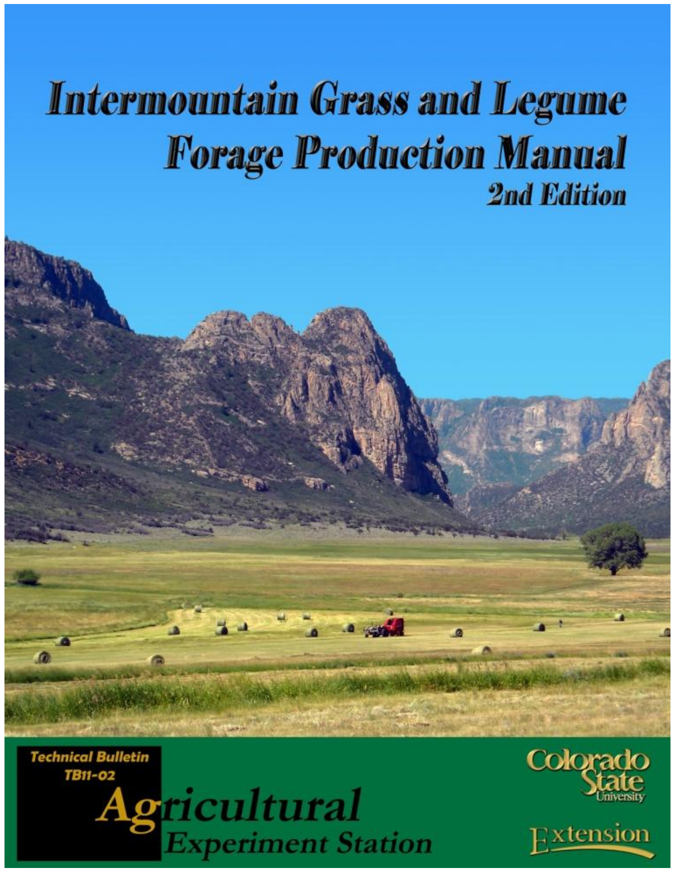

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Section II

Alfalfa

Chapter 15

Alfalfa Irrigation Water Management

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Alfalfa is a deep-rooted, perennial crop with a big appetite for water (Table 1). Hence, proper irrigation management to optimize alfalfa hay production, while minimizing water losses through evaporation, runoff, and deep percolation, is important to meet the ever increasing demand for water in the western US.

Table 1. Estimated seasonal alfalfa consumptive water use (CU) for selective locations in Colorado.

Location	CU (in)
Burlington	35.6
Cortez	29.4
Delta	35.3
Greeley	31.6
Monte Vista	23.6
Rocky Ford	37.7

Source: Natural Resources Conservation Service (NRCS), Colorado Irrigation Guide, 1988.

Alfalfa is one of the most widely grown crops in Colorado (Smith et al., 2006). Generally, two to five cutting of alfalfa hay are produced per season in Colorado, depending on the climatic zone, with annual average yields of 3 to 8 tons/acre. Studies in Colorado, New Mexico, Idaho, and Utah indicate that it usually takes 5 to 6 inches of water to produce one ton of hay. Thus, a 6 ton/acre hay crop will require 30 to 36 inches of net or consumptive water use. Consumptive use is equivalent to evapotranspiration (ET), which is the sum of water that evaporates from the soil surface (E) and that which moves through the plant and out into the atmosphere as vapor (T). The value of E decreases as the crop canopy develops and shades the ground.

Evapotranspiration estimates for the major crops grown in Colorado are posted daily on the Colorado Agricultural Network (CoAgMet) at: http://ccc.atmos.colostate.edu/~coagmet/ CoAgMet is a network of automated weather stations situated throughout Colorado and managed by Colorado State University. Similar weather networks are available at other western States. Crop water requirements can be supplied by rain, irrigation, or stored soil water. In most of Colorado's farmland, irrigation is necessary to produce hay yields above 2 to 3 tons/acre. See Table 1 for seasonal water requirements for alfalfa around Colorado. Full-season alfalfa ET in the Great Plains and Intermountain West averaged 35.8 in (Lindenmayer et al., 2011). Alfalfa biomass increases with increasing ET in a linear fashion.

