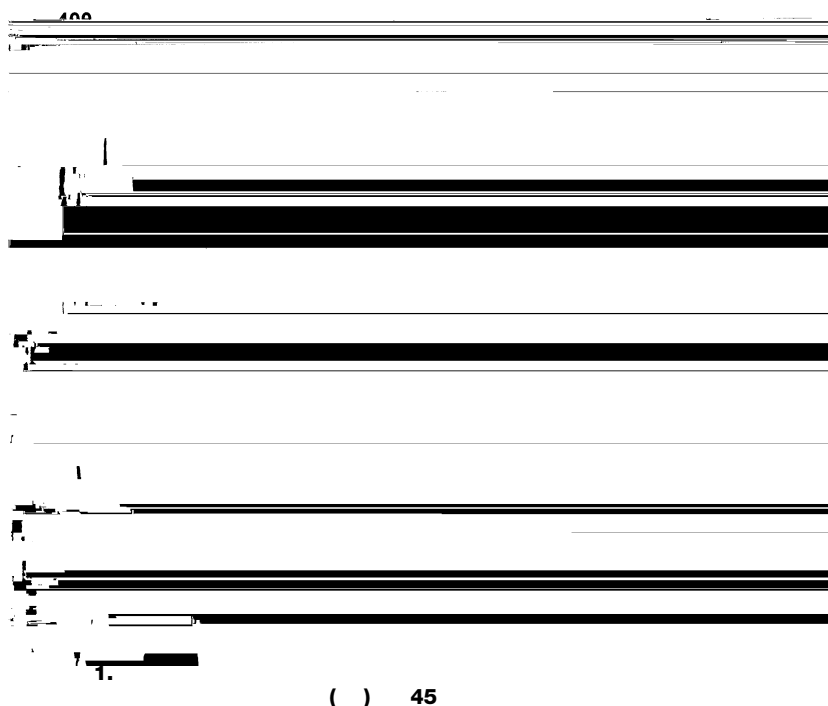
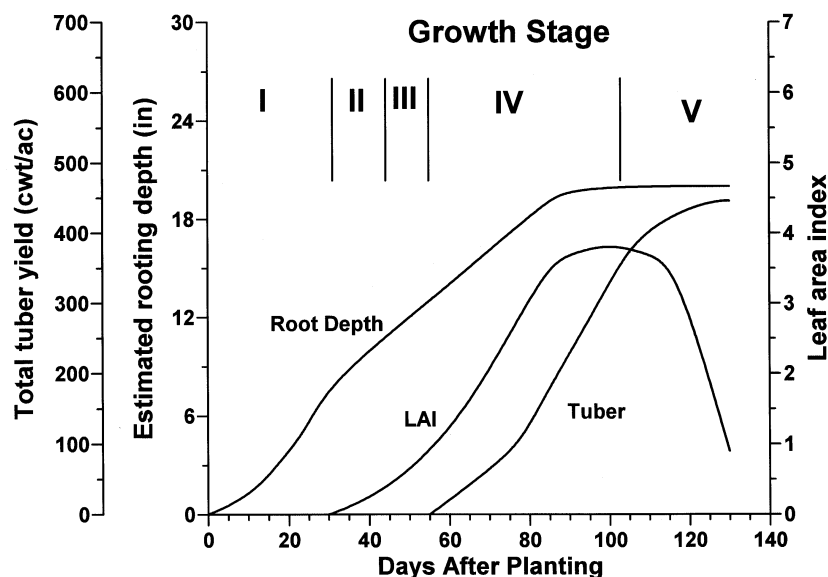


Irrigation is essential for profitable commercial potato production in Idaho. Maximum economic return requires, among other things, that soil water content be maintained within a certain range throughout the growing season. Potatoes are often considered to be a high water use crop, when in fact many of the crops grown in Idaho have equal or greater seasonal water requirements. This misconception arises from the fact that potatoes are sensitive to water stress compared to most of the crops, have a relatively shallow root-zone depth and are often grown on soils with low to medium water holding capacities. These conditions necessitate a reliable irrigation systems capable of high, frequent, uniform water applications based primarily on soil water availability throughout the growing season. These conditions also dictate that an effective potato irrigation management program include (i) regular and accurate monitoring of soil water, (ii) scheduling irrigations according to crop water use and soil water holding capacity, and (iii) a water saving 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 southern Idaho (Sack, 1996). Potato yield is reduced by both over- and under-irrigation. A mere 10% deviation from optimum water application for the growing season may begin to decrease yield. This sensitivity of water management is attributable to the sensitivity of potato plants to water stress, combined with



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(A),

be yield. Leaf area index is the dimensionless ratio of leaf surface area to ground surface area. Growth stage I is the period of laning emergence and ranges from 20 to 35 days depending on variable 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 on site-specific conditions. Solons begin to develop during growth stage II, but become noticeable only after 10- to 14-day period, which is called "tuberization" or tuber initiation and occurs during growth stage III. During this growth stage, the LAI is generally in the range of 1 and 2, which corresponds to 50-80 percent of close depending on site-specific conditions and variety.

