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Comparison of Tensiometer and Climatological Methods for Estimating Soil Moisture Depletion and Scheduling Irrigation for Potatoes

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COMPARISON OF TENSIOMETER AND CLIMATOLOGICAL METHODS FOR ESTIMATING SOIL MOISTURE DEPLETION AND SCHEDULING IRRIGATION FOR POTATOES

by

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I first became interested in the subject of scheduling irrigations while working with James D. Nafziger, an Idaho consultant in 1969. This experience introduced me to the contribution of proper irrigation management to modern agricultural production. I would like to acknowledge my father, Emery L. Wiser, whose practical knowledge of agriculture and personal encouragement has contributed greatly to whatever accomplishment this study might be.

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Thayne B. Wiser

Thayne B. Wiser

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOTATION

The following symbols are used in this thesis:

cb - centibar
DB - dry bulb temperature (^{O}F)
E* - potential evaporative flux (cal. cm.$^{-2}$)
ed - estimated actual vapor pressure (mb.)
Ep - potential evapotranspiration (in.)
es - mean saturation vapor pressure (mb.)
Et - evapotranspiration (in.)
g - pneumatic potential (cb.)
G - soil heat flux (cal. cm.$^{-2}$)
I, Irr. - irrigation (in.)
K - radiometer calibration factor (cal. cm.$^{-2}$/count)
Kc - crop coefficient
Ki - integrator calibration factor (mv. min./count)
Ks - solar cell calibration factor (mv. cal.$^{-1}$ min.)
m - matric potential (cb.)
mb - millibars
o - osmotic potential (cb.)
p - pressure potential (cb.)
Rb - net outgoing long wave radiation, langleys
Rbo - clear day net outgoing long wave radiation, langleys
Re - effective rainfall (in.)
Rn - net radiation (cal. cm.$^{-2}$)
Rs - solar radiation (cal. cm.$^{-2}$)
Rso - clear day solar radiation (cal. cm.$^{-2}$)
TD - dew point temperature (^{O}F)
Tmn - minimum daily temperature (^{O}F)
Tmx - maximum daily temperature (^{O}F)
TX - average daily temperature (^{O}F)
W - daily wind run (miles)
WB - wet bulb temperature (^{O}F)
Wd - drainage (in.)
z - gravitational potential (cb.)
γ - psychrometric constant
Δ - slope of saturation vapor pressure-temperature curve
Θ - soil volumetric water content (%)
Ψ - water potential (cb.)

ABSTRACT

Comparison of Tensiometer and Climatological Methods
for Estimating Soil Moisture Depletion and
Scheduling Irrigation for Potatoes

by

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Utah State University, 1972

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The purpose of this thesis was to compare the tensiometer and climatic methods of scheduling irrigation of potatoes under field conditions. Tensiometers were placed in a 160 acre field to maintain the crop within the optimum moisture range and schedule irrigations. An automatic solid set system was used to apply water to the potato crop. Instrumentation was used to determine daily input for the climatological method. Daily evapotranspiration (Et) was computed and Et (tensiometer) was compared with Et (climatic). The results showed total variation of the climatic method from the tensiometer method of .62 inches or less than 5 per cent. The study indicated that the climatological method would have under irrigated the potato crop by .62 inches during the 48 day study. Variations are also shown for each irrigation interval. Results indicated that a combination of both methods would allow the most feasible approach to scheduling irrigation of potatoes. (55 pages)

INTRODUCTION

In commercial food production many managers and owners are being forced to critically readjust approaches in farming to maximize production and profits while minimizing their costs of operation. The academic world has made countless innovative discoveries which can greatly help agricultural producers to accomplish their objectives. Nonetheless, there seems to be a "generation gap" between academics and application. Experience has proven that many farming operators are not well acquainted with basic principles which govern agricultural production.

While much scientific information has little application in the practical world of modern agriculture, some has great applicability if properly used. One of the most nebulous areas in farming and ecology is the proper use of commercial fertilizers and water in arid agricultural production. Nitrate nitrogen is very soluble in the soil water and therefore, excessive irrigation can affect the efficiency of its use. In addition, irrigation water is being recognized as a precious resource and must be conserved.

In light of the above setting, one of the greatest contributions that can be made to agriculture is to provide a consulting service to farm operators--one that will supply them with feasible solutions to their problems.

The efficient use of irrigation water to optimize plant growth is one of the most important present problems that can be solved by appropriate consulting advice. This thesis attempts to treat part of this problem.

The key to efficient use of irrigation water management is the determination of proper timing and amount of irrigation water application. Two general methods have been advocated to determine when to irrigate and how much water to apply. The first is a direct method of monitoring the availability of water to plants using tensiometers and applying water when the soil water potential reaches a given value. The second method involves estimation of water depletion by Et from climatic data and a water budget accounting to determine when soil water depletion reaches a given low value.

Objective

The objective of this study is to compare the tensiometer and climatological methods of estimating soil moisture depletion to schedule irrigation of potatoes. The tensiometer method tested will be that used by Soil Moisture Control Service, Inc. of Twin Falls, Idaho. The specific climatological method tested will be that of Jensen (1971).

LITERATURE REVIEW

Soil Moisture Control of Potatoes

Irrigation has allowed greater crop production through the utilization of arid soils. Also, where rainfall has been the main source of water, irrigation has been employed to supplement natural precipitation for the production of many crops including potatoes. The potato is very specific in its moisture needs. These needs can be met by a combination of the reserve of water in the soil, irrigation, and precipitation (Singh 1969). Potatoes are very sensitive to fluctuations of soil moisture (Thompson and Kelley 1951). Thorne and Peterson (1954) have pointed out that potato plants are sensitive to moisture variations, more so than other plants, because of a high requirement for soil aeration. Therefore the plants require moisture variation within a narrow range to allow aeration but at the same time allow good availability of soil moisture. Temporary drouth will reduce yields and quality as will over-irrigation (Vomocil 1969).

Most research work related to potato production has been on effects of seed, fertilizers, and factors other than moisture control (Haddock 1961). Recently attention has been directed to the control of soil moisture and its effect on quality and yield of potatoes (Jensen, Robb, and

Franzoy 1969). Potatoes are very sensitive to over-irrigation because of induced anaerobic conditions which reduce size of tubers and the amount of tuber sets (Jackson 1962). This is especially critical when the plants are small (Singh 1969).

The amount of moisture available to a potato plant is critical through various stages of the plant life cycle (Prince and Blood 1962). If a potato is kept within the optimum moisture range, maximum yield and quality will be realized (Struchtemeyer 1961). The three stages of plant development referred to by Prince and Blood (1962) have been defined by Steinek (1958). The time from emergence to three weeks is the first stage termed stolon formation. The second stage is tuber setting, which occurs from four to five weeks, and the third stage including the second stage is defined as tuber formation. The third and final stage lasts from tuber set through maturation.

Abnormalities in tubers are often directly related to wide fluctuations of soil moisture beyond the optimum range (Thompson and Kelley 1951). These abnormalities often occur with the plant in stage two. The author has observed that during the first stage if plants are irrigated with a normal two inches of moisture, plant damage will result, possibly due to reduced soil aeration for extended periods and incidence of rhizoctonia root rot. This has been verified by Thorne and Peterson (1954), Thompson and Kelley (1951), Prince and Blood (1962) and Bauer (1951). Bauer

(1951) also indicated that high moisture conditions in the root zone adversely affect the physiological processes of the plant. A report from Robin and Domingo (1956) showed that high moisture stress during any stage of plant growth caused abnormalities and reduced yields.

