Irrigating with Limited Water Supplies

A PRACTICAL GUIDE TO CHOOSING CROPS WELL-SUITED TO LIMITED IRRIGATION

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Acknowledgments

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Abstract

Irrigation management involves commitment of substantial time, capital, labor, equipment, and water. Lack of any of these resources can mean the difference between profit and loss. Drought throughout much of Montana and the Northern Plains and Mountains Region has caused water supplies to become increasingly inadequate to satisfy crop needs during the entire irrigation season. In addition, competition for water for purposes other than irrigation has placed a growing demand on irrigators to be more efficient and less consumptive in their water use. Thus, this project seeks to provide irrigators with a user-friendly, regionally applicable publication containing practical, low cost strategies to help achieve highest possible economic returns with limited water. Such strategies include fine tuning irrigation scheduling, capturing and storing precipitation, and growing crops well suited to limited irrigation. While the first two strategies are important in stretching water supplies, primary emphasis of this publication is placed on analyzing commonly irrigated determinate, indeterminate, and forage crops in terms of individual water use characteristics and effective management strategies to maximize their production.

Determinate crops, including wheat and sunflower, have fixed growth periods and are relatively insensitive to moisture stress during early vegetative stages and highly sensitive during seed formation. Indeterminate crops, such as potato and sugarbeets, have season-long, cumulative yield production and, therefore, can endure 4 to 5 day periods of moisture stress throughout the growing season. Because of their long growing season, determinate crops require more water than indeterminate crops. Perennial forage crops generally have deep, well-established root systems. Thus, they capitalize on early season moisture and generally withstand moisture stress better than determinate and indeterminate crops.

Considering these water use characteristics, irrigators are encouraged to substitute low water requirement crops for high requirement crops, choose crop varieties short in stature, and split fields between low and high-water-requirement crops or early and late season crops. While drought poses many challenges to irrigators, these strategies can help ease the burden of limited water supplies.

Introduction

Irrigation management is a complex process involving commitment of substantial time, capital, labor, equipment, and water. Often, availability of one of these resources during the cropping season can mean the difference between profit and loss. In the past decade, drought and reduced water resources throughout much of the Northern Plains and Rocky Mountain Regions have resulted in inadequate water supplies to satisfy crop moisture needs during part, or all, of the irrigation season.

Irrigation water may be inadequate due to drought, lost well capacity, or changes in operation or administration of project water. When irrigation water is not available to meet crop demand, managers need strategies to achieve the highest possible economic return with limited water, particularly when dealing with difficulties such as steep slopes, sandy soils, erosive or eroded fields, or compacted soils. When considering a long term limited irrigation system, consult with farm management advisors to determine the economic impacts and/or insurance implications of management options. While reducing irrigated acreage and/or purchasing additional equipment are ways to manage limited water supplies, they may not maintain or improve economic return. Alternate strategies requiring minimal capital and equipment investment include fine tuning irrigation scheduling to optimize crop water use efficiency, taking steps to capture and store precipitation, and growing crops well suited to limited irrigation. While the way one deals with limited water supplies differs depending on whether the shortage is temporary or permanent,

Center pivot sprinklers along the Columbia River near Hermiston, Oregon. Photo courtesy of Doug Wilson and ARS.

the following list provides some strategies for dealing with limited irrigation water in either case.

- ❒ Reduce irrigation during non-critical growth stages.
- ❒ Use soil moisture and evapotranspiration (ET) measurements to schedule irrigations. Do not rely on crop appearance. Understand ET and how seasonal water use requirements vary by crop type, elevation, short-term weather and length of growing season.
- ❒ Increase residue, reduce tillage, and manage weeds with best available herbicide X crop technology and plant population reduction. These measures help capture and store precipitation, reduce runoff and evaporation and maximize water use efficiency.
- ❒ A limited root zone is a problem in water short situations. Avoid soil compaction by using no till, strip till, ridge till, conservation tillage, and chemical weed control. For guidelines on conservation tillage under furrow irrigation, see CO AES Publication TR02-06, 2002.
- ❒ Make equipment upgrades to improve irrigation system efficiency and uniformity of application through an incentive cost share program, where available.
- ❒ Under furrow irrigation, optimize row lengths and slope to shorten surface irrigation set times and increase uniformity. Use polyacrylamide (PAM) and surge valves to increase application rates. This increases uniformity and decreases set times.
- ❒ Manage soil water depletion carefully. Allow soil to reach its maximum allowable depletion (MAD) before completing the next irrigation.
- ❒ In situations where good quality water is unavailable, producers may consider using marginal quality water for irrigation. This is NOT a long-term strategy. It is a short-term solution requiring constant monitoring and depends on crop type and electrical conductivity (EC) of soil and water. If the only available water source is saline, consider reducing acreage and applying full irrigations to ensure leaching of salts through the root zone.
- ❒ Reduce irrigated acreage. Revert some land to dryland crops or grass.
- ❒ Switch to shorter season crops or plant combinations of cool and warm season crops in the same field.
- ❒ Forage crops are a good way to take advantage of precipitation when it occurs and accommodate drought conditions, while high value or quality driven crops are not good choices for limited irrigation.

