

Irrigation Water Management When and How Much to Irrigate

by USDA Soil Conservation Service in cooperation
with MSU Extension Service Staff

Profitability of producing irrigated crops is directly related to water management. Applying too much or too little water at the wrong time is a common problem in Montana. Applying too much water causes leaching of nutrients, erosion, high water tables and salinity problems. Many times problems show up on a neighbor's property, down slope of irrigated land. Too much water at the wrong time can retard plant growth and production. Too little water at critical crop stages can significantly reduce production.

Irrigation water management is managing soil moisture so that an optimum quantity of irrigation water is applied at appropriate times. Good water management can both increase crop production and reduce costs.

The first step in good irrigation water management is knowledge of basic soil, water and crop relationships.

PRINCIPLES OF IRRIGATION WATER MANAGEMENT

Soil Water Holding Capacity

Soil is made up of minerals, organic matter, air and water in the approximate proportions illustrated in Figure 1. The mineral fraction consists of various particle sizes, including sand, silt, clay and rock. As a plant growth medium, soil serves to supply plant nutrients, to provide mechanical support and to store water. Effective irrigation water management requires knowledge of how much water soil can store.

When soil is irrigated, water moves down through pores or openings between soil particles, forming a film around each individual soil particle. This film of water is tightly held around soil particles when small amounts of water are present. When the amount of water increases, the film becomes so thick that surface tension will no longer resist the pull of gravity, and the extra water moves downward. This gravitational water is measured in atmospheres (A), which is a measure of the effort required by plant roots to extract water from the soil. The maximum amount of water that can be held around soil particles against the pull of gravity is called the field capacity (FC). This moisture condition for

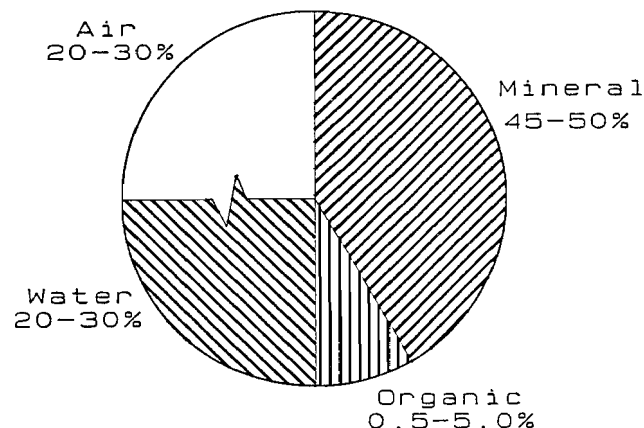


Figure 1. Composition of a typical agricultural soil

a well-drained soil occurs one to three days after a thorough irrigation.

Water films around soil particles become thinner and more tightly held as plants use water from a soil. Plants wilt when water films become so thin that plants can no longer pull water from around the soil particles. When plants wilt to the point that they can no longer fully recover, the soil is at the permanent wilting point (PWP). Available water holding capacity (AWC) of a soil is the amount of water that can be held between field capacity and permanent wilting point, as shown in Figure 2.

In irrigated crop production it is convenient to think of water holding capacity in terms of inches of water held per foot of soil depth. Moisture held in any given soil profile depth or crop root zone is the sum of amounts held in each soil layer. The amount of stored water depends on soil texture, depth, organic matter content, structure, bulk density, stratification and crop rooting depth.

Figure 3 illustrates how soil texture affects AWC. Generally, as the percentage of fine particles increase, AWC will increase. However, since clay particles and small spaces (voids) between them hold soil water more tightly than do sand and silt particles, most soils which

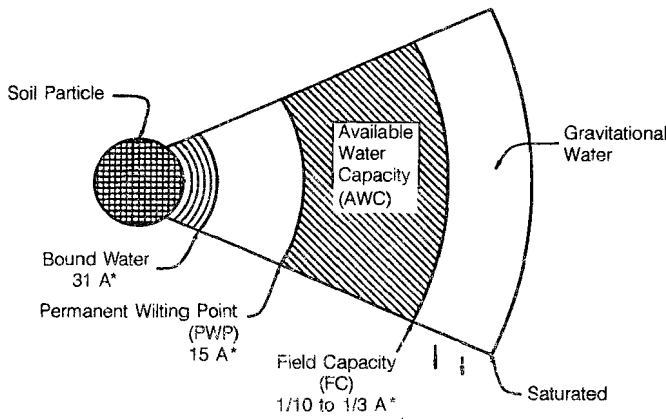


Figure 2. Soil Moisture Characteristics of Individual Soil Particles

* Atmosphere (A) = 14.72 psi

are predominantly clay tend to hold less “available” water than do silt soils.