Harris (1917) found reduced yields and quality of potatoes occurred when irrigation was too early, too late or if the amount applied was too small or too large. The first irrigation was advised after emergence, toward the end of stage one. If irrigation were applied before emergence, damage to the plant generally occurred.

It is apparent that optimum moisture conditions allow optimum growth due to greater stolon formation and a better tuber set. This optimum moisture range was defined as greater than 50 per cent available moisture (Bradley and Pratt 1955). Powers and Johnston (1920) observed early that the best time to irrigate potatoes was when the water content reached 20 per cent on a dry weight basis. Water content will vary on a per cent dry weight basis for each soil, emphasizing the need for a better expression of soil moisture availability. Later recommendations staged that moisture should not drop below two-thirds of the available range (Cycler 1946) or that depletion of soil moisture should not exceed 50 to 60 per cent of field capacity (Jacob et al. 1952). Blake, Grill, and Campbell (1955) reported that more frequent light irrigations (1.2 to 2.2

inches) allowed higher relative yields and quality of potatoes.

The best irrigation frequency for potatoes is a function of the irrigation system, consumptive use rate, water holding capacity of the soil, maximum and minimum allowable soil matric suctions and the water extraction patterns of the plant (McMaster 1969). To properly schedule irrigations with sprinkler systems it is necessary to know how much water is applied at each irrigation (Jensen, Wright, and Pratt 1969). This can be correlated with tensiometer readings to project the following irrigation using weather projections and past water use rates.

In summary, it is apparent that potatoes are very sensitive to moisture. It is necessary to keep the plants within an optimum soil moisture range to achieve maximum yield and quality throughout all three stages of plant development. The optimum range, using a tensiometer placed 12 inches deep within the hill, is from 15 centibars to 50 to 60 centibars. If a potato plant is maintained within this range the most efficient use of water and fertilizer will occur.

Tensiometer Method for Estimating Soil Moisture Depletion

According to Penman (1950) only the tensiometer measures directly what stress the plant must overcome to absorb water from the soil if salts in the soil solution are low. This stress is defined by Rose (1966) as the soil matric potential. Kramer (1969) states that direct field measurements of the soil matric potential can only be made with tensiometers. Soil matric potential is by definition negative. To eliminate the negative sign, soil matric suction or tension has been defined to be equal to the negative of the soil matric potential (Hanks 1970). Tensiometers fit well into the osmotic theory of water uptake by plants. The following soil water potential equation exists:

$$\Psi = z + p + o \qquad (1)$$

where $p = m + g$, and where (Rose 1966)

Ψ is defined as the soil water potential, z the gravitational potential, p the pressure potential and o the osmotic potential. The pressure potential is the summation of the matric potential (m) and pneumatic potential (g) (Rose 1966, Hanks 1970). In most field situations the pneumatic potential and the osmotic potential are essentially zero. If water flow is small in the verticle, the gravitational potential is also zero. With the above restrictions the tensiometer essentially measures the soil water potential. The actual mechanism of water uptake by plants occurs when a $\Delta\Psi$ or water potential gradient exists from the soil through the plant to the surrounding air. The ultimate force of water uptake is evapotranspiration (Salisbury and Ross 1969).

Rose (1966) discussed the tensiometer method of monitoring the soil matric potential and the use of measurements of matric potential as an index of the soil moisture depletion. Once the optimum range is defined for the specific crop and soil, the tensiometer data can be used to schedule irrigations. Graphs of tensiometer data can be found in Kramer (1969). At 3600 feet mean sea level the tensiometer indicates well from 10 centibars to 70 or 80 centibars. This fits perfectly into the range needed for potatoes (Timm and Flocker 1966, Oebker 1962).

It is undoubtedly more meaningful for plant growth to set standards of optimum soil moisture range than soil water content (Hanks 1970). Tensiometers have been widely used to monitor soil matric suction. Oebker (1962) reported that in using a tensiometer to monitor soil matric suction at approximately 12 inches deep in the potato row, irrigation should be made between 50 to 60 centibars to allow maximum quality and yield. Other data from Timm and Flocker (1966) indicated that the most effective use of water and fertilizer occurred when potatoes were irrigated near 50 centibars for a 12 inch tensiometer. Stockton (1962) advised that the range of 40 to 60 centibars at 10 inches with tensiometers, is the optimum time to irrigate, while Blake, Grill, and Campbell (1955) advocated an optimum range, in sandy soil at 6 inches, from 67 centibars to 133 centibars. To relate tensiometer readings to available moisture in silt loam soils, Haise and Hagan (1967) reported that at 50 centibars, approximately 30 per cent of the available moisture is depleted. If 100 centibars were approached, about 57 per cent of the available moisture should be depleted in the same soil.

The lower values of the optimum matric suction range have not numerically been defined by any investigations. However, from the information given by Thorne and Peterson (1954), Thompson and Kelley (1951) and Bauer (1951), irrigation should not be applied to the extent that 12 inch tensiometers remain below 15 centibars for more than 24 hours after irrigation.

Commercial operators use the tensiometer method to schedule irrigation for many crops. Soil Moisture Control Service, Inc. of Twin Falls, Idaho uses the tensiometer data to schedule irrigation of potatoes and other crops. The company has determined that the instrument requires readings every second to third day in order to properly graph the fluctuations of soil moisture tension. The data from tensiometers can be used in conjunction with weather forecasts and past information to schedule irrigations. The basic disadvantage is the need to maintain and read the instruments on a regular basis.

Climatological Method for Estimating Soil Moisture Depletion

Jensen (1971) of Idaho is the "father" of computerized irrigation scheduling. He has worked extensively on application of the climatological approach to sequentialize the delivery and application of water to farms not only in Idaho but in Washington, Arizona, and other states. In

Southern Idaho much attention has been given to the use of computer methods to schedule irrigation of many crops including potatoes (Jensen 1971). Brown and Buchheim (1971) reported the results of the Minidoka Project at the National Conference on Water Resources Engineering. Climatological data was used to compute daily moisture loss. Correlation with soil and field data allowed the scheduling of irrigation of 54 farms including many different crops. Jensen and Heermann (1970) point out that this concept of irrigation scheduling using climatological data is not new. It has not, however, been developed for practical use until the last two years (Jensen, Robb, and Franzoy 1969).

The individual farmer has not adopted the latest scientific principles of irrigation rapidly because he lacks time, technical background, and sufficient information to implement such principles. This provides service companies an opportunity to supply farm operators the necessary recommendations and data to properly schedule irrigations (Jensen 1971).

The climatological method is currently being used by the Salt River Project in Phoenix, Arizona. C.E. Franzoy, senior engineer, is supervising computerized irrigation scheduling of some 3,690 acres. Problems of proper crop coefficients, optimum moisture depletion, stages of plant growth, and irrigation uniformity are being solved to upgrade the program. Limitations in the system at the present time are weather data and crop cover date assignments

(Franzoy and Tankersley 1970). The results of the Salt River and the Minidoka Projects indicate that the climatological method is very sound, being practically limited only by nonprecise field and crop data.

Input data

Three categories of input data for the climatological method are required: (a) Basic or fixed data for each field, (b) current meteorological data for the region, and (c) current data for each field.

The basic data consist of area meteorological data used to compute potential Et and data for each field. The latter involves the crop factor, estimated effective cover data and the maximum amount of soil water that should be depleted by evapotranspiration for each crop (Heermann and Jensen 1970).

