University of Idaho
College of Agricultural and Life Sciences
CIS 1122

Potato Production with Limited Water Supply

by B.A. King, J.C. Stark, and S.L Love

Introduction

Irrigation is required for profitable commercial potato production in Idaho. Potatoes have a relatively shallow root zone and a lower tolerance for water stress than most other crops grown in Idaho. The preference for producing this drought sensitive crop in coarse-textured soils with limited water holding capacity makes precise irrigation management a necessity to obtain optimum yield and quality. The practice of deficit irrigation, in which deliberate and planned water stress occurs during the growing season, is generally not considered a viable economic alternative in irrigated potato production. The minimal cost savings from reduced irrigation does not begin to cover the income loss due to lower tuber yield and quality. However, when restricted water availability reduces potato production potential, options for increasing water use efficiency need to be considered.

The objective of this publication is to provide research-based guidelines for irrigation, nutrient, and cultural management practices of potatoes grown with limited water supply. This information can be used to plan for anticipated water deficits and for determining how best to allocate and manage limited water supplies for potatoes under developing drought conditions.

Irrigation Management

The first step in optimizing the efficiency of any irrigation management program is to make sure the irrigation system is designed, maintained, and managed properly. Increasing irrigation efficiency to derive the most crop yield from every increment of water available will generally produce greater economic return than any other change in management.

Irrigation scheduling and irrigation uniformity are two key management factors affecting irrigation efficiency. Irrigation scheduling involves determining the correct timing and amount of water necessary to maintain root zone moisture within the optimal range for crop growth. Irrigation uniformity is related to how evenly water is distributed over the field area. Detailed information on potato irrigation scheduling is presented in University of Idaho (UI) Cooperation Extension System CIS 1039 *Irrigation Scheduling with Water Use Tables* and in Chapter 14 in *Potato Production Systems*. Detailed information on management practices for achieving and sustaining high irrigation uniformity is available in UI Cooperation Extension System BUL 824 *Irrigation Uniformity*.

An additional course of action is to evaluate possibilities for increasing the amount of available water per acre of potatoes produced. Potential courses of action include purchasing additional water from surrounding water users, reducing or eliminating potato acreage, and transferring water to the potato crop from other crops by reducing acreage of other crops or selecting crops that are more drought tolerant.

Research has shown that potato tuber yield and quality will be impacted by even short periods of water stress. The extent of the damage to tuber yield and quality will depend upon the severity, timing, and duration of water stress during the growing season. Several studies have shown that water stress during the tuberization and early bulking growth stages causes the greatest reductions in tuber yield and quality relative to other growth stages. Water stress spread over the whole growing season has less impact on tuber yield and quality than an equivalent reduction in crop water use over a shorter period of time. However, extending water stress over the whole season may not be an option. In order to determine the most profitable use of limited water supplies, it is critical to have an understanding of how water stress at each growth stage influences tuber yield and quality. Specific irrigation management guidelines for each growth stage are presented below.

Vegetative Growth Stage

The vegetative growth stage begins at seedpiece sprouting and extends to stolon formation. This growth stage typically has a 20- to 25-day duration, depending upon variety, cultural practices, and environmental conditions. Water stress during the vegetative growth stage tends to acclimate (harden) the plant to water stress, often reducing the effect of water stress in later growth stages and improving tuber quality. This may explain why extending water stress over the whole season is better than isolated periods of water stress in later growth stages.

Water stress during the vegetative growth stage reduces leaf area, vine and root expansion, and plant height, and delays canopy development. Water deficits during vegetative growth have also been shown to decrease the number of tubers set per plant, which then results in fewer and larger tubers at harvest.

