CO652.0308 State Supplement

(a) IRRIGATING WITH LIMITED WATER SUPPLIES

Irrigation managers can do something other than purchase additional equipment or reduce irrigated acreage to accommodate limited water supplies. Well-timed irrigations may help managers irrigate more acres without lowering crop yields.

By making the best use of water, irrigation managers can better manage both water and equipment. Seed-producing crops respond more to irrigations during one particular stage of development than during other stages. Some of those crops include corn, barley, sunflowers, wheat, and beans. Yields of storage and forage crops (sugar beets, potatoes, alfalfa, and grasses) are more directly related to climatic demand and cumulative water use during the season than to stress during any particular growth stage.

Once established, sugar beets are quite drought-tolerant. They can withstand extended periods without rainfall or irrigation water by using water stored in the soil. Limited water can even increase the efficiency of sucrose production. Sucrose yield per unit of water use can be increased above that where maximum water use is allowed simply by cutting off irrigations three to four weeks before harvest operations. Sugarbeets are only moderately sensitive to plant stress, except during the early growth stages. Afternoon leaf wilting during hot, dry, windy conditions has negligible effects on total sugar production. Water can be used more efficiently on sugarbeets by applying one last major irrigation to recharge the entire soil profile at the onset of the major stress period. Sugarbeets adapt to limited irrigations by using deeply stored soil water and quickly recovering when water is made available following major stress periods. Normal irrigations of sugarbeets could be reduced after the middle of July. Sucrose yield is likely to be reduced very little when such a practice is used and a final heavy irrigation is applied in early August.

Corn is sensitive to drought stress during the flowering and reproductive stages. Stress during the early vegetative stage is not nearly as serious as stress during flowering, pollination, and early seed filling. Grain corn is most sensitive to drought stress between the three and four leaf stage when the ear size is set, and is then fairly tolerant until the12-leaf and blister kernel stages; this period includes flowering, pollination, and initial seed filling. Stress during any part of the cropping season affects grain corn production. To maximize water use efficiency in grain corn, it is best to limit irrigations during the vegetative stage.

Barley responds to drought stress much like corn and other cereal crops. Yield is likely to be reduced very little when drought stress occurs during the vegetative period. However, a major disadvantage of early drought stress is the tendency for plants to tiller more than usual. Although the increased tillering is desirable, often the tillers never produce grain-yielding heads. Barley is most sensitive to stress during jointing, booting, and heading. Considering drought stress before, during, and after heading, yield is reduced the most by drought before heading. Flowering and pollination appear to be the most sensitive periods.

Several studies have been conducted with spring wheat and winter wheat to evaluate the effect of limited irrigations on crop quality and production. Stress was most critical during and after heading. This response is similar to that for barley. There is little or no measurable benefit from irrigating spring grains before the boot stage, unless moisture stress is evident. Stress is likely to occur when the plants appear wilted and the leaves curl. The period between grain filling and maturity is critical. Yield is reduced the most when stress starts during soft dough or during or following heading. Stress during the maturing process results in about a 10 percent lower yield. Moderate stress during the early vegetative period has essentially no effect on yield. Irrigation managers can use water most efficiently on spring-planted grains by reducing early-season irrigations and minimizing crop stress during flowering, pollination, and seed filling.

Drought stress on winter wheat production during early spring regrowth results in premature heading approximately seven to 10 days prematurely. The consequence of early heading is early maturity and a shortened growth period; thus, yield is reduced. Early stress results in development of more heads than usual; however, many of the heads may fail to produce grain. Winter wheat is most sensitive to drought stress during shooting and booting. It is essential to avoid even slight water stress at jointing. Withholding water to increase tillering may lead to premature heading and grain maturity.

High-quality potato yields can be achieved only by maintaining a uniformly high level of available water throughout the crop season. Short four-to-five day stress periods do not lower yields significantly or deteriorate the quality of potatoes compared to unstressed crops. Potato production is directly related to crop water use between emergence and defoliation. Potatoes are not susceptible to severe yield reductions from very short periods of moderate stress during any single period of production.