Current meteorological data required for each region are: Minimum and maximum daily air temperatures (Tmn and Tmx respectively), daily solar radiation (Rs), daily dew point temperature (TD), and wind run (Wd) for each calendar day. An optional, brief weather forecast can be included for the area (Jensen and Heermann 1970).

Current data for each field are: The date of the last irrigation, the allowable soil moisture depletion at the particular stage of plant growth, the date of the last irrigation if it falls within the current computation period, and the rainfall and/or irrigation amount with its date of occurrence (Jensen and Heermann 1970).

Other Methods of Estimating Soil Moisture Depletion

Other commercial methods of measuring soil moisture depletion are limited in practice to a few procedures. Gypsum blocks are employed measuring electrical conductivity of a saturated gypsum solution whose volume is controlled by soil moisture tension (Vomocil 1969). Some direct electrical resistance probes are used but are not recommended because readings are affected by many factors in addition to soil moisture content (Hanks 1970). Gravimetric samples have been used by a firm in Washington to determine soil water content but this has many disadvantages. Soil samples must be taken at regular intervals and placed in ovens to determine the water content. Excessive time and processing of samples along with soil-plant calibrations for each field have limited this method. Instruments such as the neutron and gamma probes have not been used extensively by commercial service organizations due to the technical nature of the instruments and their cost.

Another climatological method uses direct pan evaporation to determine daily moisture loss from an irrigated field (Hagood 1964). The Washington State Experiment Station prepared a scheduling board to keep daily water budgets. The basis of this approach is that plant consumptive use will equal pan evaporation times a pan coefficient. The disadvantage of the pan evaporation method is the need for proper care and placement of the pan in a standard environment. This has not been used extensively due to these disadvantages (Jensen and Middleton 1969).

MATERIALS AND METHODS

The research data collected for this thesis were from a 160 acre potato field on the Bell Rapids Irrigation Project west of Twin Falls, Idaho. The irrigation project will expand to about 20,000 acres in various stages. The research field was first irrigated in 1970 and produced an excellent potato crop. Soil Moisture Control Service, Inc. of Twin Falls provided moisture control for this potato crop using tensiometers.

Tensiometer data were collected by the company during the 1971 season on the second potato crop. These data were used for this thesis to maintain the potatoes within the defined optimum moisture range.

The 160 acre potato field was irrigated with an automatic solid-set system (Figure 1). Tensiometers were placed in the potato rows at 10-12 inch depths at 10 locations and 16-18 inch depths at 4 locations (Figure 1). The instruments were placed midway between the 4 sprinklers of the rectangular spacing. This allowed for all tensiometers to monitor relatively the same location with respect to water source to facilitate correlation of data to schedule irrigations.

Soil Water Budget

The objective of this study requires that a common point be defined so that the tensiometer and climatological methods can be compared. The following equation relates the components of the soil water budget:

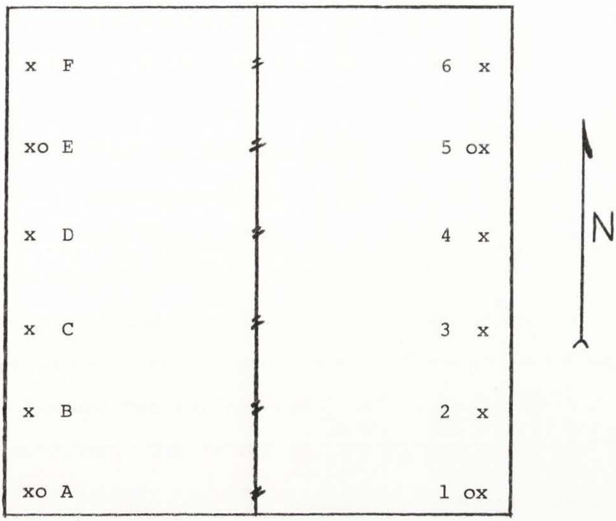
$$Et = I + Re - Wd - \Delta\Theta \qquad (2)$$

where $\Delta\Theta$ = change in soil water content, Et = evapotranspiration, Re = rainfall, I = irrigation and Wd = drainage from the root zone. All units are in inches of water. Inputs to soil moisture are rain and irrigation. These were measured and accounted for in this study. Outputs of soil moisture were evapotranspiration and drainage. In this study there was no effective rainfall, and drainage was assumed zero (discussed later). Thus using the tensiometer method, from which $\Delta\Theta$ was measured, Et (tensiometer) was computed after I was measured.

When the climatic method was used, Et (climatic) was estimated which allowed for computation of $\Delta\Theta$ when I was measured. Thus the tensiometer and climatic methods were compared by making a comparison of measured $\Delta\Theta$ (tensiometer) with estimated $\Delta\Theta$ (climatic) or on the other hand, a comparison of estimated Et (tensiometer) was compared with calculated Et (climatic).

Tensiometer Method

Tensiometers were installed by Soil Moisture Control Service, Inc. of Twin Falls to schedule irrigation in the 160 acre test field. The tensiometers were installed on July 1 and problems of proper tip contact, soil settling, and calibration were minimized by July 15 to improve the quality of tensiometer data for this study. Readings of soil matric suction were taken approximately the same time of the day every two or three days throughout the period of the study (see Table 1). Irrigation of the potatoes was done when soil matric suction approached 55 to 60 centibars. Tensiometers were spaced to estimate moisture variability in the field and the relative depletion between irrigations. Irrigation was done using five groups of 10 one-half mile lateral solid-set lines each. Complete irrigation therefore could be made in five sets. Twelve-hour irrigations required two and one-half days for complete coverage of the field and eight-hour irrigations allowed complete coverage in less than two days. Figure 1 shows the position of tensiometer stations in the potato field. The stations were placed between the third and fourth sprinklers from the end to minimize field perimeter effects and to facilitate readings.



where —//— signifies the sprinkler mainline, x indicates a 12 inch tensiometer and o indicates an 18 inch tensiometer. Three inch lateral lines were on 40 X 50 foot rectangular spacings. Letters A through F and numbers 1 through 6 identify individual tensiometer stations. 1 inch = 660 feet.

Figure 1. Solid set irrigation layout on 160 acre potato field.

Climatological Method

The climatological method includes use of meteorological data to estimate daily Evaporation (Ep) for a given crop and location. The basic data for computation of Ep from climatological parameters included minimum and maximum daily temperatures, total wind run in miles, wet and dry bulb temperature (WB and DB respectively) at 5 PM each day and total observed radiation. This complies with Jensen (1971) and other references except Jensen uses 8 AM wet bulb-dry bulb temperatures. The 5 PM readings allow Tmx and Tmn for the same day including wet bulb-dry bulb readings. The latter should approach the average relative humidity and dew point temperature for the day. According to Salt Lake City summer data, at 5 PM a dew point temperature would approach its minimum value causing the Ep to be overestimated slightly. Since the dew point temperature varies from a maximum in the morning to a minimum in late afternoon, these data resulted in a higher estimation of the Ep. However, this error probably increased the application of the climatological method where advective conditions are prevalent by compensating for underestimation by other factors (Jensen and Heermann 1970). Bell Rapids is situated in a desert area where advection has a great influence on irrigation. To evaluate the magnitude of error, data from Salt Lake International Airport were obtained. These data show that the daily variation and range of dew point temperatures throughout the day (see Table 1). The deviation of 5 PM readings were about equal to one-half the daily dew point temperature range. This would affect calculated Ep slightly.

