BUL 789

Potato Irrigation MANAGEMENT

by
Bradley A. King
and
Jeffrey C. Stark

Introduction

Irrigation is required for profitable commercial potato production in Idaho. Maximum economic return requires, among other things, that soil water content be maintained within rather narrow limits throughout the growing season. Potatoes are often considered to be a high water use crop, when in fact many other crops grown in Idaho have equal or greater seasonal water use requirements. This misconception arises from the fact that potatoes are sensitive to water stress compared to most other crops, have a relatively shallow root-zone depth and are often grown on soils with low to medium water holding capacities. These conditions necessitate that reliable irrigation systems capable of light, frequent, uniform water applications be used to optimally control soil water availability throughout the growing season. These conditions also dictate that an effective potato irrigation management program include (i) regular quantitative monitoring of soil water, (ii) scheduling irrigations according to crop water use and soil water holding capacity, and (iii) a water supply and irrigation system that is capable of providing the needed irrigation on schedule.

The sensitivity of potato yield to irrigation management is depicted in figure 1. The results were obtained from a 1995 research study of water management practices on 45 commercial potato fields in southeast Idaho (Stark, 1996). Potato yield is reduced by both over- and under-irrigation. A mere 10 percent deviation from optimum water application for the growing season may begin to decrease yield. This sensitivity to water management is attributable to the sensitivity of potato plants to water stress, coupled with very little buffering of the soil-plant system to water management errors resulting from limited soil water storage. Yield reductions due to over-irrigation can be attributed to poor soil aeration, increased disease problems, and leaching of nitrogen from the shallow crop-root zone. Efficient irrigation management can increase marketable yield while reducing production costs by conserving water, energy, and nitrogen fertilizer, as well as reducing potential ground water contamination. Efficient irrigation management is a prerequisite for consistent maximum economic return from commercial potato production in Idaho.

Potato Development

Growth Stages The physiological development of the potato can be divided into five growth stages. These growth stages are shown in figure 2 in relation to typical curves representing leaf area index (LAI), root-zone depth, and

University of Idaho
Cooperative Extension System
College of Agriculture

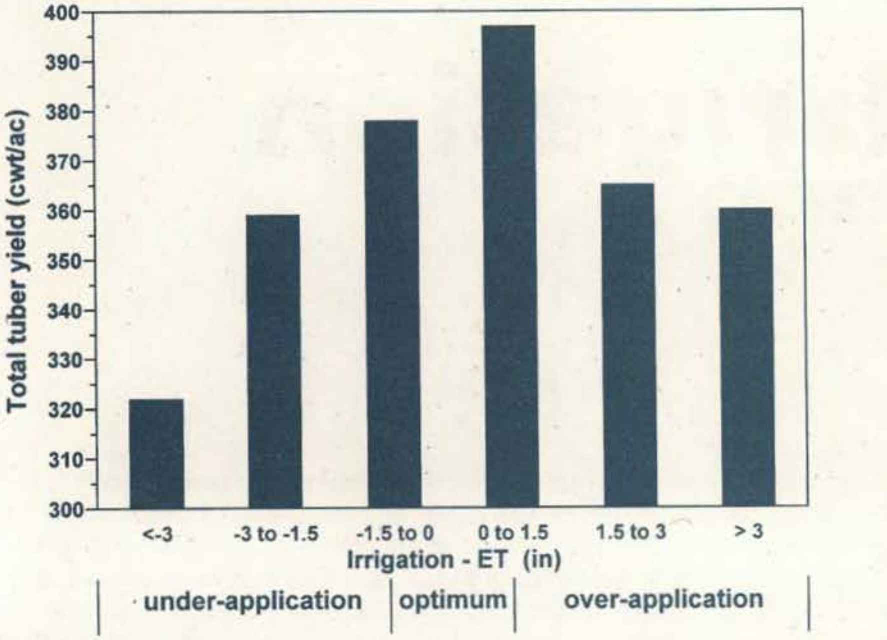

Figure 1. Total tuber yield as influenced by the difference between irrigation and evapotranspiration (ET) on 45 commercial potato fields in southeastern Idaho.

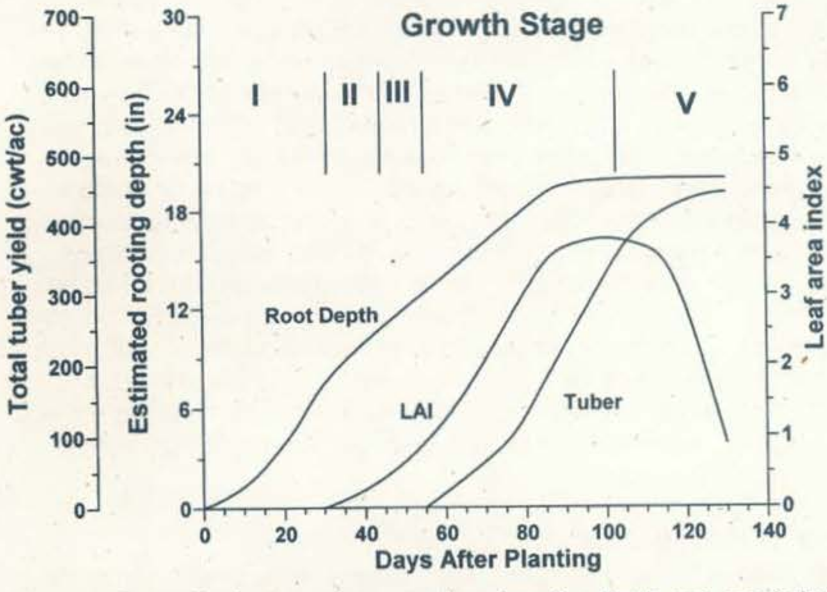

Figure 2. Generalized seasonal progression of rooting depth, leaf area index (LAI), and tuber yield of potato.

tuber yield. Leaf area index is the dimensionless ratio of leaf surface area to ground surface area. Growth stage I spans the period of planting to emergence and ranges from 20 to 35 days depending upon varietal differences, cultural practices, and environmental conditions. Growth stage II encompasses early vegetative development from emergence to tuber initiation and ranges from 15 to 25 days depending upon the site-specific conditions. Stolons begin to develop during growth stage II, but tubers are not yet present. Tubers form at the tips of the stolons over a 10-to-14-day period, which is called "tuberization" or tuber initiation and represents growth stage III. During this growth stage, the LAI is generally in the range of 1 and 2, which corresponds to 50-80 percent row closure depending upon site-specific conditions and variety.

Tuber enlargement or "bulking" occurs largely throughout growth stage IV. The increase in tuber size is approximately linear with time over a 30-to-60-day period under optimal environmental conditions. Near the end of growth stage IV, LAI reaches a maximum range of 3.5 to 6.0, depending upon variety and environmental conditions (Wright and Stark, 1990). Water use or "transpiration" by the potato plant also reaches a maximum at this time. Near the end of growth stage IV, the growth rate of the canopy begins to decline.

During growth stage V, plants begin to die and lose leaves. Tuber growth rates decline as the result of reduced leaf area and photosynthetic activity, and tuber skins begin to mature. The remaining tuber growth results primarily from translocation of plant materials from stem, leaf, and roots to the tubers.

Root System Potato plant root system development is relatively shallow, 18-24 inches, with the majority of roots in the surface 12 inches. The shallow rooting depth is attributed to the inability of its relatively weak root system to penetrate tillage pans or other restrictive layers. Soil compaction by field vehicle traffic can greatly restrict potato root penetration. Soil water content at the time of tillage operations has a major influence on the degree of compaction resulting from field traffic.

Many soils in Idaho have a weakly cemented calcium carbonate layer within 24 inches of the soil surface, which restricts potato root penetration but not water movement. Field determination of actual potato plant rooting depth is of primary importance to proper irrigation management.

Potato Growth and Soil Water Availability The sensitivity of potatoes to plant water stress is likely due to their rather shallow root system and complex physiological responses to moderate plant water deficits (Curwen, 1993). The first physiological response is closure of the leaf stomata: the small pores in the leaf that control gas exchange between internal leaf cells and the environment. Evaporation of water from within the leaves serves to cool the leaves, resulting in a plant canopy temperature below air temperature under well-watered conditions. The stomata in the leaf close under plant water deficits as a defense against further water loss. The physical indication is an increase in canopy temperature as a result of reduced evaporative cooling of the leaves.

While stomatal closure reduces water loss through the leaves, it also reduces carbon dioxide diffusion into the leaf. This slows photosynthesis, reducing the production of photosynthetic products (starch and sugars) by the plant and their translocation from the leaves to the tubers. Potato yield and quality depend upon maximizing the steady accumulation of photosynthetic products in the tubers. When production of these products exceeds that needed for respiration and continued plant growth, they are stored in the tubers.