Alfalfa forage yield is directly related to available water and actual plant water use. Alfalfa is not nearly as sensitive to plant water stress at different times of the season as are most of the grain-producing crops. Forage increases have been obtained from one-sixth to one-fifth ton per acre per year for each inch of applied water. Maximum water use by alfalfa is not likely to exceed 24 inches between late April and the latter part of August. When subjected to plant water stress, most alfalfa varieties will go into dormancy, thus dramatically reducing both water use and production. When irrigation reduces stress, the crop resumes growth. Alfalfa is much less sensitive to plant water stress, regardless of when it occurs during the growing season.

Essentially two types of responses occur when irrigated crops are subjected to drought stress. Determinate crops, which are grown primarily for the harvest of mature seed and depend upon day length and season length, are most sensitive to drought stress during the seed formation period. This period includes heading, flowering, and pollination. Crops most affected by stress during this period include small grains, other cereal crops, and oilseed crops. Drought stress that occurs between seed development and maturity also limits yield, but to a lesser degree. These same crops are relatively insensitive to drought stress during the early vegetative period.

Indeterminate crops, such as tuber and root crops that are grown primarily for the harvest of storage organisms, are relatively insensitive to moderate drought stress for short intervals throughout the entire crop growing season. Crops like potatoes, sugar beets, alfalfa, and pasture quickly recover from short stress periods and little reduction in yield occurs.

Irrigation managers confronted with limited irrigation water should consider making the most efficient use of water by their crops. For seed crops, this means cutting back on early-season irrigations and ensuring minimum stress conditions between seed development and maturity. For root, tuber, and forage crops, irrigation managers should minimize the number of early-season irrigations and eliminate late-season irrigations.

Further information on deficit irrigation is located at:

http://www.montana.edu/wwwpb/ag/baudr298.html

For additional information or to receive a regular email distribution of agronomy notes such as the one above, Jim Bauder can be contacted by email at "jbauder@montana.edu".

The Colorado State University Extension Service has prepared a fact sheet addressing crop water use at different growth stages for crops. This fact sheet can be found at:
http://www.ext.colostate.edu/PUBS/crops/04715.html

(b) CROP NUTRIENT CONTENT

A tool on the web has been developed by NRCS to approximate the amount of nitrogen, phosphorus, and potassium that is removed by the harvest of agricultural crops.

This site can be found at:

http://npk.nrcs.usda.gov/nutrient_body.html

Additional information on nutrient management can be found in the Colorado NRCS Standard (Code 590) in the Electronic Field Office Technical Guide (eFOTG). A link to this standard can be found at:

http://efotg.nrcs.usda.gov/references/public/CO/CO590.pdf

Other technical information on nutrient management such as job sheets, nitrogen leaching indices, and phosphorus leaching indices can be found at:

Job Sheets:
http://efotg.nrcs.usda.gov/references/public/CO/CO590_JS.xls

Nitrogen Leaching Indices:
http://efotg.nrcs.usda.gov/references/public/CO/COATN_97v2.pdf

The Colorado State University Cooperative Extension Service has prepared a fact sheet addressing nitrogen and irrigation water. A link to the fact sheet can be found at:
http://www.ext.colostate.edu/PUBS/crops/00514.html

(c) SALINITY

Salinity is defined as the concentration of dissolved mineral salts in waters and soils. The concentration can be expressed on a mass, volume, or chemical basis. Expressed on a mass basis, the most familiar units are probably parts per million (ppm), while on a volume basis, the typical units are milligrams per liter (mg/l). Another useful way of expressing the dissolved mineral concentration is on an equivalent basis, since many chemical composition calculations involve equivalence calculations. The common unit is milliquivalents per liter (meq/l) or millimoles of charge per liter ($m\text{mol}_c$/l). These two units are equivalent and interchangeable. For any reported value, the chemical equivalent is equal to the reported value either divided by the ion's equivalent weight, or multiplied by the reciprocal of the equivalent weight. The equivalent weight of any given ion is the atomic mass divided by its valence. For example, calcium, which has a valence of +2 and an atomic mass of 40.078, has an equivalent weight of 20.039. Today most laboratories report each constituent in both mg/l and meq/l. The major solutes comprising dissolved salts are the cations (sodium, calcium, magnesium, and potassium) and the anions (sulfate, chloride, carbonate, bicarbonate, and nitrate). On occasion, the term hypersalinity may be encountered. Use of this term indicates a reference to the minerals listed above plus other constituents that may include manganese, boron, lithium, fluoride, barium, strontium, uranium, aluminum, rubidium, and silica; and specifically describes land salt sources found in enclosed, inland water bodies that have solute concentrations well in excess of sea water.

