

Utilizing Soil-Moisture Monitoring to Improve Alfalfa and Pasture Irrigation Management

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Abstract

In the arid, western U.S., improper irrigation management limits alfalfa and pasture yields more often than any other production factor. However, determining when to irrigate and how much water to apply is not simple. This management guide provides information on soil moisture monitoring, a relatively simple and effective method for managing irrigation on alfalfa and irrigated pasture. Monitoring soil moisture is easier and more practical than most other irrigation scheduling techniques, and it can help determine when to irrigate, if irrigations are too frequent or too infrequent, and if the proper amount of water is being applied. Relatively minor adjustments in irrigation practices can increase forage yields or save water.



Fig. 1. Irrigation water is essential for profitable crop production in most of the arid, western U.S. Shown here is alfalfa being watered with sprinkler irrigation. Proper irrigation techniques can help producers increase forage yields and save valuable water.

Irrigation water is essential for profitable crop production in most of the arid West. Proper irrigation management is key for high yields and to avoid stress from too much or too little water. Improper irrigation management limits yields more often and to a greater degree than any other production factor. Perhaps the reason why irrigation practices often fall short of optimum is that nearly all the action occurs in the soil out of our view.

Determining when to irrigate and how much water to apply are not simple tasks. How can you assess whether irrigation practices are correct? This guide provides information on soil moisture monitoring, a relatively simple and effective method for managing irrigation on alfalfa and irrigated

pasture (Fig. 1). Monitoring soil moisture is easier and more practical than most other irrigation scheduling techniques, and it can help determine when to irrigate, if irrigations are too frequent or too infrequent, and if the proper amount of water is being applied.

What's the Best Strategy for Irrigation Scheduling?

The decision of when to irrigate is usually based on past experiences, weather-based information (crop evapotranspiration data), or soil-based measurements. Past experiences may not be applicable and are often not adjusted for annual changes in weather.

Scheduling irrigations based on crop evapotranspiration can be difficult because, unlike other crops with a single harvest per season, the multiple

harvests of alfalfa and pasture confound the process. Irrigation water cannot be applied too close to a cutting, and fields obviously cannot be irrigated while the crop is curing. Therefore, there is typically a 6- to even 20-day period during which fields cannot be irrigated. This can make irrigation scheduling using weather-based information problematic. In addition, it may be difficult to obtain accurate evapotranspiration data for some locations and, even when data are available, the task of keeping track of data for individual fields can be time consuming. Because of the difficulties and shortcomings of these methods, soil-based irrigation scheduling may be the preferred technique.

Soil-based measurements may be far more practical and easy-to-use for alfalfa and pasture producers. Soil moisture content often goes unchecked. If soil moisture is monitored, it is usually only done using a shovel or soil auger. While better than nothing, using a shovel or auger is imprecise and is only useful for a gross evaluation of the soil moisture content in the upper foot, or less, of soil. Several inexpensive technologies may help growers monitor soil moisture.

Expressing Soil Moisture Content

Soil moisture levels can be expressed in different ways, depending largely on the instrument used. Soil moisture content is often expressed as a percent (the weight of the water in the soil divided by the weight of oven-dried soil \times 100). Other soil moisture monitoring devices use soil moisture tension to indicate soil moisture levels. Soil moisture tension refers to how strongly water is held on soil particles; the higher the tension the more difficult it is for plant roots to extract water from the soil. Therefore, low soil moisture tension indicates moist soil and high soil moisture tension indicates dry soil. Soil moisture tension is usually expressed in centibars. For some types of soil moisture resistance blocks, the instrument readings must be converted to soil moisture tension using appropriate calibration relationships.

Resistance Blocks: A Useful Tool

More than six years of field studies in the Scott Valley (a high-elevation valley in northern California) demonstrated the usefulness of soil moisture monitoring in alfalfa and irrigated pasture fields. These studies showed that significant improvements in irrigation management were possible in many fields by monitoring soil moisture levels and adjusting irrigation practices accordingly. In some cases, yield losses were corrected through additional irrigations, and in other cases, over-irrigation was prevented, producing improvements in water-use efficiency (*S. Orloff, unpublished data*). While Resistance blocks do not directly measure volumetric soil moisture, in many cases resistance readings may be a better indication of plant-available water, since soil moisture tension is more directly related to the ability of a plant to obtain water from the soil. The simplicity of electrical resistance blocks provides a cost-effective technique for improving irrigation management for growers.

Ask Questions About Water Management!