Although AWC is not constant for each soil textural class, general values have been determined. Table 1 lists average AWC values along with the expected range for different textural classes. Note these AWC values are expressed as inches per foot of soil depth. Total water-holding capacity is estimated by multiplying the AWC by soil depth or depth of rooting.

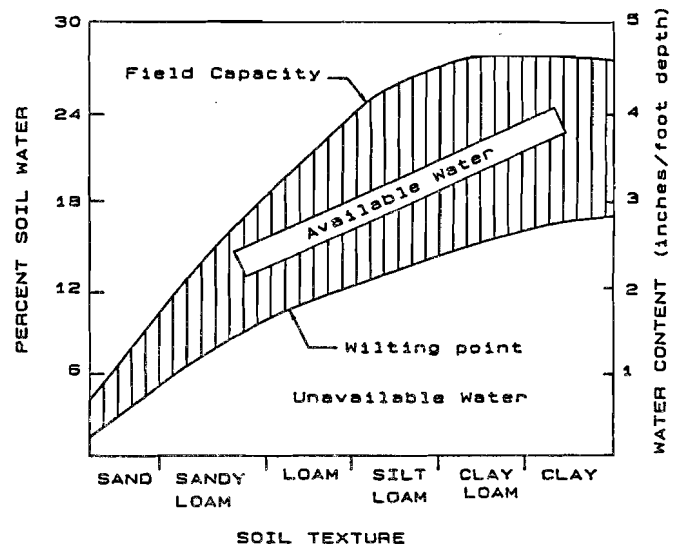


Figure 3. Soil texture as it affects “average” available water capacity

Many areas in Montana have published Soil Conservation Service soil surveys which give detailed information about soil in the area, including soil textures and available water-holding capacity.

The most accurate way of determining AWC is to determine it in the field. This can be done by heavily

**Table 1
Soil textural groupings and associated average water-holding capacities.**

Soil Textural Class	Soil Texture	Average Available Water Holding Capacity (AWC) inches/foot ¹	AWC Range inches/foot
Coarse Textured	Sands	0.5	0.1-1.4
	Loamy Sands	1.0	0.5-1.7
	Loamy Fine Sands		
	Loamy Very Fine Sands	1.25	0.7-2.2
	Very Fine Sands		
Moderately Coarse Textured	Sandy Loam	1.5	1.0-2.2
	Fine Sandy Loam		
Medium Textured	Very Fine Sandy Loam		
	Loam		
	Silt Loam	2.0	1.4-2.6
	Silt		
Moderately Fine Textured	Clay Loam		
	Sandy Clay Loam	2.2	1.4-2.9
	Silty Clay Loam		
Fine Textured	Sandy Clay		
	Silty Clay	2.0	1.2-2.6
	Clay		

^{1/} Soluble salts and gravel will decrease plant available water-holding capacity; organic matter and good soil structure will increase available water-holding capacity. The water-holding capacity increases about 0.1 inch per foot for each 1 percent increase in organic matter. Soils with compact subsoils, shallow bedrock, or stratification can increase plant AWC in the overlying layer; but shallow rooting depth, often caused by these layers, can decrease the total amount of available water. Soils that are deep, medium texture, and uniform can have decreased plant AWC but allow for deeper rooting.

watering a representative soil which has been summer fallowed. Then, three days after watering, the soil should be sampled to the depth of maximum wetting. This method will provide a measure of AWC as affected by texture and soil stratification. An alternative, but less accurate method is to have a lab analyze the soil. Three data items are required: 1) moist bulk density, 2) 1/3 atmosphere moisture content (field capacity), and 3) 15 atmosphere moisture content (permanent wilting point). The Extension Service, Soil Conservation Service or private consultants can provide information on where these tests can be conducted.