Tuber enlargement or "bulking" occurs largely throughout growth stage IV. The increase in tuber size is a primarily 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 on variety and environmental conditions (Wright and Sak, 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 habit of the canopy begins to decline.

During growth stage V, plants begin to die and lose leaves. The growth habit declines as the shed of old leaf area and photosynthetic activity, and tubers begin to mature. The remaining tuber growth is primarily from allocation of plant materials from stem, leaf, and roots to the tubers.

2. y 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 relatively weak root systems to penetrate a tillage and/or other restrictive layers. Soil compaction by field vehicle traffic can greatly restrict root growth and aeration. Soil water content at the time of tillage operation has a major influence on the degree of compaction resulting from field traffic.

Mary soils in Idaho have a weakly cemented calcimachabona layer within 24 inches of the soil surface, which restricts root growth and aeration by root water movement. Field decomposition of actual root length is of imaginary importance to irrigation management.

A **G** **A** **A**
Ava **a** **y** The sensitivity of root growth to soil water stress is likely due to the shallow root system and complete physiological responses to moderate soil water deficits (Cohen, 1993). The physiological response is close to the leaf stomata: the small pores in the leaf have control gas exchange between internal leaf cells and the environment. Evapotranspiration of water from within the leaves serves to cool the leaves, resulting in a transpiration stream that moves water and nutrients upward in the plant. The stomata in the leaf close under soil 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 photosyn-

thetic products (sugars and gases) by the plant and their translocation from the leaves to the roots. Poor yield and quality depend on maximizing the steady accumulation of photosynthetic products in the roots. When production of these products exceeds the needed for assimilation and confined plant growth, they are stored in the roots.

One of the first physiological responses affected by soil water deficit is the expansion of leaves, stems, and roots. Water deficit reduced cell elongation by reducing the internal water pressure in plant cells (turgor pressure), which is necessary for expansion. Red cedar vine and leaf growth limits overall photosynthesis, while the reduced root development limits the plant's ability to take water and nutrients. Water deficits also disturb normal root growth rates by reducing rooting behavior. The root growth response following relief of soil water deficits, but the duration of the normal root expansion may be limited in some malformations such as jointed ends, dumbbells, bottle necks, and knobs. Widely fluctuating soil water content causes the greatest opportunity for development of these defects. Growth cracks are also associated with wide fluctuations in soil water availability and corresponding changes in temperature and volume of internal tissues.

Potatoes are particularly sensitive to water stress during germination and early development. Water deficit at this time can substantially reduce U.S. No. 1 yields by increasing the proportion of culls, misshapen tubers. Early season water stress can also reduce specific gravity and increase the amount of anhydrous ammonia.

Water stress during tuber bulking severely affects overall tuber yield and

quality. A large photosynthetically active leaf surface area is necessary to maintain high 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 inhibits new leaf formation, resulting in an unacceptable loss of bulking.

Soil water content at harvest has a significant influence on mechanical damage sustained by tuber during the harvesting process. Tubers have a reduced ability to absorb water from low soil water content at harvest and more susceptible to black rot blight. Tubers have a tendency to absorb water from high soil water content at harvest and more susceptible to shatter blight and stem nail canking.

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 nitrogen below the plant root zone, potentially resulting in nitrogen deficiency, reduced fertilizer efficiency, and an increased hazard of groundwater contamination. Saturation of the soil profile for more than 8-12 hours can cause root damage due to a lack of oxygen, resulting in normal assimilation. Excess soil water at planting promotes seed piece decay and delays emergence due to decaying soil moisture. Potatoes have a over-irrigated during vegetative growth and germination have a greater potential for developing bacterial and hollow heart, and a generally more susceptible to early die problems. Excess soil water can also lead to other quality and storage problems.

The coarse-textured soils and

hydrolysis of the soil has a characteristic
 isic of soil in Idaho make irrigation
 essential for producing reliable,
 economically sustainable crop
 yields. The use of irrigation
 management is to maximize crop
 yield and quality by maintaining soil
 water content within specified limits
 throughout the growing season
 through timely and controlled water
 application of the crop.