The daily Tmx and Tmn were taken in a standard weather bureau shelter near the corner of the potato field. Daily wind run was taken above the crop from a totalizing anemometer at 2 meters elevation. A sling psychrometer was employed to determine the dew point temperature at 5 PM every day. This was done in accordance with the manufacturer's recommendations for the psychrometer. A solar radiometer was utilized with a silicon sensor and a portable integrator to measure incoming solar radiation as follows:

$$Rs = \int_{t1}^{t2} Sdt = K\ (C_1 - C_2)\ \text{counts}$$

where

$$K = \frac{Ki}{Ks} = \frac{9.22\ \text{mv. min./count}}{34.05\ \text{mv. cal.}^{-1}\ \text{min.}} = .271\ \text{cal. cm.}^{-2}\text{/count} \quad (3)$$

and K is the calibration coefficient of the integrator and a solar cell with Ki and Ks the constants for each, respectively. The system integrated solar radiation with respect to time allowing determination of total radiation to the crop. The silicon sensor was mounted atop a potato cellar roof to eliminate shadowing effects and minimize problems of foreign matter covering the sensor. Two silicon sensors were calibrated so if failure occurred, a replacement would be available. All data were taken by cell 1 with a K factor of .271.

Table 1. Daily variation of dew point temperatures

	June	July	August
Time of Day	Dew Point Temperature ^{0}F		
0500	41.2	45.7	46.6
1100	39.7	44.0	46.3
1700	37.2	40.5	42.2
2300	42.3	45.9	46.2
Range	5.1	5.4	4.4

NOTE: Average temperatures from 1951 through 1963 taken at Salt Lake City International Airport (Richardson 1972).

The objective of the climatological method was to estimate soil moisture depletion ($\Delta\Theta$) by computing the value of Et. With measurement of rainfall (Re), irrigation (I), and drainage (Wd), the method can be compared with the tensiometer results depicted in Equation 2 as follows:

$$Et = I + Re - Wd - \Delta\Theta$$

Values for $\Delta\Theta$ were obtained from the tensiometer.

Potential evapotranspiration

The potential evaporative flux E* was computed as follows:

$$E^* = \frac{\Delta}{\Delta+\gamma}(Rn - G) + \frac{\gamma}{\Delta+\gamma}(15.36)\ (1.0 + 0.01W)\ (es - ed) \quad (4)$$

where Δ is the slope of the saturation vapor pressure-temperature curve (de/dt), γ is the psychrometric constant, ed is the actual vapor pressure based on saturation vapor pressure at mean dew point temperature, and es is the mean saturation vapor pressure in millibars. W is the total daily wind run in miles at 2 meters, Rn is daily net radiation in cal. $cm.^{-2}$, and G is the soil heat flux in cal. $cm.^{-2}$ (values of $\frac{\Delta}{\Delta+\gamma}$ are found in Appendix Table 7) (Jensen and Heermann 1970).

The Penman equation tends to underestimate E* when high advective conditions occur (Jensen, Wright, and Pratt 1969). The daily potential evaporative flux E* was converted to inches of potential evaporation, Ep using 585 cal. $gm.^{-1}$ as the latent heat of vaporization, (Ep = 0.000673 E*) (Jensen, Robb, and Franzoy 1969).

Net radiation

Daily net radiation was estimated using:

$$Rn = 0.77\ Rs - Rb \qquad (5)$$

$$Rb = (a\,\frac{Rs}{Rso} + b)\ Rbo \qquad (6)$$

$$Rbo = (0.32 - 0.044\ \sqrt{ed})\ (11.71 \times 10^{-8})\ \frac{Tmx^4 + Tmn^4}{2} \qquad (7)$$

where Rn is daily net radiation, Rs is observed solar radiation for the day, Rso is clear-day solar radiation, 0.77 is 1-albedo (.23) for a green crop with full cover, Rb is the net outgoing long wave radiation, Rbo is the net outgoing long-wave radiation on a clear day, ed is the saturation vapor pressure at mean dew point temperature in millibars, 11.71×10^{-8} is the Stefan-Boltzman constant in cal. $cm.^{-2}\ day^{-1}\ {}^{0}K^{-4}$, and Tmx and Tmn are the daily maximum and minimum air temperatures, respectively, in ^{0}K (values for Rso are found in Appendix Table 8) (Heermann and Jensen 1970). The constants a and b in Equation 5 are valued 0.75 and 0.25, respectively, under Idaho arid conditions where nights are generally clear.

Soil heat flux

The daily soil heat flux (G) was estimated by Jensen and Heermann (1970) as: G = (average air temperature - average air temperature for the three previous days in ^{0}F) X 5. However, where larger temperature variations do not occur from day to day, G will be small and can be neglected (Jensen, Robb, and Franzoy 1969, Hanks 1970).

Evapotranspiration

Evapotranspiration (Et) for a specific crop and field was estimated using:

$$Et = Kc\ Ep \qquad (8)$$

where Kc is a dimensionless crop coefficient representing the combined relative effects of water movement from the soil to the evaporative surface and the relative amount of radiant energy available as compared to the reference crop. The value of Kc for potatoes through the period of this study was defined as .9. The crop factor was used in Southern Idaho because the crop was at full effective cover for the length of the experiment. This allows the following expression of Et:

$$Et = .9\ Ep \qquad \text{(Wright and Jensen 1971)}$$

Rainfall and irrigation

Daily inputs of moisture into the soil are recorded and entered for each field. The runoff should be considered and deducted from the values (Jensen and Heermann 1970).

Drainage

Water applied through irrigation or rainfall may cause soil moisture depletion to be zero. If additional depression occurs the drainage must be deducted from total input to account for runoff or deep percolation through the root zone.

Treatment of Data and Irrigation Procedure

Thirty five gravimetric samples were taken from representative areas to calibrate the matric potential in terms of volumetric water content (Θ) (Figure 2). This was done on July 15 at which time the first irrigation for this study was initiated and at the end of the study on August 30. Other irrigations were made when appropriate tensiometer readings of 55-60 centibars occurred at 12 inch depths. Since the instruments were on the drying cycle each time irrigation occurred, hysteresis was not a problem (Hanks 1970).

The tensiometers were used to evaluate the field moisture content (Θ) at initiation of the study. Θ was determined using the 12 inch tensiometer reading to evaluate the moisture content from 6 to 15 inches. The 18 inch tensiometer reading was used to evaluate the 15 to 24 inch soil moisture content. Since all readings were taken prior to irrigation each time, the change in Θ at 0 to 6 inches and below 24 inches was assumed constant for the length of the study.