Crop Root Zone

The root zone determines soil depth from which the crop can draw moisture. The active root zone is that part of the soil profile where the major portion of plant roots is located. Water below the active root zone is

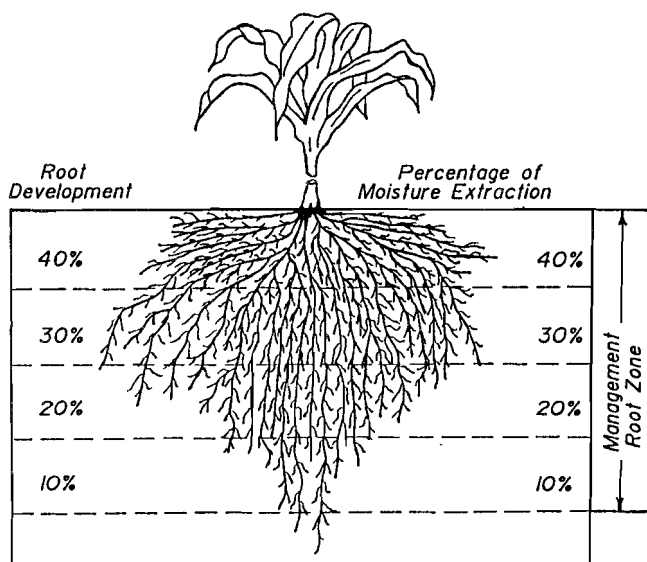


Figure 4. Root development and percentage of moisture extraction from the active root zone in deep, uniform soil

lost to deep percolation or is not immediately used by the plant. Root distribution in the root zone and water use from the root zone by a crop is not uniform in depth. This point is illustrated in Figure 4. About 70 percent of the crop's water requirement is taken up from the upper one-half of the root zone.

Rooting depths are determined by characteristics of the plant and soil. Rooting depths are often modified by soil compaction, stratification and moisture conditions. Roots of only a few plant species will penetrate dry soil, thus a layer of dry soil below the surface can restrict root growth. A high water table limits root growth. Fluctuating ground water may kill roots that have previously grown below the rising groundwater surface. High salt concentrations will also restrict root development.

Table 2 shows recommended management root zones (MRZ) for mature crops in deep soil without restrictive soil characteristics. Where impediments to root growth are encountered, rooting depth must be

determined in the field. This is accomplished by using a bucket auger or other device to collect soil samples and examining the samples for presence of live roots.

Root depth varies with the growth stage of a crop. Figure 5 and Table 2 provide information as to how long it will take roots to reach their mature depth in