Severe soil erosion in a wheat field near Washington State University. Photo courtesy of Jack Dykinga and ARS.

Managing Soil Moisture

Irrigation scheduling is a critical key to managing soil moisture before, during, and after the growing season. By knowing the soil's available water holding capacity, the crop's water use and growth stage, and the irrigation system's capabilities, managers can determine optimum timing and amount of irrigation water application. Such irrigations apply sufficient water to meet crop water needs and replenish depleted moisture within the crop's active root zone, while minimizing loss to deep percolation and runoff. In certain cases, maximizing irrigation efficiency (percentage of applied water actually used by the crop) can free up water and/or equipment for use on other land parcels, providing that the water is not tied by regulation or contract to specific acreage.

When dealing with limited moisture, irrigators must consider individual system capabilities and make adjustments to increase uniformity and efficiency. For example, time pivot revolutions so that the same part of the field does not receive water at the same time each day, and check nozzles for wear. Turn off pivot end guns to increase field-wide uniformity while eliminating acreage that typically yields lower than the rest of the field. On flood irrigated acres, increase water application rates to improve uniformity, and use surge valves and PAM to combat erosion. Subsurface drip irrigation (SDI) systems, which reduce surface evaporation, runoff, and deep percolation, work well for high value crops and fields too small or irregular for pivots. However, since very little water percolates below the root zone to carry away salts, such systems require good quality water, which often becomes a commodity when supplies run short.

Trimmer (1994) outlines several more practical steps for improving irrigation efficiency. First, keep track of soil moisture. Using a probe or soil auger and knowledge of the soil's available water holding capacity, determine how much water the crop's root zone can hold, and run the irrigation system, or apply water, only long enough to fill the profile. If odd set times pose a problem, use a timer. Watch the weather in order to avoid irrigating during hot, windy periods, or when it is raining, thereby reducing evaporative, drift, run-off and leaching losses.

Because precipitation occurring on an already saturated soil either percolates below the crop's root zone or runs off, avoid non-growing season irrigations, thereby ensuring room in the soil profile to store precipitation that may fall before the next growing season. Utilize crop residues to intercept rainfall and snow, enhance infiltration, and reduce evaporation from the soil surface.

Reduced yields caused by excessive water stress can occur when a plant or crop depletes most of the available soil moisture (Hanson and Orloff, 1998). Therefore, the maximum allowable depletion (MAD; frequently expressed as a percentage of available soil moisture) is the amount of soil moisture depletion that causes no yield loss. Recommended MAD by crop type are given in Table 1.

Table 1. Recommended maximum allowable depletion (MAD) for some commonly irrigated crops.

Crop	MAD (%)
Potato	25
Sunflowers, Beans	45
Grass Hay	50
Barley, Alfalfa	50-55
Corn (grain and silage), Annual Forage	50-60
Wheat	50-70 (growing season), 90 (ripening)
Sugarbeet	50-80

Compiled from Hanson and Orloff, 1998; MSU, 1990.

Extension agent Wayne Cooley, ARS agronomist Randy Anderson, and farmer Gilbert Lindstrom work as a team to figure the best methods for growing wheat in a dryland cropping system relying on a wheat/corn/fallow rotation. Photo courtesy of Scott Bauer and ARS.

Crop Considerations

When seeking to conserve irrigation water, managers must be aware of specific crop water use characteristics and grow those crops which best utilize water at the time and in the volume in which it is available. While soil moisture depletion to the point of wilting reduces vegetative growth of nearly any plant, most crops have critical growth periods during which drought stress is especially damaging to yield (Table 8). This critical growth period often coincides with a crop's reproductive stage. Knowing this, irrigation managers can conserve water during appropriate growth periods and apply water when it is most critical to yield or crop quality.

Determinate, Indeterminate, and Forage Crops

Crops fall into one of three general groups or types of plants- determinate crops, indeterminate crops, and forages (Table 2). Determinate crops, including grain, cereal, and oil crops, are grown for harvest of mature seeds and have a fixed growth period. They tend to be relatively tolerant of moisture stress during early vegetative stages and highly sensitive during seed formation, which includes heading, flowering, and pollination. Removal of stress, once it has occurred during these critical periods, generally does not lead to recovery of yield. Moisture stress can also be manifested as reduced resistance to pests. For example, spider mites are frequently a problem in moisture-stressed corn in Colorado while aphids are a frequent problem in moisture-stressed cereal grains, and producers must scout and treat to maintain yields.

