Guide to Choosing Crops Well-Suited to Limited Irrigation

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Introduction

Irrigation water may be insufficient 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. While reducing irrigated acreage and/or purchasing additional equipment are ways to manage limited water supplies, such actions may not maintain or improve economic return.

Drought throughout much of the Northern Plains and Mountains, the Southern High Plains, and the Southeastern Coastal Plains has caused water supplies to become increasingly inadequate to fully satisfy crop needs during the entire irrigation season. In addition, competition for water for needs other than irrigation has placed a growing demand on irrigators to be more accountable and efficient and less consumptive in their water use. Irrigation with limited water supplies involves commitment of substantial management, lack of which can make the difference between a successful crop and a failed crop and the difference between profit and loss.

Annual summer crops, such as wheat, corn, beans and sunflower, have fixed growth periods. Typically, these crops are relatively insensitive to stress due to moisture shortages during early vegetative growth stages and highly sensitive during reproductive growth stages. Perennial and biennial crops, like potato, sugar beet, alfalfa, and various grasses, have longer growing season and cumulative yield production. As a result, these crops can endure 4-5 day periods of stress due to limited moisture throughout the growing season. They can also capitalize on early season moisture and generally withstand longer duration stress better than annual crops.

Author’s note: The term ‘moisture stress’ is frequently used to describe the condition when the water in a plant's cells is reduced to less than optimal levels. This can occur because of a lack of water in the plant's root zone or higher rates of transpiration than the rate of moisture uptake by the roots. This latter circumstance can occur because of an inability to absorb water due to a high salt content in the soil water or loss of roots due to transplantation. In the context used here, moisture stress is comparable to ‘drought stress’, a condition when maximum plant performance is limited due to lack of water.

Irrigators facing limited water supplies may benefit by including crops requiring less water over those requiring more water, including crops that are less sensitive to moisture stress, choosing short season, dwarf or semi-dwarf crop varieties, and splitting fields between low and high-water-requirement crops or between early and late season crops. The primary emphasis of this article is to describe commonly irrigated crops, their water use characteristics and effective management strategies with limited water supplies.

Crop Considerations

When seeking to conserve or make the most of irrigation water, managers must be aware of crop water use characteristics and select crops that best utilize water at the time and amount 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 moisture stress is especially damaging. 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.

Winter and spring annual, biennial and perennial crops

Depending on growth duration and characteristics, crops can be grouped into annuals, biennials, and perennials (Table 1).

Table 1. Critical moisture stress periods of annual, biennial, and perennial crops.

Type of Crop	Examples	Critical Period
Annual grain and seed crops	Cereal grain, and oil seed crops (wheat, barley, oats, corn, sunflower)	Seed formation - heading, flowering, and pollination
Annual forages	Triticale, peas, forage millet, forage sorghum, sudan grass	Generally no specific period – maximum biomass results from rapid vegetative growth
Biennials	Tuber and root crops (potato, carrot, sugar beet)	Early growth stages; quality affected by late-season moisture stress
Perennials	Native and introduced grasses, alfalfa, perennial crops grown for forage	No specific period, but show highest production with early season irrigation for cool season forages

Winter and summer annuals have life cycles that last only from seed to seed. Annual crops, including cereal grain, and oil crops, are typically grown for the harvest of their mature seeds. These crops have various levels of indeterminancy, although they generally have a relatively fixed growth period. Annual grain and seed crops tend to be relatively tolerant of moisture stress during early vegetative stages and highly sensitive during seed formation, which includes heading, flowering, and pollination. Relieving water stress, once it has occurred during these critical periods, generally does not lead to yield recovery.

Biennial and perennial crops have life cycles that last two or more years. Biennial crops take two years to complete a life-cycle, although the commodity harvested is usually the storage organ produced in the first year. In the first year the plant grows roots, stems, and leaves (vegetative structures), after which the plant enters a period of dormancy. The following spring or summer, the stem of the biennial plant elongates and flowers, producing fruits and seeds, before it finally dies. Examples include potato, sugar beet, and carrot. Because of their season-long, cumulative yield production, biennial (and perennial) crops often can endure 4-5 day periods of mild moisture stress throughout the growing season with little reduction in quality or yield. Crop quality often declines as a result of stress. Because of their longer growing season, biennial and perennial crops generally require more water than annual crops.