A general irrigation management guideline for silt loam soils is to withhold irrigation until full emergence. This guideline is based on the assumption that winter precipitation has been sufficient to fill the top two feet of the soil profile to near field capacity. In drought years, however, irrigation may be needed before full emergence to limit water stress, particularly on coarse-textured soils. Under these conditions, it is usually best to irrigate before planting to minimize disease development. As a general guide, available soil water in the upper twelve inches of the root zone should not be allowed to drop below 55 percent during vegetative growth. Extreme caution must be used to ensure that water stress is reduced or eliminated at the time of tuber initiation and early bulking. This will not normally be a problem with irrigation systems other than center pivots or linear-moves. However, center pivots or linear-move systems with flow rates of less than 7 to 7.5 gpm per acre may never be able to catch up to water demand for the remainder of the season.

Tuberization

Tuberization begins when stolon tips begin to swell and tubers begin to develop but are not appreciably enlarging (less than 1/2-inch in diameter). This growth stage typically has a duration of 10 to 14 days. Although additional tubers may continue to form on stolons during later stages of plant development, tubers that contribute the most to marketable yield are formed at this time.

Water stress during tuber initiation can substantially reduce tuber yield and quality. In a 1987 field study at the UI Aberdeen Research and Extension Center, Russet Burbank potatoes were exposed to moderate (10-day) to severe (14-day) periods of water deficits during different stages of tuber development. These trials had lower overall yields as well as lower yields of U.S. No. 1 potatoes when stress occurred during tuber initiation rather than during tuber bulking (Table 1). Tubers that are stressed during tuberization often are severely misshapen, with pointed stem ends, multiple knobs, and other malformations.

Table 1. Effect of deficit irrigation during tuberization and early tuber bulking on Russet Burbank yield and quality, Aberdeen Research and Extension Center, 1987.

Period Without Irrigation	Total Yield	U.S. No. 1 Yield
days	*cwt/acre*	*cwt/acre*
None	342	230
Tuberization (10 days)	313	185
Tuber bulking (10 days)	317	182
Tuberization (14 days)	262	112
Tuber bulking (14 days)	293	175

Adapted from: Stark, J.C and R.B. Dwelle. 1989. Antitranspirant effects on yield, quality, and water use efficiency of Russet Burbank potatoes. Am. Potato J. 66:563-574.

Tuber Bulking

The tuber bulking growth stage extends from the stage when tubers are about one-half inch in diameter to canopy senescence. This growth stage has a duration of 60 to 120 days, depending upon variety, nutrient availability, environmental conditions, and pathogen severity. Under ideal conditions, this growth stage is characterized by a constant rate of increase in tuber size and weight. Interruptions in tuber growth by water stress often result in misshapen tubers with knobs, growth cracks, and irregular shapes characterized as “bottlenecks,” “dumbbells,” and other irregular curved shapes. The common explanation is that water and/or heat stress results in irregular tuber growth rate and changes in apical dominance,

Table 2. Effect of two levels of water stress during three periods of the tuber bulking growth stage on yield and grade of Russet Burbank tubers, Aberdeen Research and Extension Center, 1988-89.

Irrigation Level	Water Stress Timing	U.S. No. 1 4-10 oz	U.S. No. 1 >10 oz	Undersize <4 oz	U.S. No. 2 Total	Specific Gravity	Yield Total	Yield U.S. No. 1
%	E,M,L[1]	%	%	%	%		cwt/ac	cwt/ac
100	—	65	5	4	6	1.083	417	292
80	EML	57	7	31	5	1.081	381	245
80	EM	56	6	32	6	1.079	363	228
80	ML	58	9	26	7	1.082	360	240
80	EL	56	7	31	6	1.080	380	240
60	EML	52	6	36	6	1.079	338	197
60	EM	52	7	36	5	1.078	316	186
60	ML	56	6	33	5	1.081	298	194
60	EL	54	7	32	7	1.080	333	203

Adapted from: Stark, J.C. and I.R. McCann. 1992. Optimal allocation of limited water supplies for Russet Burbank potatoes. *Amer. Potato J.* 69:413-421.

[1]Three-week water stress intervals are designated as early (E), mid (M), and late (L) bulking.

creating the irregular shape. Thus, periods of water stress during tuber bulking often decrease U.S. No. 1 yield by increasing the percentage of U.S. No. 2 tubers. If sustained deficit irrigation occurs during the growth stage, total marketable yield will be reduced. This occurs because the overall tuber growth rate is reduced, resulting in smaller tubers, a greater proportion of which are not marketable due to their small size.