One of the first physiological responses affected by plant water deficits is the expansion of leaves, stems, and tubers. Water deficits reduce plant growth by reducing the internal water pressure in plant cells (turgor pressure), which is necessary for expansion. Reduced vine and leaf growth limits total photosynthetic capacity, while the reduced root development limits the plant's ability to take up water and nutrients. Water deficits also disrupt normal tuber growth patterns by reducing or stopping tuber expansion. Tuber growth resumes following relief of plant water deficits, but the disruption of the normal tuber expansion rate may result in tuber malformations such as pointed ends, dumbbells, bottlenecks, and knobs. Widely fluctuating soil water contents create the greatest opportunity for developing these tuber defects. Growth cracks are also associated with wide fluctuations in soil water availability and corresponding changes in tuber turgidity and volume of internal tissues.

Potatoes are particularly sensitive to water stress during tuber initiation and early tuber development. Water deficits at this time can substantially reduce U.S. No. 1 yields by increasing the proportion of rough, misshapen tubers. Early-season water stress can also reduce specific gravity and increase the amount of translucent end.

Water stress during tuber bulking usually affects total tuber yield more than quality. A large photosynthetically-active leaf surface area is necessary to maintain high tuber bulking rates for extended periods. Maintenance of this large active leaf surface area requires continued development of new leaves to replace older, less efficient ones. Water stress hastens leaf senescence and interrupts new leaf formation, resulting in an unrecoverable loss of tuber bulking.

Soil water content at harvest has a significant influence on mechanical damage sustained by tubers during the harvesting process. Tubers that are dehydrated as a result of low soil water content at harvest are more susceptible to blackspot bruise. Tubers that are turgid as a result of high soil water content at harvest are more susceptible to shatter bruise and thumbnail cracking.

Potato yield and quality are susceptible to excess soil water as well. Excess soil water from frequent or intensive irrigation or rainfall during any growth stage leaches nitrate nitrogen below the plant root zone, potentially resulting in nitrogen-deficient plants, reduced fertilizer use efficiency, and an increased hazard to ground water. Saturation of the soil profile for more than 8-12 hours can cause root damage due to a lack of oxygen required for normal respiration. Excess soil water at planting promotes seed piece decay and delays emergence due to decreased soil temperature. Potatoes that are over-irrigated during vegetative growth and tuber initiation have a greater potential for developing brown center and hollow heart, and are generally more susceptible to early die problems. Excess soil water can also lead to tuber quality and storage problems.

Irrigation Management

The coarse-textured soils and

hot, dry summers that are characteristic of southern Idaho make irrigation essential for producing reliable, economically sustainable potato yields. The purpose of irrigation management is to maximize potato yield and quality by maintaining soil water content within specified limits throughout the growing season through timely and controlled water application to the crop.

Optimum Soil Moisture Content Many field research studies have focused on determining optimum soil water content for irrigated potato production. Most studies on the water stress sensitive Russet Burbank variety indicate that available soil water (ASW) in the root zone (0-18 inches) should be maintained above 65 percent to avoid yield and quality losses. Results from research studies using irrigation frequencies of one to three days on silt loam soils have shown that intermittent ASW levels below 65 percent may not reduce tuber yield and quality. In general, however, the average ASW of the root zone should be maintained between 65 and 85 percent during the active growth period for optimum results. In practice, ASW in the root zone will fluctuate above and below this range for short periods of time immediately before and after irrigation. This is particularly true with set-move sprinkler systems and furrow irrigation systems. Drip irrigation systems and solid-set, center-pivot, and linear-move sprinkler systems allow for light, frequent irrigations and can be managed to minimize soil water fluctuations.

The optimal range for water content at planting is about 70 to 80 percent ASW. This soil water level will provide ideal conditions for planting and early sprout development. Excessively wet soil conditions may slow soil warming and delay sprout development and emergence. Cool, wet soil conditions can increase seed piece decay and increase physiological aging of seed, resulting in higher stem and tuber numbers. Excessively dry soils should be irrigated prior to planting to avoid potential seed piece decay problems that sometimes result from irrigating between planting and emergence.

During the latter part of the growing season (growth stage V) plants begin to senesce and crop water use rates markedly decrease. Consequently, care should be taken to adjust irrigation amounts to avoid developing excessively wet soil conditions. High soil water contents during this period can produce enlarged lenticels that provide openings for soft rot bacteria to enter the tubers. Pink rot and Pythium Leak infections are also increased by excessive late-season soil water.

Available soil water should be allowed to decrease to about 60 to 65 percent at vine kill to provide optimal conditions for promoting tuber skin set and russeting. Drier soil conditions at vine kill increase the chances of developing stem-end discoloration.

Pre-harvest irrigation should be timed to optimize soil conditions and tuber hydration levels at harvest. Tubers that have matured under relatively dry soil conditions (less than 60 percent ASW) will likely be dehydrated, which will increase their susceptibility to blackspot bruise. Under these conditions, fields should be irrigated at least one week prior to harvest to completely rehydrate tubers. If ASW has been kept above 60 percent during tuber maturation, fields can be irrigated two to three days prior to harvest. Care should also be taken to avoid getting fields too wet at harvest because of increased potential for shatter bruise, greater difficulty separating soil from tubers, and storage rot problems.

Soil Water Holding Capacity Soil serves as the reservoir for plant nutrient and water needs. Soil has a finite capacity to hold water against gravity, which is called water holding capacity. A graphical representation of how water is held in soil is shown in figure 3. A given volume of soil consists of solids composed of minerals and organic matter and pores filled with air and water. When the soil pores are completely filled with water, the soil is said to be saturated (figure 3a). Under conditions of free drainage, the force of gravity will drain water from the largest pores. This free-draining water is called gravitational water. After 12 to 48 hours, drainage will decrease to a rather negligible rate. The soil water content at this point is commonly called field capacity or upper drained limit (figure 3b). In the presence of an active root system and actively transpiring plants, some of the gravitational water will be utilized by the plant, reducing the actual volume of drainage below the crop-root zone, effectively providing short term soil water storage. Irrigation should not be managed to produce gravitational water, but rather should only be applied in amounts necessary to bring root-zone soil water content back to field capacity.

Water is held in the soil as a film around soil particles by molecular attraction and by water surface tension forces producing what is commonly called capillary action. Hence, water held in soil pores is called capillary water (figure 3c) and is available for plant use. As plants remove water from the soil, water is extracted from progressively smaller pores until the remaining water exists as a film around soil particles. The attraction of soil particles to this thin film of water is so strong that a great amount of energy is required to remove the remaining water from the soil–to the degree that plants cannot obtain water and consequently wilt and die. The soil water content at this point is called the permanent wilting point and is graphically illustrated in figure 3d. The volume of water held in the soil between field capacity and permanent wilting point is called available water. It is commonly expressed as inches of water per inch or foot of soil depth and referred to as the water holding capacity of the soil.

The actual field soil water content for field capacity and permanent wilting point depend upon many factors (e.g. soil structure, soil texture, crop, etc.) and need to be determined by field and laboratory testing procedures. However, the somewhat vague definitions of field capacity and permanent wilting point, coupled with field spatial variability, make precise determination impractical for irrigation management. Therefore, the energy per unit volume required to extract water from soil at the permanent wilting point is usually accepted to be 1500 kPa (15 bars). Since energy input is required to extract water from the soil, the energy potential of water in the soil at permanent wilting point is -1500 kPa (-15 bars). Energy required to extract water from soil at field capacity is not as well defined because coarse-textured soils reach field capacity (negligible drainage) at a higher energy status than soils consisting of finer particles. Thus, coarse-textured soils with larger voids have a higher soil water energy potential at field capacity than silt-loam-textured soils with smaller voids. The energy potential of soil water at field capacity is usually -20 kPa (centibars) for silt loam and clay soils, and -10 kPa (centibars) for sandy soils with a gradual transition between them.