Irrigation Scheduling: The Water Balance Approach

Knowing when to irrigate and how much water to apply is as much of an art as it is a science. These decisions are contingent upon water availability and they rely on experience and information, such as; the type of irrigation system used, crop growth stage, weather conditions, soil water holding capacity and infiltration rate, etc. A sound method of irrigation scheduling is the Water Balance Approach. Using the Water Balance Approach requires knowledge of soil type (water holding capacity), root zone depth, and daily crop water use. The soil that surrounds the crop roots is thought of as a water "checking account" as it absorbs and releases water from irrigation. Rain and irrigation act as deposits, while crop consumption (ET) is the primary withdrawal. The goal is to keep the "account" in the black (above wilting point) without drowning the crop. See Extension Fact Sheet 4.715 (Al-Kaisi and Broner, 2009) for more detail on the Water Balance Approach.

The wilting point is the state at which plant roots cannot extract water from the soil, resulting in wilting of the plant. Soil water holding capacity is the amount of water retained by the soil after it is saturated and allowed to drain freely (e.g., by gravity). The point at which water drainage stops is called field capacity. The field capacity for various soil types are shown in Table 2.

Table 2. Water holding capacity of various soil textural classes.

Soil Type	Range (in/ft)
Sands	0.5-1.1
Loamy sands	0.7-1.2
Sandy loams	1.3-1.8
Fine sandy loams	1.5-2.2
Loams	2.0-2.8
Silt loams	2.0-2.5
Clay loams	1.7-2.5
Silty clay loams	1.7-2.5
Clays	1.3-2.2

Adapted from Waskom et al. (1994) and Scherer et al. (1996).

Irrigators should be cautioned when using the Water Balance Approach: it does not account for poor irrigation water management. For example, poorly maintained equipment, that does not distribute water evenly and efficiently to the field, needs to be addressed before improvements with irrigation scheduling will make a measurable difference. If used in conjunction with a soil moisture checking method, such as soil moisture by feel, an irrigator is usually able to detect distribution problems or equipment malfunction in time to make adjustments that don't affect crop health. Consult with your local NRCS or Extension staff for assistance with checking irrigation equipment.

Rainfall can and will alter irrigation scheduling, depending on how much of the measured rainfall actually infiltrates the soil and contributes to soil moisture [known as effective rainfall (ER)]. It is important to note that even low ER amounts have a cooling effect on alfalfa, which reduces daily ET amount. Measurement of ER can be time-consuming and may not transfer easily from one situation to another; thus, irrigators should use their judgment to decide how much of the rainfall is available for crop use or apply estimates such as those shown in Table 3.

Table 3. Effective rainfall (ER) as a percentage of measured rainfall (RF).

RF (in)	ER (%)
1	95
2	90
3	82
4	65
5	45
6	25
>6	5

Source: Bureau of Reclamation Manual, Release No. 50, June 1953.

If salt concentration in the soil or water is high, excess water may need to be applied, known as "leaching fraction," to leach salts below a threshold level to maintain optimum crop growth (Cardon et al., 2007). If salt concentrations in irrigation water are high, the health of alfalfa may be adversely affected. Soil conductivity[1] due to salts above 2.0 dS m^{-1} can cause measurable losses in alfalfa yields.

Typical irrigation application efficiency is shown in Table 4. If the seasonal consumptive use of an alfalfa crop is 35 inches, ER is 8 inches, and irrigation efficiency is 50% (furrow irrigation), then the gross irrigation requirement is: (35-8)/0.5=54 in.

[1] This is an ECe or soil paste conductivity.

Table 4. Application efficiencies of surface, sprinkler, and microirrigation systems.

System Type	Application Efficiency Range* (%)
Surface Irrigation	
Level Basin	80-95
Graded Border	50-80
Furrow	50-80
Surge	60-90
Sprinkler Irrigation	
Handline/Wheelline	60-85
Traveling Big Gun	55-75
Center Pivot & Linear	75-95
Solid set	60-85
Microirrigation	
Point source emitters	70-95
Line source emitters	75-95

*Efficiencies can be much lower due to poor design and management.
Source: USDA-NRCS Colorado Supplement for Chapter 6 of National Irrigation Guide; Table CO6-2; 2009.

An example of how the water balance approach works is shown in Table 5. The alfalfa field, in this example, was irrigated with gated pipe on furrows (50% efficiency). Daily reference ET was obtained from the nearest CoAgMet station. The following assumptions were made:

- Soil water holding capacity = 2.0 in/ft (silty clay loam)
- Effective root depth = 5 ft, thus, total water holding capacity is: 5 ft x 2.0 in/ft = 10.0 in. Orloff et al. (1995) and Shewmaker and Seyedbagheri (2005) used a rooting depth of 4 ft.
- Available water immediately after irrigation to field capacity = 10.0 in.
- Management allowable depletion (MAD) = 50% of soil water holding capacity or 5.0 in.