When do I start irrigating? This is often a difficult decision. The soil profile is often filled from winter rains. But after the crop resumes growth in spring and the weather warms, you must decide when the soil moisture is depleted enough to require irrigation. Most irrigation systems do not have the capacity to “catch up” when the soil profile has been excessively depleted in spring.

Answer: The first irrigation should occur when soil moisture tension reaches the recommended value for your soil type (Table 1).

Do I irrigate again before harvest? 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 duration of the harvest period until irrigation can be resumed.

Answer: Track soil moisture to predict the rate of soil moisture depletion. By graphing the data and extending the line through the harvest period, you can anticipate soil moisture loss during harvest. If anticipated soil moisture levels fall well below the recommended values for your soil type (Table 1), an irrigation or partial irrigation may be desirable before cutting.

Did I fill the profile? Soil moisture sensors are very useful in assessing the moisture status at the lower end of the root zone -- especially for a deep-rooted crop like alfalfa. The lower half of the root zone supplies moisture reserves to draw upon when needed and should not be excessively depleted.

Answer: If the soil profile is filled after irrigation, soil moisture readings at all depths should return to less than 10 centibars for a sandy soil and less than about 30 centibars for medium/fine-textured soil. If the sensors do not respond after irrigation, the water did not penetrate to the depth for the sensor. Monitor soil moisture after each irrigation to determine how many irrigations are needed to refill the profile.

Should I change my irrigation practices? Soil moisture monitoring is helpful to verify that current irrigation practices satisfy, but do not exceed, the needs of the crop. A graph of soil moisture readings over the season provides a sound basis for altering and fine-tuning irrigation practices.

Answer: Plot soil moisture readings on a graph (Figs. 2, 3, and 4). The lines on your graph should oscillate as they do in Fig. 2. The highest soil moisture tension reached should be the values where irrigation is recommended (Table 1). Then, following irrigations, the values should return to less than 10 for a sandy soil and less than about 30 for a medium/fine-textured soil. If values exceed the recommended range, the soil is becoming excessively dry between irrigations and the field should be irrigated more frequently or with more water per irrigation. If values are low (indicating adequate moisture), irrigation can be skipped or delayed until soil moisture sensors indicate irrigation is needed.

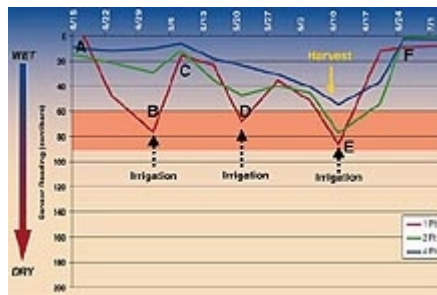


Fig. 2. Proper Irrigation Management. Shaded area indicates where irrigations should occur for a loam soil. At the start of the season the soil is moist from winter and spring rains; the readings are less than 20 centibars (A). Gradually the soil dries and the readings increase, beginning with the sensor located at the 1-ft depth followed by the deeper depths. When the soil moisture reading dropped to near 80 in early May (B), irrigation water was applied and the centibar readings at all three depths went to below 20 (C), indicating the soil profile had been refilled. The drying cycle resumed until a partial irrigation occurred in late May (D). A partial irrigation was needed to replenish enough soil moisture to carry the crop through the harvest period 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, E). Following cutting, irrigation resumed until the soil moisture content at all three depths was restored (all readings below 20 centibars at point F).

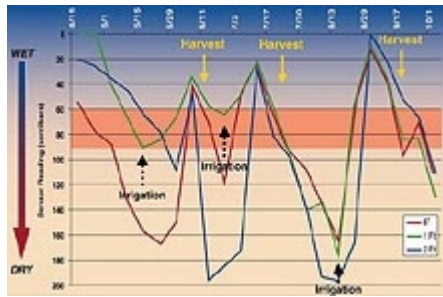


Fig. 3. Under-irrigation example. Soil moisture tension levels for an irrigated alfalfa/grass field. The first irrigation occurred too late, and soil moisture remained extremely low for much of the season. Not until late August was the soil profile refilled -- too late for much benefit to the crop. This field would have benefited from careful monitoring of soil moisture and timely early irrigation.

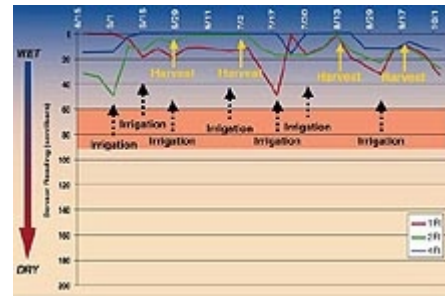


Fig. 4. Over-irrigation example. Soil moisture tension never exceeded 50 centibars and remained below 30 centibars for most of the season. (Irrigation should occur at 60 to 90 centibars; shaded area). One or two irrigations could have been eliminated or less water applied per irrigation.