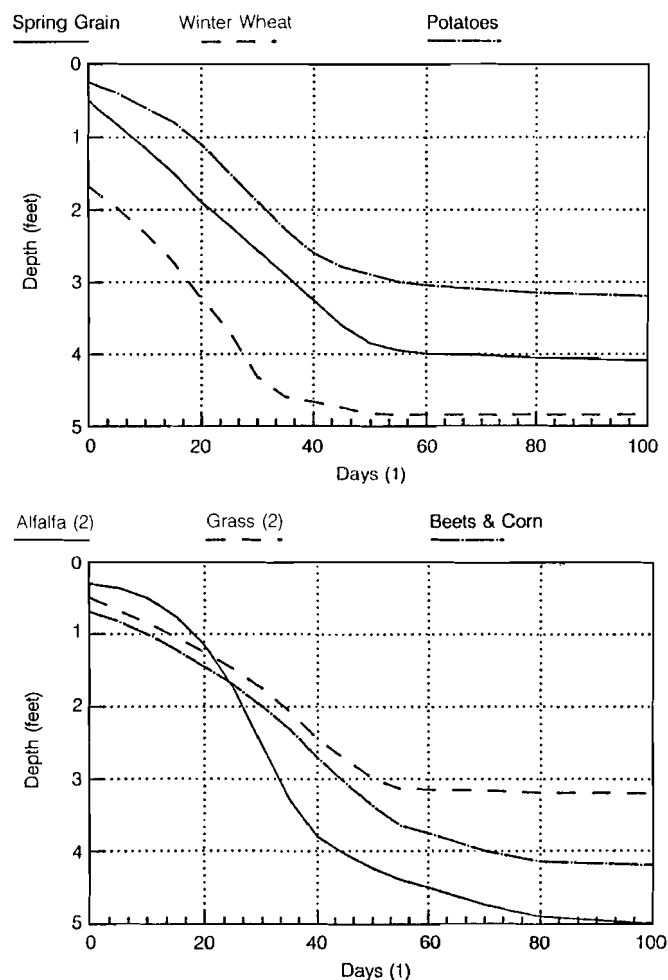


Figure 5. Root development over time.
 (1) Days after plant has emerged from ground
 (2) New planting

deep, unrestricted soils with adequate moisture. Awareness of the root depth during all stages of crop development will enhance your ability to manage nutrients and water in those layers containing active roots.

Management Allowed Depletion

Plant-available water remaining in the soil is held under increasingly higher tensions with each increment of water removal. As soil moisture tension increases, it becomes progressively more difficult for the crop to remove water from the soil. The crop may begin to exhibit symptoms of moisture stress when from 40 to 85 percent of the AWC has been used. Because of root distribution, plant-available water will be depleted more rapidly and to a greater extent in the upper portion of the active root zone. The amount of plant-available soil

Table 2
Root Zone Depths for Selected Crops

Crop	Management Root Zone (Deep Soil) (ft)	Typical Management Allowed Depletion (MAD%)*	Approximate Time to Reach Mature Root Depth (Good growing cond.)
Alfalfa	5	50	60 days new planting
Beans	3	40	50 days after emergence
Corn (field)	4	50	10 days after tasseling
Corn (sweet)	3	40	10 days after tasseling
Grass Pasture	3	50	50 days new planting
Orchard	5 +	50	--
Potatoes	3	35	60 days after emergence
Small Grains	4	50	Heading
Sugar Beets	5	50	110 days after planting

* This value is the recommended maximum allowable depletion of Available Water Holding Capacity.

moisture depletion that can be tolerated without having an adverse effect on crop yield and quality depends upon the crop being grown, the stage of crop development, root distribution, soil texture and rate of water use by the crop.

As a general rule, stress sensitive crops such as potatoes and sweet corn should be irrigated when 35 to 40 percent of AWC has been used. Other crops should be irrigated when 50 percent of the available water has been depleted. Table 2 gives recommended management allowed depletion (MAD) levels for several crops.

Critical Periods of Growth

For most crops there are critical periods in the growth season when high moisture level must be maintained for high yields. The critical period for annual crops almost always occurs in the later part of the season during the flowering and ripening stages. The critical period for commonly irrigated crops is shown below:

- Potatoes Flowering, tuber set to harvest
- Corn Tasseling, silk stage until grain becomes firm
- Sugar beets . . . Entire growing season*
- Small grains . . . Boot, blossom and early head stage. Malting barley, soft dough stage
- Pasture First 90 days of establishment
- Alfalfa Seedling and immediately after cutting
- Orchards Any point during growing season

* There is no real significant period that is critical for sugar beets. In Montana the length of the growing season is limiting to production. Any drought period becomes critical, so soil moisture should be kept above 50 percent until 2 or 3 weeks before harvest to ensure rapid plant development and highest production.

Water Use by Crops

The amount of water used by crops depends on the rate of water vapor lost to the atmosphere through

evaporation and transpiration. The term consumptive use (CU) is used to describe the amount of water lost through evapo-transpiration. CU depends upon a number of factors including radiant energy, humidity, temperature, length of growing season, wind, crop and soil moisture supply.

The net irrigation requirement for a given crop is that portion of the CU which is not satisfied by precipitation. Based on CU values computed for 90 locations in Montana, using the modified Blaney-Criddle formula, the state can be divided into five climatic areas, as depicted in Figure 6.

