MONITORING ALFALFA WATER USE WITH SOIL MOISTURE SENSORS

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ABSTRACT

Water management is key for profitable alfalfa production in the West. However it is one of the most difficult aspects of alfalfa production, in part because of the difficulty in monitoring and evaluating irrigation practices. The soil moisture content of several alfalfa fields was monitored over the last four years for the duration of the irrigation season using Watermark® resistance blocks. Soil moisture content fluctuated considerably during the season; the driest periods corresponded with alfalfa harvests. Soil moisture content also varied greatly between growers reflecting differences in soil type and irrigation practices between farms. A potential area for improvement in irrigation management was observed at nearly all sites. The most common areas for improvement were over-irrigation in spring, under-irrigation in midsummer, and too late an irrigation starting date. Several years of research and recent commercial use have demonstrated the value of Watermark® resistance blocks for monitoring soil moisture status, evaluating current irrigation practices, and for irrigation scheduling in alfalfa. Experience has demonstrated that routine soil moisture monitoring can significantly improve irrigation management.

Key Words: water management, irrigation scheduling, Watermark® sensors, resistance blocks

INTRODUCTION

Proper irrigation management is essential for profitable alfalfa production in the West. However, of all the different production inputs water is perhaps the most difficult to manage. Improper water management often goes undetected. Water stress from deficit irrigation may be difficult to observe until significant yield reduction has occurred. The effects of over-irrigation are also not readily apparent. Consequently, determining precisely when the best time to irrigate is and how much water to apply are not simple tasks.

It can be more difficult to schedule irrigations for alfalfa than other crops because, unlike most other crops, alfalfa is harvested multiple times per season. Irrigation water cannot be applied too close to a cutting and fields obviously cannot be irrigated while the alfalfa is curing. Depending on soil type and irrigation practices there is typically a 6- to even 20-day period during which fields cannot be irrigated. This can make irrigation scheduling extremely challenging, especially when an irrigation is due to occur around the time of cutting.

Weather-based irrigation scheduling involves tracking estimates of daily crop water use, also referred to as evapotranspiration (ET). Once the estimated crop water use totals a predetermined

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amount (usually 50% of the available water-holding capacity of the soil) the field is irrigated. Even though this method is accurate, it is seldom used in alfalfa because of the involved task of keeping track of ET data, an inability in some cases to find a representative weather station, and difficulties scheduling irrigations around cuttings. It is especially complicated to use ET data to schedule irrigations when entire alfalfa fields are not irrigated at once. This is usually the case with sprinkler irrigation where fields are typically irrigated in sets. In theory, evapotranspiration would have to be monitored for each section of the field and each section irrigated accordingly.

SOIL BASED MEASUREMENTS

Soil-based measurements may be a far more practical and easy method for alfalfa growers to use to schedule irrigations and assess current irrigation practices. At the present time soil moisture content in most alfalfa fields usually goes unchecked. Common methods to assess soil moisture content include the 'feel method', a neutron probe, or soil moisture sensors. The 'feel method' entails using a shovel or soil auger to collect a soil sample and then squeezing the soil in your hand and fingers to estimate soil moisture content. This method is relatively imprecise and is generally only useful for a gross evaluation of the soil moisture content in the upper foot or less. In contrast, a neutron probe is very accurate but is expensive, complicated to use, and requires special licensing. Therefore, only irrigation consultants typically use it. Several other types of soil moisture monitoring equipment are available but resistance blocks are perhaps the most common because they are one of the least expensive, easy to use, and they are reasonably accurate.

Resistance blocks

Soil moisture sensors (also called gypsum blocks or resistance blocks) are not a new invention but recent advances have improved their accuracy and ease-of-use. These moisture blocks evaluate soil moisture by measuring the electrical resistance between two electrodes imbedded in the sensor. The blocks take up and release moisture as the soil wets and dries. The higher the water content of the blocks, the lower the electrical resistance.

Resistance blocks are available from several manufacturers. Of the ones tested, the Watermark® sensors were more accurate because they were more sensitive to moisture changes in the upper range of soil moisture (Hanson et al unpublished data). Some types of resistance blocks do not respond until the soil moisture content is relatively low.

The Watermark® soil moisture sensor estimates soil moisture tension in centibars. The soil moisture tension refers to how strongly water is held onto soil particles. The higher the tension the more difficult it is for plant roots to extract water. The Watermark® sensor reads from 0 to 200 centibars. Low soil moisture tensions indicate moist soil and high soil moisture tensions indicate dry soil. Studies comparing the Watermark® sensors with tensiometers and neutron probes indicated differences in soil moisture readings and a less than perfect correlation between devices. While the actual values were somewhat different, the same trends occurred over the wetting and drying cycles confirming their value for irrigation scheduling purposes.