Peterson (1972) reported that the best alfalfa growth can be expected when 35% to 85% of the available moisture remains in the active root zone. However, for soils with low water holding capacity (e.g., shallow or light-textured soils), he recommended that irrigations should be made when available soil moisture is closer to 50%.

The example presented in Table 5 shows a two week-period over which the soil moisture in the root zone surrounding the alfalfa crop went from "full" or field capacity to "empty" or wilting point. Based on this approach, an irrigation should be scheduled for June 24th. The amount of water applied at this time is dependent on efficiency and cost or availability of labor. Ideally, an irrigation would not fully saturate the soil, especially since alfalfa is sensitive to over-irrigation. An application of about 2.5 to 3 inches would be ideal (5 to 6 inches to the field at 50% efficiency). If irrigations are constrained by labor, then an irrigation applying 4.87 inches of water (9.74 inches to field at 50% efficiency[2]) would return soil moisture to field capacity, reducing irrigation frequency. The addition of 4.87 inches of water will reset the field soil moisture balance to 10.0 inches in the "Day Start" column. Alfalfa is a hardy perennial, so unlike annual crops, it can tolerate stress and still rebound with sufficient water, though yield(s) from ensuing cutting(s) may be lower or delayed. Depending on the weather conditions after cutting and the haying method (e.g., small vs. large bales), it may take a few days to two or more weeks to dry, bale the hay, and remove the bales from the field. After bales are removed, there is a "green-up" period that varies in length from about one to two weeks. This "green up" period requires use of a multiplier to reduce the daily ET or water consumption of the crop. The CoAgMet website has this function included: consult with Extension staff on how to calculate daily ET values after a cutting during alfalfa "green up".

[2] See Chapter 9 Irrigating Pasture Hay Production for more on irrigation efficiency.

Table 5. Water balancing for alfalfa.

Date	Day Start (in)	CoAgMet ET (in)	Effective Rainfall	Day End (in)	MAD (in)	Above/Below MAD (in)
June 10th	10.00	0.29	0	9.71	5.0	4.71
June 11th	9.71	0.32	0	9.39	5.0	4.39
June 12th	9.39	0.27	0	9.12	5.0	4.12
June 13th	9.12	0.30	0	8.82	5.0	3.82
June 14th	8.82	0.40	0	8.42	5.0	3.42
June 15th	8.42	0.31	0	8.11	5.0	3.11
June 16th	8.11	0.31	0.1	7.90	5.0	2.90
June 17th	7.90	0.35	0	7.55	5.0	2.55
June 18th	7.55	0.35	0	7.20	5.0	2.20
June 19th	7.20	0.37	0	6.83	5.0	1.83
June 20th	6.83	0.34	0.2	6.69	5.0	1.69
June 21st	6.69	0.41	0	6.28	5.0	1.28
June 22nd	6.28	0.38	0	5.90	5.0	0.90
June 23rd	5.90	0.38	0	5.52	5.0	0.52
June 24th	5.52	0.39	0	5.13	5.0	0.13
June 25th	5.13	0.35	0	4.78	5.0	-0.22

It is not uncommon to plant oats with alfalfa in its first year. Some producers also prefer to retain a grass/alfalfa mix for the life of the stand. Such a mix creates some challenges for irrigation scheduling, since the grass has a shallower root zone and lower water demand than alfalfa. Grass will stress before alfalfa, so a good compromise is to time irrigation application based on alfalfa ET and apply enough water to fill the grass root zone. Depending on irrigation management, local climate, and soils, the mix may shift over time towards a mostly alfalfa or mostly grass mix, at which point it is probably safe to schedule irrigations based solely on the dominant crop.