The primary source of salts in irrigated agricultural systems is the chemical weathering of geological materials and anthropogenic processes. Dissolution and redox reactions are responsible for salt accumulation in soils and water by chemical weathering. Anthropogenic salinization processes are driven by evapotranspiration processes. The concentrations of soluble salts increases in soils as the soil water is removed to meet atmospheric demand though evaporation and transpiration. The salts, which are left behind, will concentrate in the shrinking soil-water volume with each successive applied irrigation passing through the soil profile. Soils with shallow, saline water tables can become salinized as the result of upward flux of water and salts into the root zone. If these salts are not managed, they will eventually build up in irrigated soils to the point that crop yield is adversely affected. **Table CO 3-2** lists salt tolerance values for some common crops in Colorado.

The Agriculture Research Service has developed a web site for salt, boron, and chloride tolerance in crops. The sites are:

Salt Tolerance (Fiber and Grain Crops):

http://www.ussl.ars.usda.gov/pls/caliche/SALTT42A

Salt Tolerance (Grass and Forage Crops):

http://www.ussl.ars.usda.gov/pls/caliche/SALTT42B

Salt Tolerance (Vegetable and Fruit Crops):

http://www.ussl.ars.usda.gov/pls/caliche/SALTT42C

Salt Tolerance (Woody Crops):

http://www.ussl.ars.usda.gov/pls/caliche/SALTT43

Boron Tolerance:

http://www.ussl.ars.usda.gov/pls/caliche/BOROT46

Chloride Tolerance:

http://www.ussl.ars.usda.gov/pls/caliche/CLTT49

An older, but still very useful guide to management and improvement of saline soils is the USDA Salinity Handbook 60. This publication is no longer in print, but can be accessed electronically at the following link:

http://www.ars.usda.gov/Services/docs.htm?docid=10158&page=2

Colorado State University Cooperative Extension Service has prepared several fact sheets relating to the management of saline and sodic soils. These fact sheets can be accessed at the following links:

Managing Saline Soils:

http://www.ext.colostate.edu/PUBS/crops/00503.html

Managing Sodic Soils:

http://www.ext.colostate.edu/PUBS/crops/00504.html

Diagnosing Saline and Sodic Soil Problems:

http://www.ext.colostate.edu/PUBS/crops/00521.html

(d) WETLAND/WATER BODY K_c (CROP COEFFICIENT)

Evaporation from the open water areas of a wetland can be much different from that of the vegetated area and should be calculated separately. This is especially true in a temperate climate. In a temperate climate there may be portions of the fall, winter, and spring months, in which the vegetation is dead and therefore becomes”protective" mulch above the wet soil or water, and thereby reduces the K_c dramatically. Researchers have measured a K_c of less than 0.2 for dead cattail vegetation in northern Utah. During the summer, the tall, lush cattail or bulrush vegetation can approach a K_c of even 1.4 in an arid climate based on grass reference due to the tall roughness and general "oasis" effect of transport of sensible heat and dry air from outside of the wetland.

It is correct in presuming that the "K_c end" (end season) value can be used until the "greenup" of the following year. However, in a freezing climate, the K_c can go even lower than a typical K_c end (not a problem in California). The value of the K_c during non-growing season will of course change with precipitation frequency, and is best estimated using a daily calculation time step and a K_c procedure that separately includes the evaporation of water from the soil and vegetation surface (interception).

Evaporation from water can be very different and is a strong function of the water depth, the turbidity, and variation in temperature during the year. Shallow (less than 1 m) or turbid water will intercept solar radiation near the water surface and therefore will facilitate the conversion of radiation to evaporation at the surface in near real time (but will be impacted by night-time evaporation and carry over of heat from hot to cool days). In deep water, however, the radiation from the sun is transmitted deeply into the water and is converted directly into heat which can only be transported to the water surface to supply evaporation by convection within the water body (and a little conduction). This can be an extremely slow process for deep, cold water bodies such as in the Rocky Mountain area of the USA. A simple calculation using specific heat of water multiplied by the depth of water will indicate the tremendous storage capacity for heat in deep lakes. Researchers have measured K_c values for evaporation from Bear Lake, Utah of less than 0.40 in the summer months due to the heat storage effect. Bear Lake is quite deep, extremely clear, and has a cold winter.