An irrigation system must be designed to apply enough water to satisfy crop requirements during the period of peak consumptive use. The consumptive use rate determines the quantity of water used during the period of peak demand and consequently the frequen-

Table 3
Typical peak consumptive use rates by climatic area for selected crops grown in Montana*

Crop	Climatic Area				
	1	2	3	4	5
 inches/day				
Alfalfa	.31	.28	.25	.23	.20
Grass	.25	.23	.20	.19	.16
Small Grains	.27	.25	.24	.24	.18
Corn Silage	.26	.23	.20	.18	--
Sugarbeets	.30	.28	.25	--	--
Potatoes	.34	.31	.26	.25	--

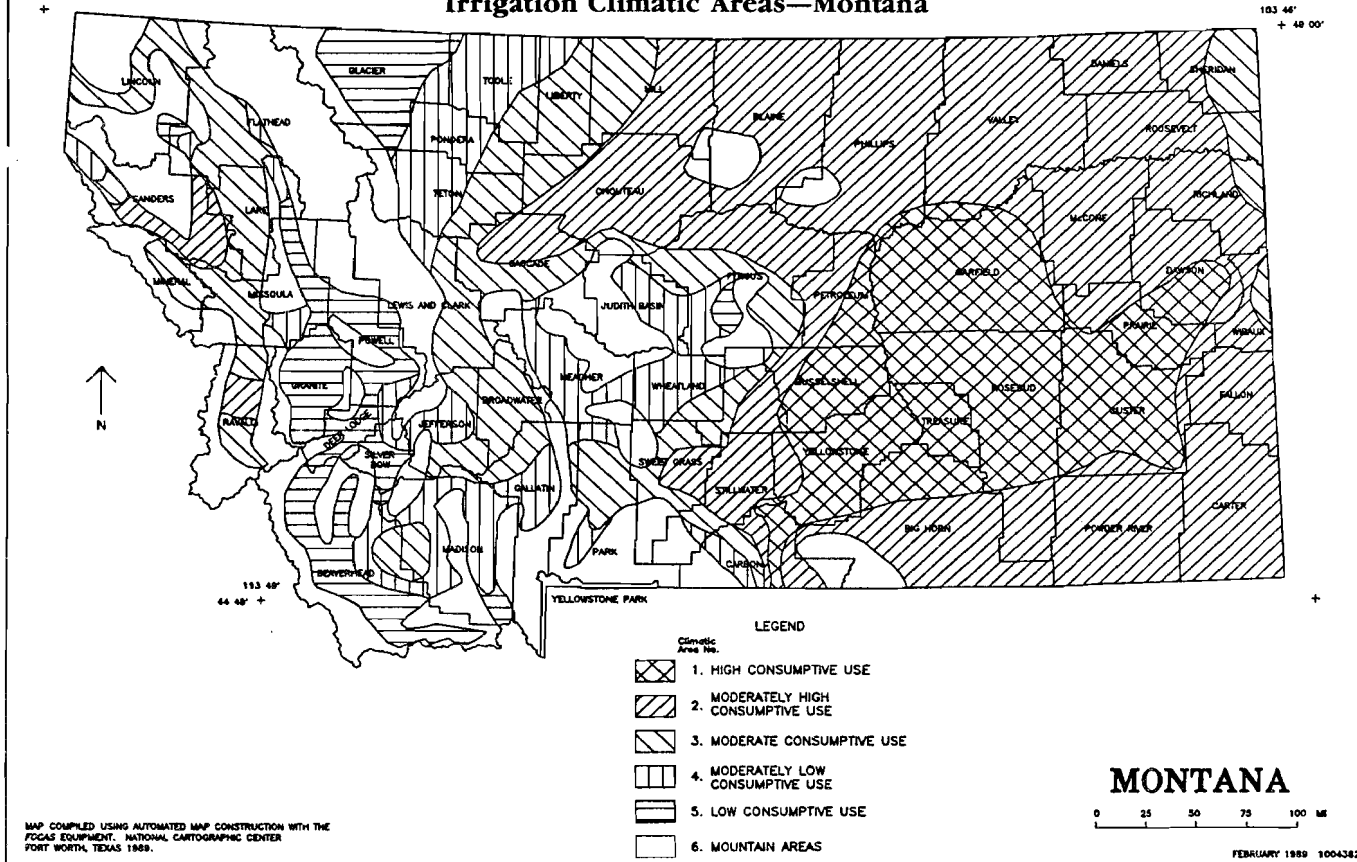
* Adopted from USDA-SCS Irrigation Guide for Montana

cy of irrigation. Typical peak period consumptive use rates by crop and climatic areas are given in Table 3.