Perennial crops, including alfalfa and various grass mixes grown for biomass, generally have deep, well-established root systems and the ability to maximize production by taking advantage of early season irrigation and precipitation. Thus, they generally withstand moisture stress better than annual and biennial crops. Typically, biomass production of perennial forage crops is a function of transpiration, which is the amount of water used by the plant. Thus, when water is in short supply, transpiration and biomass production are limited by available water.

Crop Management Options

When faced with limited amounts of water, but available water throughout the growing season, 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 harvestable crop.

Potential water use varies with environmental conditions and with different crop types. However, the relative water use among a selection of crops is generally the same in different locations. Average seasonal water requirements for crops addressed here are shown in Table 2 for several general localities. Averages are for the entire state or Canadian province and will differ, depending on climate and geographic location.

Table 2. Estimated average seasonal consumptive water use of select crops in Montana, Colorado, Alberta, Utah, North and South Dakota.

Crop	Average seasonal consumptive water use (inches)					
	Montana	**Colorado**	**Alberta**	**Utah**	**North Dakota***	**South Dakota**
Barley	17	16	15-17	22	13-15	14-16
Wheat	17	18	19	18	16	16-20
Corn	18.5	24-28			18-20	18-24
Silage Corn	19	20-33		22	18-20	18-24
Sunflower		23			18	17-23
Bean	13.5	19	15	20	16	15-23
Sugar beet	23	32	22	33	22-24	
Alfalfa	17-26	30-38	27	33	25-28	22-30
Grass Hay	28	26-28				
Annual forage		27		26		17-23

Compiled from multiple data sources for each state. Alberta Sugar beet Growers, 2005; Bauder et al., 1983; Broner and Schneekloth, 2003; Dixon, 2001; Hill et al., 2001; Kresge and Westesen, 1980; Werner, 1993.
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The time it takes for a crop to reach maturity and harvest stage is also an important consideration when water is limited. Short season crops use less water because they are harvested earlier. Additionally, dwarf and semi-dwarf crop varieties tend to use less water than their taller counterparts, while producing comparable yields. The following is a brief overview of specific characteristics of commonly irrigated crops, and how limited irrigation water supplies can be most effectively managed to maximize production of these crops.

The generalized effect of water shortages on crop yield is presented in Table 3 (FAO, 1979) for the total growing period and for specific growth periods for selected crops. Under conditions of limited water which is distributed equally over the total growing season (i.e., not enough water at any specific time to satisfy the crop water needs but some water throughout the entire growing season) the crop with the higher ‘yield response factor’ for the total growing period will suffer a greater yield loss than the crop with a lower ‘yield response factor’. In general, for the total growing period, the decrease in yield is less with the increase in water shortage for crops such as alfalfa, safflower, sunflower, and sugar beet, while it is proportionally greater for crops such as corn, wheat, sorghum, and barley. For example, under conditions of limited water supply and with water deficit equally spread over the total growing season, the yield decrease for corn (total growing period yield response factor = 1.25) will be greater than for sorghum (yield response factor = 0.9). Consequently, when these two crops are within the options available to an individual irrigator, and limited water is an assurance during the growing season, sorghum would suffer less yield loss than corn.

Similarly, such a quantification is possible when the likely yield losses arise from differences in the yield response factor of individual growth periods, i.e., crop yield will be adversely affected the most when moisture is withheld during the growth period having the highest yield response factor value for a given crop.

As previously noted and reported by numerous researchers, anticipated decrease in yield due to water deficit during a specified growth period is relatively small for the vegetative and maturing period and relatively large for the flowering and yield (seed) formation periods. In terms of water management, this would mean that water allocations of a controlled but limited supply should be directed toward meeting the full water requirements of the crop during the most sensitive growth periods for water deficit rather than spreading the available limited supply to the crop equally over the total growing period. For example, for corn, the available water would be directed particularly to the flowering and yield formation periods. It follows that where crops are grown under supplemental irrigation, the water application must be scheduled so that sufficient water is available in the soil during flowering and yield formation. Perennial and annual forages represent the most efficient water use crops in terms of yield production.

Table 3. Yield Response Factor (FAO, 1979. Agriculture 21. Land and Water division. Yield Response to Water, Part A of Irrigation and Drainage paper No. 33. Section 5, Table 24.)