Much of the stored heat in Bear Lake returns to the surface in the fall months as the lake cools. During this later period, the vapor pressure deficit of the air is less, so that less of the energy is converted into evaporation as it would be during summer, and more is used to warm the cooler air. Therefore over the course of a year, a smaller ratio of total solar radiation is converted to evaporation for a clear, deep lake as opposed to a shallow or turbid lake, and therefore the K_c is lower than for a shallow lake.

The FAO 56, a revision of the FAO 24 publication on Crop Evapotranspiration, suggests two different K_c values. The first one is for shallow water bodies (and "usually" water bodies near wetlands are shallow, fortunately, otherwise there would be no emergent vegetation). The other set of K_c values is for deep lakes. For open water less than 2m deep, or for all water bodies in tropical climates having little change in water temperature, FAO 56 suggests using a K_c of 1.05 for all months. This coefficient is based on the grass reference. For deep-water bodies (greater than 2m deep) in temperate climates with winters, the FAO 56 suggests using a K_c = 1.25 for the fall and winter and .65 for spring and summer. Of course, these average values will vary, as discussed above, with actual depth, turbidity, and variation in climate during the year.

The K_c for wetland varies substantially with the "clothesline" effect caused by occurrences of limited stands of wetland vegetation that are surrounded by vegetation or other cover that is evaporating at a lower rate. This is common for wetland vegetation that occurs along roadways or canals. In this instance the K_c can go as high as 1.8.

The FAO 56 publication suggests an average K_c during midseason of 1.2 for large areas (greater than 2 acres) for cattails and bulrushes in subhumid climates. For semi-arid and arid climates the mid-season K_c increases to 1.3 to 1.4. For an average K_c at the beginning and end of the growing season 0.3 is suggested for cattails and bulrushes in a killing frost climate, and 0.6 without a killing frost. An average K_c for wetlands with short vegetation is 1.05 to 1.10.

CONVERSION BETWEEN ALFALFA AND GRASS REFERENCE CROP COEFFICIENTS (K_c VALUES).

The revised FAO 56 suggests that the ratio of alfalfa reference to grass reference (ETr/ETo) varies from about 1.05 for humid, calm conditions, to 1.2 for semi-arid, moderately windy conditions, and to 1.35 for arid, windy conditions. The first condition is dominated by net radiation, which is similar between the references. The latter two values are influenced more by the differences in aerodynamic roughness and bulk surface resistance.

An equation for predicting the conversion between the two references that is in the revision is the following:

ETo/ETr = 1.2 + [0.04 (u2-2) -0.004 (RHmin-45)] (h/3) ^0.3

Where u2 is average wind speed at 2m in m/s, RHmin is daily minimum relative humidity, % , and h is height of the alfalfa (generally 0.5 m is used for the alfalfa reference and 0.12 m is used for grass). The "0.3" exponent is used on the h/3 term to indicate the effect of roughness (height) on the impact of dryness and windiness on the ratio. This same "adjustment" expression is used in the revision to adjust K_c values for all crops for climate for use with the grass reference ET_o.

The above equation happens to predict a ratio ETr/ETo = 1.24 at Kimberly, Idaho, where u2=2.2 m/s during the summer period and RHmin averages 30 percent. This is similar to values of ET_R/ET_O that have been measured by Dr. Jim Wright at Kimberly using weighing lysimeters.

RHmin can be predicted from daily or monthly dewpoint temperature as

$$RHmin = 100\, e^{\circ}(Tdew)/e^{\circ}(Tmax)$$

where e°() is the saturation vapor function. If no Tdew data are available,

$$RHmin = 100\, e^{\circ}(Tmin)/e^{\circ}(Tmax)$$

where Tmin and Tmax are average daily minimum and maximum air temperatures.

$$e^{o} = \exp\left(\frac{16.78T - 116.9}{T + 237.3}\right) \quad \text{T in °C}$$

Prepared by Dr. Rick Allen, Utah State University, 5/12/98, in response to a question raised by Dr. Dean Reynolds on SOWACS and Irrigation-L discussion groups.

