ADVANTAGES AND CONSTRAINTS OF SOIL MOISTURE MONITORING FOR RESOURCE-EFFICIENT IRRIGATION MANAGEMENT OF ALFALFA

Daniele Zaccaria¹ and Steve Orloff ²

ABSTRACT
Alfalfa is grown on nearly 1 million acres throughout California under all types of irrigation systems, and farmers often obtain sub-optimal yields as a result of improper irrigation management practices. In this respect, monitoring soil moisture has proved to be a cost-effective method to help farmers taking informed decisions about adequate irrigation timings and amounts. This note briefly discusses advantages and constraints of soil moisture monitoring for tailoring irrigation applications to optimize water use, sustain high-yielding and high-quality crop production, and prevent resources degradation.

Key words: soil moisture, irrigation scheduling, soil hydraulic properties, adequate irrigation management

INTRODUCTION
Farmers often face challenges in irrigating adequately and efficiently alfalfa, regardless of the irrigation methods used, due to a combination of factors related to crop features (depth of rooting systems, indeterminate growth, periodic cutting and re-growth cycles), soil hydraulic properties and farming operations (harvesting schedules) that together with uncertainties of soil-water relations often lead to improper irrigation management and sub-optimal yields.

In times of reduced and unreliable water supply, and in view of existing and upcoming water-related regulations, monitoring of soil moisture represents a key method to help farmers matching irrigation application with actual soil water conditions and crop water use. Soil moisture monitoring allows monitoring of what is happening in the soil root zone with regard to water infiltration during and after irrigations, and to water uptake by plants between irrigations, thus enabling informed irrigation decisions on when to irrigate and how much water to apply to avoid crop water stress.

IMPROVEMENT OF IRRIGATION MANAGEMENT THROUGH SOIL MOISTURE MONITORING

Despite the basic criteria for scheduling irrigation on different crops are well defined and understood by the majority of farmers and irrigators, their implementation under field conditions, i.e. determining when to start irrigation and how much water to apply, are often challenging tasks due to a number of uncertainties related to crop features, soil characteristics, and dynamics of water flow through the soil and uptake by the crop.

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Alfalfa is a deep-rooted perennial crop with indeterminate growth, and can produce dry matter throughout the year if environmental conditions are favorable (FAO, 2012). Also, alfalfa has a drought avoidance mechanism by accessing water through its deep root system (Sheaffer et al., 1988) and by entering drought-induced dormancy periods during which it limits above ground growth while storing energy for rapid re-growth from buds when water becomes available. In other words, alfalfa growth and biomass production are rapidly affected by water shortages, making inadequate irrigation management often the number one limiting factor to yield under the typical weather and farming conditions of California.

Commonly, the decisions of when and how much to irrigate alfalfa fields are based on growers’ past experience, or applying weather-based scheduling. Both methods are somewhat problematic and present shortcomings to growers: past experiences are not easily adjustable to weather variability, whereas scheduling irrigation on the basis of estimated crop evapotranspiration requires farmers to do some calculations and adjustments for field-specific conditions that are often complicated owing to the periodic harvesting and re-growth cycles. In addition, irrigations are cut back a few days prior to cutting, and alfalfa fields are usually not irrigated after cutting while the herbage is kept on the ground for curing. As a result, irrigation decisions are often driven and constrained by the harvesting schedules, with actual soil water conditions often going unchecked and impending risks of water stress to the crop.

A Decision Tool. Among the different methods, soil-moisture based irrigation scheduling may be more practical to use by alfalfa producers, and easy-to-deploy sensors and technologies are now available to help growers measure soil-water conditions and follow soil moisture depletion trends. These sensors can be categorized in two main groups, those that give information on soil moisture content (percent in weight or volume), and those that provide data in terms of soil moisture tension (centibars). Soil-specific calibration relationships are needed to convert readings of soil moisture tension to soil moisture content, and visa-versa.

Several applied-research experiences conducted in California have shown that irrigators who measure soil moisture in irrigated alfalfa fields, and tailor irrigation schedules to soil water conditions increase their ability to achieve higher yield, reduce stress to the crop from too much or too little water in the root zone, optimize water and energy use, while preventing soil and water degradation. Soil moisture monitoring provides easy-to-interpret information helping growers to address the following questions:

- What is the proper irrigation timing?
- Has enough water infiltrated the soil during and after an irrigation?
- What is the soil depth reached by irrigation water?
- Is the water being applied insufficient, enough or excessive?
- What is the water depletion pattern by crop roots uptake and soil evaporation?
- Is there in the soil profile sufficient water to buffer irrigation mistakes?
- Is there sufficient deep soil water reserve for crop water uptake during periods of no irrigation?
Usually, measuring soil moisture in terms of tension is more advisable and straightforward to growers, as it expresses how tightly water is held by the soil particles and pores, and conversely how strong suction must be exerted by plants to uptake water from the soil root zone. When soil moisture is near saturation, soil tension values are low (5-10 centibars), whereas higher values indicate moisture being depleted from the soil.