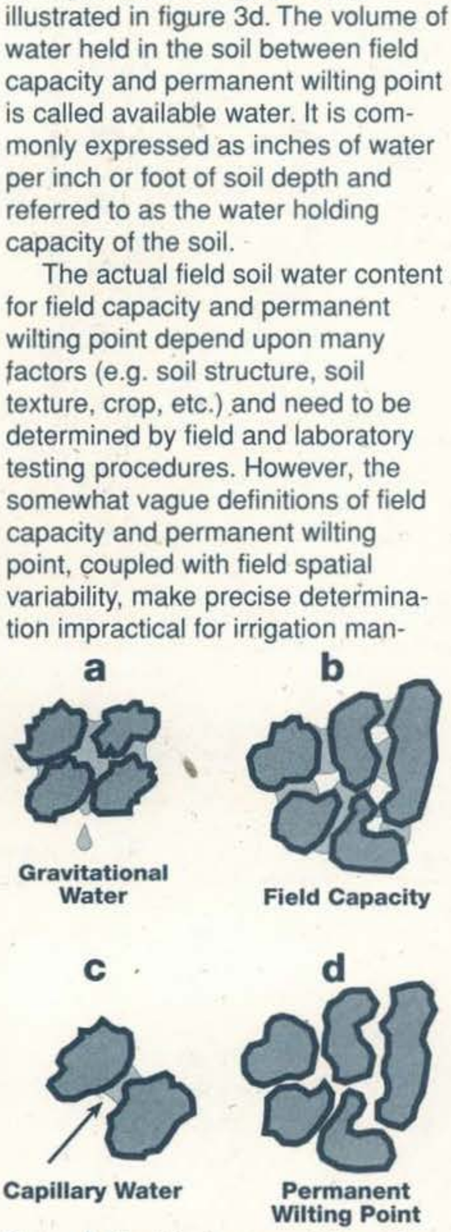

Figure 3. Graphical representation of soil water states.

Each soil has a unique relationship between soil water content and soil water energy potential called the soil water release curve. This relationship, which is highly dependent on soil texture, is shown graphically in figure 4 for four soil textures. The rather flat curve of a typical loamy sand soil indicates a narrow range in water content between field capacity and permanent wilting point, indicating low water holding capacity. In contrast, the sloping curve of the silt loam soil has a much wider range in soil water content between permanent wilting point and field capacity, indicating greater water holding capacity.

Soil water content is often expressed as a percentage on either a weight or volumetric basis. Care must be taken to make sure which water content basis is used. Conversion between the two requires knowledge of soil bulk density, which is dry soil mass per unit volume. For example, if the volumetric soil water content of a silt loam soil with a bulk density of 1.37 g/cm^3 is 32 percent, soil water content on a weight basis is then 23.4 percent (32÷1.37=23.4). Soil water content measured on a volumetric basis is preferred for irrigation management computations because bulk density of the soil is not required. Soil water content used in this publication is expressed on a volumetric basis. General soil water contents at critical points, along with water holding capacities for agricultural soils, are given in table 1. Inspection of available water listed in table 1 reveals that soils having a significant portion of silt have the greatest water holding capacities, offering the greatest flexibility in potato irrigation management.

Evapotranspiration and Yield

Evapotranspiration (ET) represents the sum of water used by plants for transpiration and water loss due to evaporation from plant and soil surfaces. Evapotranspiration varies according to meteorological conditions, plant and soil surface wetness, crop type, soil water content, and amount of crop cover (LAI). The meteorological parameters that affect ET are solar radiation, relative humidity, ambient air temperature, and wind speed. Since these can vary considerably from day-to-day, so will ET. Furthermore, seasonal ET will vary from year-to-year in response to annual meteorological trends.

Evapotranspiration for potatoes throughout the 1993 and 1994 growing seasons for three locations in southern Idaho (Parma, Twin Falls, and Rexburg) are shown in figure 5. The dependence of ET on meteorological conditions is evident by the variation in daily ET throughout the growing season. The 1993 growing season had a cool, wet spring and a cool summer, which resulted in potato quality problems across the state that were attributed to excessive soil water and cool soil temperatures in growth stages II and III. The 1994 growing season had a warm spring and an unusually hot summer, which resulted in many irrigation systems having difficulty in meeting crop water use. The 1993 and 1994 growing seasons likely represent the near extremes in seasonal ET for potatoes in southern Idaho.

Differences in the start, peak, and end of daily ET values shown in figure 5 for the three locations are due to differences in planting and harvest dates, and seasonal meteorological conditions. Daily ET throughout the season is noticeably reduced for the Rexburg area compared to the other locations due to the cooler average daily temperatures throughout the growing season attributable to geographical location. Published daily ET values, as shown in figure 5, provide a basis to develop an irrigation management program. In-field soil water measurement is also required to account for site-specific differences in ET based on type of irrigation system used, soil type, and local meteorological conditions such as wind and precipitation.

The typical response of potato yield, total and U.S. No. 1, to total seasonal water application (including precipitation) is shown in figure 6 for three potato cultivars at Kimberly, Idaho (Wright and Stark, 1990). Yield is linearly related to seasonal water application. Yield decreases when total seasonal water application exceeds seasonal evapotranspiration. The differences in total water application that maximize yield reflects the differences in growing season length between the cultivars and not necessarily differences in daily ET rates. The seasonal water application that maximizes yield will vary year-to-year in response to meteorological trends and differences in growing season length. The trend in yield response to water application observed under controlled research conditions (figure 6) is similar to that observed under commercial field conditions (figure 1).

Irrigation Method

Potatoes can be grown with all types of irrigation, however, some

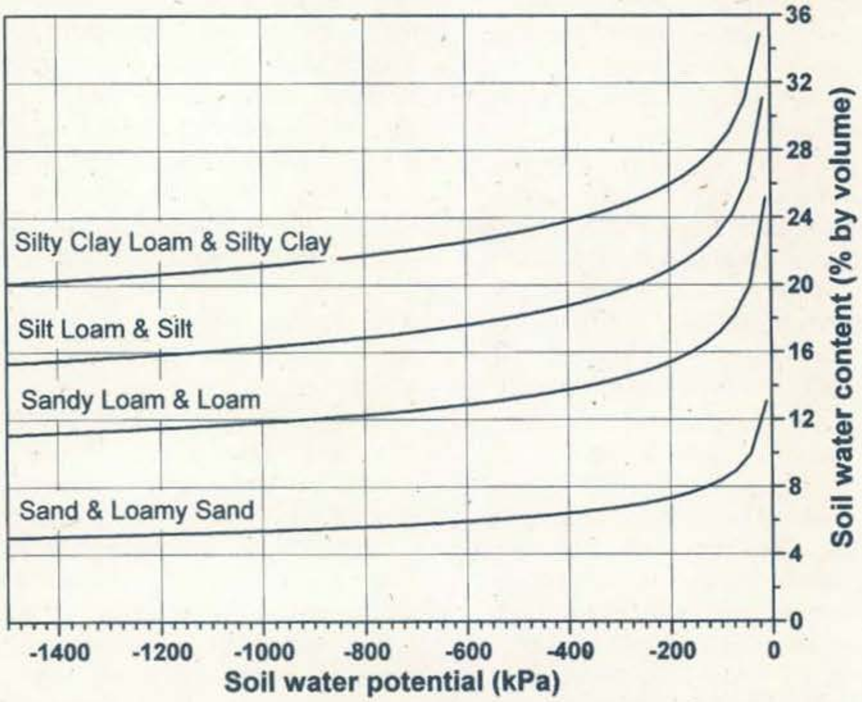

Figure 4. Soil water release curves for four soil textures common in agriculture.

Table 1. Soil water contents for agricultural soils.

	Soil Water Content on Volumetric Basis (%)							
	Field Capacity		Permanent Wilting Point		Available Water		Water Holding Capacity (in/ft)	
Texture Class	Average	Range	Average	Range	Average	Range	Average	Range
Sand	12	7-17	4	2-7	8	5-11	0.96	0.60-1.32
Loamy Sand	14	11-19	6	3-10	8	6-12	0.96	0.72-1.44
Sandy Loam	23	18-28	10	6-16	13	11-15	1.56	1.32-1.80
Loam	26	20-30	12	7-16	15	11-18	1.80	1.32-2.16
Silt Loam	30	22-36	15	9-21	15	11-19	1.80	1.32-2.28
Silt	32	29-35	15	12-18	17	12-20	2.04	1.44-2.40
Silty Clay Loam	34	30-37	19	17-24	15	12-18	1.80	1.44-2.16
Silty Clay	36	29-42	21	14-29	15	11-19	1.80	1.32-2.28
Clay	36	32-39	21	19-24	15	10-20	1.80	1.20-2.40

(Source: Jensen et al., 1990.)