The tuber bulking period for Idaho is on the order of twelve weeks or less, depending upon the variety, location, and season. Research conducted at the Aberdeen Research and Extension Center in the late 1980s investigated the effect of water stress during tuber bulking on Russet Burbank tuber yield and quality. The results are given in Table 2. The nine weeks immediately following tuberization were divided into three three-week intervals and designated as early (E), mid (M), and late (L) bulking. Constant water stress was imposed during two or three of these periods by irrigating at the rate of 80 or 60 percent of normal crop water use (evapotranspiration). The greatest reductions in total yield generally occurred when deficit irrigation was imposed during early-mid (EM) and mid-late (ML) bulking, regardless of water stress intensity. Spreading deficit irrigation evenly over the three periods or during the early- and late-bulking periods resulted in less total yield reductions. The effects on U.S. No. 1 yields were similar to those for total yield. Water stress during the tuber bulking growth stage increased the percentage of undersized tubers with a corresponding decrease in the 4- to 10-oz size tubers. Water stress during the early- and mid-bulking periods resulted in the lowest specific gravities. The results of this study indicate that water stress during the early-bulking period increases the amount of reducing sugar in the stem end and negatively affects fry color.

Irrigators who must rely on surface water supplies can be subject to early delivery termination (cutoff) during extended periods of drought. In drought years, irrigation terminations during the month of August are highly probable. The effect of early irrigation termination on Russet Burbank tuber yield and grade was investigated at the Aberdeen Research and Extension Center in 1992 (Figure 1). Water application was terminated during the first or third week in August, either abruptly or gradually over a two-week period. The same amount of water was applied under both cutoff methods for a given termination date.

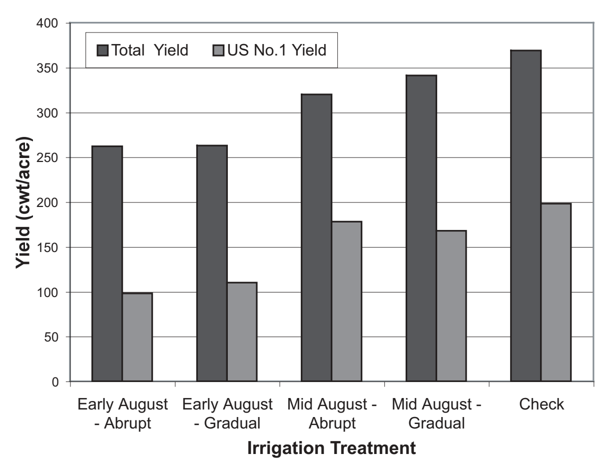

Figure 1. Effect of early irrigation cutoff on Russet Burbank total and U.S. No. 1 yield, Aberdeen Research and Extension Center, 1992.

The mid-August cutoff reduced total and U.S. No. 1 yields by about 13 percent. By comparison, cutting off water the first week in August reduced total yield by 30 percent and U.S. No. 1 yield by 50 percent. When compared to abrupt irrigation cutoff, there was little benefit from gradual irrigation cutoff. Late July and early August is a period of peak tuber growth. Severe water stress during this time will substantially reduce tuber yield and grade, regardless of whether it occurs abruptly or gradually.

Over the past 20 years, research at the Aberdeen Research and Extension Center has shown that total yield of Russet Burbank will generally decline 20 to 25 cwt per acre for every inch of crop water use reduction, due to water stress during the tuber bulking growth stage. The actual yield and quality loss that results from water stress during the tuber bulking growth stage will vary considerably from year to year. Losses will generally be higher under favorable growing conditions and lower in years when overall conditions are less favorable for potato growth, such as years with high temperatures, low humidity, and/or windy conditions.