(e) CHEMIGATION AND FERTIGATION

Chemigation and fertigation are methods for applying chemicals and nutrients to a crop through the irrigation water. While these methods have had limited use for years in surface flood irrigation systems with anhydrous ammonia and certain other chemicals, chemigation and fertigation are primarily used under sprinkler and microirrigation systems. Chemigation or fertigation is not simply putting chemicals into the irrigation water or injecting nutrients into a pressurized delivery system. There are advantages and drawbacks to these methods. Some of the advantages to chemigation are the uniformity of application, timeliness of application, reduction of soil compaction, and the economics of the application. Disadvantages include higher management levels for the irrigation system, additional equipment, possible environmental impacts, and the requirements for permitting. Under the *Colorado Chemigation Act*, permitting is required for the majority of chemical applications through irrigation systems. Additionally, not all chemicals or nutrients can be applied by chemigation techniques due to the nature of the chemical or improper labeling for legal application. A link to the Colorado Department of Agriculture website is:

http://www.colorado.gov/ag

Additional information about the *Colorado Chemigation Act*, copies of the Act, information about permit fees, permit applications, and information about inspections can also be obtained from the Colorado Department of Agriculture at the following address:

Colorado Department of Agriculture
Division of Plant Industry
700 Kipling Street, Suite 4000
Lakewood, Colorado 80215-5894
Tel:(303) 239-4149

The Colorado State University Extension Service has prepared a fact sheet discussing fertigation. A link to the fact sheet can be found at:

http://www.ext.colostate.edu/pubs/crops/00512.html

The Mississippi State University has prepared a fact sheet discussing the advantages and disadvantages of chemigation systems and some of the related safety concerns and equipment. A link to this fact sheet can be found at:

http://msucares.com/pubs/publications/p1551.htm.

(f) CROP PLANTING

Seeding rates will generally vary due to the presence or absence of an irrigation system, cultural factors, or other variables. Underseeding can adversely affect yields. Overseeding can reduce crop yields or potentially lead to a crop failure if irrigation and soil moisture are severely limited. To maximize yields, it is imperative to accurately apply seed to the field. A fact sheet has been prepared by the Colorado State University Extension Service that discusses seeder calibration and typical seeding rates for common Colorado crops. A link to this fact sheet can be found at:

http://www.ext.colostate.edu

(g) CROP GROWTH CURVES

Further information on crop K_c values can be found in the fact sheet *Irrigation Scheduling: The Water Balance Approach* from the Colorado State University Extension.

(h) CROP FACT SHEETS

Several fact sheets and informational publications exist for a variety of crops commonly grown in Colorado. The fact sheets presented in this section are from the Colorado State University Extension unless otherwise noted.

General

Best Management Practices for Colorado Agriculture: An Overview

Canola

Rapeseed / canola production

Corn

Colorado State University Extension Water Quality Programs:

Best Management Practices for Colorado Corn

Colorado State University Extension:

Dry Beans

VegNet for Dry Beans

Onions

VegNet for Onions

Potatoes

VegNet for Potatoes

Sorghum

Fertilizing Grain and Forage Sorghums

Spring Wheat

Fertilizing Spring-Seeded Small Grains

Vegetable Crops

Colorado VegNet

(i) EXAMPLE: MANAGEMENT ALLOWABLE DEPLETION (MAD) AND IRRIGATION FREQUENCY

Following is an example of how to select a Management Allowable Depletion (MAD) and use it to calculate net irrigation water requirement and irrigation frequency.

Given: The operator is growing potatoes on a sandy loam soil. The crop ET rate is .34 in./day.

Solution: Select an appropriate MAD value and determine the net irrigation requirement and the irrigation frequency.

Step 1. Using procedures mentioned in Chapter 2, the available water capacity for a potato crop with 18” rooting depth on a loam soil with 30% coarse fragments is estimated at 2.16 inches.