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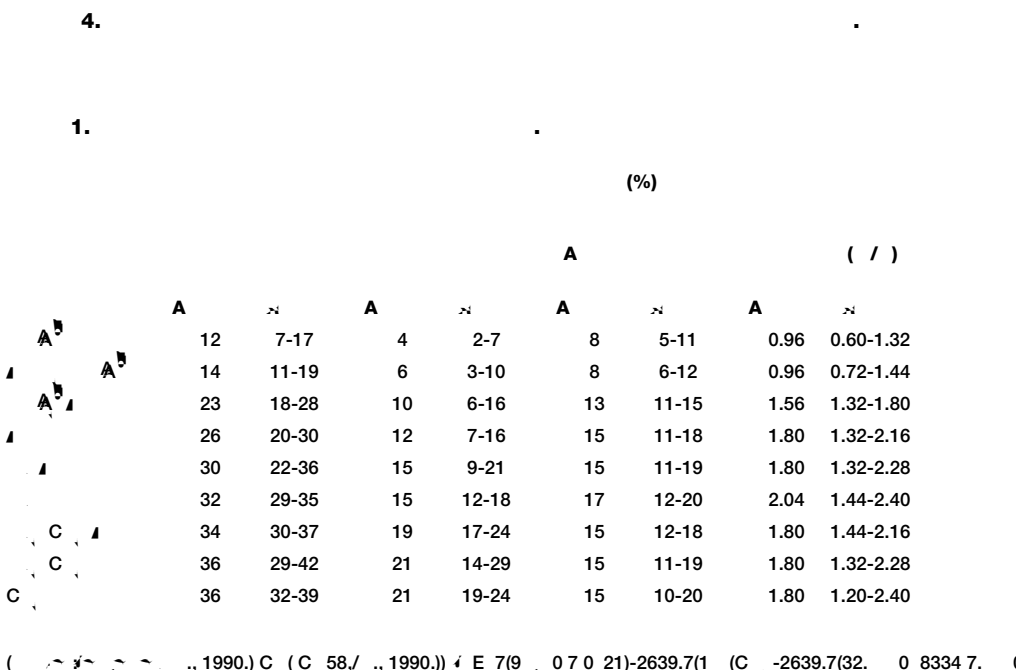
Many field research studies have
 focused on determining optimum soil
 water content for irrigated crop
 production. Most studies on the
 water stress sensitive Rouse
 Bank variety indicate that avail-
 able soil water (ASW) in the root
 zone (0-18 inches) should be
 maintained above 65 percent to
 avoid yield and quality losses.
 Results from each study using
 irrigation frequencies of one or three
 days on silty loam soils have shown
 that in the minimum ASW levels below
 65 percent may not be
 yield and quality. In general, how-
 ever, 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
 a naturally evapotranspiration-move
 sink systems and flow irrigation
 systems. Drip irrigation systems
 and solid-set, center-irrigation, and
 linear-move sink systems allow