Table 2. Critical moisture stress periods of determinate, indeterminate, and forage crops.

Type of Crop	Examples	Critical Period
Determinate	Grain, cereal, and oil seed crops (wheat, barley, oats, corn, sunflower)	Seed formation - heading, flowering, and pollination
Indeterminate	Tuber and root crops (potato, carrot, sugarbeet)	Early growth stages
Forage	Native and introduced grasses, alfalfa, determinate crops grown for forage	No specific period, but show highest production with early season irrigation

Tuber and root crops, such as potato, carrot, and sugarbeet, are known as indeterminate crops. Because of their season-long, cumulative yield production, such crops can endure 4 to 5 day periods of moisture stress throughout the growing season with little reduction in quality or yield. While yield generally does not suffer from longer periods of stress, quality may decline. Because of their longer growing season, indeterminate crops generally require more water than determinate crops.

Perennial forage crops, including hay and pasture grown for biomass production, generally have deep, well-established root systems and the ability to maximize production by taking advantage of early season irrigation and precipitation. Thus, they may withstand moisture stress better than determinate and indeterminate crops. Recall that biomass production is a function of evapotranspiration (ET); stomata must be open and actively transpiring water in order to assimilate carbon and build biomass. Thus, a good understanding of ET and crop water requirements will help irrigators maintain production with limited irrigation water supplies.

Crop Management Options

When faced with limited water supplies, substituting low water requirement crops, such as sunflower or winter wheat, for high-water-requirement crops, such as corn, can conserve water while producing a valuable crop. Average

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seasonal water requirements for crops discussed in this publication are listed in Table 3. Averages are for the entire state and may differ depending on climate and geographic location.

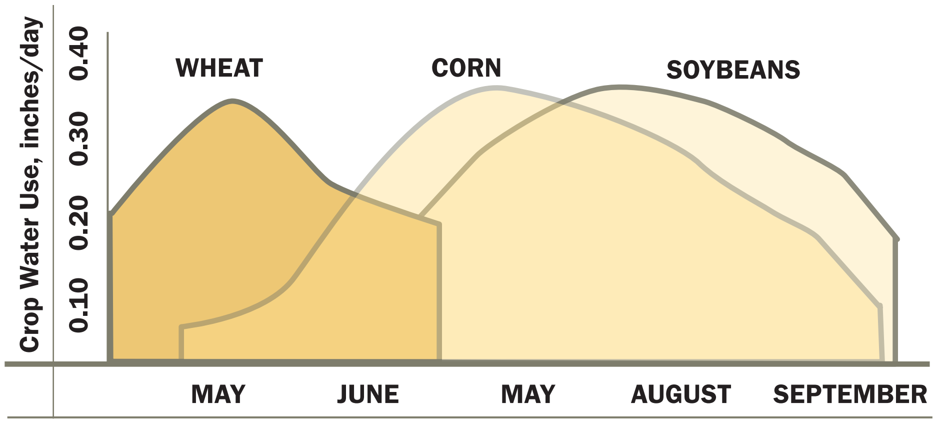
Table 3. Estimated average seasonal consumptive water use of select crops in Montana, Colorado, Utah and Alberta.

Crop	Average seasonal consumptive water use (inches)			
	Montana	Colorado	Alberta	Utah
Barley	17	14	15-17	22
Wheat	17	14	19	18
Corn	18.5	21		
Silage Corn	19	20		22
Sunflower		23		
Bean	13.5	19	15	20
Sugarbeet	23	32	22	33
Potato	39		16-20	27
Alfalfa	17-26	30-32	27	33
Grass Hay	28	26-28		
Annual forage		27		26

Compiled from multiple data sources for each state. Bauder et al., 1983; Broner and Schneekloth, 2003; Alberta Sugarbeet Growers, 2005; Hill et al., 2001; Kresge and Westesen, 1980; Dixon, 2001.

Season length required by the crop is also an important consideration when water is limited. Short season crops use less water because they are harvested earlier. Additionally, crop varieties that are short in stature tend to use less water than their taller counterparts, while producing comparable yields. Thus, short-season crops or short-stature varieties can be a wise option when faced with limited water supplies. Another management option is to plant irrigated fields in portions of low and high-water-requirement crops, early and late-season crops, or warm and cool-season crops to spread out irrigation water requirements. These options can reduce total water applied to a field and distribute water use across an entire growing season. For example, a split field of wheat and corn or soybeans in Colorado has high water demands in May, June, July and August, but only on half the field at a time. Peak water demand for wheat is in May and June, while corn and soybean use the most water in July and August (Figure 1).

Figure 1. Daily ET during the growing season for wheat, corn and soybean in Colorado. From Broner and Schneekloth, 2003.



