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Successful Potato Irrigation Scheduling

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In the late 1980s, the U.S. Pacific Northwest potato industry faced a crisis. Potato tuber quality was inadequate to meet the needs of potato processing companies due to a condition called "sugar ends" or "dark ends" in fried tuber slices. This defect was common in tubers grown on stressed Russet Burbank plants, but the stresses aggravating the condition were poorly defined. Growers lost contracted acres.

In 1989, northern Malheur County was declared a groundwater management area due to groundwater nitrate contamination. The groundwater contamination was linked, at least in part, to furrow irrigation of potato. All irrigation systems in arid regions require some leaching fraction to avoid salt accumulation. However, with the high nitrogen fertilizer rates used through the 1980s, and heavy water applications on furrow-irrigated potato, nitrogen and other mobile nutrients were readily lost to deep percolation and in runoff.

In response to these problems, Malheur Experiment Station began research to determine the soil water requirements for potato production in the Treasure Valley by carefully monitoring soil water status using soil moisture sensors. As growers modified irrigation and other practices to **minimize water stress** on potato plants during tuber development, sugar ends became less prevalent.

At the same time, Experiment Station research and grower experience found that **sprinkler irrigation** could reduce sugar ends and improve tuber grade. Some growers purchased or leased sprinkler irrigation systems. Growers regained contracted acreage by learning to schedule irrigation, shifting to the Shepody variety, and converting from furrow to sprinkler irrigation.

Other growers, however, were unwilling to plant potatoes again. If potatoes were so unpredictable, they wondered, how could they consistently produce a quality crop? However, new understanding of potato development and new information resources have largely taken the mystery out of irrigated potato production in the Treasure Valley.

Irrigation methods

Irrigation method is an important consideration in irrigation scheduling. For potatoes, the leading irrigation method is sprinkler irrigation of hilled rows. Furrow irrigation is still widely used worldwide. Drip irrigation has grown in popularity as the agricultural community has gained familiarity with the system. Drip irrigation advantages, disadvantages, and methods are discussed in *Drip Irrigation Guide for Potatoes in the Treasure Valley*, EM 8912-E (Shock et al., 2006).

Irrigation scheduling

Potatoes have little tolerance for water stress. Tuber market grade, tuber specific gravity, and tuber processing quality for French fries are all critically influenced by water stress during tuber bulking. The incentives for a grower to maintain a precise irrigation schedule to keep the soil water potential within a narrow range of values are significant.

- Underirrigation leads to losses in tuber quality, market grade, total yield, and contract price.
- Overirrigation leads to erosion, disease susceptibility, water loss, extra energy costs for pumping, nitrogen leaching, and increased crop N needs.

Scheduling methods

In order for an irrigation schedule to be effective, it has to tell us **when** to water and **how much** to apply. Scheduling methods that are successfully used in the Treasure Valley of Oregon and Idaho are:

- Crop evapotranspiration using the checkbook method
- Soil water tension using a graph of soil moisture
- A combination of these two methods

Crop evapotranspiration (ET)

Crop evapotranspiration (ET) is the combined evaporation of water from the soil surface and crop water use (transpiration of water through plant tissue). Crop evapotranspiration values are calculated using weather stations in a production region. In the Treasure Valley, ET data are available online through AgriMet, a U.S. Bureau of Reclamation cooperative agricultural meteorological network for the Pacific Northwest. Other areas are served by public meteorological networks. Weather stations that estimate evapotranspiration are also sold for farm use.

To illustrate how ET works, think of the soil as a checking account and the water in it as the money in the account. You keep a record (ET log) of all the charges and deposits made to the account. You can run up your charges only to a certain point; after that you must make a deposit, or get "zapped."

To use this method of irrigation scheduling, you must have access to the following:

- AgriMet or other local weather station information to estimate potato crop water use (ET) based on the crop coefficient and crop development data (Table 1, page 3).
- A rain gauge placed in each production field or group of adjacent fields.
- A good estimate for the allowable depletion of water for each soil. The allowable soil water depletion for potatoes can be calculated if you know the following: (1) potato plants' effective rooting depth in a given soil and (2) the soil's water retention characteristics in the range where the potato plant does not suffer water stress. Be careful not to overestimate either the root zone depth or the soil's capacity to hold water.