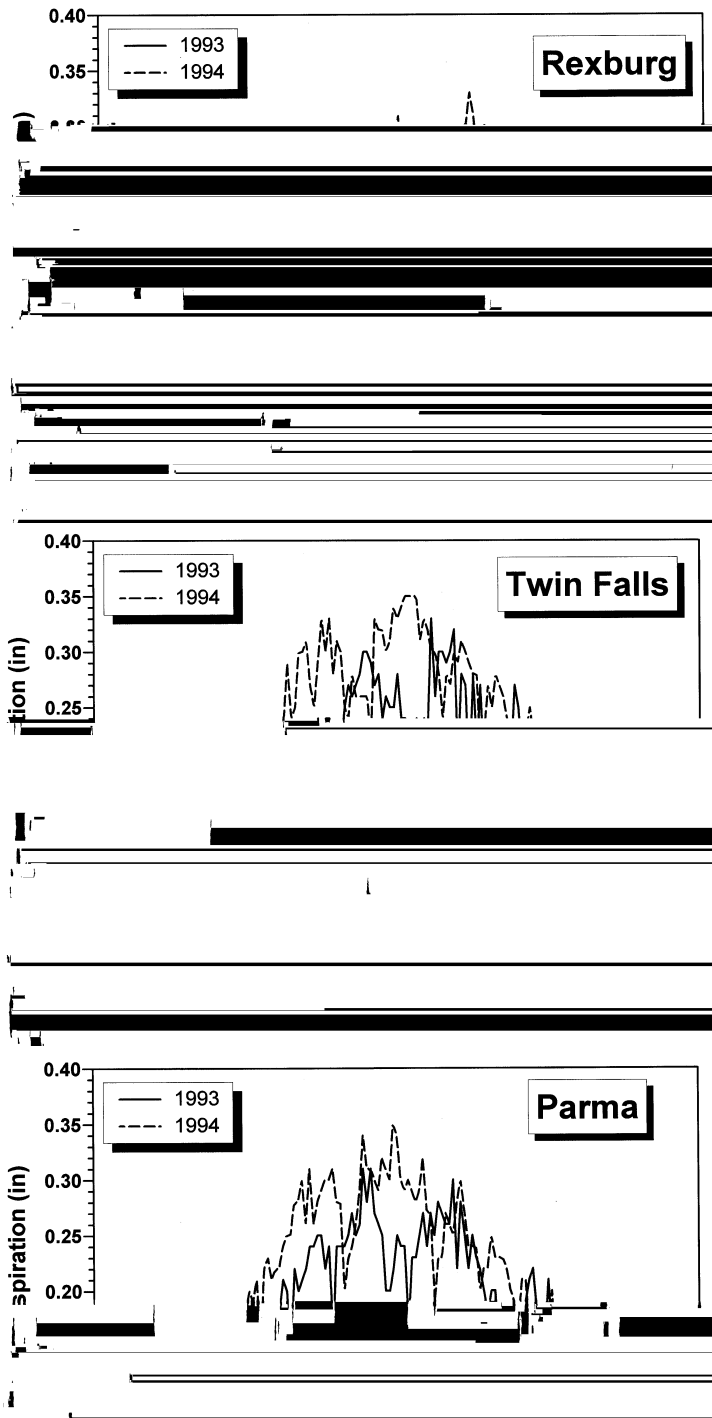


spring and a cool summer, which resulted in a variety of problems across the state. Heavy rainfall and excessive soil water and cool soil temperatures in growing stages II and III. The 1994 growing season had a warm spring and an unusually hot summer, which resulted in many irrigation systems having difficulty in meeting crop water needs. The 1993 and 1994 growing seasons likely represent the near extremes in seasonal ET for a crop 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 Reboqua area compared to the other locations due to the cooler average daily temperatures throughout the growing season at this favorable geographic location. Published daily ET values, as shown in figure 5, provide a basis to develop an irrigation management program. In-field soil water measurements are also needed 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 evaporation.

The typical response of a crop yield, total and U.S. No. 1, to total seasonal water application (including evaporation) is shown in figure 6 for the two crops, a Kimbely, Idaho (Wright and Sak, 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 have a major yield effect. The differences in growing season length between the crops and no necessary differences in





5.

1993 1994

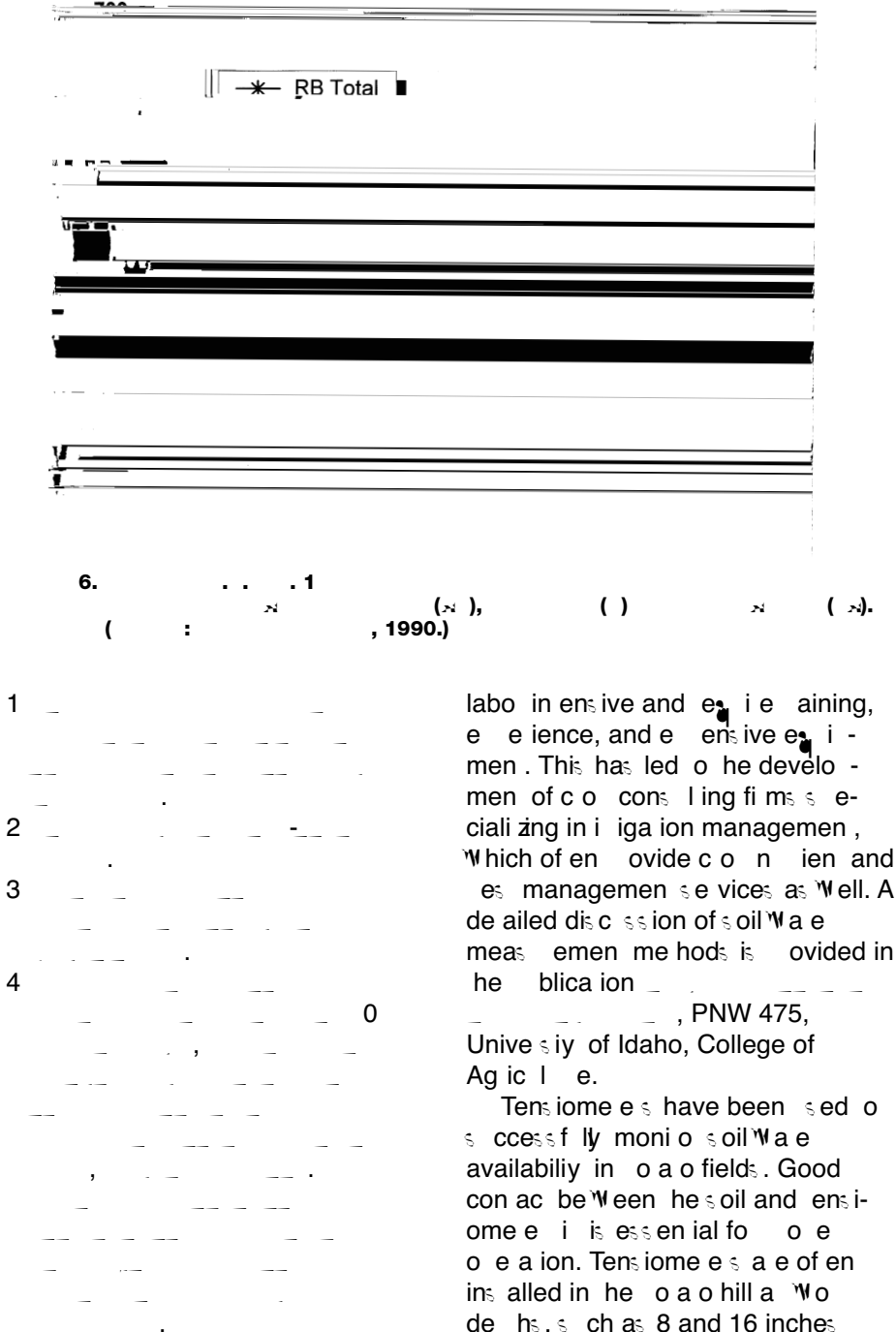
are being used than others for consistently obtaining high yields. The water sensitive nature of potatoes, combined with its shallow root zone, favors irrigation systems that are capable of light, frequent, and uniform water applications. Using these criteria as a basis for ranking the suitability of 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 flood. In practice, economics are the overriding factor in irrigation system selection. Compatibility with soil type, climate, and cultural practices are also important considerations. Bordered by its extensive, incompatible with conventional potato production practices, and is not suitable for establishing stands of some of the commonly grown potato varieties, especially in coarse-textured soils. Solid-set portable is extensive, as is linear-move. Center-pivot is a highly susceptible to excessive runoff the other ways unless conservation tillage practices, such as basin or ridge tillage, are utilized. Side-roll and hand-move sinkle systems are more wind-susceptible under windy conditions common across the northern Idaho. Flood irrigation is susceptible to poor water application uniformity, excessive deep leaching, and leaching. Sinkle irrigation is the most common method used for potatoes in Idaho, with center-pivot, side-roll, and hand-move being widely used.