The following pages highlight specific characteristics of eleven commonly irrigated crops of the Northern Plains and Inter-Mountain Region, and discuss how limited irrigation water supplies can be most effectively managed to maximize crop production.

Barley

Barley, a cereal crop, does not tolerate prolonged or excessive drought. While drought stress during early vegetative stages has limited impact on yield, such stress tends to cause excess tillering, often resulting in tillers that never produce heads. Barley is most sensitive to stress during jointing, booting, and heading, and significant stress during grain fill substantially degrades malt barley quality. Grain yield reductions of 14 percent, 8 percent, and 4 percent were measured for these three respective periods in a study conducted by Mogensen in 1980. Considering drought stress before, during and after heading, yield was reduced the most by stress just before heading. Thus, to eliminate yield-reducing moisture stress, plan to irrigate before heading. Results of the Mogensen (1980) study and other research indicate that stress prior to or just after flowering reduces yields the most, compared to stress at other stages. While these yield reduction effects can be alleviated somewhat if the stress is relieved later in the season, yield recovery from stress near the flowering stage is lower than recovery from stress in early vegetative stages (Bronsch, 2001). The Mogensen (1980) study also showed that each day of severe stress during the heading period was equal to a one-bushel per acre reduction in yield.

Timing the last irrigation for barley and wheat is always difficult. Late season moisture stress can reduce kernel weight, test weight, and yield, but unneeded irrigation can cause lodging and wastes limited water supplies. Thus, managers must assess crop water use during these final stages, consider the water requirements of late-ripening tillers, and determine whether additional water will be necessary to finish the crop and, if planned, facilitate post-harvest tillage.

Barley. Photo courtesy of Jack Dykinga and ARS.

As a rule of thumb, soil moisture levels should remain above 50 percent MAD in the active root zone from seeding to soft dough to optimize yield (Bronsch, 2001). Additionally, a barley crop needs three to four inches of water to carry it from soft dough to maturity (Ottman, 2001). The average sandy loam soil holds about this amount of plant available water in the active root zone. This means that a barley crop on a sandy loam soil, with a full profile, should require no irrigation between soft dough and maturity. However, barley grown on soil types having lesser water holding capacities may need irrigation during these late stages.

Wheat

Wheat is a great crop choice for limited irrigation. Similar to barley, wheat tolerates moisture stress during early vegetative stages much better than it tolerates stress during reproductive growth stages. Results of a study by Robins and Domingo (1962) showed little or no measurable benefit from irrigating spring grains before the boot stage, unless moisture stress was evident, as indicated by wilting and leaf curl. They also reported that the period between grain filling and maturity was particularly sensitive to drought stress, with greatest yield reductions occurring when stress began during or following heading or during the maturing process. Stress during maturing resulted in about a 10 percent yield reduction, while moderate stress during the aerial vegetative stage had essentially no effect on yield. By reducing early-season irrigations and minimizing stress during flowering, pollination, and seed filling, irrigation managers can most efficiently use available water on spring grains. Table 4 summarizes spring grain irrigation principles under low irrigation water conditions.

Harvested wheat field. Photo courtesy of MSU Extension Water Quality Program.

Table 4. Summary of spring grain irrigation principles.

• Avoid irrigation during early vegetative stages, unless signs of stress appear.
• Monitor soil moisture, and apply water in amounts that promote deep, extensive rooting.
• Ensure adequate moisture during critical reproductive periods, including jointing, booting, heading, and flowering.
• Schedule the final irrigation to carry the crop through harvest.
Al-Kaisi & Shanahan, 1999

Drought stress on winter wheat during early spring regrowth results in premature heading (approximately 7 to 10 days), a shortened growth period, and thus, reduced yield (Ehlig and LeMert, 1976). Early stress results in development of more heads than normal, but many fail to produce grain. Winter wheat is most sensitive to drought during shooting and booting, and greatest yield reductions are likely to occur when stress happens during and after heading. Ehlig and LeMert (1976) concluded it is essential to avoid even slight water stress at jointing and discouraged withholding water to increase tillering, as this practice may lead to premature heading and grain maturity.

Corn field nearing maturity. Photo courtesy of MSU Extension Water Quality Program.

Corn

Like other determinate crops, corn has low daily water needs during the first 3 to 4 weeks of vegetative growth, making it relatively insensitive to moisture stress during these early stages. Reproductive stages, including tasseling, silking, pollination, and early seed filling, represent corn's most moisture sensitive growth period. To maximize efficient use of limited water, irrigation can be restricted during early vegetative stages and saved for more critical reproductive stages. While this method can improve yield, managers must make sure their irrigation systems have the capacity to compensate for early season moisture depletion and meet crop water needs during reproductive stages.