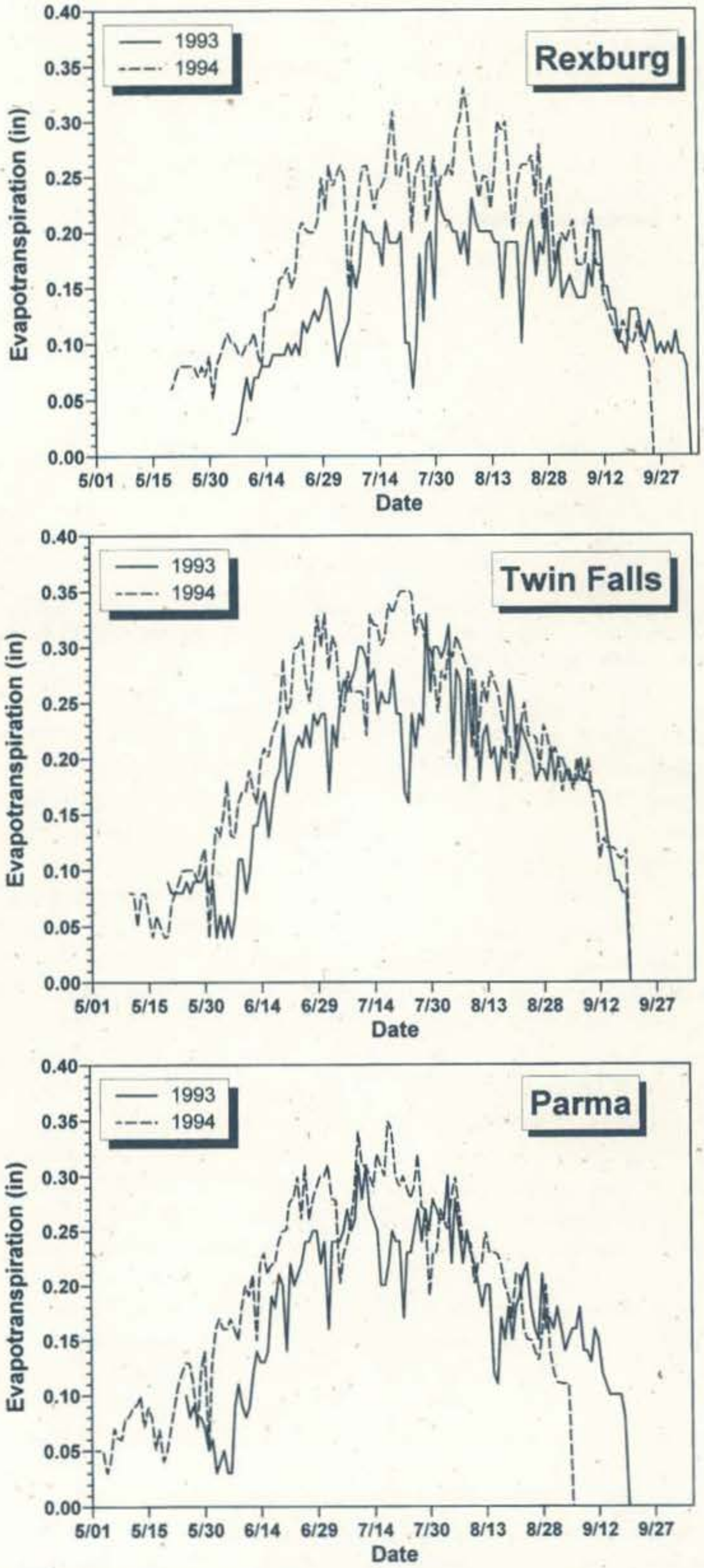

Figure 5. Daily evapotranspiration for potatoes at three locations in southern Idaho throughout 1993 and 1994 growing seasons.

are better suited than others for consistently obtaining high quality tubers. The water sensitive nature of potatoes, combined with its shallow root zone, favors irrigation systems that are capable of light, frequent, and uniform water applications. Using these criteria as a basis for ranking the suitability of common irrigation methods, the order of preference from highest to lowest would be: drip, solid-set (portable), linear-move, center-pivot, side-roll, hand-move, and furrow. In practice, economics are the overriding factor in irrigation system selection. Compatibility with soil type, crop rotation, and cultural practices are also important considerations. Buried drip is expensive, incompatible with conventional potato production practices, and is not suitable for establishing stands of some crops commonly grown in rotation with potatoes, especially in coarse-textured soils. Solid-set portable is expensive, as is linear-move. Center-pivots are highly susceptible to excessive runoff under the outer towers unless conservation tillage practices, such as basin or reservoir tillage, are utilized. Side-roll and hand-move sprinkler systems are prone to wind skips under the windy conditions common to southern Idaho. Furrow irrigation is susceptible to poor water application uniformity, excessive deep percolation, and leaching. Sprinkler irrigation is the most common method used for potatoes in Idaho, with center-pivot, side-roll, and hand-move being widely used.

Irrigation Scheduling

Potato irrigation scheduling for maximum profit requires that the timing and amount of water application be determined and applied to minimize soil water fluctuations throughout the growing season.

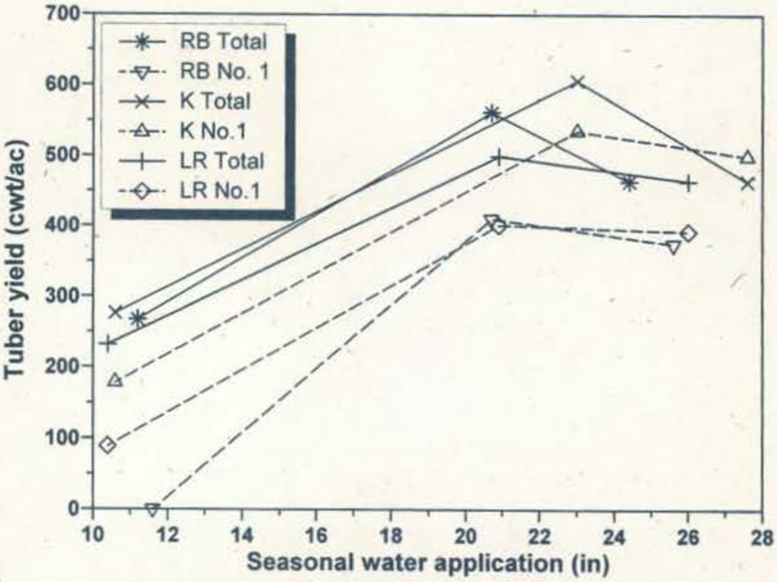

Figure 6. Total and U.S. No. 1 tuber fresh yield as influenced by total seasonal water application for Russet Burbank (RB), Kennebec (K) and Lemhi Russet (LR). (Source: Wright and Stark, 1990.)

Successful irrigation management requires regular quantitative monitoring of soil water and knowledge of field crop water use, soil water holding capacity, and crop-rooting depth. Excess irrigation usually results from applying too much water at a given irrigation rather than from irrigating too frequently. This is particularly true for side-roll and hand-move sprinkler systems where soil water holding capacity and crop-rooting depth are frequently overestimated; and furrow irrigation, where application depth is difficult to control. These situations lead to plant water stress when soil water falls below acceptable limits two to three days before irrigation, and subsequent irrigation applications are in excess of soil water storage capacity. This characteristic problem can generally be attributed to inadequately designed systems, irrigation system equipment limitations, or improper irrigation management.

Determining the appropriate timing of irrigations usually involves the use of daily ET estimates based on local meteorological data to maintain a daily soil water balance throughout the irrigation season. This technique, combined with periodic quantitative measurements of soil water to adjust the computed soil water balance to actual field conditions, provides a cost effective means for determining the timing of irrigations. This approach has the added benefit of implicitly determining the irrigation application amount as well. The computational mechanics of the soil water balance approach are provided in the publication *Irrigation Scheduling Using Water-Use Tables*, CIS 1039, University of Idaho, College of Agriculture. The basic steps involved are:

1. *Estimate field capacity and permanent wilting point based on the predominate soil texture in the field.*
2. *Estimate current crop-rooting depth.*
3. *Maintain a daily soil water balance based on published values of ET.*
4. *Irrigate when daily soil water balance approaches 65 to 70 percent ASW, applying the net amount required to increase the soil water content to field capacity or less in the case of light, frequent irrigation.*
5. *Periodically monitor soil water content or soil water potential and adjust the daily soil water balance to match actual field conditions.*

Several methods are available to quantitatively measure soil water content. Only some are suitable for potatoes, however, because of the critical threshold level of available soil water and the limited root-zone depth. Many of the methods are labor intensive and require training, experience, and expensive equipment. This has led to the development of crop consulting firms specializing in irrigation management, which often provide crop nutrient and pest management services as well. A detailed discussion of soil water measurement methods is provided in the publication *Soil Water Monitoring and Measurement*, PNW 475, University of Idaho, College of Agriculture.

Tensiometers have been used to successfully monitor soil water availability in potato fields. Good contact between the soil and tensiometer tip is essential for proper operation. Tensiometers are often installed in the potato hill at two depths, such as 8 and 16 inches below soil level. Typically, the upper tensiometer is used to track soil water potential within the bulk of the root zone, while the lower one is used to determine whether soil water potential at the bottom of the root zone is increasing or decreasing over time.