Potato irrigation scheduling for maximum efficiency has been timing and amount of water application determined and applied to minimize soil water fluctuations throughout the growing season.

Successful irrigation management requires regular and active monitoring of soil water and knowledge of field conditions, soil water holding capacity, and crop rooting depth. Efficient irrigation systems are those that allow the grower to maintain a given irrigation schedule from irrigation to irrigation only. This is practically the case for side-roll and hand-move sprinkler systems where soil water holding capacity and crop rooting depth are easily overestimated; and for furrow irrigation, where application depth is difficult to control. These estimations lead to plant water stress when soil water falls below acceptable limits too often days before irrigation, and subsequent irrigation applications are in excess of soil water storage capacity. This challenge is a problem that can generally be attributed to inadequately designed systems, irrigation systems, irrigation limitations, or improper irrigation management.

Deermining 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 the periodic and active measurements of soil water to adjust the computed soil water balance to actual field conditions, provides a cost-effective means for deermining the timing of irrigations. This approach has the added benefit of implicitly deermining the irrigation application amount as well. The conceptual mechanics of the soil water balance approach are provided in the publication

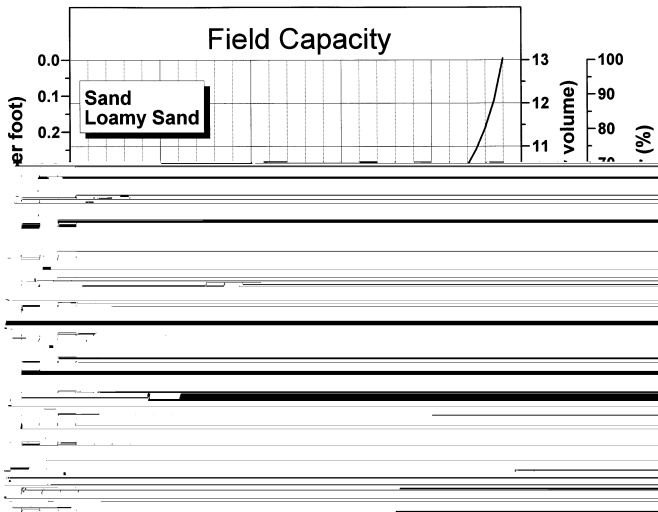
_____ , CIS 1039, University of Idaho, College of Agriculture. The basic steps involved are:



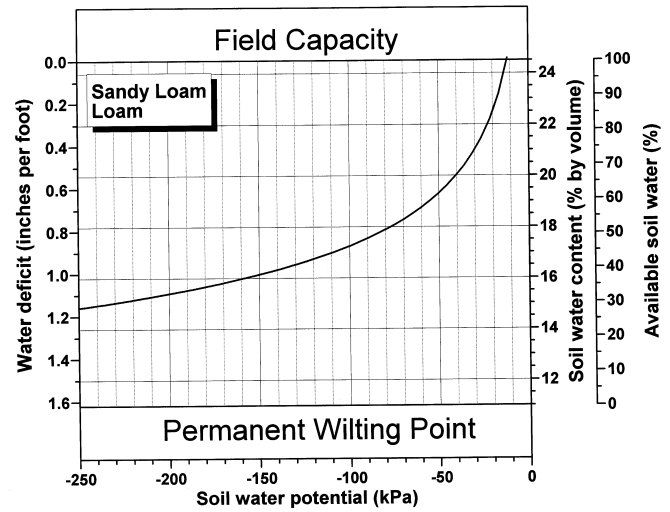
Several methods are available to actively measure soil water content. Only some are suitable for a grower, however, because of the critical threshold level of available soil water and the limited root-zone depth. Many of the methods are

labor-intensive and expensive, requiring expertise, and expensive equipment. This has led to the development of consulting firms specializing in irrigation management, which often provide consultation and management services as well. A detailed discussion of soil water measurement methods is provided in the publication _____ , PNW 475, University of Idaho, College of Agriculture.

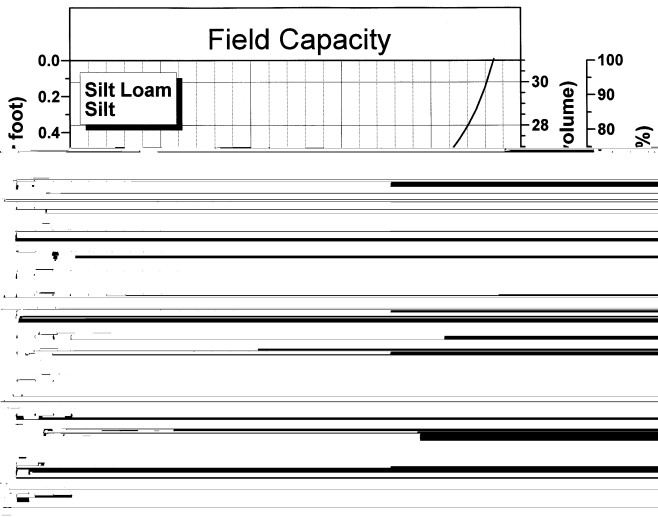
Tensiometers have been used successfully to monitor soil water availability in row crops. Good contact between the soil and tensiometer is essential for proper operation. Tensiometers are often installed in the row crop hill at depths, such as 8 and 16 inches below soil level. Typically, the tensiometer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



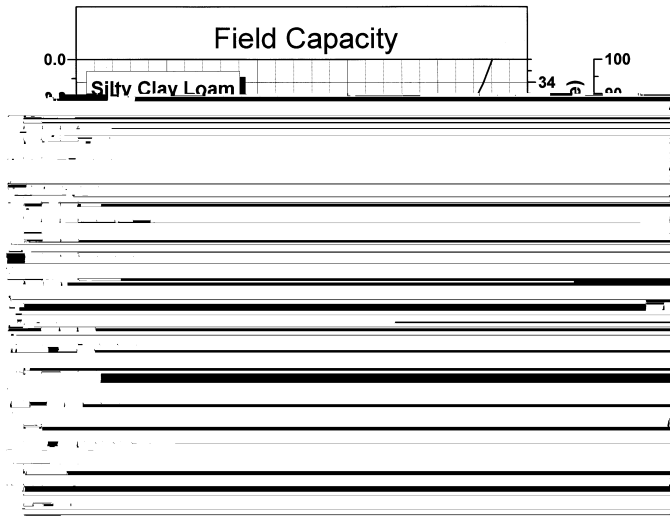
7.



8.



9.



10.

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 on construction firms and large farms. Time domain reflectometry (TDR) offers many features that make it well suited to

soil water measurement in a field. However, the initial equipment cost is quite high. Consequently, each effort 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 content, ASW and water deficit. These curves are essential in the soil water relations that are needed for the development of an effective irrigation management program. They allow soil water content to water potential

measurements to be used to calculate the net irrigation application amount needed to fill the soil water release volume field capacity. For example, if ensiometer shows an average soil water potential of -40 kPa (center) on a sandy loam soil (figure 7), then ASW is 62

the center, 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 the formed 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 net 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 an active soil water measurement.