Understanding the resistance block readings

When the soil is saturated after a rainfall or irrigation (air spaces are mostly filled with water) the Watermark® reading is low, typically less than 5 to 10. Then with evaporation from the soil surface and transpiration by the alfalfa plant, the soil dries and the moisture sensor readings gradually increase. Eventually the soil dries enough that an irrigation is necessary. The centibar reading at which irrigation is needed is somewhat dependent on soil type. A general recommendation is to irrigate sandy soils when the upper sensor(s) reads 50-70 centibars. For sandy loam or loam soils irrigate when the readings reach 60 to 90 centibars. Clay soils retain more water and centibar readings over 100 can be obtained without a significant yield reduction. Soil moisture sensors may not be useful for very sandy soils with inherently low water holding capacity, as the sensors may not respond quickly enough to the rapid decline in soil moisture.

After the field is re-irrigated the centibar readings typically drop into the teens or single digits. Sometimes the sensor readings at the lower depths do not change after an irrigation. This is an indication that the amount of water applied was insufficient to reach the depth of the sensor. Therefore, not only are the sensors useful to determine when to irrigate they also help to ascertain the depth or adequacy of an irrigation.

The key to proper irrigation management using the soil moisture sensors is to irrigate when the centibar readings are in the desired range for your soil type. Irrigating when the soil moisture readings are beyond the desired range may result in crop stress and yield loss. Irrigation before the readings reach the desired range may result in excessive irrigation.

Interpreting a soil moisture graph

The best way to use the soil-moisture measurements is to plot the values on a graph. The plotted data present a picture of how fast the soil is drying. After a few points have been plotted, you can estimate approximately how many days it will take for the soil to dry before irrigation is needed. The author prefers inverting the y-axis (the centibar readings) so that zero is at the top of the graph instead of the bottom. This simplifies interpretation. Using this orientation, the line on the graph drops as the soil dries and rises when the soil is re-wetted. This pattern is more consistent with how one conceptually thinks of changes in soil moisture content.

The graph in Figure 1 shows effective irrigation management and illustrates how readings typically fluctuate from spring through the first alfalfa cutting. At the start of the season the soil is moist from winter and spring rains; the readings are less than 20 centibars. Gradually the soil dries and the readings increase, beginning with the sensor located at the one-foot depth followed by the deeper depths. The uppermost sensor reading normally climbs first, as there is greater root activity in the upper portion of the soil profile than at deeper depths. Furthermore, moisture readings at the 4-foot depth are typically lower (more soil moisture) and fluctuate far less than the shallow depths. When the soil moisture content dropped to near 80 in early May, an irrigation was applied and the centibar readings at all three depths went to below 20, indicating the soil profile had been refilled. The drying cycle resumes until a partial irrigation occurred in early June. The reason for the partial irrigation was that it was needed to replenish enough soil moisture to carry the crop through the cutting process without excessive soil moisture depletion and crop stress. The first cutting occurred in early June (note point on graph when soil moisture content was lowest). Following cutting irrigations resumed until the soil moisture content of all three depths was restored (all readings below 20 centibars).

SAMPLE RESULTS OF SOIL MOISTURE MONITORING

Watermark® resistance blocks were installed in ten alfalfa fields in Scott Valley, Siskiyou County, California. The purpose was to assess current irrigation practices and evaluate the usefulness of Watermark® sensors for irrigation management in alfalfa. Soil moisture levels were monitored weekly from spring through September. The sensors were installed at 3 depths, 1 foot, 2 foot, and 4 foot.

The Watermark® readings were very useful to characterize the changes in soil moisture that occurred in the different fields. Soil moisture content fluctuated considerably over the season in most fields. As noted by the oscillation in the lines (Figures 1-3), there was far more fluctuation in soil moisture at the shallow depths (1 and 2 feet) than at the deepest depth (4 feet). As noted before this is because of the greater root activity in this zone. Soil moisture levels in all fields were high in early spring before crop transpiration depleted the soil moisture supplied by winter and spring rains. Soil moisture remained relatively high throughout spring in most fields; crop evapotranspiration is low and sporadic spring rains occur so irrigations usually keep pace with crop water needs. In June the soil moisture tensions start to increase significantly in most fields. The figures show a spike in soil moisture tension (very dry soil) in early June for most fields. This spike corresponds with first cutting. A spike in the sensor readings (low soil moisture levels) also occurred at each subsequent cutting. Some irrigation systems were not capable of keeping up with the peak water demands of alfalfa in midsummer. In contrast, midsummer water needs were met in other fields.