Table 1. Recommended values at which to irrigate alfalfa and pasture for different soil types

Soil Type	Moisture Reading (centibars)
Sand or loamy sand	40-50*
Sandy loam	50-70
Loam	60-90
Clay loam or clay	90-120

*Caution: Soil moisture sensors may not be useful for very sandy soils with extremely low water holding capacity, as the sensors may not respond quickly enough to the rapid decline in soil moisture.

Note: These values were based on 50% depletion of available soil moisture for different soil types.

Using Soil Moisture Data

Resistance Blocks. Electrical resistance blocks (also called gypsum blocks or resistance blocks) are not new, but recent advances have improved their accuracy and ease-of-use. Resistance blocks evaluate soil moisture tension by measuring the electrical resistance between two electrodes. 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. The electrical resistance is measured with a portable meter that is connected to wire leads coming from the moisture sensors (Fig. 5). Because there is a known and consistent calibration between electrical resistance and soil moisture for the Watermark® block (a resistance block made by Irrometer Company, Inc.), it can closely estimate soil moisture tension in centibars. The authors have used other sensors, but of those tried, the Watermark block had the best correlation between electrical resistance and actual soil moisture content. *(This does not constitute an endorsement of any particular sensor type or, by omission, exclude other types of sensors).*

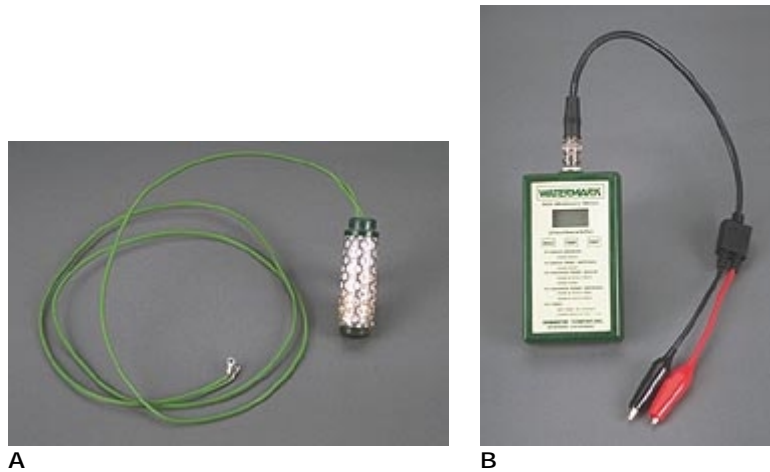


Fig. 5. The Watermark® soil moisture sensor is an example of an electrical resistance block. Resistance blocks evaluate soil moisture by measuring the resistance between two electrodes imbedded in the sensor (A) using a calibrated portable meter (B). The blocks absorb moisture as the soil wets and release moisture as the soil dries -- the higher the water content, the lower the electrical resistance.

Interpreting the Resistance Block Readings. An important point to understand when using the Watermark sensors is that the lower the reading the higher the soil moisture content, and conversely, the higher the reading the lower the moisture content. 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 centibars. As evaporation from the soil surface and transpiration by the crop dry the soil, the moisture sensor readings gradually increase until they indicate need for an irrigation.

The centibar reading at which irrigation is necessary depends on soil type (Table 1). Sandy soils retain far less water than soils with a high clay or organic matter content, so irrigation on sandy soils should occur more frequently and at a lower soil moisture tension value. Soil moisture sensors may not be useful for very sandy soils with extremely low water holding capacity, as the sensors might not respond quickly enough to the rapid decline in soil moisture.

After the field is irrigated the centibar readings typically return to the teens or single digit values. These wetting and drying cycles continue throughout the season as the crop is irrigated and then the soil dries with crop water use. The key to proper irrigation management using soil moisture sensors is to monitor the sensors regularly, track the soil moisture level, and irrigate when the centibar readings are in the desired range for your soil type (Fig. 2). Irrigating when the soil moisture readings exceed the desired range may result in crop stress and yield loss. Irrigation before the readings reach the desired range may result in excessive irrigation, water wastage, or runoff.

Using and Interpreting a Soil-Moisture Graph. The best way to use the soil-moisture measurements is to plot them on a graph. The plotted data present a picture of the soil moisture status and indicate how fast the soil is drying. After a few points are plotted, you can estimate approximately how many days it will take for the soil to dry before irrigation is needed. Plot the data from each Watermark sensor with a different color line so that the various depths can be easily distinguished. An Excel-based spreadsheet template for entering field data is available for free from the authors or from the website of the University of California Alfalfa & Forage Systems Workgroup (see Appendix).