The range of soil water potential and volumetric soil water content in the root zone at which time irrigation should occur to maintain ASW above 65% 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 ensiometer locations aligned radially to the wheel from the center of a center-pivot irrigated to a field is -40 kPa. The predominate soil type is sandy loam, which at -40 kPa has an ASW of 67% and water

2. 65% ASW

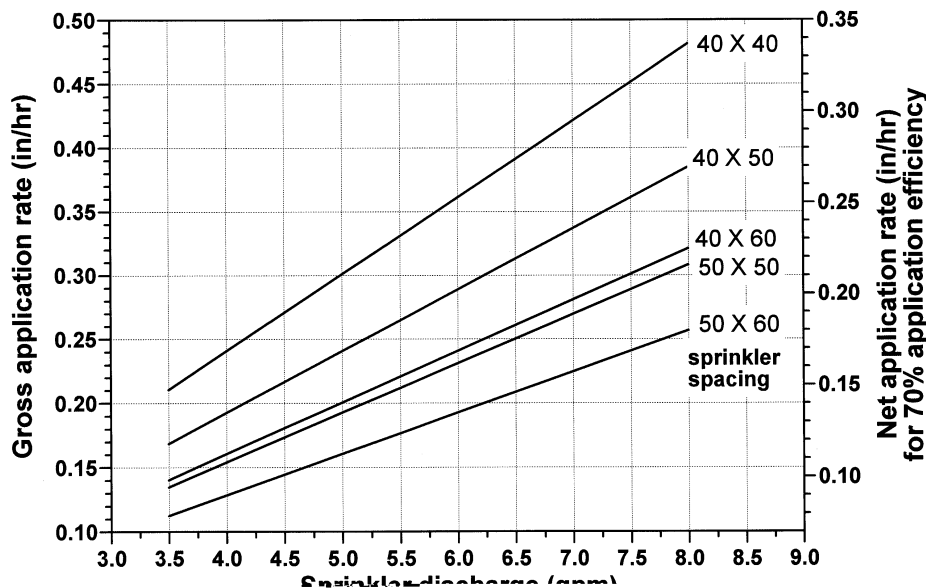
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Gross work rate application rates for
 set-move and solid-set sinkle
 systems, as a function of sinkle
 flow rate and spacing, are presented
 in figure 12. Sinkle flow rate can
 be obtained from figure 13 for
 single-boiler nozzles, as a function
 of nozzle size and pressure. Net
 application rates for 70% efficient
 application efficiency are given in
 figure 12 (right side axis). Net
 application rate for any application
 efficiency can be calculated as:

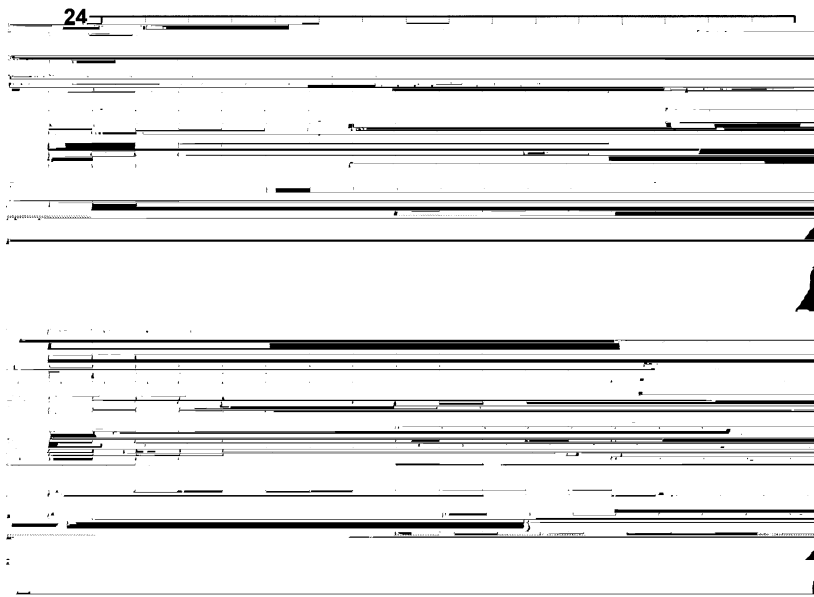
$$E = \frac{A}{B} :$$

(figure 5). However, a full soil water reserve 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-irrigation 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 downward of ASW occurs during the peak-season period.



12. (-) () .



13. (-) () .