The graphs presented in Figures 2 and 3 illustrate two extremes in irrigation management and demonstrate the usefulness of soil moisture monitoring. The first example (Figure 2) is a mixed stand of alfalfa and orchardgrass. Because of the shallow rooting pattern of the orchardgrass, the soil moisture sensors were installed at 0.5, 1, and 2 feet. The first irrigation was delayed until early June and did not occur until the soil moisture sensors read 160 centibars, which is too high a value. Irrigations did not recharge the soil profile and extremely low soil moisture contents occurred for much of the summer. The soil moisture was depleted even at the 2-foot depth (readings occurred at the 200 centibar maximum). As with many irrigation systems, it was not possible to compensate or 'catch up' for the extremely depleted soil moisture caused by the late date for the initial irrigation. Most systems can barely keep up with the water demands of alfalfa in midsummer and do not have the capacity to 'catch up'. It was not until late August when the water needs of alfalfa had begun to subside that the soil profile was refilled and the soil moisture tension at all three depths was less than 20 centibars. However, it was unnecessary to completely refill the soil profile at this late date because the growing season was nearly over (early September is normally the date of the final cutting in the intermountain area).

The graph in Figure 3 shows over-irrigation. The soil moisture tension never exceeded 50 centibars. Soil moisture tensions for most of the season remained below 30 centibars.

Remember irrigation should occur on this soil type when the soil moisture tension is approximately 60 to 90 centibars. Because this field was irrigated more often than needed, the graph does not demonstrate the usual drop in soil moisture that occurs at the time of each cutting. Maintaining the soil so moist actually created a problem. This field had more summer annual weeds, lambsquarters and pigweed, than any other field evaluated. A probable explanation for the weed infestation was the high soil moisture during harvest periods. High soil moisture encourages emergence and establishment of annual weeds soon after the alfalfa is cut when there is little alfalfa canopy to shade out the weeds. Ordinarily these summer annual weeds have a difficult time becoming established because the soil is too dry after cutting. In addition, the soil moisture was unnecessarily high at the end of the growing season. Usually there is a large drop in soil moisture after the last cutting because growers cease irrigating. Based on this graph, perhaps one or two irrigations could have been omitted, or less water could have been applied per irrigation, without reducing yield.

INSTALLATION OF SENSORS

Proper placement and installation of resistance blocks is important. It is recommended that growers install two or three sensors per evaluation site. One sensor should be located in the upper one quarter of the root zone of the crop. The other should be placed toward the bottom of the root zone. If three sensors are used, install them at 1 ft., 2 ft., and 3.5 or 4 ft (depending on the depth of the soil). The upper two sensors are used to determine when to irrigate. It is also informative to the centibar readings with each other. The deepest sensor is useful to evaluate the depth reached by the last irrigation. The deepest sensor is also useful to make sure that you are not excessively depleting moisture reserves deep in the root zone of the crop.

For the soil moisture information to be valuable it is critical that the sensors be installed in an area that is representative of the field (i.e., soil type typical of the field and an area that receives full sprinkler or flood-irrigation coverage). If the field is uniform (i.e., consistent soil type and alfalfa growth across the field) a single site with 2 or three sensors installed at different depths is sufficient. However, if the field is variable two or more monitoring sites are recommended.

A detailed explanation of the sensor installation procedure can be found in literature from the manufacturers. However some installation hints specific to alfalfa production may be helpful. Since you don't want to destroy the soil moisture sensors with a swather, it is advisable to make the reading station near ground level. It is important to mow the alfalfa over the sensors when the field is cut so that water use near the sensors is representative of the field.

The sensors can be glued to the end of a PVC pipe so they can be retrieved at a later date and reused. This is especially desirable when the alfalfa is removed and the field planted to another crop. The wire leads coming from the sensors are threaded through the PVC pipe. The leads come up to the soil surface where they can be protected in a PVC cap attached to the end of the pipe. The cap or the leads should be marked in a way that they can be distinguished so you know the depth of each sensor.

SUMMARY AND CONCLUSIONS

This research and recent commercial experience clearly demonstrates the usefulness of monitoring the soil moisture content of alfalfa fields. Soil moisture readings are particularly valuable to:

- **Determine when to begin irrigating in spring**. This is often a difficult decision. The soil profile is usually filled from winter rains, but after alfalfa resumes growth in spring and the weather warms up, the grower must decide when the soil moisture is depleted enough to initiate irrigation.