Highest seasonal water use occurs during the four weeks centered around silking. This is the single most important time to avoid water stress, which may dessicate silks and pollen grains, causing poor pollination and seed set and barren ear tips (Benham, 1998). See Table 5. Rapid kernel development and weight gain cause water requirements to remain high from early grain development (blister kernel and milk stages) to physiological maturity.

Table 5. Percent reduction in corn grain yield caused by 4 consecutive days of wilting at various stages.

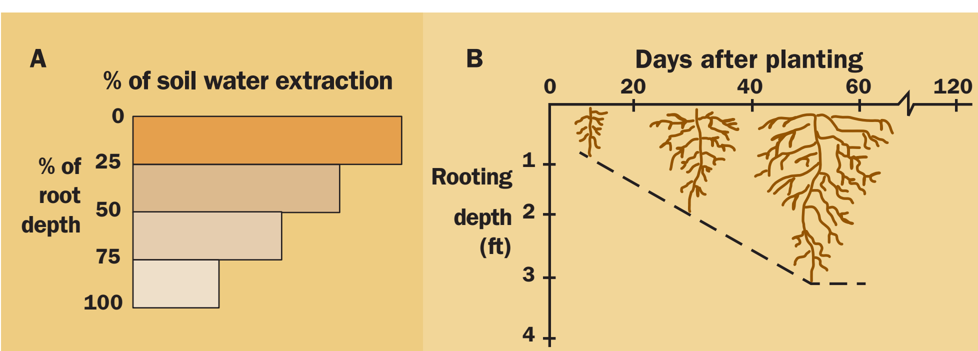
Stage of Development	Percent Yield Reduction
Early vegetative	5-10
Tassel emergence	10-25
Silk emergence, Pollen shedding	40-50
Blister	30-40
Dough	20-30

Source: Classen and Shaw (1970)

Research by Stegman and Faltoun (1978) defined three major growth stages for corn (emergence to 12-leaf, 12-leaf to blister kernel, and blister kernel to maturity) and evaluated effects of drought stress during each stage on grain yield. Results of this research indicated that moisture stress during any part of the cropping season limited grain corn production compared to stress-free growth. However, they concluded that the period from emergence to 12-leaf was least sensitive to moisture stress, while the most sensitive stage appeared to be between the 12-leaf and blister kernel stages; this period includes flowering, pollination, and initial seed filling. Stress during the blister kernel to maturity stage was detrimental to grain yield, but less detrimental than stress during the previous stage. Low, moderate, and severe drought stress all limited production, but severe stress resulted in the greatest reduction in grain yield.

The goal of irrigation is to provide adequate moisture to meet crop demand and minimize yield-reducing stress. To accomplish this, one must understand the relationship between water extraction from the root zone and plant root development (Figure 2).

Figure 2. A) Root zone soil water extraction; and B) Plant root development for corn. From Benham (1998).



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In general, corn extracts the majority of its water from the top 1/2 of the root zone. A good approximation of water extraction is the "40-30-20-10" or "4-3-2-1" rule: 40 percent of the water comes from the top fourth of the root zone, 30 percent from the second 1/4 and so on (Benham, 1998). Fifty to sixty days after planting, corn roots reach their maximum depth, but the majority of water still comes from the top half of the root zone (Figure 2). Therefore, applying excess water can actually leach nutrients below the active root zone and inhibit soil aeration (Benham, 1998). Field research from the Nebraska West Central Research and Extension Center near North Platte has shown that corn can use water from deep in the soil profile when necessary; thus, early season irrigations that store water deep in the profile can be beneficial late in the season.

The Department of Bioresource Engineering at Oregon State University assembled a sweet corn irrigation guide which includes an irrigation scheduling worksheet. It can be found at http://biosys.bre.orst.edu/bre/docs/sweetcor.pdf.

Silage Corn

Water requirements for silage corn and grain corn differ only near the end of the irrigation season, since farmers typically harvest silage corn earlier than

Corn Field in Colorado. Photo courtesy of Scott Bauer and ARS.

grain corn. Depending on soil type and management, silage corn generally requires one less flood irrigation or two fewer pivot circles than grain corn, making it shorter season crop. If examination determines that drought stressed corn originally intended for grain harvest will not produce a profitable crop, such corn can often be salvaged for silage (Hesterman and Carter, 1993). Because the fermentation process eliminates most nitrates, this approach produces valuable feed with low risk of toxicity. Before harvesting drought stressed corn for silage, check that all applied chemicals are cleared for use on silage corn.

While drought stress reduces corn biomass production, stressed corn generally produces silage with feed values 90-100 percent of unstressed corn. Crude protein and crude fiber increase somewhat with moisture stress, and total digestible nutrients generally decline. If corn has pollinated, delaying harvest as long as some green leaf and stalk tissue remain and the black layer stage has not been reached can increase grain dry matter and overall silage quality.