When using this checkbook method, keep the following in mind:

- **Spending depletes your account.** Water use by the plant plus losses from evaporation make up the ET estimated by AgriMet.

Table 1. This sample of an AgriMet table gives ET for Shepody potato (POTS) with an emergence date of May 5 (Start Date 505), and for Russet Burbank potato (POTA) with emergence dates of May 15 and May 23. Columns entitled Daily Crop Water Use display the calculated value as inches per acre for the past 4 days, while the Daily Forecast predicts water use for the current day. The last two columns provide the 7- and 14-day accumulated ET.

ESTIMATED CROP WATER USE - AUG 15, 2005 ONTO

CROP	START DATE	DAILY CROP WATER USE-(IN) PENMAN ET - AUG 11	12	13	14	DAILY FORE CAST	COVER DATE	TERM DATE	SUM ET	7 DAY USE	14 DAY USE
POTS	505	0.29	0.27	0.26	0.20	0.24	610	901	25.9	1.8	3.6
POTA	515	0.39	0.36	0.35	0.28	0.33	710	920	22.7	2.4	4.6
POTA	523	0.40	0.37	0.36	0.28	0.33	710	925	21.7	2.4	4.6

- **Deposits refill the account.** Applied irrigations plus rainfall (measured at the field) are considered deposits.
- **You can get "zapped."** Overcharging your bank account or paying a bill late results in a penalty. The same is true here. Letting the field get too dry will result in tuber yield and grade penalties. Keep in mind that **water stress can occur by watering only 1 day late.**
- **The soil water account for potato has a limited size.** If there is more rain or irrigation than the soil can hold, the excess is lost.

How much?

Table 2 shows an example of the checkbook method of irrigation scheduling by crop evapotranspiration. In this example, ET is tallied for a potato root zone with an allowable depletion of 1.2 inches of water. The soil is Owyhee silt loam, a common soil around Ontario, Oregon. The daily potato evapotranspiration amounts are the August 2005 AgriMet estimates at this arid location, but the rainfall events are hypothetical, for instructional purposes. Let's suppose that each irrigation supplies 1.2 inches of water, thus replenishing the allowable depletion.

Table 2. The checkbook method of irrigation scheduling where a silt loam soil has 1.2 inches of allowable depletion for potatoes.

Action	Date (August)	Daily ET (inches)	Rain (inches)	Accumulated ET (inches)
	1	0.35		0.35
	2	0.34		0.69
	3	0.34		1.03
Irrigate	4	0.32		0.15
	5	0.31		0.46
	6	0.29	0.08	0.67
	7	0.27	1.45	—0—
	8	0.29		0.29
	9	0.31		0.60
	10	0.40		1.00
Irrigate	11	0.40		0.20
	12	0.37		0.57
	13	0.36		0.93
	14	0.28		1.21
Irrigate	15	0.26		0.27
	16	0.25		0.52
	17	0.24		0.76
	18	0.26		1.02
Irrigate	19	0.25		0.07
	20	0.23		0.30
	21	0.25		0.55
	22	0.27		0.82

The checkbook method consists of keeping a record of rainfall, estimated daily ET, and the accumulated net ET from one irrigation to the next. Estimated daily ET is available online at www.usbr.gov/pn/agrimet/h2ouse.html.

Rainfall is subtracted from the net ET. If rainfall makes the net ET account negative, the negative balance is dropped, and net ET is set to zero for that day. The negative balance is dropped because it represents water applied in excess of the root-zone water-holding capacity; this water is lost to runoff or leaching, typically within 24 hours.

Note that the ET for the day of irrigation is also added; thus, net ET accumulated up to the day of irrigation includes the ET for that day. Irrigation never exceeds 1.2 inches because the extra water would be quickly lost to runoff or leaching.

When?