- **Decide whether another irrigation is needed before cutting**. Alfalfa is most sensitive to water stress after cutting when the plants start to regrow. Resistance block readings help assess whether the soil-moisture content is sufficient to avoid water stress through the cutting and hay curing period until irrigation can be resumed. The sensors may indicate that alfalfa should be irrigated closer to a cutting or sooner after the bales are removed to avoid moisture stress to alfalfa regrowth.

- **Ascertain if the last irrigation was adequate to refill the soil profile**. Soil moisture sensors give an indication of the depth of water penetration. If the sensors do not respond after an irrigation the water did not penetrate to the depth of the sensor. The soil-moisture readings indicate how many irrigations are necessary to refill the soil profile after cutting.

- **Assess the deep-moisture status of a field**. The soil moisture sensors were extremely useful to assess the moisture status at the lower end of the alfalfa root zone. The lower half of the root zone supplies a moisture reserve to draw upon when needed and should not be excessively depleted.

- **Evaluate current irrigation practices**. Soil moisture monitoring is helpful to verify that current irrigation practices satisfy, but do not exceed, the needs of the crop. Use the sensor readings to keep track of the soil moisture so that it can be maintained near optimum levels. The sensors may indicate the soil is getting excessively dry between irrigations, in which case more water or more frequent irrigation is needed – or that the soil has sufficient water even though an irrigation is planned, then an irrigation can be skipped or delayed until soil moisture sensors indicate irrigation is needed.

It may be difficult to make major changes in irrigation practices because of the limited flexibility of most alfalfa irrigation systems (i.e., irrigations must be scheduled around cuttings, pump capacity is limited, the number of wheel lines per field are often fixed, etc.). In most cases it is not necessary to make major changes or to redesign an existing irrigation system. Relatively minor adjustments in irrigation practices could pay large dividends in increased yield or water savings. Soil moisture sensors have been proven to be very useful to diagnose changes needed and fine-tune irrigation practices.

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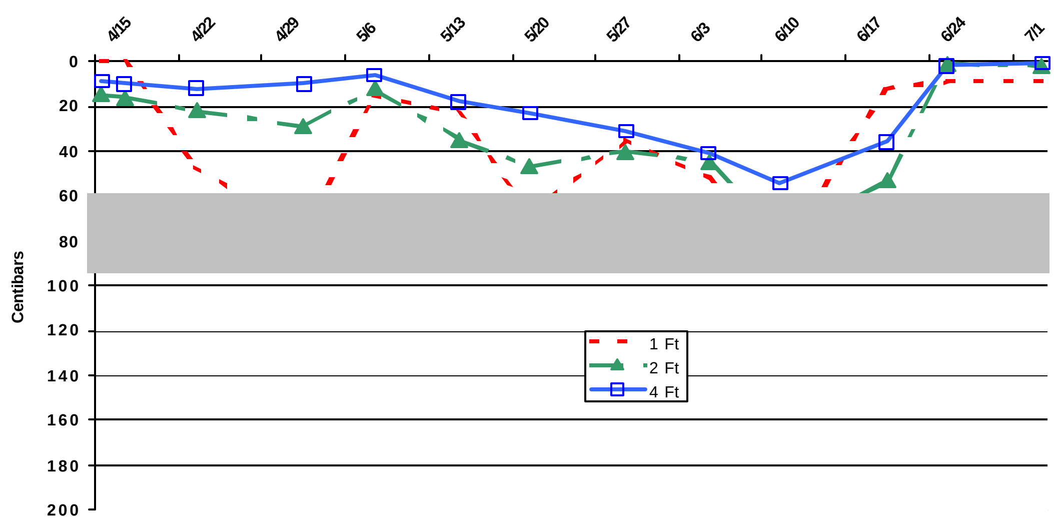

Figure 1. Soil moisture content in centibars from April to July illustrating effective irrigation management. Note that when the soil moisture at 1 foot drops into the centibar range where irrigation is needed (60–90 centibar zone shaded gray) the field is irrigated and the soil moisture increases. Soil moisture was never depleted to levels greater than 90 centibars where yield could potentially be adversely affected. Similarly, irrigation did not occur until soil moisture readings indicated it was necessary.