As with unstressed silage corn, timing of harvest of stressed corn depends on plant moisture content. Table 6 contains recommendations for corn silage moisture content for various silos from The Ontario Ministry of Agriculture and Food.

Table 6. Recommended corn silage moisture content.

Horizontal bunker silos	65 - 70 %
Bag Silos	60 -70 %
Upright concrete stave silos	62 - 67 %
Upright oxygen limiting silos	50 - 60 %

Bagg (2004)

Sunflower

While uncommon in the past, irrigated commercial sunflower production has been steadily increasing in the western U.S. Sunflower readily adapts to limited water supplies because it roots deeply and extracts water at depths not attained by other crops.

Research by Stegman and LeMert (1980) of North Dakota State University demonstrated yield potential of sunflower grown under optimum moisture conditions and effects of water stress at different stages of growth. As with other determinate crops, moisture stress most adversely affected yield during reproduction and seed development and had least impact during vegetative stages. A 20 percent reduction in applied irrigation water during the early vegetative period reduced yield by only 5%, while the same reduction in irrigation during the flowering stage resulted in a 50% yield reduction.

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Sunflowers at the Montana State University Agronomy farm in Bozeman, Montana. Photo courtesy of MSU Extension Water Quality Program.

Irrigation managers faced with limited water supplies for their sunflower crops should consider limiting irrigations during early vegetative stages and late in the season, conserving water for critical reproductive stages.

Beans

Although not considered drought resistant, dry beans use less total water than many other crops because they have a relatively short growing season. While their cumulative water use may be low, daily bean ET can reach 0.30”, similar to corn, wheat, or alfalfa (Brick, 2003). With root depths of 24-30” and approximately 85 percent of moisture and nutrients drawn from the top 18” of the root zone, beans are considered shallow-rooted crops and require more frequent irrigation than crops which utilize more of the soil profile. For maximum yield, moisture levels in bean fields should not fall below 50 percent available soil moisture.

Like other determinate crops, the most drought sensitive period for dry beans occurs during reproductive stages, specifically during flowering and pod fill. Drought stress during these stages leads to poor pod filling, small beans, and low yield compared to stress during earlier vegetative stages. A Colorado

State University study by Bandaranayake (1990) subjected plots to high or low moisture stress conditions during vegetative and/or reproductive growth stages. Plots subjected to high moisture stress were maintained at 30% available soil moisture, while those subjected to low stress were maintained at 70% available soil moisture. Yield from plots maintained at 70% available soil moisture during early vegetative stages and 30% available soil moisture during reproductive stages was 2,443 lbs./ac., compared to 3,335 lbs./ac. from plots maintained at 70% available soil moisture throughout the growing season. This represented a 27% yield reduction attributable to moisture stress during reproductive stages.

The most obvious strategy for irrigating beans under drought conditions is to reduce or eliminate irrigation during vegetative stages, conserving water for the more critical reproductive stages. Keep in mind that beans may be more susceptible to pathogens under drought stress than under ideal moisture conditions. Additionally, remember that beans are highly sensitive to salinity. Therefore, they should not be grown on soils with salinity problems, particularly if irrigation volumes may not be adequate to maintain a net downward movement of salts.

Sugarbeet

Sugarbeet, a long-season indeterminate crop, is most susceptible to moisture stress during early growth stages (germination and seedling development). However, once the 5-6' tap root system becomes established (about 2½ months post-planting), it can withstand extended periods without irrigation or rainfall by using plant-available stored soil moisture (Winter, 1980). Afternoon leaf wilting during hot, dry, windy conditions has negligible effect on total sugar production, so irrigation managers should avoid irrigating simply because their beet crop shows signs of mid-afternoon wilting. When available water is still present in the soil, sugarbeet will recover the same day, after high evaporative conditions cease.

Table 7 outlines several measures which can maximize sugarbeet water use efficiency and sugar content. In Montana, normal irrigations can be reduced

Sugarbeet in Salinas, California. Photo courtesy of Scott Bauer and ARS.

after mid-July, followed by one last major irrigation in early August to fill the soil profile in preparation for onset of the major moisture stress period. Because late-season moisture stress increases sucrose yield, this method is an effective way to limit irrigation and maximize return. If irrigation continues past early August, water should be cut off 3-4 weeks prior to harvest in order to maximize sucrose content (Ehlig and LeMert, 1979).Over-irrigation, especially near harvest, can reduce sugar concentration in the root (Alberta Sugarbeet Growers, 2005).

Table 7. Tips for irrigation water management on sugarbeet[1].