Crop	Vegetative Period			Flowering Period	Yield Formation Period	Ripening Period	Total Growing Period
	Early Vegetative	Late Vegetative	Total				
Alfalfa*			0.7-1.1				0.7-1.1
Bean*			0.2	1.1	0.75	0.2	1.15
Corn*			0.4	1.5	0.5	0.2	1.25
Pea	0.2			0.9	0.7	0.2	1.15
Potato	0.45	0.8			0.7	0.2	1.1
Sorghum*			0.2	0.55	0.45	0.2	0.9
Soybean*			0.2	0.8	1.0		0.85
Sugar beet*							0.7-1.1
Sunflower	0.25	0.5		1.0	0.8		0.95
Spring wheat*			0.2	0.6	0.5		1.0
Winter wheat*			0.2	0.65	0.55		1.15

* No distinction between impact of stress during early and late vegetative stages. 'Yield response factor' is a relative index of the degree to which the yield or quality of a specific is adversely impacted by moisture stress during the specified growth stage. For example, in the case of cabbage, moisture stress during the early vegetative stage is only slightly affected, as reflected in a yield response factor of 0.2. A small 'yield response factor' reflects only limited adverse response to stress while a large 'yield response factor' reflects significant adverse response to stress.

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 4 summarizes in narrative terms critical moisture stress periods and symptoms of water stress for commonly irrigated crops of temperate climates.

Table 4. Critical growth stages of selected irrigated crops[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
Sugar beet	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 grasses	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.

Crop Charactertistics

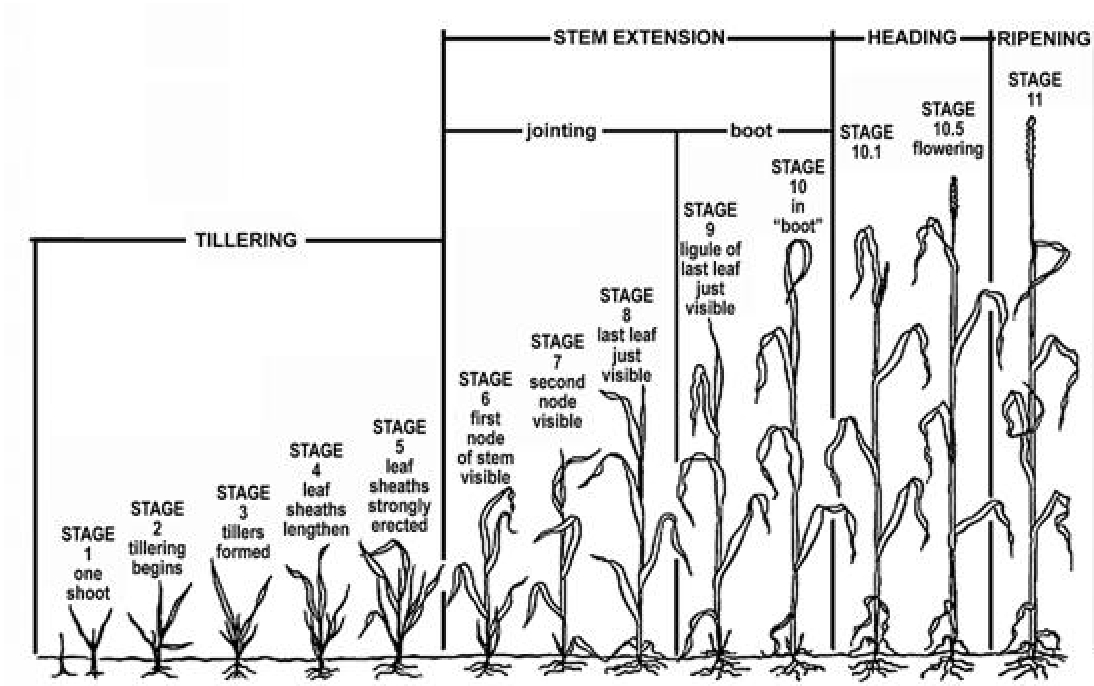
Barley does not tolerate prolonged drought. While moisture stress during early vegetative stages has limited impact on yield, such stress tends to cause excessive tillering, often resulting in tillers that never produce grain. Barley yield is most sensitive to stress during jointing, booting, and heading, leading to grain yield reductions of 14%, 8%, and 4%, respectively (Morgensen, 1980). Significant stress during grain fill substantially degrades malt barley quality. 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 caused a one-bushel per acre reduction in yield. Thus, to eliminate yield-reducing moisture stress, plan to irrigate before heading.

Timing the last irrigation for barley (and wheat) is always difficult. Late season moisture stress can reduce kernel weight, test weight, and yield, but excessive irrigation can cause lodging. As a rule of thumb, a barley crop needs three to four inches of water to carry it from soft dough to maturity (Ottman, 2001).