We prefer inverting the y-axis (the centibar readings) so that zero is at the top of the graph instead of the bottom (Fig. 2). This simplifies interpretation. Using this orientation, the line on the graph drops as the soil dries and rises when the soil is wet. This pattern is more consistent with how one conceptually thinks of changes in soil moisture content.

The graph in Fig. 2 is an example of effective irrigation management and illustrates how readings typically fluctuate from spring through the first alfalfa cutting. Soil moisture at the uppermost sensor normally declines first, as there is

greater root activity in the upper portion of the soil profile than at deeper depths. There was also far more fluctuation in soil moisture at the shallow depths (1 and 2 ft), as noted by the oscillation in the red and green lines, than at the deepest depth (4 ft). Again, this is because of more extensive root activity in this zone. Figure 2 illustrates effective irrigation management -- irrigations occurred when the 1-ft sensor readings (red line) reached the appropriate range for this soil type (60-90 centibars). Figures 3 and 4 illustrate inadequate and excessive irrigation examples, respectively.

Interpreting Soil Moisture Data: Using Soil Data to Guide Irrigation Decisions

Why monitor soil moisture? Soil moisture tension data can help "train" the manager or irrigator to make wise irrigation decisions. Combined with observations of the crop and other irrigation scheduling techniques (e.g., the "checkbook" method), soil moisture blocks can help you know what is happening in the soil, and to 'ground truth' your decisions. It can help answer questions such as:

When do i start irrigating? Figure 3 shows a real-life example from a field where irrigation was delayed too late in the spring. The first irrigation did not occur until early June, when the soil was much too dry (160 centibars at the 6-inch sensor). It is likely that moisture stress occurred and yield was reduced. Monitoring would have triggered an earlier irrigation decision.

Is there enough deep moisture? It is important to have adequate soil moisture in the lower half of the root zone. Deep moisture serves as a reserve for use when needed, such as harvest periods during the hot summer. While the field in Fig. 2 shows plenty of subsurface moisture, Fig. 3 shows a field where moisture was excessively depleted at lower depths, stressing the plants. Information about a lack of deep moisture may enable a grower to take corrective action to refill the profile.

Am I applying enough water? Under-irrigation is a common hazard of forage production. Figure 3 shows a real-life example from a field that was watered too infrequently throughout much of the growing season. Many of the readings are above 160 centibars, indicating very dry soil. All but the last irrigation was inadequate to wet the entire profile. Soil moisture monitoring indicates the grower should irrigate more frequently to correct this situation.

Am I watering at the wrong time? In some cases, water is applied at a time when it's not needed by the crop or could be better used at other times during the season. In Figs. 3 and 4, the growers irrigated late in the season (late August to early September) to fill the profile. The August irrigation in Fig. 3 would have resulted in much better returns had it been applied earlier in the season. The September irrigation in Fig. 4 was most likely unnecessary because the growing season was nearly over, and the crop needed less water. Soil monitoring can help indicate when to stop watering, as well as when to start.

Am I watering too much? Figure 4 shows over-irrigation, or too-frequent irrigation. Soil moisture tension never exceeded 50 centibars, and for most of the season remained below 30 centibars, indicating a continually wet soil (since the soil was a loam, the grower should have waited until soil moisture tension was 60 to 90 centibars). In this case, maintaining the soil too wet resulted in higher than necessary pumping costs and an increased infestation of the summer annual weeds, lambsquarters and pigweed. Based on this graph, one or two irrigations could have been omitted, or less water applied per irrigation, without reducing yield.

Match irrigation to crop needs! The principle behind irrigation management is to irrigate only enough to meet crop needs. Irrigation mistakes are easy to make, even for experienced growers. Soil moisture sensors improve the chances of making the right irrigation decisions.

Installation and Management Recommendations

Site Selection. A critical part of sensor installation is selecting an appropriate site. Since irrigation of the whole field is based on the sensor readings, the sensors need to be in an area that represents the field. Locate the sensors in an area having the soil type typical of the field, uniform crop growth, and in an area that receives full uniform sprinkler or flood-irrigation coverage. If the sensors are placed in an area that is not representative, the results can be very misleading.

One sensor site per field is usually sufficient; however, if the field is variable, two sites are desirable. It may be helpful to install one of the sensors in a slightly sandier area of the field to use as an early indicator of when irrigation may be required.