The grower decides when to irrigate by not allowing net ET to exceed the allowable depletion. To avoid getting zapped, he must begin irrigation on the day the balance would have exceeded 1.2 inches.

The grower knows how much to irrigate by replacing only the soil's allowable depletion (1.2 inches). There is no mystery here. We have made clear decisions about when to irrigate and how much water to apply: the result is successful potato irrigation.

The checkbook method on sandy soil?

The checkbook method operates in the same way on a sandy soil, but the irrigation frequency is much higher and irrigations typically are much smaller. Assume irrigations of 0.33 inch and a 0.5-inch allowable water depletion for potatoes (Table 3).

Table 3. The checkbook method of irrigation scheduling where a sandy soil has 0.5 inch of allowable depletion for potatoes.

Action	Date (August)	Daily ET (inches)	Rain (inches)	Accumulated ET (inches)
	1	0.35		0.35
Irrigate	2	0.34		0.36
Irrigate	3	0.34		0.37
Irrigate	4	0.32		0.36
Irrigate	5	0.31		0.34
Irrigate	6	0.29	0.08	0.22
	7	0.27	1.45	—0—
	8	0.29		0.29
Irrigate	9	0.31		0.27
Irrigate	10	0.40		0.34

Irrigation scheduling by soil water content

On sandy soils, irrigation scheduling by the checkbook method alone has a narrow margin of error. Measuring the trend in soil water content in conjunction with the checkbook method can help assure that the field is not getting too dry or too wet. Regular measurements are made by neutron probe or by other equipment and are plotted over time.

Irrigation scheduling by Soil Water Tension (SWT)

Another effective method for irrigation scheduling is based on soil water tension. SWT is a measure of how strongly water is held by the soil. Potato plant performance is closely related to the amount of tension the plant has to exert to move water from the soil into the plant roots. That force can be measured using either tensiometers or Granular Matrix Sensors (GMS).

GMS (manufactured as Watermark soil moisture sensors by Irrometer Co., Riverside, CA) measure SWT using a battery-powered meter. These measurements are recorded, and they provide information about **when** to irrigate. Since 1988, SWT readings from GMS have been used to schedule irrigations in Malheur County growers' fields.

Six or more GMS can characterize the soil water tension in a field, provided they are installed in representative areas and are responsive to ET and irrigations. The six GMS may be distributed widely across an area with similar irrigation needs. Sensors are installed 8 inches deep in the potato row between two healthy plants. Wires from sensors in a given area are brought to a single easily accessible location, such as a field edge, for rapid reading.

Irrigation onset criteria must be developed for each production environment. Criteria for irrigation onset by SWT depend on the climate, soil, and irrigation system in use. Studies have determined criteria from 20 to 60 centibars (cb). The SWT irrigation criteria that optimize potato yield and grade vary by production area. Based on potato yield and grade responses to irrigation, ideal potato SWT irrigation criteria are as follows:

- 50 to 60 cb for sprinklers on silt loam in Oregon (Figure 1)
- 60 cb and 30 cb for furrow and drip irrigation, respectively, on silt loam in Oregon (Figure 2)
- 50 cb for furrow irrigation on loam in California
- 25 cb for sprinklers on silt loam in Maine
- 20 cb for sprinklers on sandy loam in western Australia

When to irrigate on silt loam in the Treasure Valley?

Read sensors daily and plot the data on a graph for immediate interpretation. On silt loam, tuber growth and grade are maximized when irrigation occurs before the average readings at the 8-inch depth reach 60 cb for sprinkler and furrow irrigation systems or 30 cb for drip systems (Figures 1 and 2).

Moderate water stress causes little damage to potatoes before tuber initiation, but during tuber development even small amounts of water stress

An SWT scale for potato

- > 80 cb indicates dry soil and water stress for potato plants.
- 20 to 60 cb is the range that indicates it's time to irrigate, depending on location, soil type, and irrigation system.
- 10 cb is close to field capacity.
- 0 to 10 cb indicates the soil is saturated with water.

