that smaller irrigations at wetter SWT using tensiometers resulted in much more productive rose productivity.

Carnations grown in raised beds responded well with growth medium maintained in the 0 to 10 cbar range (Marsh et al. 1962). Tensiometers needed to be designed to be accurate and responsive in the 0 to 10 cbar range.

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