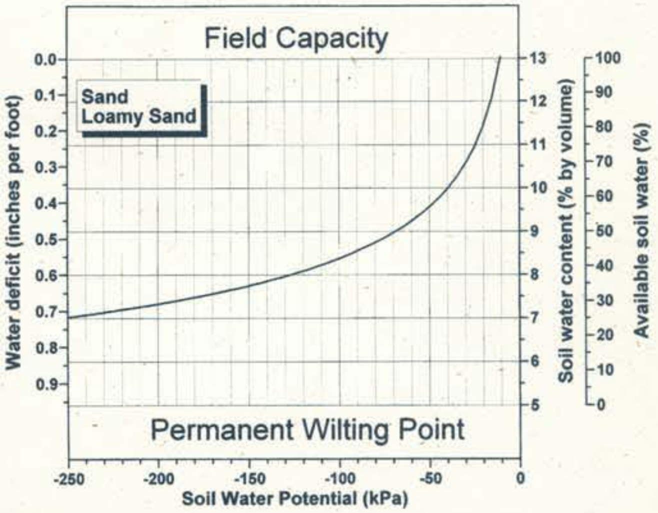

Figure 7. Generalized soil water release curve for sand and loamy sand soils.

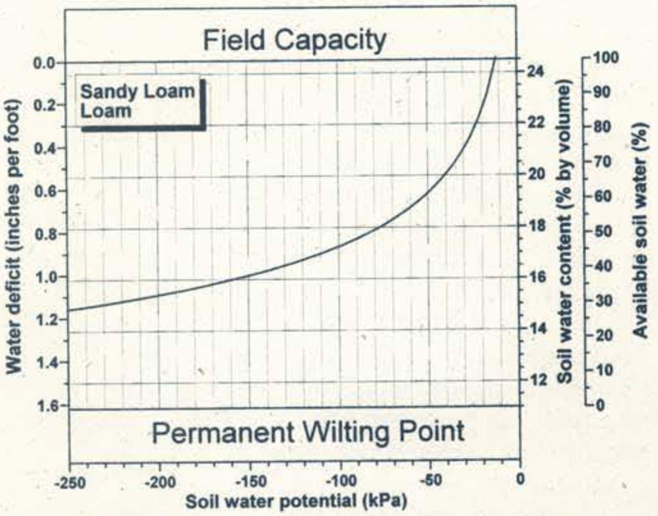

Figure 8. Generalized soil water release curve for sandy loam and loam soil.

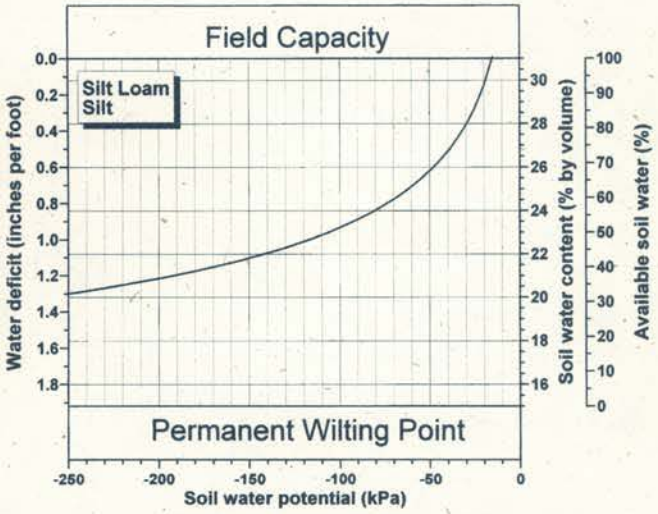

Figure 9. Generalized soil water release curve for silt loam and silt soil.

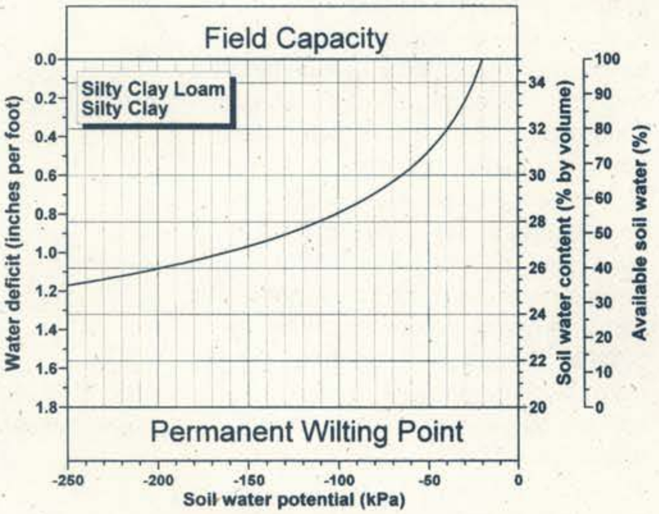

Figure 10. Generalized soil water release curve for silty clay loam and silty clay soil.

The neutron probe is likely the most precise and reliable tool for soil water measurement since it determines volumetric soil water content. However, licensing, training, and associated operational costs limit their use to consulting firms and large farms. Time domain reflectometery (TDR) offers many features that make it well suited to soil water measurement in potatoes. However, the initial equipment cost is quite high. Current research efforts to develop less expensive TDR units may make it the method of the future. Other methods are also available and may be suitable.

A soil water release curve is needed to relate soil water potential to volumetric soil water content. The generalized soil water release curves shown in figures 7 through 10 can be used to relate soil water potential to volumetric soil water, ASW and water deficit. These curves represent the primary soil water relationships needed for the development of an effective irrigation management program. They allow soil water content or water potential measurements to be used to calculate the net irrigation application amount needed to fill the soil water reservoir to field capacity. For example, if tensiometers show an average soil water potential of -40kPa (centibars) on a sandy loam soil (figure 7), then ASW is 62 percent, which indicates it's time to irrigate with a net application of 0.36 in/ft of crop root-zone depth. Soil water monitoring alone can be used for irrigation scheduling if performed on a real-time basis and used to directly control an irrigation system capable of immediate response. In practice though, most field scale irrigation systems are not capable of immediate response. Thus, a soil water balance is computed daily using both estimated and forecasted daily ET to anticipate when the next irrigation should occur and amount to apply. This computed soil water balance is reconciled to actual field conditions through use of the soil water release curve and quantitative soil water measurement.

The range of soil water potential and volumetric soil water content in the potato root zone at which time irrigation should occur to maintain ASW above 65 percent is shown in table 2. These values are obtained from the generalized soil water release curves shown in figure 7 through 10. These values are not absolute, but serve as a general guide for effective irrigation management.

An example of irrigation scheduling for a center-pivot system over a nine day period in July is outlined in table 3. On the morning of 7/10, the average reading for several tensiometer locations aligned radially outward from the center of a center-pivot irrigated potato field is -40 kPa. The predominate soil texture is sandy loam, which at -40 kPa has an ASW of 67 percent and water

Table 2. Soil water potential and volumetric water content ranges corresponding to 65 percent ASW.

Soil Texture	Soil Water Potential (kPa)	Soil Water Content (% by volume)
Sand, Loamy Sand	-25 to -35	9-12
Sandy Loam, Loam	-35 to -50	19-22
Silt Loam, Silt	-50 to -65	24-26
Silty Clay Loam, Silty Clay	-65 to -75	29-31

Table 3. Center-pivot irrigation scheduling example.

Date	ET (inches)	Rainfall (inches)	Net Irrigation (inches)	Computed Soil Water Deficit (inches)	Measured Soil Water Deficit (inches)	Comments
7/9	.29	—	—	0.91		
7/10	.31	—	0.5	0.62	0.81	Adjust deficit to 0.8, irrigate
7/11	.27	—	—	0.89		
7/12	.25	—	0.5	0.64		
7/13	.22	—	—	0.86		
7/14	.18	.05	0.5	0.54		Neglect rainfall <0.1"
7/15	.25	—	—	0.79	0.9	Adjust deficit to 0.9, irrigate
7/16	.31	—	0.5	0.71		
7/17	.28	—	0.5	0.49		

Table 4. Set-move sprinkler irrigation scheduling example.