Spring wheat is a low-risk crop under limited irrigation in some areas. Spring wheat tolerates moisture stress during early vegetative stages much better than it tolerates stress during reproductive growth stages. Robins and Domingo (1962) showed little or no measurable benefit from irrigating spring grains before the boot stage except when irrigation was necessary to promote germination and early plant establishment. Moderate stress during the early vegetative stage had essentially no effect on yield, unless moisture stress was evident, as indicated by wilting and leaf curl. The greatest yield reductions occurred when stress began during or following heading or during the maturing process. Stress during maturation resulted in about a 10 percent yield reduction. Table 5 summarizes spring grain irrigation principles under low irrigation water conditions.

Table 5. Summary of spring grain irrigation principles.

1. Avoid irrigation during early vegetative stages, unless signs of stress appear.
2. Monitor soil moisture, irrigate as infrequently as possible, and apply as much water as possible to completely wet the profile, thereby promoting deep, extensive rooting.
3. Ensure adequate moisture during critical reproductive periods, including jointing, booting, heading, and flowering.
4. Schedule the final irrigation to carry the crop through harvest.



Source: Growth stages in small grains. Pest Management Guidelines, Cornell University Cooperative Extension, Figure 5.4.1; available at: http://ipmguidelines.org/FieldCrops/content/CH05/CH05-4.asp

Winter wheat is sensitive to moisture stress during early spring regrowth and the joint and boot stages. Early-season stress results in premature heading (approximately 7-10 days), a shortened growth period, and substantially reduced yield (Ehlig and LeMert, 1976). Early stress (during spring green-up) results in development of more heads than normal, but many of them fail to produce grain. However, the greatest yield reductions are likely to occur when stress happens during the jointing and boot stages and after heading. Ehlig and LeMert (1976) concluded that 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, like most other annual crops, has low daily water needs during the first 3-4 weeks of vegetative growth, making it relatively insensitive to moisture stress during these early stages. 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 moisture stress during each stage on grain yield. 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.

According to Classen and Shaw (1970), four days of stress (i.e. corn wilted for four consecutive days) can have a significant effect on yield, depending on when the stress occurs (Table 6). For instance, stress at the 12th-14th leaf stage may reduce yield by 5-10 percent, while four days of stress between silk emergence and pollination has the potential to reduce yields 40-50%.

Table 6. 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)

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.

Silage Corn water requirements differ from grain corn water requirements only near the end of the growing season. Consequently silage corn generally requires less water than grain corn, because it is a shorter season crop. Moisture stressed corn originally intended for grain harvest often can be salvaged for silage (Hesterman and Carter, 1993). Stressed corn generally produces silage with feed values 90-100% 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 can increase grain dry matter and overall silage quality. If the original intent for corn is for silage, moisture stress during the vegetative growth stage will reduce overall tonnage.

Sunflower production has been steadily increasing in the western U.S., in part because sunflower has the ability to root deeper, tolerate heat stress better, and adapt readily to limited water supplies. Stegman and LeMert (1980) demonstrated that moisture stress to sunflower during seed development adversely affected yield the most, while stress during vegetative stages had the least impact. A 20% reduction in applied irrigation water during the early vegetative period reduced yield only 5%, while the same reduction in irrigation during the flowering stage resulted in a 50% yield reduction. That being the case, irrigation managers faced with limited water supplies for sunflower crops should consider limiting irrigations during early vegetative stages and late in the season, conserving water for critical reproductive stages. Delaying irrigation until the reproductive growth stage requires that soil moisture at emergence be close to field capacity to a depth of 4 to 5 feet. Limiting or delaying irrigation without adequate stored soil moisture will result in lower seed yield. For oil seed varieties, delaying irrigation until after flowering begins results in higher oil content (Unger, 1982; Schneekloth, 2005). Although yields will likely be less than with full irrigation when irrigating only during the flowering growth stage, oil content increases offset some of the reduced yield. Irrigating only during the bud or early flowering growth stages resulted in less grain yield and reduced oil content, compared to either full irrigation or irrigation during late flowering.