Maturation

The maturation stage of growth begins with canopy senescence. Older leaves gradually become chlorotic and then necrotic. Later, necrosis spreads to younger leaves throughout the vine, eventually resulting in canopy loss. Tuber growth rates gradually decline with loss of canopy. Exceptionally dry soil conditions late in the growing season not only reduce yield but can also shorten dormancy, reduce specific gravity, and increase reducing sugar content. Dry soil conditions can also dehydrate tubers, making them more susceptible to blackspot bruise. Consequently, available soil water should not drop below 50 percent prior to vine kill. Complete vine kill or vine removal is also important, since remaining live vines will continue to extract soil moisture. Tubers should not be allowed to remain in dry soil for extended periods. Ideally, they should be harvested soon after they reach maturity.

Under dry soil conditions, the tuber moisture content or hydration level will steadily decrease, resulting in increased susceptibility to blackspot bruise. Tubers can be partially rehydrated by irrigating prior to harvest. For tubers maturing in moderately dry to dry soils (less than 50-60% available soil water), irrigation should be applied about seven to ten days prior to harvest to adequately rehydrate tubers. Irrigating two to three days prior to harvest can usually adequately rehydrate tubers in soils with moisture levels above 60 percent available soil water.

Growers and irrigation districts should always hold back adequate water to properly condition the soil and rehydrate the tubers before harvest. This is particularly important in medium and heavy textured soils where soil conditioning is necessary to soften clods and minimize tuber damage during harvest.

Fertility Management

If deficit irrigation management is going to be implemented, the nitrogen management plan needs to be adjusted accordingly. The degree of yield response to nitrogen fertilizer decreases markedly as crop water use is reduced by water stress. Specific gravity is also greatly affected by water and nitrogen management. Specific gravity generally decreases when water stress and high N application rates are combined. High nitrogen availability during late tuber bulking also often delays tuber maturity. However, these effects are dependent on duration and amount of both nitrogen and water availability, location, environment, variety, and other stresses on the crop.

Nitrogen application should be reduced if late season water stress is anticipated. Research at the Aberdeen Research and Extension Center has shown that for every 15 to 20 percent reduction in water application from the optimum amount during the growing season, nitrogen requirements for maximum yield decline by 40 lb N per acre (Table 3). Applying large amounts of preplant nitrogen should also be avoided since it will likely

Table 3. Russet Burbank yield response with five nitrogen application rates and four seasonal water application amounts at the Aberdeen Research and Extension Center, 1988.

	Seasonal Irrigation Applied (inches)			
N Rate	13.0	15.4	16.8	18.2[1]
lb/ac	Relative Yield (%)			
0	87.4	89.5	86.0	89.6
40	100.0	100.0	97.0	95.9
80	98.6	100.0	100.0	98.8
120	93.5	96.8	97.0	100.0
160	91.3	95.6	93.6	95.9

Adapted from Ojala, J.C., J.C. Stark, and G.E. Kleinkopf. 1990. Influence of irrigation and nitrogen management on potato yield and quality. Am. Potato J. 67:29-43.

[1]This irrigation level represents 100% of crop water requirements.

Table 4. Comparison of relative U.S. No. 1 yields of six potato varieties for five irrigation deficit scenarios averaged over a two-year period, Aberdeen Research and Extension Center, 2002-03.

Variety	Yield as % of 100 % ET Treatment				
	100% ET[1]	100% Cut Off[2]	75% ET[3]	75% Cut Off[4]	100-75-50%[5]
Alturas	100	71	71	37	77
GemStar Russet	100	76	80	58	82
Ranger Russet	100	72	78	53	82
Russet Burbank	100	80	76	68	96
Russet Norkotah	100	97	84	81	98
Summit Russet	100	79	83	54	83

[1]Application of irrigation water to provide 100% ET replacement for the full season
[2]Providing 100% ET replacement until Aug 10 with no application thereafter
[3]Providing 75% of ET replacement for the full season
[4]Providing 75% of ET replacement until Aug 10 with no application thereafter
[5]Providing 100% of ET replacement until July 20 with a reduction to 75% of ET until Aug 10 and then decreasing to 50% ET replacement until vine kill

NOTE: Data are presented as the percent yield in comparison with the control treatment (full ET replacement, season-long).

delay tuber bulking and increase the impact of late season water stress.