• If water is available, fill the soil profile before planting to minimize irrigations and potential crusting due to irrigation just after planting.
• On soils that crust, sprinkler irrigate only when necessary for germination and emergence. Apply light, frequent irrigations.
• After germination, keep soil moisture in the expanding beet root zone adequate, but not excessive, for disease control. Root zone depth begins at about 6" and expands to 3-3.5' by mid-season.
• After emergence and for the remainder of the season, soil should dry to 50% available soil moisture before irrigation. Tensiometer or gypsum block-type moisture sensor readings at 12-18 inches should rise to 30-40 centi-bars on sandy soils or 50-70 centi-bars on silt or loamy soils before application of irrigation water.
• After emergence and up to nearly the peak use period, center pivots should keep soil moisture at 50% MAD. As the peak use period approaches, the pivot should be managed to keep the entire root zone nearly full in anticipation of soil moisture mining by the crop during the peak use period when system capacity cannot meet peak crop water use.

[1]Presented at Sugarbeet Schools on January 27-31, 1997 (Neibling and Gallian, 1997).

Recent research by Sakellariou-Makrantonaki et al. (2002) evaluated surface and subsurface drip irrigation (SDI) effects on sugarbeet performance under two levels of water application depth. Irrigation method had a significant effect on crop performance while water application depth had a lesser effect. Results indicated that subsurface drip irrigation (SDI) lead to greater yield and higher sugar content than surface drip irrigation, indicating significant water savings compared to surface drip irrigation.

Potato plant. Photo courtesy of Scott Bauer and ARS.

Potato

Because of its high consumptive water use, suitability to well-drained, sandy soils, and relatively shallow rooting depth, potato is far more sensitive to moisture stress than many Northern Plains and Mountains crops. Therefore, potato is not a good crop choice for producers under permanent limited irrigation. However, a uniform, high quality potato crop requires a uniform, high level of available water between emergence and defoliation. Because crop water use directly affects potato production, any depletion past 60-80 percent MAD leads to decreases in quality and/or yield. Results of a 10-year potato water management research program at the Canada-Saskatchewan Irrigation Diversification Center showed that irrigation to 40 percent MAD significantly improved "seed" grade tuber yield, and irrigation to 65 percent MAD significantly improved yield of "consumption" grade tubers compared to yield on dryland sites.

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Alfalfa field in the Shasta Valley near Yreka, California. Photo courtesy of Doug Wilson and ARS.

Alfalfa

Like most perennial forages, alfalfa has a deep root system and ability to enter dormancy when faced with severe moisture stress. These characteristics make alfalfa much less susceptible to yield loss and plant damage from moisture stress than other crops. While alfalfa has no single critical period during which moisture stress dramatically reduces yield, careful irrigation management can maximize yield.

In general, the greatest percentage of season-long production, 35-45%, comes from the first harvest. Thus, when faced with limited irrigation water supplies, concentrate alfalfa irrigation efforts early in the season. Irrigate adequately for the first cutting only, and get a second cutting if precipitation occurs or irrigation water becomes available. When water is available for irrigation after the first harvest, adequate moisture to the plant the first 14 days after harvest is critical to subsequent alfalfa yield. Keep in mind that alfalfa and most other perennial forages produce biomass in response to water transpired. In the case of alfalfa, each inch of water use equates to 0.20 to 0.25 tons of biomass production per acre per year.

Grass Hay

While grass hay can be a great limited irrigation crop, irrigators must maintain good management practices in order to both produce a quality crop and ensure long term health of the crop.


Hay bales in Montana. Photo courtesy of MSU Extension Water Quality Program.

Washington State University Cooperative Extension and the U.S. Department of Agriculture have compiled a bulletin outlining the following six management strategies for maintaining healthy, productive perennial pastures and hayfields, reducing loss of livestock due to nitrate toxicity, and ensuring field recovery after drought (Fransen et al., 2001).

- ❒ Protect plant crowns, or "stubble," which consist of the bottom 3-4 inches of plant growth. Crowns act as a safety net for grasses and legumes by storing sugars necessary for plant growth and respiration. Because they contain these sweet-tasting sugars, livestock will graze crowns down to the soil surface. Unfortunately, without an adequate crown, many forage plants die under stress. Therefore, avoid grazing or harvesting pastures below 3-inch stubble height. If needed, designate one area as a sacrifice site for feeding animals hay or other feedstuffs. This will restrict crown damage to one location.
- ❒ Rotational grazing allows pastures a longer recovery and rejuvenation period than continuous grazing. Longer recovery periods, combined with use of a sacrifice site, help to maintain the 3-inch stubble height recommended for crown protection.
- ❒ In order to more accurately manage and prioritize water allocations, identify dominant grasses and legumes in each field. Different species have different root systems, water requirements, and other characteristics which make them more or less tolerant of drought conditions.
- ❒ Weeds are water wasters, so early identification and control of weeds saves valuable water and increases quality and quantity of forage.