Sensor Placement. Proper sensor placement is critical for accurately representing soil moisture in the crop root zone. We recommend installing two or three sensors at each evaluation site (Fig. 6). One sensor should be in the upper one quarter of the root zone. Another should be toward the bottom of the root zone. When three sensors are used in an alfalfa field, install them at 1 ft, 2 ft, and 3.5 or 4 ft (depending on the depth of the soil). In cases where the rooting depth is more restricted, installations at 9 inches, 1.5 ft, and 3 ft are recommended. Because of shallower rooting in irrigated pastures, the sensors should be installed at 6 inches, 1 ft, and 2 ft.

Three sensors present a more complete soil moisture picture and allow better evaluation of the depth reached with each irrigation.

The uppermost sensor indicates when to irrigate. The second sensor helps determine the depth of the last irrigation and is a check for the first sensor to make sure it is operating properly. The deepest sensor measures moisture reserves deep in the root zone. Maintain the deepest sensor within an acceptable range -- not too dry (over 90 centibars) or not too wet (saturated conditions, readings less than 5 or 10 centibars).

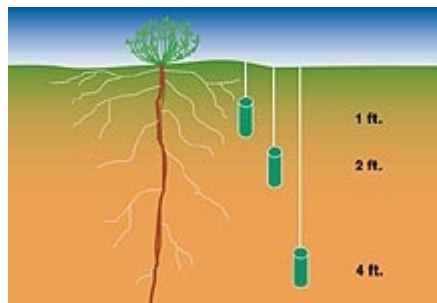


Fig. 6. Two sensors at each evaluation site are acceptable but three are preferred because it provides a more complete picture of the soil moisture status at different depths, allowing the irrigator to determine the depth of the last irrigation. For alfalfa install sensors at 1 ft, 2 ft, and 4 ft (9 inches, 1.5 ft and 3 ft in shallow soils). For pasture install sensors at 6 inches, 1 ft and 2 ft.

Installation. Use a probe or coring device to create a hole slightly larger than the diameter of the sensor (Fig. 7). The sensor must be in direct contact with the surrounding soil. To ensure contact, prepare a small slurry (mixture of the surrounding soil and water) to pour into the hole before seating the sensors. As the sensor is pushed into the hole, the slurry at the bottom squeezes up around the sensor to provide good contact between the soil and sensor.

The wire leads come up from the sensors to the soil surface. Carefully back-fill the hole so as not to damage the wires. A 4- to 6-inch length of 2-inch PVC with a screw-on cap works well and protects the wire leads from a swather or cattle. Dig a shallow (3- to 6-inch) trench for the wire leads coming from each sensor to the PVC housing. You can color code the wires to keep track of the depth of the sensors by tying a small piece of colored wire to each lead.

An alternative installation involves gluing a section of PVC pipe onto each sensor and feeding the wires through the pipe (Fig. 8). This installation allows the sensors to be retrieved and reused. One-half-inch Class 315 PVC has an inside diameter that fits exactly over the top of the sensor collar. Use PVC to ABS cement to weld the sensor to the PVC. A cap can be fitted directly on the pipe to house the wire leads and the depth of the sensor engraved on the cap.



Fig. 7. This steel rod is pounded into the soil to create a hole slightly larger than the diameter of the sensor. A coring device can also be used. Direct contact between the sensor and the soil is essential for reliable soil moisture readings.



Fig. 8. Soil moisture sensors can be glued to the end of PVC pipe. Wire leads from the sensor are connected to bolts protruding from a PVC cap for easy access while taking readings. This installation allows the sensors to be retrieved and reused.

How Often to Take Soil Moisture Readings. How often you take soil moisture readings depends on their intended use. Weekly readings should provide an overall picture of the seasonal soil-moisture status of the field for evaluating current irrigation practices. However if the Watermark readings are used for irrigation scheduling, readings should be taken at least twice a week, especially immediately before and after an irrigation. Commercial data logging devices are available that constantly record readings at predetermined intervals.

Conclusion

Irrigation management for alfalfa and irrigated pastures can be difficult; growers must schedule around harvests, making it problematic to use many irrigation-scheduling techniques. However, years of research and field experience have shown that soil moisture sensors are very useful in diagnosing needed changes and in fine-tuning irrigation practices. Relatively minor adjustments in irrigation practices could pay large dividends in increased yield or water savings.

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To simplify information, trade names of products have been used. No endorsement of named products is intended, nor is criticism implied of similar products that are not mentioned.

Appendix: Electronic Resources for Further Information

For additional information and an Excel Spreadsheet to graph data, see ["California Alfalfa & Forages," a website of the University of California Alfalfa & Forage Systems Workgroup.](#)