Cultural Management

Management strategies for dealing with water shortages are relatively limited and are often controlled by decisions made at the irrigation or water district level. However, producers can partially mitigate these effects by preparing for anticipated water shortages before the crop is planted. In addition to deficit irrigation management, producers should also consider changing other cultural practices under their control, including extent of potato acreage, field choice, variety selection, and seed condition and spacing.

Potato Acreage

Potatoes grown in southeastern and south-central Idaho require 18 to 23 inches of water for maximum yield. An additional two to three inches is required in southwestern Idaho due to the longer growing season. Peak daily crop water use is 0.31 to 0.34 inches. In locations where irrigation districts can and do elect to reduce delivery rates to extend the length of delivery, reducing potato acreage to match the available water supply is likely a better management option than deficit irrigation.

Field Choice

If possible, potatoes should be grown on fields that have the greatest potential for maintaining adequate soil moisture under deficit irrigation management. Coarse-textured soils such as sands and sandy loams have low water-holding capacities, which will lead to rapid development of water stress under deficit irrigation. In comparison, soils with relatively high water-holding capacities, such as loams and silt loams, allow water stress to develop at a slower rate, reducing its impact on yield and quality. In locations where irrigation districts elect to reduce the number of water delivery days per week to extend the water delivery period, fields with predominately loam and silt loam soils are the best choice for potato production.

Variety Selection and Management

Variety choice can be an important tool in dealing with irrigation water deficits. Potato varieties vary widely in maturity and in ability to withstand water stress. One or both of these traits can help avoid serious losses in short water situations. Planting an early maturing variety can help a grower avoid crop damage resulting from a late-season loss of water supply. Planting a drought resistant variety will minimize losses caused by any condition imposed by water shortage.

Varietal differences in drought resistance are illustrated by the results of a recent study in which six potato varieties were exposed to five different water deficit scenarios (Table 4). Treatments included:

100% ET - Application of irrigation water to provide 100% evapotranspiration (ET) replacement for the full season

100% Cut Off - Providing 100% ET replacement until Aug 10 with no application thereafter

75% ET - Providing 75% of ET replacement for the full season

75% Cut Off - Providing 75% of ET replacement until Aug 10 with no application thereafter

100-75-50 - Providing 100% of ET replacement until July 20 with a reduction to 75% of ET until Aug 10 and then decreasing to 50% ET replacement until vine kill

A three-variety subset from these trials can be used to illustrate drought avoidance or assistance mechanisms (Figure 2). First, providing full irrigation through mid-bulking, followed by a slow reduction in irrigation amounts, was the best scenario in a limited water situation for all three varieties. Second, a late-maturing, stress-susceptible variety such as Russet Burbank is subject to large losses of marketable tubers under either moderate season-long stress or sudden severe water stress caused by termination of irrigation. An early-maturing variety like Russet Norkotah can withstand late season loss of water with little or no loss of yield as long as there is sufficient water during tuber bulking. A drought tolerant variety like GemStar Russet can maintain high yields of marketable tubers, even under fairly severe stress.

Additional results from this same study show that even varieties within a similar maturity class are affected differently by water stress (Table 4). Alturas, for example, is a late maturing variety like Russet Burbank and Ranger Russet, but it is even more affected by late season loss of water supply. This is likely due to a high late-season water demand, and its tendency for late tuber bulking.

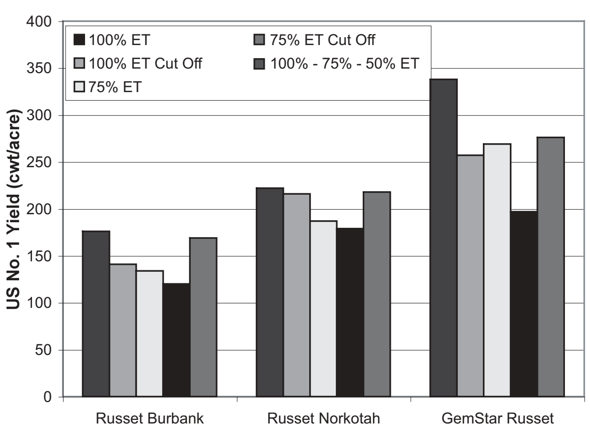

Figure 2. Impact of irrigation deficits on the US No. 1 tuber yields for Russet Burbank, Russet Norkotah, and GemStar Russet, Aberdeen Research and Extension Center, 2002-03.