**Understand your Soil.** Research trials allowed identifying recommended threshold values of soil moisture at which to irrigate in the different types of soils to prevent water stress to alfalfa. These threshold values are soil-specific and are presented in Table 1 in terms of soil moisture tension, and in Table 2 in terms of soil moisture content. Such threshold values are based on a 50% allowable depletion of available soil moisture.

The rationale for adequate irrigation management is to measure soil moisture at regular intervals, tracking the soil water trend, and irrigating when soil moisture readings have increased to a level near the recommended threshold value for the specific soil textures, thus not high enough to cause water stress to alfalfa. Irrigating at moisture values higher than those recommended may result in water stress to crop and yield reduction. Irrigation should stop when the soil moisture reach values near field capacity (10-20 centibars).

### Table 1. Irrigation Guidelines Based on Soil Moisture Tension Readings

<table>
<thead>
<tr>
<th>Soil Type/Interpretation</th>
<th>Soil Moisture Tension (centibars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated soil</td>
<td>0-10 (no irrigation)</td>
</tr>
<tr>
<td>Field capacity for most soil</td>
<td>10-20 (no irrigation)</td>
</tr>
<tr>
<td>Sandy or loamy sand</td>
<td>40-50 (start irrigation)</td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>50-70 (start irrigation)</td>
</tr>
<tr>
<td>Loam</td>
<td>60-90 (start irrigation)</td>
</tr>
<tr>
<td>Clay loam or clay</td>
<td>90-120 (start irrigation)</td>
</tr>
<tr>
<td>Crop water stress in most soil</td>
<td>&gt;100</td>
</tr>
</tbody>
</table>

*Adapted from Orloff et al. (2002) and Watermark Soil Moisture Sensors, The Irrometer Company, Riverside, CA*

### Table 2. Recommended values of soil moisture content at which irrigation should occur

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Soil Moisture Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>7</td>
</tr>
<tr>
<td>Loamy Sand</td>
<td>12</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>15</td>
</tr>
<tr>
<td>Loam</td>
<td>20</td>
</tr>
<tr>
<td>Silt Loam</td>
<td>23</td>
</tr>
<tr>
<td>Silty Clay Loam</td>
<td>28</td>
</tr>
<tr>
<td>Clay Loam</td>
<td>27</td>
</tr>
<tr>
<td>Sandy Clay Loam</td>
<td>24</td>
</tr>
<tr>
<td>Sandy Clay</td>
<td>22</td>
</tr>
<tr>
<td>Silty Clay</td>
<td>30</td>
</tr>
<tr>
<td>Clay</td>
<td>31</td>
</tr>
</tbody>
</table>

*Adapted from Hanson and Orloff (2002)*
This information is very valuable to alfalfa growers, as maintaining proper soil moisture conditions in the soil profile is the key factor to optimal crop yield. In addition, re-filling the soil profile with sufficient water when excessive moisture depletion has occurred requires large system capacity and operating the irrigation system for long durations, which most of the times complicate the on-farm irrigation management and rotations among the different fields.

**MAIN LIMITATIONS AND CONSTRAINTS**

The key factors where attention should be focused towards resource-efficient soil-moisture based irrigation practices are reported below:

- Preliminary evaluation of site-specific conditions
- Adequate selection of soil moisture sensors
- Proper site-selection, sensors installation and maintenance
- Correct interpretation and use of soil moisture data

**Understanding Field Variation.** Preliminary investigations are necessary to evaluate the soil features as referred to soil texture, soil depth, and hydraulic characteristics, as well as and their variability over the irrigated fields. As a general recommendation, soil moisture sensors should be placed in areas of the fields that accurately represent the soil water conditions in the root zone, and specifically where most of the soil moisture uptake by roots activity occurs. If soil features vary widely across the field, also crop roots distribution and activity may vary, requiring the installation of sensors at multiple sites. Figure 1 shows a 80-acre field located in Yolo county that comprises three different textural classes, from gravelly-loam to silt-loam and silty-clay loam soils, with available soil moisture varying from less that 5 inches to more than 12 inches in a 5-ft soil profile. From such information, it can be easily inferred that physical soil features may likely affect the effective root zone depth, root distribution and activity in the different soil textures. Differences in infiltration and hydraulic conductivity of applied water can be also anticipated among these soils. Under large variability of soils, appropriate number of sensors and installation sites should be carefully selected. One moisture monitoring site per soil zone is recommended for effective soil-moisture based irrigation management.