Date	ET (inches)	Rainfall (inches)	Net Irrigation (inches)	Computed Soil Water Deficit (inches)	Measured Soil Water Deficit (inches)	Comments
7/9	.29	—	—	1.25		
7/10	.31	—	1.41	0	1.1	Adjust deficit to 1.1 in, irrigate 9.4 hrs
7/11	.27	—	—	0.27		
7/12	.25	—	—	0.52		
7/13	.22	—	—	0.71		
7/14	.18	.05	—	0.92		Neglect rainfall <0.1"
7/15	.25	—	—	1.17		
7/16	.31	—	1.56	0	1.25	Adjust deficit to 1.25 in, irrigate 10.4 hrs
7/17	.28	—	—	0.28		

depletion of 0.54 inches per foot, based on the generalized soil water release curve (figure 8). The total soil water deficit is 0.81 inches for an 18-inch effective crop-root zone. The computed soil water deficit, based on estimated daily ET ending on 7/9, is 0.91 inches. Since it is greater than the measured value, an adjustment is necessary. The actual soil water deficit is greater than the net application of 0.5 inches from a single 36-hour center-pivot rotation, so irrigation should be continued. The soil water balance is maintained through 7/14 using estimated daily ET. Precipitation amounts less than 0.1 inches are neglected when computing the daily soil water deficit, but are effectively accounted for by periodic adjustment to measured soil water deficit. On the evening of 7/15, the average tensiometer reading is -45 kPa, which translates to an ASW of 64 percent and total soil water deficit of 0.9 inches. This is greater than the computed soil water deficit of 0.79 inches and greater than the 0.5 inch net application from a single irrigation. Therefore, the soil water balance should be adjusted to actual field conditions and irrigation should be continued. This process continues throughout the growing season and when the actual or computed soil water deficit is less than the net application by a difference of approximately the daily ET, then irrigation should be discontinued until the computed or measured soil water deficit is greater than the net application depth.

An example of irrigation scheduling for a side-roll or hand-move sprinkler system over a nine day period in July is shown in table 4. The irrigation system is designed to provide a net irrigation application rate of 0.15 inches per hour with a minimum six days between irrigations based on two sets per day. On the morning of 7/10, the average reading for several tensiometers placed so that they all receive irrigation nearly the same day is -52 kPa. The predominate soil texture is silt loam. Based on the generalized water release curve (figure 9), it has an ASW of 67 percent and water depletion of 0.66 inches per foot for a total soil water deficit of 1.1 inches for a 20-inch effective crop-root zone. The computed soil water deficit based on estimated daily ET ending on 7/9 is 1.25 inches, which is greater than the measured value, so an adjustment in the computed deficit is necessary. The net irrigation application required for the day is 1.1 inches plus one day's ET of approximately 0.31 inches for a total of 1.41 inches. The irrigation set time is then 9.4 hours (1.41 inches/0.15 in/hr). This set time is used throughout the remaining five-day period, unless significant rainfall occurs. The irrigation set time should be reduced one hour for every quarter inch of rainfall. The soil water balance is maintained through 7/15.

On the morning of 7/16, the average tensiometer reading is -65 kPa, which translates to an ASW of 62 percent and total soil water deficit of 1.25 inches. This is slightly greater than the computed soil water deficit of 1.17 inches, so the soil water budget needs to be adjusted to actual field conditions. The net application required for the day is 1.25 plus one day's ET of approximately 0.31 inches for a total of 1.56 inches. The irrigation set time is then 10.4 hours (1.56 inches/0.15 in/hr). This process is continued throughout the growing season and the irrigation set times are adjusted to match the water use over the six-day irrigation interval.

Irrigation System Operational Parameters The primary irrigation system information needed for irrigation scheduling is net irrigation application amount or rate. For center-pivot and linear-move irrigation systems, the net application amount is dependent upon system capacity, wet run time between irrigations, and system application efficiency. For side-roll, hand-move, and solid-set sprinkler systems, the net application rate depends upon sprinkler spacing, flow rate, and application efficiency. System application efficiency is a measure of how much water exiting the irrigation system actually goes to fulfilling crop water requirements. Water is lost due to wind drift and evaporation under sprinkler irrigation, and to deep percolation resulting from non-uniform water application with all irrigation systems. Typical irrigation system application efficiencies for Idaho are given in table 5.

The first step in calculating net irrigation application is to determine gross water application. Gross water application depth per rotation for a center-pivot irrigation system, as a function of system capacity and rotation time, is presented in figure 11. System capacity in terms of gpm/acre is needed to use the curves in figure 11 and can be obtained from the system sprinkler package specifications or by dividing total system flow rate by the acreage irrigated. Net application depth for 80 percent application efficiency can be obtained directly from the right-side axis of figure 11. Net application depth for any application efficiency can be calculated as:

$$\text{Net Depth} = \frac{\text{Gross Depth} \times \text{Application Efficiency (\%)}}{100}$$

Example:

$$\text{Net Depth} = \frac{0.8 \text{ in} \times 85\%}{100} = 0.68 \text{ in}$$

Gross water application rates for set-move and solid-set sprinkler systems, as a function of sprinkler flow rate and spacing, are presented in figure 12. Sprinkler flow rate can be obtained from figure 13 for straight-bore nozzles, as a function of nozzle size and pressure. Net application rates for 70 percent application efficiency are given in figure 12 (right-side axis). Net application rate for any application efficiency can be calculated as:

$$\text{Net Application Rate} = \frac{\text{Gross Application Rate} \times \text{Application Efficiency (\%)}}{100}$$

Example:

$$\text{Net Application Rate} = \frac{0.22 \text{ in/hr} \times 70\%}{100} = 0.154 \text{ in/hr}$$

Management Under Limited Water Supply Many research studies have focused on investigating the effects of water stress timing on tuber yield and quality. When water resources are limited, the best practice is to schedule irrigations to cover the period from tuber initiation through mid-bulking, and select cultivars that use less water and/or are less sensitive to water stress. Results from a few studies have indicated that water stress can best be tolerated during the early vegetative growth and late tuber bulking. Actual water stress effects on yield and quality depend on ET rate, soil water holding capacity, irrigation frequency, crop growth stage, and cultivar.

Irrigation System Management

Center-Pivot Sprinklers Center-pivot systems are generally not designed with sufficient capacity to meet peak period daily water use. Instead, soil water-banking (building up soil water reserves in the root zone) is used to supply a small fraction of daily ET over the duration of the peak period. This allows for reduced system capacity, resulting in smaller pump size, lower electrical demand charges, and reduced water application rates. Water-banking is allowed because center-pivot systems are capable of providing light, frequent irrigations. It applies to linear-move systems as well, but to a reduced extent to account for dry run time during repositioning. Water-banking can potentially be applied to any irrigation system capable of light, frequent irrigations such as drip and solid-set sprinklers. The degree to which water-banking can be utilized is directly proportional to soil water holding capacity and crop-rooting depth. Potatoes grown on coarse-textured soils having water holding capacities less than 1 inch per foot do not allow for water-banking and must have a net system capacity equal to peak daily ET. For example, if peak ET is 0.34 in/day then the net system capacity must be 6.4 gpm/acre [0.34 in/day x 18.86 (gpm/acre)/(in/day)] or a gross system capacity of 7.5 gpm/acre, if application efficiency is 80 percent.

Center-pivot systems that utilize water-banking must be managed to ensure that the soil water reservoir is full at the beginning of the peak water use period. This requires planning and field soil water monitoring to the full depth of the crop-root zone. Failure to do so will likely result in crop water stress near the end of the peak-use period; the extent depends on soil and climatic conditions. The timing of the peak-use period varies season-to-season. For example, a center-pivot system operating in 1994 near Twin Falls, having a net system capacity of 0.28 inches per day, would need to have been managed so that the soil water reservoir was full by 6/20 when ET became greater than 0.28 in/day

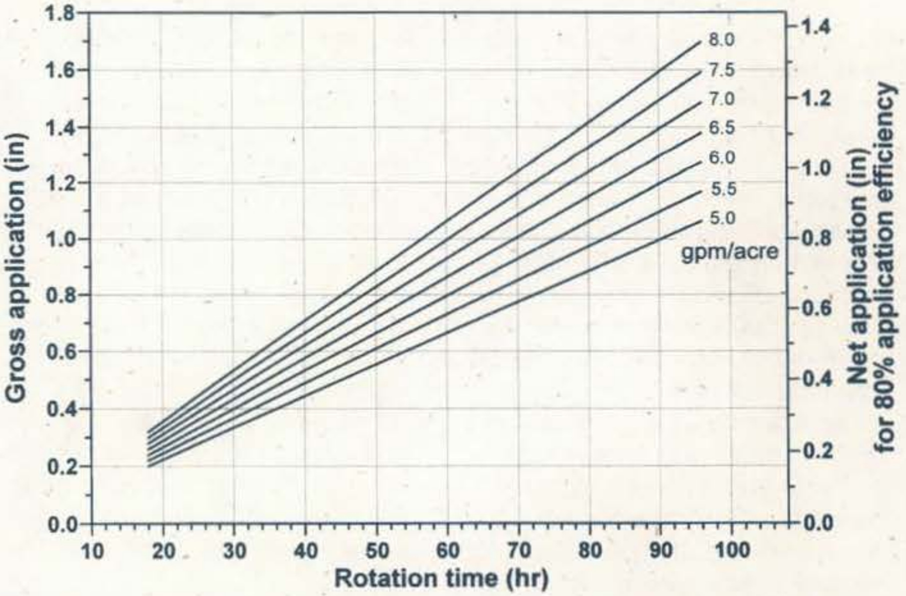

Figure 11. Center-pivot application depth as a function of system capacity and rotation time (x-axis) for system capacities ranging from 5 gpm/acre to 8 gpm/acre.