Recommendations

1. Irrigate when 50% or less of the available water in the effective root zone has been depleted.
2. Allow the field to dry long enough, before cutting alfalfa, to minimize soil compaction.
3. Complete haying operations (e.g., baling the hay) and remove the hay from the field as quickly as possible and resume irrigating shortly afterwards.
4. Avoid applying more water than the soil can take in to minimize runoff and deep percolation. For pivots, this might mean an adjustment in cycle rate; for gaited pipe it may mean fine-tuning the gate opening.
5. With sprinkler and subsurface drip systems, early season irrigations are critical: apply as much water as possible to maintain adequate soil water reserves and help meet peak crop ET demand. With furrow systems, it is easier to "catch up" if you fall behind on soil moisture. However,
6. Do not over irrigate! Too much water (e.g., prolonged flooding) can "suffocate" alfalfa plants by restricting the flow of oxygen to the roots, and promote diseases such as phytophthora root rot.

Where irrigation water is affordable and available for an extended period of time, some farmers irrigate their fields after the last cutting, usually in the fall, to re-fill the soil profile, or even when alfalfa is dormant in some areas. One drawback of this practice is that it could promote weed growth.

Alfalfa water requirements may be easier to meet with wheel-line (side rolls) sprinkler systems (Fig. 1), or furrow irrigation (Fig. 2), since more water can be applied at each irrigation event. These systems are generally less efficient and more labor-intensive than center pivots (Table 4).

Fig. 1. Alfalfa field being irrigated with a side roll. Photo taken by Abdel Berrada on June 2, 2008 at the Southwestern Colorado Research Center. (Ute Mountain in the background)

With side rolls, one needs to consider the time it takes to irrigate a given area. Four side rolls (1320 ft with 40 ft sprinkler spacing) will cover a quarter section of land or 160 acres. To do this efficiently, it requires half day (~12 hour) irrigation sets with moves of 60 ft. In windy conditions, one may want to move the side rolls 40 ft. instead of 60 ft. after each set to increase irrigation uniformity. Application rate (in/h) will increase as well, but it would take longer to irrigate the whole field, unless one uses more or longer side rolls per unit area. A side roll can also be used with the Water Balance Approach. Contact Extension for help with side roll application rates and efficiencies.

Fig. 2. Irrigation of an alfalfa field with siphon tubes, shortly after the first cutting. Photo taken by Abdel Berrada on June 17, 2008 at the Arkansas Valley Research Center near Rocky Ford, CO.

Other Irrigation Scheduling Tools

It is a good idea to check soil water content/availability occasionally to adjust the water balance if need be. Where a CoAgMet station is not nearby, satisfactory ET measurements can be made with an atmometer (Broner, 1990).

There are several ways to assess soil water content. The feel method, tensiometers, gypsum blocks, and Watermark ^{TM} sensors (Ley, 1994; Orloff and Hanson, 1998) are a few of the more common methods. The feel method is simple, but requires experience. An example of a Watermark^{TM} sensor and accompanying Hansen^{TM} data logger is shown in Fig. 3. Sensors measure soil tension as a vacuum, the higher the tension, the more vacuum created and the lower the soil

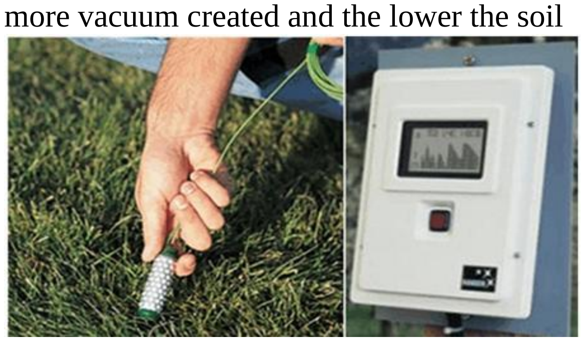

Fig. 3. Watermark^{TM} sensor (c/o www.Gemplers.com) and accompanying Hansen^{TM} datalogger (c/o Kimberly Research Center, University of Idaho).

moisture. There is no fixed correlation between soil tension and soil moisture, as it is highly dependent on soil type, but a typical soil tension range for optimum alfalfa yield is between -60 and -15 centibars.

Other methods of irrigation scheduling include experience and crop condition such as darkening of the leaves and wilting. Water stress can also cause tipping of growing points and a gray cast. Mid-season "wave patterns" in a field may indicate water stress from either uneven irrigation or soil type. When alfalfa shows signs of water stress, yield loss may have already occurred.

Caution: *Do not confuse symptoms of water stress with those caused by phosphorus deficiency (stunting), stem nematodes (dying plants), or vascular wilt diseases (stunting, wilting, foliar desiccation, premature defoliation), for example.*

Irrigation Management with Limited Water Supplies

Established alfalfa can extract water from 10 ft. or deeper (Peterson, 1972) and thus avoid severe stress in many environments. However, prolonged or severe droughts can cause stand reduction and yield loss. A thinner or weaker alfalfa stand will sustain greater losses from insect damage and weed competition than a healthier, thicker stand.