On July 14, the average 12 and 18 inch tensiometer readings were recorded to evaluate initial soil moisture content. Using a calibration curve, the readings in centibars were converted to volumetric water content. The average value of Θ was approximated by using the average of the 12 and 18 inch tensiometer readings. The procedure was

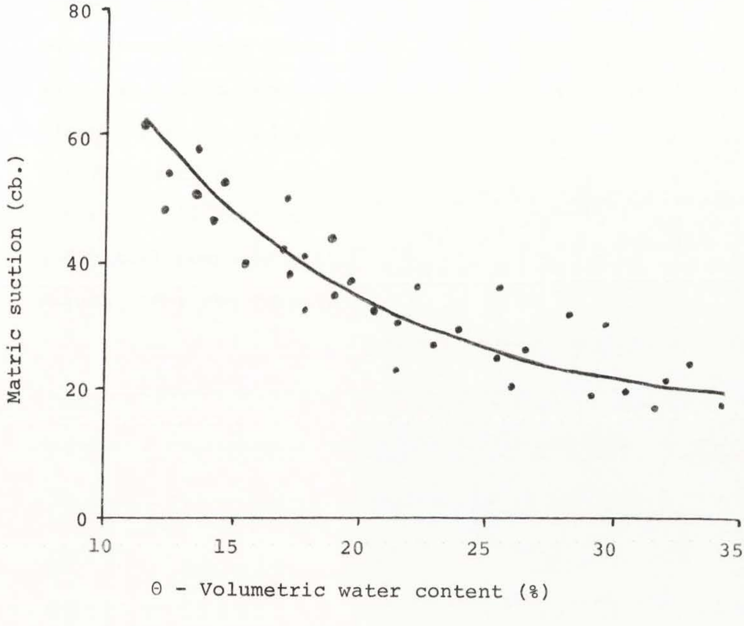


Figure 2. Moisture calibration curve for soil in the Bell Rapids Project.

used in estimating $\Delta\Theta$ by evaluating Θ on July 14 and August 31.

During the study, all necessary data were compiled to compute Ep for the climatological method. Wet buld and dry bulb temperatures were converted to dew point temperatures using a standard wet bulb-dry bulb-dew point temperature table. The values of $\frac{\Delta}{\Delta+\gamma}$ and $\frac{\gamma}{\Delta+\gamma}$ were taken from Appendix, Table 1. A yearly average of clear day solar radiation at Kimberly, Idaho, was used for values of Rso. Those data were included in Appendix, Table 2. All data were recorded and Etp computed using a digitial computer with focal programming (see Appendix, Figure 7 for the computer program).

RESULTS AND DISCUSSION

Individual tensiometer readings for the study are shown in Table 2. The data indicated that throughout the study the potatoes were generally maintained within the optimum moisture depletion range of 15 centibars to 60 centibars. Some instruments indicated higher values but these were individual problems caused by irrigation problems. Variations near station A were attributed to the shallow soil.

The soil moisture content (Θ) at the beginning of the experiment was evaluated by the tensiometers. To measure the precision of the calculated Et (tensiometer) it was necessary that the field moisture conditions on August 31 be compared with those of July 15 when the experiment was initiated to determine if any difference in water content existed. Table 3 compares the initial and final moisture conditions of the study. The final moisture content on a volumetric basis was 1.2 per cent less on August 31 than July 14 at the 12-inch depth. The 18 inch moisture status was 4 per cent less on August 31 than July 14 (Table 3). Even though this error seems small with an effective root zone of 24 inches and an average $\Delta\Theta$ of -2.6 per cent, the actual difference in soil moisture content $\Delta\Theta$ was -.62 inches of water (Table 3). With $\Delta\Theta = -.62$ inches of water from July 15 through August 31, the total amount of

Table 2. Tensiometer data

Date	Stations					
	A^{12} A^{18}	B^{12}	C^{12}	D^{12}	E^{12} E^{18}	F^{12}
	1^{12} 1^{18}	2^{12}	3^{12}	4^{12}	5^{12} 5^{18}	6^{12}
July 14	44-50	46	22	50	52-50	47
	21-38	42	38	38	42-41	46
July 16	49-51	irr	12	29	53-49	20
	29-38	irr	18	41	41-40	24
July 20	22-27	40	44	irr	22-35	24
	51-63	42	44	irr	38-40	44
July 23	23-29	41	32	48	32-32	39
	55-66	31	34	55	45-50	59
July 26	56-73	29	63	63	50-53	40
	21-30	35	33	42	32-32	34
July 28	62-70	39	64	62	57-58	55
	20-30	40	49	40	37-36	50
July 31	irr	62	24	58	25-40	26
	irr	42	25	26	28-38	27
Aug. 1	XW-X	27	25	46	31-39	34
	30-39	30	26	32	29-31	24
Aug. 2	26-61	31	19	50	38-43	43
	16-40	34	30	42	33-33	27
Aug. 4	38-59	41	47	54	50-47	irr
	27-37	47	45	52	37-37	irr
Aug. 6	irr	29	15	24	26-32	25
	irr	22	18	26	31-34	27
Aug. 9	28-32	34	31	39	42-38	48
	18-20	38	34	30	35-34	45
Aug. 11	41-40	48	48	55	66-45	57
	27-32	53	43	48	45-37	63
Aug. 13	51-48	irr	10	27	70-60	26
	37-40	irr	10	26	21-22	18

Table 2. Continued

Date	Stations					
	A^{12} A^{18}	B^{12}	C^{12}	D^{12}	E^{12} E^{18}	F^{12}
	1^{12} 1^{18}	2^{12}	3^{12}	4^{12}	5^{12} 5^{18}	6^{12}
Aug. 16	27-25 16-32	31 36	21 26	37 35	66-40 27-25	40 30
Aug. 18	34-39 21-30	44 37	27 33	53 45	70-40 29-29	51 28
Aug. 25	67-61 57-46	68 59	53 63	irr irr	XW-XW XW-69	XW XW
Aug. 31	37-68 34-56	38 36	43 47	47 45	51-XD 49-74	46 47

Irr signifies that the station was being irrigated and XW indicates that the tensiometer had broken tension but the soil was wet. To see location of each station refer to Figure 1.

Table 3. Initial and final moisture status

Tensiometer Readings in Centibars

Date	Stations						Average	
	A^{12} A^{18}	B^{12}	C^{12}	D^{12}	E^{12} E^{18}	F^{12}		
	1^{12} 1^{18}	2^{12}	3^{12}	4^{12}	5^{12} 5^{18}	6^{12}	12"	18"
July 14	44-50	46	22	50	52-50	47	40.5	45.0
	21-38	42	38	38	42-41	46		
Aug. 31	37-68	38	43	47	51-XD	46	44.5	66.0
	34-56	36	47	45	49-74	47		

Units in Centibars

Variation at 12"   44.5 - 40.5 = 15.8 - 17.0 = *1.2%

Variation at 18"   66.0 - 45.0 = 11.5 - 15.5 = *4.0%

*Taken from Moisture calibration curve, Figure 2

Given: A 24 inch effective root zone depth and an average Δθ of 2.6%, then the water content difference (Δθ) is about -.62 inches.

irrigation water applied plus .62 inches equalled the estimated amount of water evapotranspired (tensiometer) assuming no effective rainfall or drainage.

Visual observations were made in three representative areas to evaluate moisture loss from the root zone (drainage). At three feet, dry soil was observed. Due to the limited application of water through the solid set system for the extent of the study it was concluded that very little, if any, moisture was lost from drainage.

The water budget from the tensiometer method yields the following, using Equation 2:

$$Et = I + Re - Wd - \Delta\Theta$$

$$= 11.50 + 0 - 0 - (-.62)$$

$$= 12.12 \text{ inches}$$

The tensiometer method therefore shows that the total amount of Et was 12.12 inches of water for the period of July 15 through August 31 using an average of all tensiometer readings (Table 3). No measurable rainfall occurred during the study.