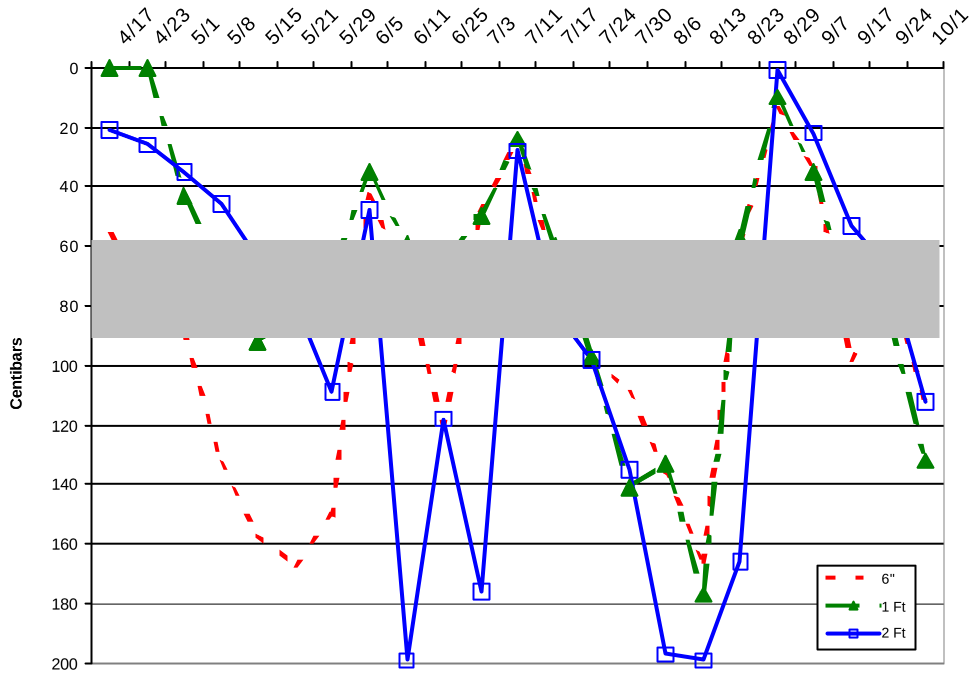

Figure 2. Seasonal soil-moisture levels at three depths for sample deficit-irrigated alfalfa field. Note how often the lines fall below the zone where irrigation should occur (60–90 centibar zone shaded gray).

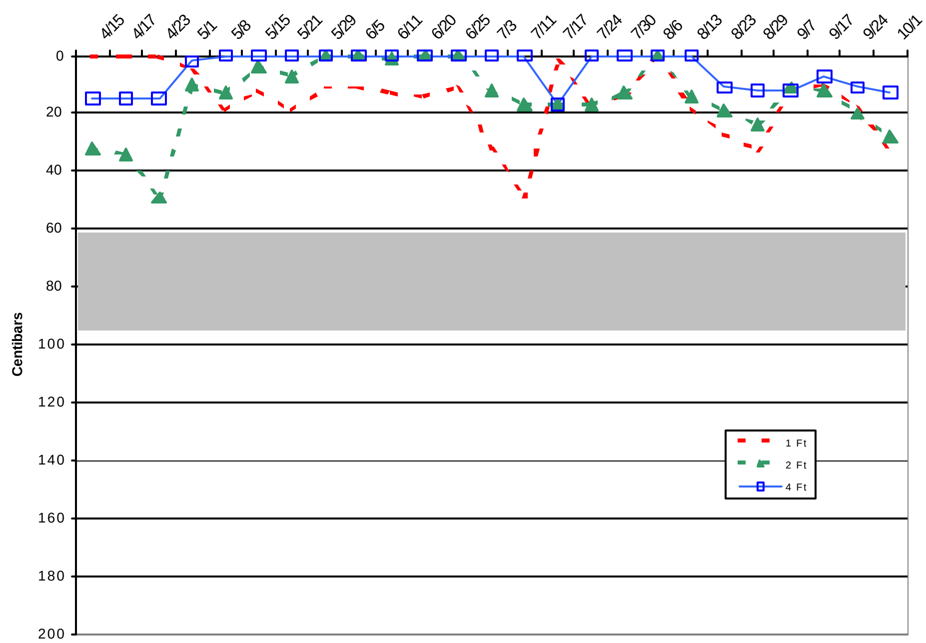

Figure 3. Seasonal soil-moisture levels at three depths for over-irrigated alfalfa field. Note that the lines do not fall into the range where irrigation should occur (60–90 centibar zone shaded gray). Irrigations always occurred before Watermark® readings reached this level.