In Colorado and other western States, alfalfa produces the most tonnage (30% to 60% of the total hay yield) during the first growth cycle, which occurs in the spring. Water use efficiency is also greatest in the spring, "when plants are using carbohydrates stored in the roots, solar irradiance is high, and temperatures are relatively low" (Lindenmayer et al., 2011). Additionally, the first growth period benefits from winter precipitation and spring rains. Hay quality is usually highest in the first cutting as well (Orloff et al., 1995).

The greater performance of alfalfa during the first harvest interval can be used to optimize limited water resources. Apply as much water as possible early to maximize forage production, and reduce or terminate water application after the first cutting. Spreading water application throughout the season may not be economical given the added expenses in labor, harvesting, etc. Research in California showed that reducing or terminating irrigation, after the first cutting, did not significantly reduce alfalfa stand or yield the following year (Orloff et al., 1995; Putman et al., 2005 cited by Lindenmayer et al., 2011). This may not be the case in sandy soils or arid climates. More research is needed to assess the effects of partial season irrigation on the productivity of alfalfa in the Great Plains and Intermountain West (Lindenmayer et al., 2011).

Alfalfa and Drip Irrigation

One of the challenges with surface and sprinkler irrigation is the time it takes for the soil to dry before alfalfa is harvested. Harvesting when the soil is dry helps to minimize soil compaction. That is where subsurface drip irrigation (SDI) may have an advantage because water can be delivered to the roots without wetting the soil surface. In theory, water can be delivered to the alfalfa crop continuously, even during haying operations, i.e., to meet crop water requirements on a daily basis, but there is little information to corroborate this claim. By keeping the soil surface dry, SDI can reduce weed and disease infestation. This, however, requires careful design and operation to avoid subbing. Another advantage of SDI is its high application efficiency ($\geq$ 90%). By eliminating runoff and minimizing evaporation and drainage, SDI can be used as a tool to manage limited water supplies.

Burying the drip tape at 12 inches or more below the soil surface and leaving 40 inches between the tapes may be adequate for alfalfa hay production in southeastern Kansas (Alam et al., 2002) and southwestern

Colorado (Berrada, 2005). Subsurface drip irrigation design considerations will vary with soil type, climate, crop, and water quality and availability, among other things (Rogers and Lamm, 2006).

The relatively high costs of installation and maintenance may outweigh the benefits for field crops such as alfalfa. However, research in Kansas demonstrated the economic feasibility of SDI for corn production, if the system is maintained for 10 to 20 years (Lamm and Trooien, 2003). A major challenge with SDI in alfalfa is rodents (gophers, voles, and mice) chewing on the drip tape.

Summary

Alfalfa is an important crop in Colorado and the Intermountain West, with a big appetite for water. Its consumptive use ranges from approximately 24 inches at high elevations (e.g., San Luis Valley of Colorado) to 38 inches or more in areas with warmer climates and longer growing seasons. In most years and locations, a large proportion of alfalfa water requirement must be met through irrigation. The Water Balance Approach can be used successfully to schedule irrigations with minimal guesswork. Another proven method involves the use of soil moisture sensors, such as those made by Watermark™. Sensors make an excellent complement to the Water Balance Approach. Optimum alfalfa hay production can be expected when 35% or more water is available in the effective root zone but it is prudent to irrigate when 50% or less water has been depleted, particularly in soils with low water holding capacity. Soil water availability can be enhanced by applying enough water early in the season to fill the soil profile and help meet peak demand dur ing the hottest period of the year. When alfalfa is mixed with grass hay, it is probably best to schedule irrigation based on alfalfa water demand and irrigation amounts based on the depth of the grass root zone. In addition, haying operations should be completed in a timely manner and irrigation started shortly thereafter. The time between irrigations, especially around cutting, can be shortened considerably with SDI. However, the costs of installation and maintenance of the SDI may outweigh its benefits for field crops, such as alfalfa, as compared to high-value crops, such as onion. SDI is an efficient way of delivering water to crops and thus, can help manage limited water supplies. Another way to optimize alfalfa hay production when water is in short supply is to satisfy ET requirements during the first growth period and terminate irrigation after the first cutting if need be.

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