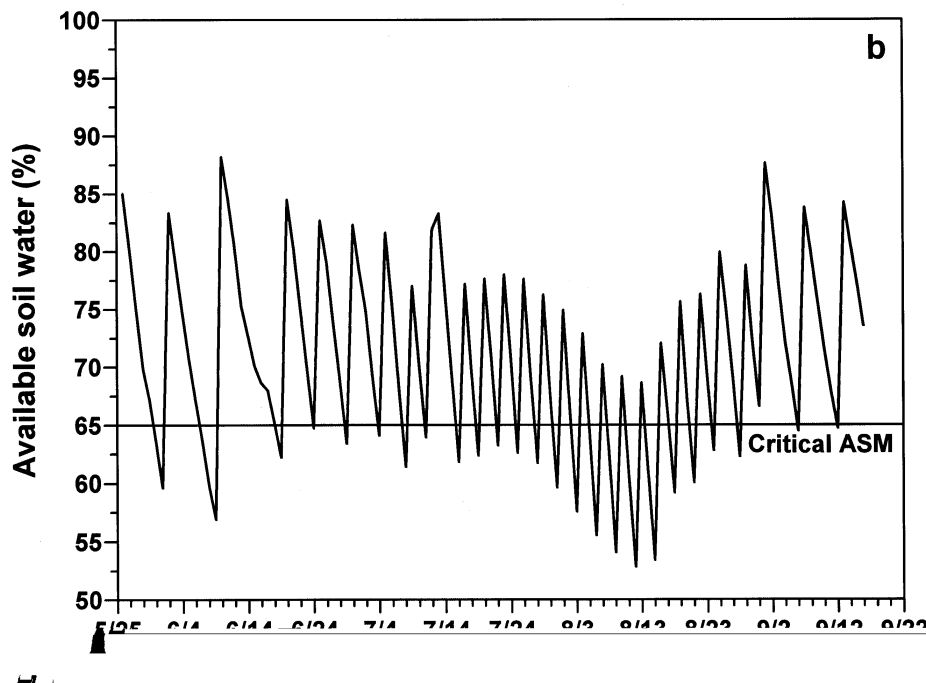
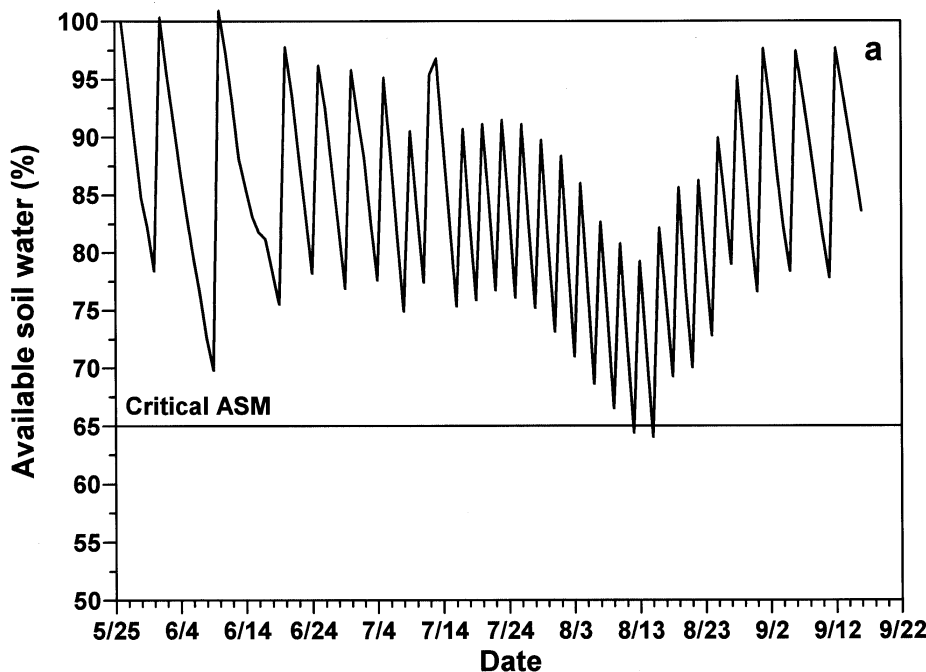
However, in the second case, low ASW values fall below recommended limits, resulting in periodic land water stresses. When this occurs, there is no collective consequence of action as system capacity is fixed. The lime yield and quality depend on the season's climatic conditions as they drive daily ET.

The natural tendency is to seed the center-irrigation system when crop water deficits (stresses) develop. This action only serves to reduce application efficiency because ET is increased by evaporation from the soil and vegetation. Increasing the seed of a center-irrigation reduces the yield of the soil and land can only, thereby increasing the total amount of water loss to evaporation and decreasing the amount stored in the soil. Thus, systems should remain the same to be considered when crop water deficits (stresses) develop. This will increase irrigation efficiency by slowing a greater percentage of water applied in the soil.

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

Conservation tillage practices, such as basin or residue tillage, are required to achieve optimum infiltration uniformity with a consistent

cence - ivo i iga ion. The hilling of
o a o lan s ca s e s Wa e o
concen a e in he f oW nde high



14. A

: () 100% () 85%

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

A common for irrigation practice for a farmer 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 downward laterally over 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, a farmer commonly wets the root zone on the top of the hill and is usually unsuccessful and experiences excessive deep percolation losses. The lateral water distribution problem exists in significant variation in soil water content, varying widely near the furrow and remaining dry on hillsides.

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 ends up the need to be a liability for irrigation and also reduces nitrogen use efficiency.

These limitations have caused many farmers to abandon furrow irrigation in favor of sprinkler irrigation. A common approach is to utilize a completely portable sprinkler irrigation system for a farmer, which can be moved around the farm according to conditions, and using furrow irrigation for the other crops. The advantages of higher gross income and reduced risk with better yields, and higher water