Dry bean, although not considered drought resistant, uses less total water than many other crops because of its relatively short growing period. However, daily water use by beans can be as much as 0.30"/day, similar to corn, wheat, or alfalfa (Brick, 2003). With root depths of 24-30" and approximately 85% of moisture and nutrients drawn from the top 18" of the root zone, beans require more frequent irrigation than most deep-rooted crops. The most sensitive period for dry beans, with respect to moisture stress, occurs during reproductive stages, specifically during flowering and pod fill. Stress during these stages leads to poor pod filling, small beans, and low yield. Bandaranayake (1990) subjected beans grown in Colorado to high or low moisture stress conditions during vegetative and/or reproductive growth stages. Beans stressed during the reproductive stage yielded 2,443 lbs/ac, compared to 3,335 lbs/ac yield from non-stressed beans.

The most obvious strategy for irrigating beans under limited irrigation conditions is to reduce or eliminate irrigation during vegetative stages, conserving water for the reproductive stages.

Sugar beet, a biennial crop, is most susceptible to moisture stress during early growth stages in the first year (germination and seedling development). However, once the 5-6' tap root system becomes established (about 2 ½ months post-planting), sugar beets can withstand extended periods without irrigation or rainfall (Winter, 1980). Afternoon leaf wilting during hot, dry, windy conditions has negligible effect on total sugar production, as long as wilting is not a daily condition or wilting does not persist through the cool evening hours. When available water is still present in the soil, sugar beet will recover the same day, after high evaporative conditions cease.

Late-season moisture stress increases sucrose yield, making it an effective way to take advantage of limited irrigation, while over-irrigation near harvest can reduce sugar concentration (Alberta Sugar Beet Growers, 2005). Sakellariou-Makrantonaki and others (2002) evaluated drip irrigation effects on sugar beet performance under two levels of water application. Subsurface drip irrigation resulted in greater yield and higher sugar content than surface drip irrigation, suggesting significant water savings with subsurface drip irrigation, compared to surface drip irrigation.

Alfalfa, due to its perennial nature, is able to enter dormancy when faced with severe moisture stress. This characteristic makes alfalfa much less susceptible to yield loss and plant damage from moisture stress than many other crops. Additionally, other than seedling establishment, alfalfa has no single critical period during which moisture stress dramatically reduces yield. Because alfalfa is a cool season crop, the greatest percentage of season-long production, 35-45%, comes from the first harvest, which should take place when approximately 10 percent of the stand is in bloom. Thus, when faced with limited irrigation water supplies, focusing use of available water on first cutting production, early in the season, will likely result in the highest water use efficiency and best crop quality. When water is available for irrigation after harvest, adequate moisture to the plant the first 14 days after harvest is critical to subsequent alfalfa yield. 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 approximately 0.20 to 0.25 ton of biomass production per acre per year (Bauder et al., 1977).

Grass hay can be a profitable, limited-irrigation crop. Irrigators should identify dominant grasses and legumes in each field. Different species have different root systems, water requirements, and other characteristics that make them more or less tolerant of drought conditions (Fransen et al., 2001). For example, in a northwestern New Mexico study, orchard grass, meadow brome, and tall fescue produced more forage at higher irrigation levels than wheat grass (intermediate and crested) but the wheat grasses yielded better when water was limited (Smeal et al., 2005). In other studies conducted in Utah (Jensen et al., 2001; Waldron et al., 2002) meadow brome out-yielded orchard grass. Where specific information does not exist, one should consult with local Extension staff to learn what grass mixes have been successfully grown with available water by other producers in their area. 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 as an early season crop or emergency livestock feed, can be grown to take advantage of cool spring temperatures, accumulated winter and early spring precipitation and irrigation water limited to spring and early summer. Typically, crops grown as annual forages, such as barley, sudan grass, millet, pea, forage sorghum, triticale, and oat. Some biennial crops, such as turnips and rutabaga, are also used as a source of temporary pasture or grazed forage. Because most annual forages, including millet, hay barley, and oats, have relatively short growing seasons, they can be grown and harvested prior to the peak water use period, when water supplies are often limited. These crops, when harvested for emergency forage, do not require perfect moisture conditions in order to produce a quality crop. While moderate moisture stress during vegetative stages can reduce yield, such stress often leads to enhanced forage quality. Producers electing to consider these alternatives under limited irrigation need to recognize the warm temperature and relatively high heat unit requirements of some of these crops and manage accordingly.

Summary

Limited water supplies for irrigation can present a significant challenge to some crop producers. Selection of crops matching their water requirements to water availability and careful irrigation water management can help maximize yield and minimize quality losses associated with moisture stress. When anticipating or managing for limited irrigation circumstances, choose crops that maximize production and assure acceptable crop quality with limited water. In general, this means selecting early-maturing, short-season crops or deep-rooted biennial or perennial crops.

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