Today, zoning of soil hydraulic features can easily be accomplished by using Veris surveying, soil sampling, lab determination of main parameters and final mapping at reasonable cost of $45-60 per acre. These preliminary evaluations enable selection of proper sensors and technology available on the market, as well as number of sensors and locations of installation sites.
Soil moisture-based irrigation scheduling has a main limitation of not providing straightforward information about the amount of water to apply through irrigations, and of required irrigation duration to achieve specific depth of water infiltration in the soil profile. If measurements of soil moisture tension are being used, a calibration is required through the development of a soil-specific moisture release curve to derive coefficients for converting moisture tension to soil moisture content, or depletion relative to field capacity. The amount of water to apply and irrigation duration can then be calculated on the basis of soil infiltration rate, soil moisture content at field capacity, which must have been preliminary estimated, as well as of the actual soil moisture depletion and available flow rate of irrigation supply. This procedure is laborious and time consuming, besides requiring multiple soil testing, laboratory determinations and field evaluations. A simpler method would be to apply water until the soil moisture sensors readings reach tensions around 20-10 centibars.

Placement of Sensors. Proper placement of sensors is also critical to represent soil moisture in the root zone and obtain meaningful data for effective irrigation management. This task entails accurate evaluation of effective root depth, which is not straightforward and requires additional investigations, sampling and testing in the field. As a general guideline, rooting depth of mature alfalfa plants may range between 4 and 6 inches. This value represents the root depth containing 80% of the feeder roots in deep, uniform, well-drained, and unconstrained soil profiles. Usually the
effective root depth corresponds to the 3/4 of the actual root depth, i.e. where 70% of the water uptake by the roots occurs.

Three sensors are recommended at each installation site, with the first sensor placed in the upper quarter of the root zone, the second within the effective root depth, and the third slightly below the actual root zone, or at maximum soil depth in case the rooting depth is restricted by hard/impermeable layers. Placement of three sensors will provide meaningful soil moisture information across the soil profile, with the upper sensor indicating when to irrigate, the second sensor indicating the depth of water infiltration at each irrigation, and the deepest sensor measuring the existence of deep soil water reserve. Maintaining such a deep reserve is critical to buffer for irrigation mistakes, inadequate irrigation frequency or amounts, and to avoid water deficits that may potentially occur during irrigation cut-back periods, such as those before cuttings and during herbage curing on the ground. The deepest sensor will also be used to indicate whether deep percolation occurs below the root zone, as a result of excessive irrigations.

**Importance of Layers.** Changes in soil texture along the soil profile usually act as temporary barriers to uniform water movement. Figure 2 represent these situations, where coarse soil overlying fine soils, and vice versa, may temporarily hold more water than uniform soils, causing water to move laterally. In these situations of layered soils with different textures, monitoring soil moisture in each layer separately is recommended.

![Figure 2. Water movement in layered soils (from NRCS Irrigation Guide, USDA NRCS, 1997)](image)

Most of the soil moisture sensors available on the market today have low maintenance needs or are maintenance free. Often, problems occur as a result of corrosion of electrical contacts, dissolution of matrix materials, lost contacts between electrodes, and erratic readings due to air gaps between the sensor and surrounding soil, or off-scale (very high) electrical resistance within the sensor.

**Understanding Soil Moisture Data.** When using soil moisture tension sensors, the lower the reading the higher the soil moisture content and vice-versa. When the soil is near field capacity, after rain or irrigation, the sensor reading is low and commonly in the range of 5-10 centibars. As soil moisture is depleted, the sensor readings gradually increase. Plotting moisture tension data on graphs helps growers visualizing what is happening in the soil root zone, providing them with a clear picture of the soil moisture status and about how fast the soil is drying as a result of crop water uptake by roots. Figure 3 presents typical plots of soil moisture tension at three different depths (1-ft, 2-ft and 3-ft deep) along the soil profile, with the identification of tension range values where irrigation should occur and trends that indicate adequate irrigation management. Figure 4 shows soil moisture tension graph at 6” and 18” depth generated by a data logger over the entire irrigation
season, with clear indication of under-irrigation and inadequate frequency and amounts of irrigation applications.

**Figure 3.** Plots of soil moisture tension data at three depths, and recommended tension threshold values (adapted from Orloff et al., 2002)

**Figure 4.** Soil moisture tension graph for the entire irrigation season at 6” and 18” depths (adapted from ATTRA-NCAT, 2006)
CONCLUSIONS

Adequate irrigation management could be a difficult task to alfalfa growers, due to harvest schedules and to uncertainties related to soil water relationships. The use of soil moisture monitoring can therefore provide very useful and cost-effective information to alfalfa growers for ground-truthing their irrigation decisions, fine-tuning irrigation practices, and allow avoiding under- and over-irrigation, which often cause a host of adverse impacts, from yield loss, to water-related diseases, higher water and energy cost, nutrient losses, leach-outs and environmental concerns. Such information are critical in day-to-day irrigation decisions to aim at maximum yields and at optimal water and energy use, especially during periods of limited or unreliable water supply.

REFERENCES


Watermark Soil Moisture Sensors, The Irrometer Company, P.O. Box 2424, Riverside, CA 92516. www.irrometer.com