- ❒ Maintain healthy levels of phosphorous, potassium, sulfur, and nitrogen by testing soil annually and fertilizing accordingly. In particular, phosphorus stimulates root rebuilding, so early season phosphorous application can strengthen roots in preparation for dealing with drought stress.
- ❒ Elevated nitrate levels in forage can lead to poisoning and death in livestock. By cutting nitrogen application by 50 percent or more, total forage yields may decrease, but what is produced will likely have safe concentrations of nitrates. Test all grazed and cut hay forage for nitrate concentration before feeding, particularly if drought stress has occurred.

While limited irrigation application can produce palatable hay, premium quality hay requires full irrigation. If hay quality must be extremely high, one possible strategy is to use the best irrigated fields to grow high quality hay while using other fields for limited irrigation of hay crops.

Annual forages

Annual forages planted for the purpose of early season haying can be an effective way to take advantage of cool spring temperatures, early season precipitation, and available irrigation water. Because most annual forage, including millet, hay barley, and oats, have relatively short growing seasons,


Forage specialist Glenn Shewmaker examines tall fescue in a test plot at the ARS Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho. Photo courtesy of Ken Hammond and ARS.

they can be grown and harvested prior to mid- to late-summer peak water use. While moderate moisture stress during vegetative stages can reduce yield, it often leads to enhanced forage quality. Thus, most annual forages do not require perfect moisture conditions in order to produce a quality crop. Other annuals that have proven effective as dependable, high quality forage crops include triticale, sorghum, and millet. Producers electing to consider these alternatives need to recognize the warm temperature and relatively high heat unit requirements of some of these crops and ensure appropriate growing conditions.

Summary

Limited water supplies for irrigation represent a significant challenge to many irrigated crop producers in the Northern Plains and Mountains Region. However, wise selection of crops and careful irrigation water management can help minimize yield and quality losses associated with moisture stress. When anticipating a low-water year, choose crops which maximize production with limited water. In general, this means selecting early-maturing, short-season crops. Perennial and annual forages represent the most efficient water use crops in terms of yield production. In decreasing order of efficiency, short season determinate, short season indeterminate, and long season indeterminate crops should be chosen judiciously. Additional management options that can maximize yield include advancing or delaying planting dates in order to coincide the crop's critical period with water availability and decreasing plant competition by reducing seeding density and controlling weeds. Table 8 summarizes critical moisture stress periods and symptoms of water stress for common crops of the Northern Plains and Inter-Mountain Regions.

Farmstead in Montana. Photo courtesy of MSU Extension Water Quality Program.

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Table 8. Critical growth stages of irrigated crops of the Northern Plains and Inter-Mountain Regions[1].

CROP	CRITICAL PERIOD	SYMPTOMS OF WATER STRESS	OTHER CONSIDERATIONS
SMALL GRAINS	Boot and bloom stages	Dull green color, firing of lower leaves. Plants wilt and leaves curl.	Apply last irrigation at milk stage
BARLEY	Jointing, booting and heading. Early drought stress may cause more tillering than usual	Erect leaves rolled toward the midrib. Stress after heading causes plants to wilt, darken in color and ripen prematurely	Under severe stress, leaves become hard, dry, and ashen to bronze in color, and florets may abort
WHEAT	During and after heading	Leaves wilt, yellow, then burn. Tillers abort prior to flowering. Empty, bleached white heads or partial heads	Reduction of tiller roots, tillers, spikelets, florets, plant growth, and yield
CORN	Tasseling, silk stage until grain is fully formed	Curling of leaves by mid-morning, darkening color	Needs adequate water from germination to dent stage for maximum production
SUNFLOWER	Heading, flowering, and pollination	Weakened stalks may lodge	Plants are predisposed to charcoal rot and stem weevil larvae
BEANS (DRY)	Bloom and fruit set	Wilting	Reduced yields
SUGARBEET	Post-thinning	Leaves wilting during heat of the day	Excessive irrigation lowers sugar content
POTATO	Tuber formation to harvest	Wilting during heat of the day	Water stress during critical period may cause cracking of tubers
ALFALFA	Early spring and immediately after cutting	Darkening color, then wilting	Adequate water is needed between cuttings
GRASS HAY	Early spring through 1st harvest and start of regrowth	Dull grayish green color	Avoid overgrazing pasture in early spring and fall
ANNUAL FORAGES	Any extended period of limited water	Reduction in forage production or quality	Prolonged drought may pose a nitrate toxicity risk
COOL SEASON GRASS	Early spring, early fall	Dull green color, then wilting	Critical period for seed production is boot to head formation

[1]Ley, 1988 and U.S. Department of Agriculture, 1988.

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