Computed Ep from climatological data is found in Table 4 for each day. Et (climatic) was determined using Equation 4. The meteorological data are also included in Table 4. Clear-day solar radiation (Rso) from seven years is included in Appendix Table 8, which was employed to compute daily Ep because of a lack of these data for the Bell Rapids Project. Since the distance of Kimberly, Idaho from

Table 4. Climatological data used to compute Ep

Date		Ep in.	Counts	Rs cal-cm^{-2}	Wind Run miles	Temperature °F Tmx	Tmn	TX	TD	WB	DB
7	15	.314	2327	630	104.6	100	63	82	61	72	96
	16	.303	2231	604	122.8	98	64	81	64	73	95
	17	.320	2371	642	87.5	100	65	83	52	69	96
	18	.258	1584	429	112.3	99	64	82	57	70	96
	19	.256	1996	540	62.0	98	65	82	59	70	94
	20	.298	2276	616	93.2	99	64	82	62	72	95
	21	.318	2374	643	108.0	95	64	80	51	66	91
	22	.260	2139	579	80.0	92	62	76	59	69	90
	23	.249	2079	563	61.0	93	60	76	57	69	91
	24	.292	2124	575	99.0	97	62	80	54	68	94
	25	.372	2185	591	207.6	96	62	81	57	70	96
	26	.365	2660	720	118.6	95	58	72	45	64	93
	27	.343	2147	581	157.0	96	59	73	54	68	94
	28	.373	2231	604	200.3	100	61	81	57	70	96
	29	.338	2471	669	92.0	102	59	81	46	66	97
	30	.312	2351	636	58.0	102	51	76	34	62	98
	31	.278	2192	593	50.7	100	63	82	32	60.5	95
8	1	.273	1911	516	102.0	101	60	80.5	63	74	98
	2	.292	2104	571	69.0	102	66	84	44	65	97
	3	.265	1851	501	77.0	98	62	80	45	64	94
	4	.230	1694	459	54.0	100	68	84	61	73	96
	5	.261	2148	581	70.0	100	63	83.5	69	77	97
	6	.243	1863	504	76.0	95	62	76.5	60	70	92
	7	.257	1859	503	82.0	98	65	81.5	58	70	94

Table 4. Continued

Date		Ep in.	Counts	Rs cal-cm^{-2}	Wind Run miles	Tmx	Temperature °F Tmn	TX	TD	WB	DB
8	8	.301	2289	620	77.0	99	65	82	49	67	96
	9	.256	2012	545	44.0	101	63	82	52	68	97
	10	.274	1718	465	101.0	99	65	82	47	66	98
	11	.281	2416	654	43.0	98	63	81	45	65	96
	12	.275	1953	529	97.0	98	62	80	55	69	96
	13	.264	1890	512	80.0	100	61	81	55	69	97
	14	.268	1902	515	76.0	103	66	85	60	72	98
	15	.219	1795	486	60.0	91	61	76	53	65	87
	16	.204	1535	416	65.0	96	60	78	60	70	92
	17	.199	1665	451	38.0	93	60	77	53	66	90
	18	.207	1871	506	30.0	92	52	72	50	65	89
	19	.253	1842	499	105.0	96	51	74	58	69	92
	20	.198	1811	490	60.0	98	54	76	73	79	94
	21	.292	1950	528	165.0	94	55	75	57	69	91
	22	.255	1967	532	102.0	92	62	77	55	67	90
	23	.264	1973	534	172.0	89	48	69	55	66	87
	24	.265	1924	521	160.0	90	41	66	52	65	88
	25	.280	1873	507	148.0	92	42	67	47	63	89
	26	.245	1735	470	91.0	96	56	76	55	68	93
	27	.234	1609	436	105.0	96	56	76	59	66	80
	28	.208	1251	339	149.0	93	55	74	61	70	88
	29	.165	1200	325	100.0	91	55	72	63	71	87
	30	.199	1325	359	128.0	92	56	74	61	70	90
	31	.249	1518	411	147.0	88	58	73	47	61	82

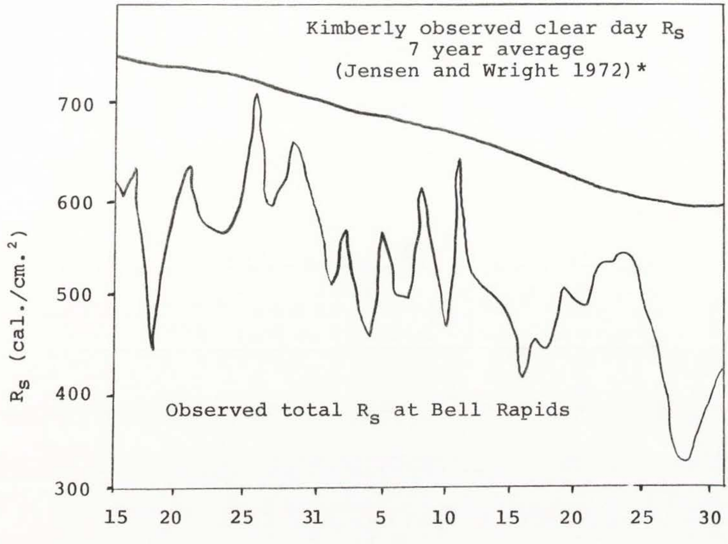
the Bell Rapids Project is only 37 direct miles, this variation should be near zero on a clear day.

Values for $\frac{\Delta}{\Delta+\gamma}$ have been taken from Appendix Table 7 where $\frac{\gamma}{\Delta+\gamma}$ is equal to $1 - \frac{\Delta}{\Delta+\gamma}$. This data is used as input into Equation 3 and the computer program in the Appendix.

Figure 3 compares the clear day and observed solar radiation on a daily basis for the period of the study. Differences between the two graphs are due to cloud cover. The observed daily radiation has been at all times below the clear day normal. Figure 4 compares the five year mean potential evaporation at Bell Rapids with the mean Ep at Kimberly with the higher daily temperatures, increased wind run, and greater vapor pressure deficits due to the desert surroundings and location.

The deviation of observed data from the Kimberly seven year mean emphasizes the need for good data obtained near the point of application. Although the average of observed data may equal the mean over 30 days, one day periods of adverse conditions can seriously affect yield and quality of potatoes. Therefore a true comparison of the two methods of scheduling irrigations should not be evaluated from the cumulative totals but rather from the deviation of Et (tensiometer) from Et (climatic) during each irrigation cycle.

Irrigation was applied in amounts of 1.10 inches and 1.64 inches per irrigation depending on the length. Table 5 shows the date of each irrigation and related tensiometer



*For daily data at Kimberly (see Table 8).

Figure 3. Daily total solar radiation values observed at the Bell Rapids Irrigation Project.

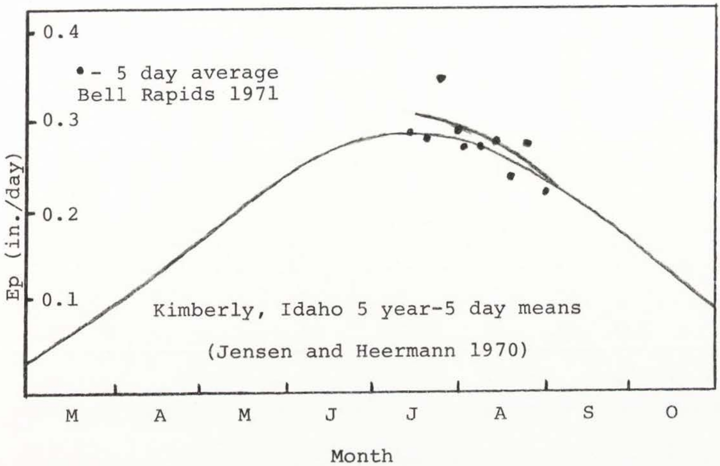


Figure 4. Distribution of mean potential evaporation at Bell Rapids and Kimberly.