Table 3-4 shows typical rooting depths. For the purpose of this example, a rooting depth of 2 feet (24”) is selected from the table, and corrected to 18”. (In an actual situation, never assume a plant root zone for management purposes; rather, check actual root development pattern and depth.) From Table 3-3 select a MAD of 35%. Net irrigation can be calculated the following way:

$$\text{Net Irrigation} = \text{Available Water Capacity (AWC, in/in)} \times \mathit{Root}\ \text{Depth} \times \frac{\text{MAD\%}}{100}$$

$$\text{Net Irrigation} = 2.16\mathit{in.} \times \frac{35\%}{100} = 0.76\,\text{in.}$$

Step 2. The Irrigation Frequency can be calculated as follows:

$$\text{Irrigation Frequency} = \frac{MAD}{Crop\ ET\ rate} = \frac{0.76\,in}{0.34\,in/day} = 2.2\,days$$

Table CO 3-1: Critical Growth Periods for Major Crops

Crop	Moisture Stress	Critical Period	Other Considerations
Alfalfa	Darkening color, then wilting	Early spring and immediately after cuttings	Normally 3-4 inches of water is needed between cuttings. Fall irrigation is desirable.
Corn	Curling of leaves by mid-morning	Three to four leaf stage, tasseling, silk stage until grain is fully formed	Needs adequate moisture from germination to dent stage for maximum production.
Sorghum	Curling of leaves by mid-morning	Boot, bloom, and dough stages	Yields are reduced if water is short during seed development.
Sugar Beets	Leaves wilting during the heat of the day.	Post thinning	Excessive fall irrigation lowers sugar content.
Beans	Wilting	Bloom and fruit set	Yields are reduced if water is short at bloom or fruit set.
Small Grains	Dull green color followed by firing of the lower leaves	Boot and bloom stage	Last irrigation at milk stage.
Potatoes	Wilting during the heat of the day	Tuber formation to harvest	Moisture stress during critical period may cause cracking of tubers.
Onions	Wilting	Bulb formation	Keep wet during bulb formation, let soil dry near harvest.
Tomatoes	Wilting	After fruit set	Wilt and leaf rolling can be caused by disease.
Cool Season Grass	Dull Green color, then wilting	Early spring, Early fall	Critical period for seed production is boot to head formation.
Fruit Trees	Dulling of leaf color and drooping of growing points	Any point during the growing season	Stone fruits are sensitive to moisture stress during the last two weeks prior to harvest.

Table CO 3-2: Approximate Yield Decrease (%) for Selected Crops due to Salinity

Crop	0% ECe (1)	10% ECe	25% ECe	50% ECe	Maximum ECe (2)
Apples	1.7%	2.3%	3.3%	4.8%	8%
Alfalfa	2%	3.4%	5.4%	8.8%	15.5%
Barley (3)	8%	10%	13%	18%	28%
Cabbage	1.8%	2.8%	4.4%	7%	12%
Cantaloupe	2.2%	3.6%	6.7%	9.1%	16%
Corn	1.7%	2.5%	3.8%	5.9%	10%
Dry Beans	1.0%	1.5%	2.3%	3.6%	6.5%
Onions	1.2%	1.8%	2.8%	4.3%	7.5%
Peaches	1.7%	2.2%	2.9%	4.1%	6.5%
Potatoes	1.7%	2.5%	3.8%	5.9%	10%
Sorghum	4.0%	5.1%	7.2%	11%	18%
Sweet Corn	1.7%	2.5%	3.8%	5.9%	10%
Sugar Beets	7.0%	8.7%	11%	15%	24%
Wheat (3)	6.0%	7.4%	9.5%	13%	20%

(1) EC means the electrical conductivity of the saturation extract of the soil reported in decisiemens per meter at 25°C.
(2) Maximum ECe means the maximum electrical conductivity of the soil saturation extract that can develop due to the listed crop withdrawing soil water to meet its evapotranspiration demand. At this salinity, crop growth ceases (100% crop decrement) due to the osmotic effect and reduction in crop water availability to zero.
(3) Barley and wheat are less tolerant during germination and seedling stage. ECe should not exceed 4 or 5 decisiemens per meter during these growth stages.

<u>Source</u>: Bernstein (1964), University of California Committee of Consultants (1974).