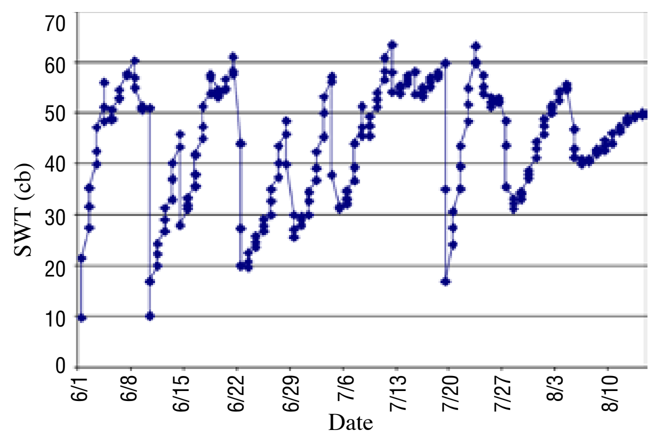

Figure 1. Sprinkler-irrigated potato with irrigation criteria of 60 cb on silt loam at Ontario, OR. Soil water tension drops following each irrigation. The irrigation on July 12, while replacing ET, did not get the soil wet around the GMS because the previous four irrigations did not refill the root zone.

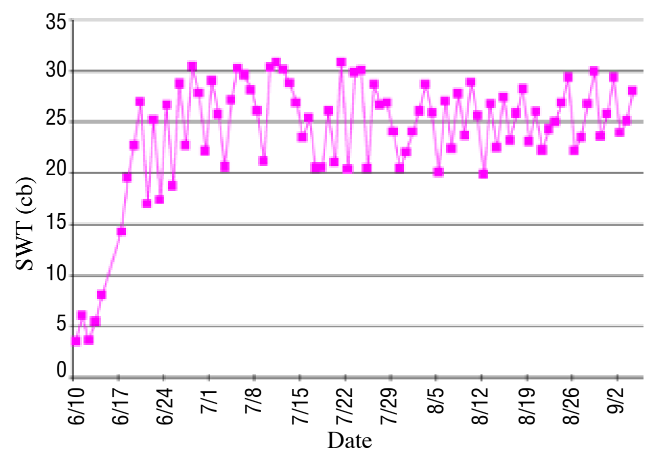

Figure 2. Drip-irrigated potato with small drops in soil water tension following irrigations on silt loam at Ontario, OR. Irrigations are much more frequent. They maintain an average SWT wetter than 30 cb and do not saturate the soil.

(higher than 50 cb) can result in decreased tuber grade. On silt loam, water stress beyond 60 cb results in decreased specific gravity and increased incidence of dark-end fry colors in susceptible cultivars such as Russet Burbank.

A single, short-duration incident of water stress (SWT drier than 60 cb, zap!) can lead to reduced tuber grade and increased dark fry colors (Eldredge et al., 1996). In one experiment, a single episode of water stress, with GMS readings reaching an SWT of 75 cb or more, resulted in a loss of USDA No. 1 grade tubers, correspondingly more USDA No. 2 grade tubers, and losses in tuber solids. A single stress episode with GMS readings of 75 cb or drier was associated with increased incidence of the darkest fry colors: USDA No. 3 and No. 4 (Eldredge et al., 1996).

Total yield generally is unaffected by one brief episode of stress, but reduced tuber quality can render the crop unprofitable (Eldredge et al., 1992). Thus, it is critical to maintain SWT at adequate levels. However, it is very difficult to gauge water stress without a quick, reliable field determination of soil water tension. GMS provides this capability. When viewed in graphical form, SWT clearly indicates the current condition of the crop root zone and how rapidly water is being depleted. Methods for determining crop water needs and installing and managing granular matrix sensors and tensiometers are discussed more thoroughly in *Irrigation Monitoring Using Soil Water Tension*, EM 8900 (Shock et al., 2005).

Combining SWT with ET

A powerful way to schedule irrigation is to combine the ET and SWT methods. The strong point of SWT is its ability to predict stress before it occurs, while the strong point of ET is its ability to prevent overirrigation. Combine the two methods by irrigating when the average tensiometer or GMS reading reaches the SWT criterion and applying enough water to replenish ET but not more than needed to refill the root zone.