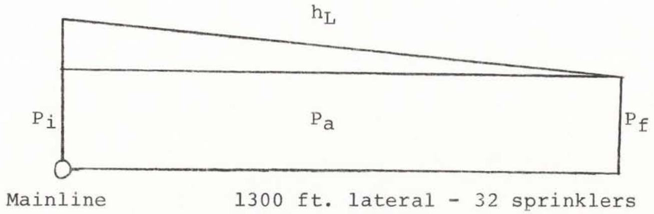
Table 5. Irrigation and related tensiometer readings

Irrigation Data

Irr. no.	Month	Day	Hrs./ set	Applied H_2O in.	Tensiometer readings before irr. in cb.
1	July	15	8	1.10	45
2	July	20	8	1.10	43
3	July	25	12	1.64	46
4	July	29	12	1.64	50
5	Aug.	5	12	1.64	45
6	Aug.	12	12	1.64	49
7	Aug.	18	8	1.10	48
8	Aug.	25	12	1.64	59
-	Aug.	31	-	-	55
		Total water applied		11.50 in.	

readings taken or interpolated from Table 2. The total water applied during the study amounted to 11.50 inches (Table 5). This was computed from average lateral pressures, sprinkler nozzle size, and spacing (Figure 5). Each irrigation and set were irrigated using the same pressures. Irrigation data were adjusted for application efficiency but not for uniformity of application. After consulting with J. D. Wright and R. Kohl of Kimberly (private communication), it was decided that the effects of application efficiency loss would be approximately 10 per cent under the conditions of this study. This correction was made by reducing the application rate (Figure 5). It is important to realize that different circumstances might make this factor even more important. Single irrigation laterals (hand-move systems) would have higher water loss as would surface irrigation where efficiency may be 65 per cent or less due to end-field losses and differential infiltration from upper to lower ends of the field.

The system employed in the study utilized block irrigation minimizing wind loss. However, the correction for evaporation was, in effect, made because the estimated Et included the time while irrigation was applied. Therefore, the 10 per cent correction allows for inefficiency due to wind drift from the irrigated field. If water application efficiency had been used to correct for evaporation, the adjustment would have been made twice.



where P_i = inlet pressure = 58 psi

P_a = average pressure = 50 psi

P_f = final pressure = 46 psi

h_L = head loss = 12 psi

40 X 50 ft. rectangular spacing

1/8" nozzle, No. 30 rainbird @ 50 psi .152 in./hr.

.152 in./hr. - 10 per cent eff. loss = .137 in./hr. application rate

Figure 5. Lateral hydraulics of solid set system.

Tensiometer Et was computed using Equation 2 and was compared with climatic Et in Figure 6. The $\Delta\Theta$ values for each irrigation interval were computed from tensiometer readings prior to irrigation using stations E and 5 (Table 5). This comparison directly relates both methods of estimating soil moisture depletion and scheduling irrigations. Et (tensiometer) indicates as precisely as possible the water evapotranspired by the plants. Table 6 compares the values of Et (tensiometer) to Et (climatic) for each irrigation period. The greatest difference was during the first irrigation where Et climatic over-estimated Et by .71 inches. Figure 6 shows the cumulative comparison of Et (tensiometer) to Et (climatic) for the study period. In Table 3 the average of all tensiometer readings were used to compute the moisture variation for the whole study which resulted in -.62 inches for $\Delta\Theta$. This compared very well with the total value computed for each irrigation period using only stations E and 5. The value of $\Delta\Theta$ with the latter was -.69 inches.

The results indicate that the climatological method gave reasonably good results in the study area. The cumulative difference between Et (tensiometer) and Et (climatic) was only .62 inches of water. The climatological method would have under-irrigated the potato crop by the same amount of water during the 48 day study. Another variation indicated by the study occurred with the time of irrigation application. With an effective root zone of

Table 6. Comparison of Et (tensiometer) and Et (climatic)

Irr. no.	Et tensiometer	Et climatic		
1	.86	1.57	July 15 - 19	5
2	1.33	1.34	July 20 - 24	5
3	1.96	1.28	July 25 - 28	4
4	1.30	1.72	July 29 - Aug. 4	7
5	2.00	1.70	Aug. 5 - 11	7
6	1.58	1.22	Aug. 12 - 17	6
7	1.64	1.62	Aug. 18 - 24	7
8	1.52	1.17		7
Total	12.19	11.62		48

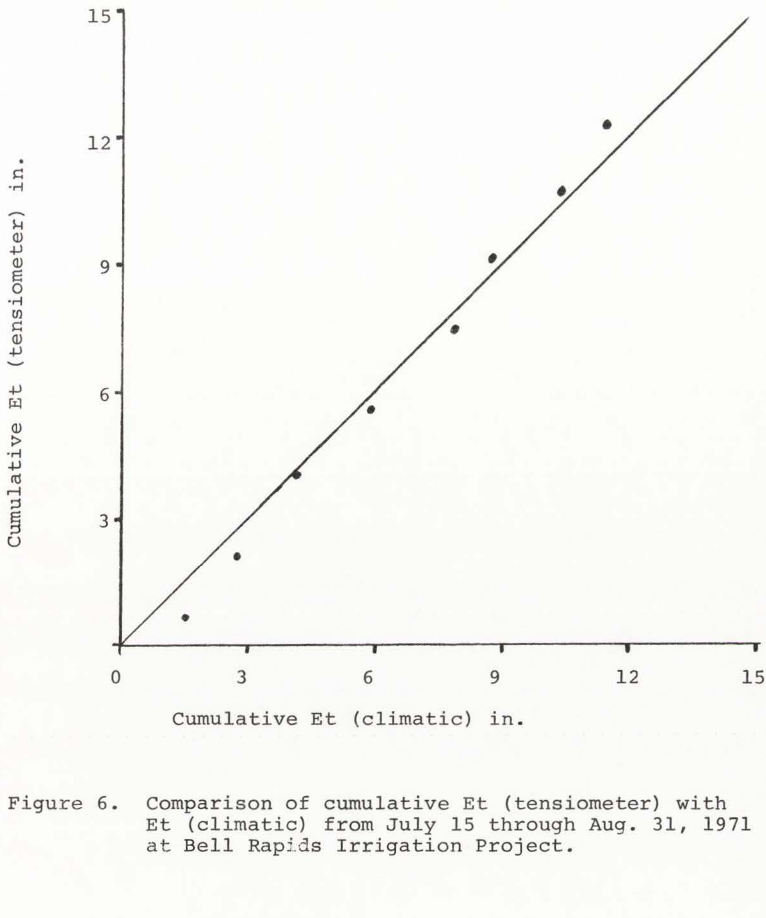


Figure 6. Comparison of cumulative Et (tensiometer) with Et (climatic) from July 15 through Aug. 31, 1971 at Bell Rapids Irrigation Project.

only 2 feet, small variations can have a marked effect on the quality and yield of a potato crop. If the soils in a field were not of uniform depth or texture, as is often the case, it would be very difficult to maintain the whole field within the optimum moisture range even with the best irrigation systems. It would then be necessary to add more detail to the procedure to account for the variability in order to make the moisture status of the field uniform. This is feasible only with solid set systems. Tensiometers can be employed to determine directly what differential water applications should be made. The climatological method requires considerable more basic soils information to do the same.