Calculating the Net Irrigation Requirement

Computing the net irrigation requirement is relatively easy, if the right information is available. The following example illustrates how this can be done. In this

Figure 6
Irrigation Climatic Areas—Montana



example we will use spring grain with a root zone of 4 feet. The root zone was selected from Table 2. Soil texture is listed below and was obtained from the published soil survey for the area where the irrigated field is located. The AWC value was obtained from Table 1.

From Table 2, the recommended MAD for spring grain is 50 percent. Calculation of allowable moisture depletion, in terms of inches of water depleted, is as follows:

$$\frac{\text{MAD\%} \times \text{AWC in.}}{100} = \frac{50\% \times 7.5 \text{ in.}}{100} = 3.75 \text{ in. depleted}$$

Therefore, if moisture is allowed to be depleted to the 50% MAD level, a 3.75-inch net irrigation will be required to bring the soil moisture back to field capacity.

The following calculations then need to be completed to determine the total AWC for the management root zone.

Irrigation System Efficiencies Determine Total Irrigation Requirement

Efficiency of applying water through an irrigation system will dictate how much water must be delivered to the field to get the net irrigation requirement into the soil. Typical irrigation system efficiencies for well managed and maintained irrigation systems in Montana are illustrated in Table 4. Irrigation efficiency refers to the percentage of water pumped or diverted which actually enters and remains in the soil root zone during irrigation.

Soil Texture	Soil Layer Thickness (inches)	Soil Layer Thickness (feet)	AWC for Texture* (inches/foot)	AWC for Texture** (inches/layer)
Loamy fine sand	0-12	1.0	1.25	1.25
Sandy loam	12-18	0.5	1.50	.75
Sandy clay loam	18-48	2.5	2.20	+ 5.50

Total AWC in 4 foot layer = 7.50 in.

* From Table 1; **Soil Layer thickness (ft) x AWC for Texture.

Table 4

Typical irrigation efficiencies for well managed and maintained systems

System Type	Efficiency (%)
Hand move or Side roll sprinkler	65%
Periodic move gun or boom sprinkler	50%
Traveling gun sprinkler	60%
Center pivot sprinkler	65%
Graded borders	50%
Graded furrows	50%
Contour ditches, border ditches	20%

Irrigation efficiency is determined by many factors, some of which are wind losses, ditch seepage, runoff, and deep percolation. Efficiency can be increased by improved water management and by system maintenance and improvements. The gross amount of irrigation water to apply is calculated as follows:

$$\frac{\text{Gross requirement (inches)} = \text{Net requirements (inches)} \times 100}{\text{Efficiency (\%)}}$$

Assuming water is applied with a side roll sprinkler system and using data from the example above, the gross irrigation requirements would be calculated as follows:

$$\frac{3.75 \text{ in. net} \times 100}{65\% \text{ efficiency}} = 5.77 \text{ in. gross irrigation requirement}$$

If you had 50 acres to irrigate, the following total amount of water should be applied:

$$50 \text{ acres} \times 5.77 \text{ in.} = 289 \text{ acre in. or } \frac{289}{12} = 24 \text{ acre ft.}$$

Other Water Management Considerations

Additional factors must be considered for complete water management. They are:

Determining how much of the available water has been used at any given time and thus when to irrigate. There are several ways to do this. The most common methods are:

- Probing and using the feel and appearance method to determine soil moisture.
- Using an evaporation pan to keep track of moisture used by the crop.
- Using a "checkbook" method of keeping track of moisture used by the crop, based on daily temperature readings and crop use estimates.
- Other methods such as tensiometer, resistance blocks and neutron probe procedures.

A home computer can aid with the bookkeeping required with some of these methods.

Knowing how much water has been put on during an irrigation is valuable information. Such information will help determine when to shut the water off. This is accomplished by:

- Knowing how much water is applied per hour by your sprinkler system.
- Using a flow measuring device such as a flume, weir or pipeline flow meter to measure the flow rate through any type of system.

You can find out more about these water management techniques by contacting your Extension agent or the Soil Conservation Service in your county.