Identifying varieties that can be used in different water deficit situations is not as simple as finding one that is simply drought tolerant. Before adopting a new variety, growers need to consider other factors as well, including market acceptance, local adaptation, resistance to common pest and stress problems, and yield. Below is a limited list of current varieties that may be used in deficit seasons.

Early Maturing Varieties

Russet Norkotah

Shepody (on early delivery contract)

Ranger Russet (on early delivery contract)

Many red varieties, including Red Norland, Red LaSoda, NorDonna, Mazama, Modoc

Drought Tolerant Varieties

Russet Norkotah

Ranger Russet

GemStar Russet

Gem Russet

CalWhite

Varieties that can be used in water deficit situations may require specific management considerations to produce a high-quality crop. Here are some useful irrigation management tips for the most common varieties grown in Idaho:

Ranger Russet: Although relatively resistant to drought stress from the standpoint of yield loss, Ranger Russet is prone to tuber quality problems if stressed during tuber set and early bulking. Stress during this critical early period results in sugar ends and long, narrow-shaped tubers. Consequently, even when water is in short supply, full water use requirements should be met during the period from tuber set through early tuber bulking. Ranger Russet also is susceptible to blackspot bruise and should not be handled when tubers are dehydrated or when soils are dry and hard. Adequate moisture should be made available to allow harvest under ideal soil moisture conditions.

Russet Norkotah: The most critical issues associated with Russet Norkotah are late-season over-irrigation. In a water deficit situation, this is not an issue. There are several line selections of Russet Norkotah including medium maturing strains (CO#8, TXNS112, TXNS223, TXNS278, and TXNS296) and a late maturing strain (CO#3). If a water shortage in the form of a late-season supply loss is expected, the standard Russet Norkotah should be planted. The medium maturing lines may produce adequately in this situation, but the late strain(s) should be avoided.

Shepody: Due to common scab susceptibility, Shepody requires high soil water levels at tuber set and early bulking to minimize infection, but otherwise can withstand drought conditions relatively well. It should not be left to mature in dry, hot soils due to a tendency for heat sprouts and a decline in tuber specific gravity.

Alturas: This variety is not a good choice when water deficit conditions are projected. Alturas is a heavy water user during most of the growing season and is especially susceptible to late-season deficits. If a water shortage occurs during production of an Alturas crop, it shows a better response to a slow decline in water supply rather than a sudden termination.

Gem Russet: Because it is a full-season variety, Gem Russet is not necessarily a good choice under late-season water supply deficits, but it does maintain good tuber quality during drought stress. Like Ranger Russet, Gem Russet is susceptible to blackspot bruise and needs good soil moisture conditions during harvest.

GemStar Russet: This variety has good drought tolerance characteristics and is a good choice during water shortage situations. It seems to respond better to season-long, moderate water stress rather than a sudden loss of supply, provided the sudden loss occurs more than one month before harvest. If water deficit timing can be managed, GemStar Russet will produce a nearly normal crop if late-season water shortages are imposed gradually rather than abruptly.

CalWhite: Tuber quality of CalWhite can decline as a result of its susceptibility to heat sprouting. If irrigation water supplies are lost late in the season, tubers should not be left to mature in dry, hot soils.

Seed Condition and Spacing

Physiological aging of potato seed often results in earlier plant emergence and tuber development. If water shortages are anticipated late in the season, deliberately trying to accelerate tuber development by planting seed that has been aged by warming during storage may be advantageous. This may reduce the magnitude of yield reduction from early irrigation cutoff by completing more of the tuber bulking growth stage before water stress develops.