Automated SWT readings

Dataloggers that automatically read GMS and record SWT can facilitate irrigation management. The data can be viewed with the push of a button and can be downloaded to a laptop computer or PDA. Downloaded data can be imported into a spreadsheet and graphed. The SWT graphs constructed from the stored data make it possible to determine soil moisture trends and to predict or modify irrigation schedules at each GMS location. The dataloggers also can include soil temperature sensors to correct the SWT data.

Irrometer Co. Inc. (Riverside, CA) makes the Watermark Monitor, which automatically stores readings from up to eight sensors, including a temperature sensor and pressure switches for recording irrigation events. Data intervals can be set from once a minute to once every 24 hours. Data can be downloaded from the Watermark Monitor to a laptop or PDA in the field, or can be transmitted by radio or cellular modem to a remote computer.

The AM400, by M.K. Hansen Co. (East Wenatchee, WA), automatically records readings every 8 hours from six GMS and a temperature sensor. By pushing a button, the grower can view soil moisture graphs of the recorded data.

Stress-resistant varieties

Potato varieties that express fewer negative characteristics when subjected to stress have been identified. One of these varieties, Shepody, has become more popular with growers and processors in the past decade. Other varieties, including Ranger Russet, Umatilla Russet, and other experimental varieties, are discussed in Malheur Experiment Station annual reports and in Shock et al. (2003b).

Irrigation and disease

Excessively wet soil is conducive to many tuber-rotting pathogens, encouraging the incidence of blights, rots, and wilts that can limit yield, tuber quality, tuber size, tuber dry matter content, and crop marketability at harvest or from storage. Dense canopy growth, long periods of leaf wetness, and high relative humidity create microenvironments that favor infection. Improperly managed irrigation often keeps the vines wet for long periods of time, exacerbating the risk of infection.

Diseases promoted by overirrigation include:

- Late blight (*Phytophthora infestans*)
- Early blight (*Alternaria solani*)
- Soft rot (*Erwinia* spp.)
- White mold (*Sclerotinia sclerotiorum*)
- Black leg (*Erwinia carotovora atroseptica*)
- Potato leak (*Pythium* spp.)
- Pink rot (*Phytophthora erythroseptica*)
- Rhizoctonia canker (*Rhizoctonia solani*)
- Powdery scab (*Spongospora subterranea*)
- Verticillium wilt (*Verticillium dahliae*)

Prolonged periods of saturation following planting can promote seed piece decay as well as poor and erratic tuber emergence.

For more information

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Quick Facts

- Potato is a water-stress-sensitive crop. Potato plants are more productive and produce higher quality tubers when watered precisely using soil water tension (SWT) than if they are under- or overirrigated.
- Potatoes are more sensitive to water stress than are most other crops.
- Potatoes have a relatively shallow root system that provides very little margin for irrigation errors.
- Yield reductions due to overirrigation can be attributed to poor soil aeration, increased disease problems, and leaching of nutrients from the shallow crop-root zone.
- Granular Matrix Sensors provide good estimates of SWT for many soils.
- SWT provides useful guidelines to avoid water stress by projecting **when** to irrigate.
- A soil water potential of -30 cb is the same as a soil water tension of +30 cb. Also, cb (centibars) is the same as kPa (kiloPascals).
- In the Treasure Valley, sprinkler- and furrow-irrigated potatoes on silt loam are irrigated at an SWT of 60 cb. With drip systems, potatoes are irrigated at an SWT of 30 cb.
- Irrigation to replace estimated crop water use (estimated accumulated crop evapotranspiration) can be an effective way to irrigate potatoes with a sprinkler or drip system.
- AgriMet provides an online estimate of daily crop water use for the Ontario, Oregon area at www.usbr.gov/pn/agrimet/chart/ontoch.txt and for other locations served by AgriMet at www.usbr.gov/pn/agrimet/h2ouse.html

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