(figure 5). However, a full soil water reservoir was not necessary in 1993, since peak ET seldom exceeded 0.28 in/day (figure 5). Figure 14 depicts available soil water throughout the irrigation season for a center-pivot system that is managed so that soil water is replenished to field capacity (100 percent ASW) early in the season (figure 14a), compared to only 85 percent ASW (figure 14b). Under both scenarios, the characteristic gradual drawdown of ASW occurs during the peak-use period. However, in the second case, low ASW values fall below recommended limits, resulting in periodic plant water stress. When this occurs there is no corrective course of action as system capacity is fixed. The ultimate tuber yield and quality depend upon the seasons climatic conditions as they drive daily ET.

The natural tendency is to speed the center-pivot system up when crop water deficits (stress) develops. This action only serves to reduce application efficiency because ET is increased by evaporation from wet soil and vegetation. Increasing the speed of a center-pivot produces lighter applications and more frequent wetting of the soil and plant canopy, thereby increasing the total amount of water lost to evaporation and decreasing the amount stored in the soil. Thus, system speed should remain the same or be reduced when crop water deficits (stress) develop. This will increase irrigation efficiency by storing a greater percentage of water applied in the soil.

Minor changes in application efficiency can result in a significant difference in center-pivot system performance. A 3 to 8 percent difference in application efficiency will occur between nighttime and daytime irrigation, resulting in differences in soil water storage. As a result, center-pivot speed should be adjusted so that rotation time is not a multiple of 24 hours. Otherwise, areas of the field consistently watered during the daytime will have 3 to 8 percent less water stored in the soil for crop use. This small difference accumulated over time can result in water stressed areas within the field.

Conservation tillage practices, such as basin or reservoir tillage, are required to achieve optimum infiltration uniformity with potatoes under

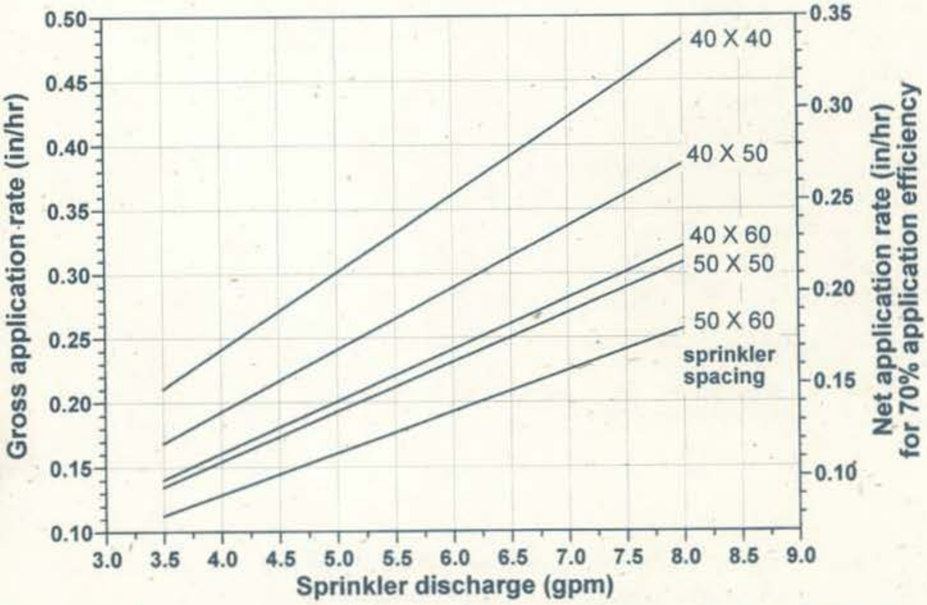

Figure 12. Set-move and solid set sprinkler application rate as a function of sprinkler discharge (x-axis) and sprinkler spacing in feet (lines).

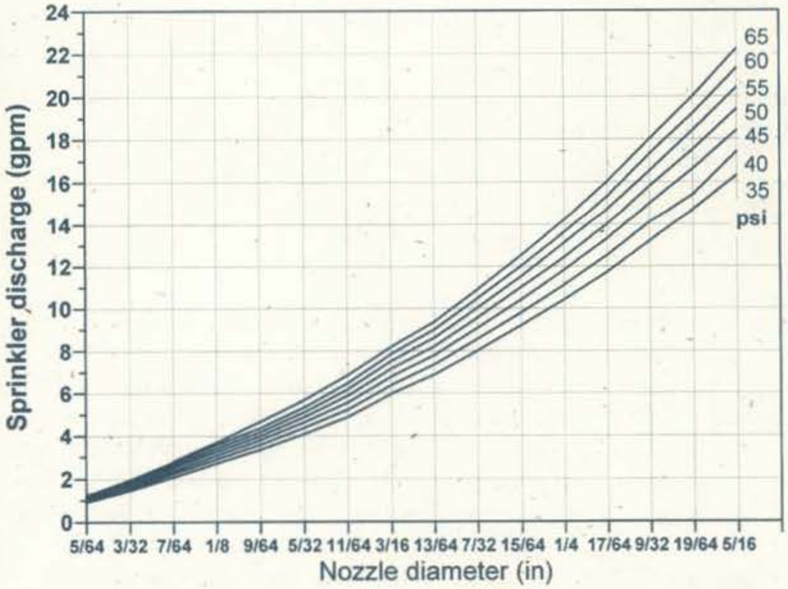

Figure 13. Sprinkler discharge as a function of straight bore nozzle diameter (x-axis) and pressure in psi (lines).

center-pivot irrigation. The hilling of potato plants causes water to concentrate in the furrow under high application rates and when combined with even slight slopes will cause runoff. Water collects in low areas causing excessive infiltration, while up-slope areas have reduced infiltration and become water stressed. The field-scale cumulative effect results in reduced yield and quality, lower water and nutrient efficiency, and localized leaching of chemicals from the root zone.

Set-Move Sprinklers Side-roll and hand-move sprinkler systems are normally designed to deplete soil water storage between irrigations during the peak-use period. Thus, soils with greater soil water storage allow for longer irrigation intervals, reducing equipment and capital costs.

This characteristic operating principal is contrary to the need to minimize soil water fluctuations for optimum tuber yield and quality. Typical potato irrigation management problems that occur with set-move sprinkler systems include scheduling irrigations too far apart and applying more water than the root zone can hold. This may be a result of over estimating soil water holding capacity and crop-rooting depth, or an insufficient number of sprinkler laterals requiring too many days to traverse the field. The maximum irrigation interval can be calculated as:

$$\text{Maximum Irrigation Interval} = \frac{\underset{(\text{in/ft})}{\text{Soil Water Holding Capacity}} \times \underset{(\text{ft})}{\text{Root-Zone Depth}} \times \underset{(0.35)}{\text{Allowable Depletion}}}{\text{Peak Daily ET (in/day)}} + 1 \text{ day irrigation time}$$

Maximum irrigation intervals based on a peak ET of 0.33 in/day for different soil types and root-zone depths are shown in table 6. Irrigation intervals in excess of five days will likely result in ASW levels below 65 percent during the peak water use period, which adversely affects tuber yield and quality.

Table 5. Typical irrigation system application efficiencies.

System Type	Application Efficiency (%)
Surface Systems	
Furrow	35-65
Surge	50-55
Cablegation	50-55
Sprinkler Systems*	
Set-move	60-75
Solid-set	60-85
High pressure center-pivot	65-80
Low pressure center-pivot	75-85
Linear-move	80-87
Microirrigation	
Drip	90-95

* Use lower efficiencies with larger spacing and windy conditions.
(Source: Sterling and Neibling, 1994.)

Table 6. Maximum irrigation interval for set-move sprinkler systems based on 0.33 in/day peak ET plus one day irrigation time.