Seedpiece spacing can also be modified to partially mitigate the effects of water stress on tuber yield and quality during tuber bulking. Field studies conducted at the Aberdeen Research and Extension Center in 1991 investigated the effect of seed spacing on tuber yield and quality under several levels of water stress during tuber bulking. Irrigation was reduced to 81, 50, and 24 percent of crop water use for successive irrigations after July 13. U.S. No. 1 yields were consistently the lowest for the 10-inch seed spacing (Figure 3). U.S. No. 1 yields for the 15- and 20-inch seed spacing were not significantly different for mild to moderate water stress. However, under severe water stress, the 20-inch seed spacing provided significantly higher U.S. No. 1 yield compared to either the 10- or 15-inch seed spacing.

Increased seed spacing reduces the number of tubers per unit area. Thus, the tubers that are set have a larger soil area from which to draw water and nutrients, resulting in increased average

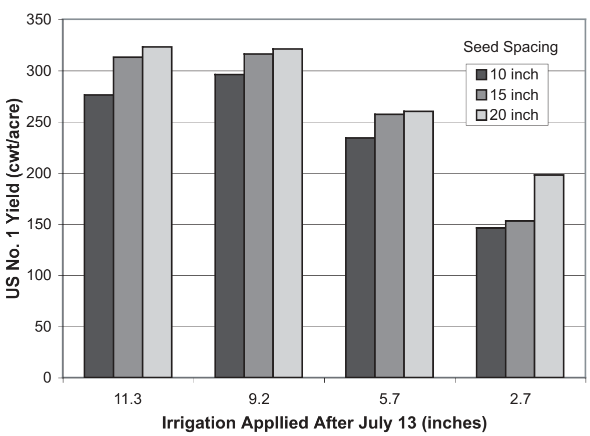

Figure 3. Seed spacing effects on Russet Burbank U.S. No. 1 yield under different levels of water stress during tuber bulking, Aberdeen Research and Extension Center, 1991.

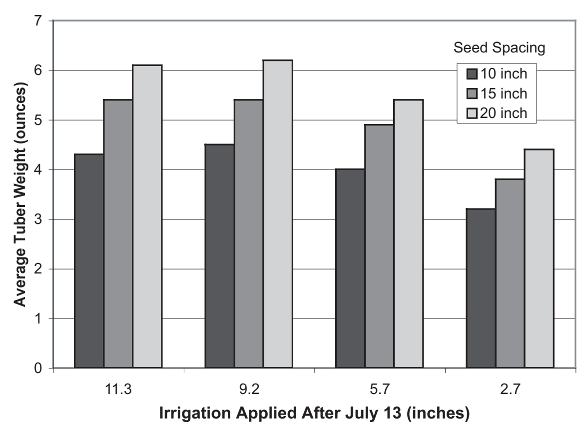

Figure 4. Seed spacing effects on Russet Burbank average tuber size under different levels of water stress during tuber bulking, Aberdeen Research and Extension Center, 1991.

tuber size, regardless of level of water stress (Figure 4). Overall, increasing seed spacing may be a profitable management option if water stress during tuber bulking is anticipated and water stress can be evenly spread over the remainder of the growing season.

Summary

Potato production under deficit irrigation is not economically justifiable under normal conditions. However, under regional drought conditions, it may sometimes be unavoidable. Timing of water stress is important in order to maximize yield and quality under restricted water availability. Spreading water stress evenly over the season will result in the least reduction in tuber yield and quality. Unfortunately, decisions made at the irrigation district level may limit the flexibility of deficit irrigation management. If possible, irrigation deficits should be avoided during tuber initiation and mid-bulking. Modification of irrigation, variety selection, fertility, and cultural management practices according to anticipated water availability can partially mitigate tuber yield and quality reductions.

Further Reading

CIS 1039 Irrigation Scheduling with Water Use Tables

BUL 824 Irrigation Uniformity

Potato Production Systems: The Definitive Guide to Potato Production

All of these publications are available from Ag Publications in print form and also on-line (see below).

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