Advantages of the tensiometer method include the direct measurement of the soil moisture status which is very important to plants. The tensiometers require a minimum of soil data and measure soil moisture variability throughout the field. This minimizes the danger of overlooking the cumulative effects of moisture depletion or buildup in different parts of the field. Tensiometers are also easily adapted to different soils and crops in different regions. The tensiometer method requires readings two or three times per week when irrigating potatoes with light, frequent irrigations. The regular readings and maintenance causes increased field expense which is not required by the climatological method. Expense of tensiometers at $20.00 each must also be considered.

Advantages of the climatological method are the relative low cost due to the minimum amount of field work and also because of computer adaptability. The computer adaptability allows data to be related to many different crops and fields with minimum labor. Disadvantages of the climatological method are the possibility of accumulated error. To eliminate this problem, some field checks must be made. Calibration of instruments can be a problem along with the detailed field-crop-soil characteristics data and assumption of water conditions.

The study points out that both methods have applicability to scheduling irrigation of potatoes. Furthermore, results conclude that each method complements the other. Disadvantages of the tensiometer method are the strong points of the climatological method and vice versa. The author feels that a combination of both methods would allow the most economical and precise scheduling of irrigations under normal conditions given input for the computational method is applicable for the field of application.

SUMMARY AND CONCLUSIONS

Irrigation scheduling has become a very important detail of potato production management. Application of properly managed irrigations has proven very effective in maximizing the return on investment where other factors such as seed, fertilizer, and soil conditions are not limiting. Farm managers have determined by "feel" the soil moisture conditions for many years. Emphasis on quality crops to compete in todays economy requires that quantitative methods be used to insure optimum moisture content throughout the growing season.

Many commercial service organizations are presently using tensiometers and other direct field methods to monitor the soil moisture and schedule irrigations for farmers. Recently, adaptation of the climatological method has been employed for computerized scheduling of irrigations. This approach has been used successfully in Southern Idaho and other areas in the Western United States.

The objective of this study was to compare the tensiometer method with the computer evapotranspiration to predict when to irrigate in a high evaporative location. No other comparison of these methods have been made under actual field conditions. Tensiometer data were taken from July 15 through August 31 to schedule eight irrigations.

Overall difference was .62 inches or less than 5 per cent total Et (tensiometer). Indications were that a combination of both methods should be used for the following reasons:

(a) Tensiometers require regular service and readings which then require an experienced technician to interpret the data and project the next irrigation time. The computational method facilitates projections better (given adequate weather data) and requires less time.

(b) The computational method will estimate the average field water loss using proper soil data. More precise data could be obtained, however, and achieve the same results as the tensiometer method. If averages for an area are used, the irrigations will apply an average amount of water to any specific field. A potato crop may not respond well to an average amount of water if soil and field variations are large. The computer will evaluate moisture conditions based on the quality of data supplied but area averages and sometimes field averages may not suffice.

(c) Tensiometers can be employed to measure field moisture variation and the data can be used to determine the field-wide depletion for the climatological method. A possibility of error accumulation would be minimized by occasional tensiometer readings. This would combine the advantages of both methods to minimize the disadvantages of either. It was concluded that both methods are complementary and can feasibly be employed together to properly schedule irrigations of potatoes and other crops.

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APPENDIX

```
*WRITE ALL
C-PS/8 FOCAL, 1971

01.10 S A=0; S B=0; S C=0; S D=0; S E=0; S G=0; S H=0;
01.60 S I=0; S J=0; S K=0; S L=0; S M=0; S N=0; S O=0;
01.80 S Q=0; S R=0; S S=0; S T=0; S U=0; S V=0; S W=0

02.05 T !"PLEASE SUPPLY THE FOLLOWING INFORMATION"!
02.07 A !"TMAX=" H
02.09 A !"TMIN=" L
02.11 A !"RS=" R
02.13 A !"WD=" W
02.15 A !"TD=" D
02.17 A !"RSO=" S
02.19 A !"DELT=" E
02.21 S A=1-E

03.10 S B=((5*(H-32))/9)+273
03.15 S C=((5*(L-32))/9)+273
03.20 S Q=H; DO 3. 90
03.25 S V=G
03.30 S Q=L; DO 3. 90
03.35 S U=G
03.40 S Q=D; DO 3. 90
03.45 S I=G
03.50 S J=(V+U)/2
03.60 GOTO 4. 05
03.90 S G+(-.6959)+(.2946*Q)-(.005195*(Q*Q))+(.000089*)
03.95 S (Q*Q*Q))

04.05 S K=(.32-(.044*(FSQT(1))))*(11.71/10 8)*((B 4)+
04.06 S (C 4))/2
04.10 S M=(.75*(R/S)+.25)*K
04.20 S N=(.77*R)-M
04.30 S O=(E*N+(A*15.36*(1+(.01*W)))*(J-1))*(.00673)
04.35 T !"THE VALUE OF ETP"=0
04.40 GOTO 1.10
```

where TMAX = daily maximum temperature
TMIN = daily minimum temperature
RS = observed solar radiation
WD = daily wind run
TD = daily dew point temperature @ 5 PM
RSO = clear day solar radiation

$$DELT = \frac{\Delta}{\Delta+\gamma}$$

$$1-E = \frac{\gamma}{\Delta+\gamma}$$

Figure 7. Computer program.

Table 7. Summary of $\frac{\Delta}{\Delta+\gamma}$ versus T*

°F	$\frac{\Delta}{\Delta+\gamma}$	°F	$\frac{\Delta}{\Delta+\gamma}$
85	.7758	75	.7040
84	.7707	74	.6980
83	.7656	73	.6920
82	.7605	72	.6880
81	.7554	71	.6860
80	.7503	70	.6840
79	.7452	69	.6830
78	.7401	68	.6820
77	.7350	67	.6755
76	.7100	66	.6890

*Computed from Smithsonian Met. Tables, 6th Ed., 1958.

Table [illegible]. Clear day solar radiation, Kimberly, Idaho

Day	Apr	May	June	July	Aug	Sept	Oct
1	568	679	758	768	699	586	449
2	571	682	760	767	696	582	444
3	575	685	762	765	693	578	439
4	579	689	763	763	690	573	434
5	583	692	764	762	687	569	429
6	587	695	766	760	684	565	424
7	592	698	767	759	681	560	419
8	596	701	769	757	678	556	414
9	600	704	770	755	675	552	410
10	604	707	771	753	671	547	405
11	608	710	772	751	668	543	400
12	612	712	773	749	664	538	396
13	615	715	774	747	661	533	391
14	618	718	775	745	657	529	387
15	622	721	776	743	653	524	382
16	626	723	777	741	650	519	377
17	630	726	777	739	647	515	372
18	634	729	778	737	644	511	368
19	638	731	778	734	640	506	364
20	642	734	778	732	636	501	360
21	645	736	778	730	632	497	355
22	649	738	777	727	628	492	351
23	652	740	776	725	624	487	347
24	655	742	775	722	620	482	343
25	659	745	774	719	616	478	339
26	662	747	773	716	612	474	335
27	665	749	772	713	608	469	331
28	669	751	771	710	603	464	327
29	672	753	770	707	598	459	323
30	676	755	769	704	594	454	319
31	0	757	0	701	590	0	314

Units = cal. $cm.^{-2}$

NOTE: Unpublished data calculated by Dr. M.E. Jensen and Dr. J.L. Wright, Snake River Conservation Research Center, Rt. 1, Box 186, Kimberly, Idaho 83341.

VITA

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