Texture Class	Root-Zone Depth (inches)				
	14	16	18	20	22
Sand, Loamy Sand	2.2	2.3	2.5	2.7	2.9
Sandy Loam, Loam	3.1	3.4	3.7	4.0	4.3
Silt Loam, Silt	3.4	3.7	4.0	4.4	4.7
Silty Clay Loam, Silty Clay	3.2	3.5	3.9	4.2	4.5

Furrow Irrigation Furrow irrigation of potatoes does not produce the tuber quality obtainable with other types of irrigation, even with best achievable management practices. Water is required to traverse the field by overland flow in the furrow. The time required for water to reach the end of the furrow leads to greater water application at the inflow end compared to the outflow end, resulting from differences in infiltration opportunity time. Furthermore, infiltration is highly variable, with

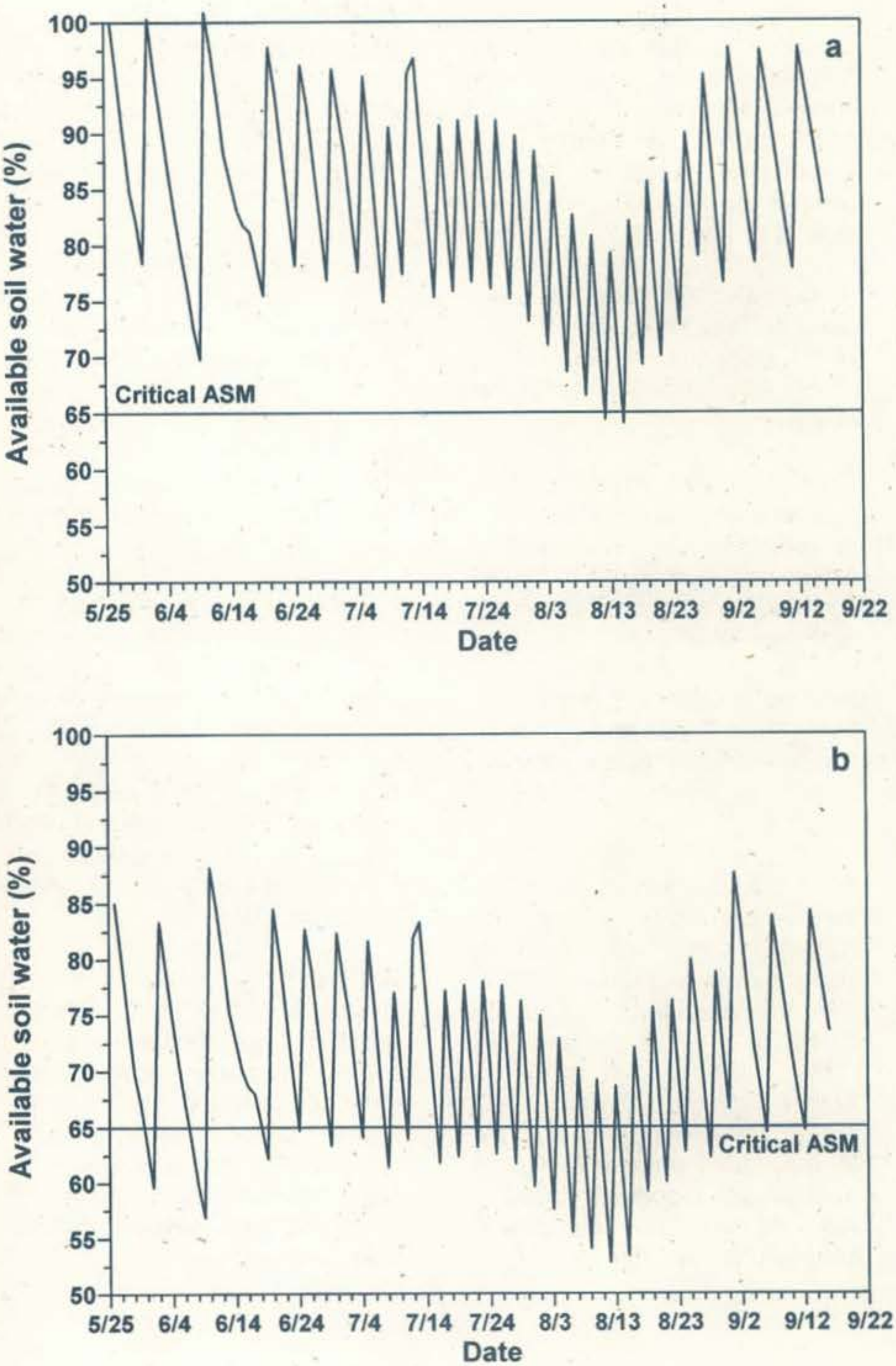

Figure 14. Available soil moisture throughout the growing season for potatoes under center-pivot irrigation for: (a) 100% and (b) 85% available soil moisture at the beginning of the peak-use period.

applications to individual plants ranging from half to twice the field average (Trout et al., 1994). Thus, furrow irrigation cannot achieve the degree of uniform water application needed to produce consistently high quality tubers on a commercial field-scale basis.

A common furrow irrigation practice for potatoes is to irrigate alternate furrows on each successive irrigation in an attempt to overcome some of the difficulty in applying small irrigation depths. Consequently, only about 15 percent of the soil surface is wetted and water is expected to move upward laterally to wet the whole root zone. In the absence of a clay soil or dense soil layers, gravity causes water to move faster downward than laterally. Thus, attempts to completely wet the root zone to the top of the hill are usually unsuccessful and result in excessive deep percolation losses. The lateral water distribution problem results in significant variation in soil water contents, varying widely near the furrow and remaining dry on hilltops.

A consequence of the non-uniform water distribution between and along furrows is the wide variation in nitrogen availability due to both dry soil regions and leaching losses. This tends to further reduce tuber quality under furrow irrigation and also reduces nutrient use efficiency.

These limitations have caused many producers to abandon furrow irrigation in favor of sprinkler irrigation. A common approach is to utilize a completely portable sprinkler irrigation system for potatoes, which can be moved around the farm according to crop rotation, and using furrow irrigation for the other row crops. The advantages of higher gross income and reduced risk with better tuber quality, and higher water and nutrient use efficiency with sprinkler irrigation, usually justify the use of sprinklers for potato production. The ability to inject fertilizers and pesticides through sprinkler systems provides another significant advantage over furrow irrigation.

Summary

The primary goal of potato irrigation management is to minimize soil water fluctuations and maintain available soil water within the optimum range of 65-85 percent. Irrigation systems best suited to this task are those that are capable of light, uniform, and frequent water applications. An effective irrigation management program must include regular quantitative monitoring of soil water availability, and scheduling irrigations according to crop water use, soil water holding capacity and crop-rooting depth. Potatoes are more sensitive to water stress than most other crops, have relatively shallow root systems, and are commonly grown on coarse-textured soils. These conditions dictate utilization of a quantitative potato irrigation management program for consistent, optimum economic return.

Literature Cited

Jensen, M.E., R.D. Burman, and R.G. Allen. 1990. Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practice No. 70. American Society of Civil Engineers, New York, NY.

Curwen, D. 1993. Water Management. *In:* R.C. Rowe (ed.) Potato Health Management. American Phytopathological Society, St. Paul, MN. pp 67-75.

Stark, J.C. 1996. Information management systems for on-farm potato research. Potato research and extension proposals for cooperative action. Univ. of Idaho, College of Agric. pp. 88-95.

Sterling, R., and W.H. Neibling. 1994. Final Report of the Water Conservation Task Force. Idaho Department of Water Resources, Boise, ID.

Trout, T.J., D.C. Kincaid, and D.T. Westermann. 1994. Comparison of Russet Burbank Yield and Quality Under Furrow and Sprinkler Irrigation. American Potato Journal 71:15-28.

Wright, J.L., and J.C. Stark. 1990. Potato. *In:* Stewart, B.A., and D.R. Nielsen (eds.) Irrigation of Agricultural Crops. Monograph No. 30. American Society of Agronomy, Madison, WI pp. 859-888.

Additional Sources of Information

Ashley, R.O., W.H. Neibling, and B.A. King. 1996. Irrigation Scheduling Using Water-Use Tables. CIS 1039. University of Idaho College of Agriculture.

Clapp, R.B., and G.M. Hornberger. 1978. Empirical Equations for Some Soil Hydraulic Properties. Water Resources Research 1464:601-604.

Kleinkopf, G.E., D.T. Westermann, and R.B. Dwelle. 1981. Dry Matter Production and Nitrogen Utilization by Six Potato Cultivars. Agronomy Journal 73:799-802.

Ley, T.W., R.G. Stevens, R.R. Topielec, and W. H. Neibling. 1994. Soil Water Monitoring and Measurement. PNW 475. University of Idaho College of Agriculture.

Ojala, J.C., J.C. Stark, and G.E. Kleinkopf. 1990. Influence of Irrigation and Nitrogen Management on Potato Yield and Quality. American Potato Journal 67:29-43.

Authors

Bradley A. King is an irrigation research engineer in the Biological and Agricultural Engineering Department and Jeffrey C. Stark is a research agronomist in the Plant, Soil, and Entomological Sciences Department, both at the University of Idaho Aberdeen Research & Extension Center.

800, 1-97

$4.50