SCHEDULING HIGH-FREQUENCY IRRIGATION FOR POTATOES

by
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The self-propelled, solid set and trickle irrigation systems apply water more evenly and precisely than was possible with furrow irrigation. They make possible frequent applications of small amounts of water so that storage of water in the soil becomes relatively unimportant as an irrigation system design parameter. Only the rate of water use by the crop and the optimum soil moisture tension need to be known to schedule an irrigation. Water can then be applied at rates sufficient to meet crop needs. The application rate of water can be adjusted to keep the moisture tension at the proper levels.

Recent advances in micrometerology and greater understanding of plant water needs make it possible to determine the daily crop water use with simple instruments and to determine the optimum water tensions in the root zone. These advances when coupled with present irrigation technology provide for efficient irrigation, maximum production of high quality potatoes and minimum ground water pollution.

Determining optimum soil water tension: Recently Campbell (1972) used a mathematical model to study potato responses to soil moisture tension. He showed that the maximum rate of water loss by a potato crop was a function of soil hydraulic conductivity and plant factors such as rooting depth, root density, resistance to water flow in the plant, and plant sap osmotic pressure. An example of results obtained with the model is shown as Figure 1 in which the maximum daily water loss rate is shown as a function of soil water tension. Figure 1 shows that during mid summer, when water loss rates may reach 0.4 inch/day, the soil moisture tension should be kept above about 0.6 bar.

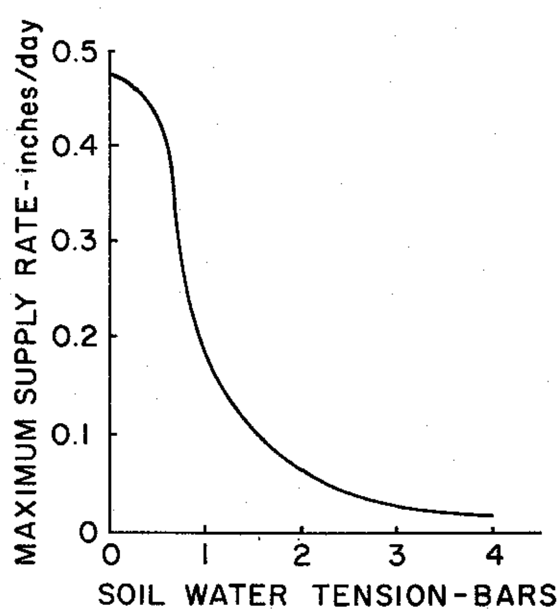

Figure 1. Example of maximum rate at which a potato crop can supply water to the atmosphere for various soil water tensions. If the daily evaporative demand exceeds the maximum supply rate, the plants will wilt to conserve water and reduce water loss to the maximum supply rate. Figure is from Campbell (1972).

Predictions of the model agreed well with measurements made in the field and laboratory by Campbell (1972), and also agree with tensions found to work well in field practice (Kunkel, unpublished data). Work to refine the model to account for other factors is continuing, but the model seems, at present, to take into account most of the relevant variables and it gives estimates of soil moisture tensions that are adequate for high yields of good quality potatoes.

Measuring Evapotranspiration: Measurements of evapotranspiration (ET) are currently in use in a number of locations for scheduling irrigation (Jensen, Wright and Pratt, 1971). Jensen's method requires the use of a digital computer to monitor soil moisture storage, moisture used, crop coefficients and potential evapotranspiration. For high-frequency irrigation we can assume that a crop always loses water at the potential rate, and soil moisture storage is not a factor, so the method becomes much simpler and ET can be easily calculated.

To determine evapotranspiration the combination method of Penman (1963) can be used. This method combines the energy budget for a crop with the equations for aerodynamic transport of heat and water vapor. The resulting terms in the equation are easily measured or estimated. The energy budget equation states that the net radiant energy from the sun and the atmosphere is divided between heating the air, evaporating water from the crop and heating the soil. In arid areas, such as central Washington, all of the radiant energy is often used to evaporate water. Additional water is evaporated by extracting heat from the air, as is done in an evaporative cooler, so the air often feels cooler as one enters an irrigated area. If the net radiant energy available at the crop surface, the soil heat flux, and the convective heating or cooling of the surface are known, we can determine ET rate from the energy budget equation directly. Net radiation is readily determined, and when the net soil heat flux is averaged for a day it is about zero. The only remaining factor to determine is convective (or sensible) heat transfer. At the present time sensible heat flux cannot be measured simply. Penman therefore used simplifying assumptions and emperical turbulent transport equations for estimating sensible heat flux. The Penman equation, modified for our use here is:

$$E = \Delta R_n / (\Delta + 0.67) + [0.67 / (\Delta + 0.67)] (a + bW)(e_s - e_a) \qquad (1)$$

where E is the rate of evapotranspiration in cm/day, R_n is the net radiation measured in terms of centimeters of water per day, Δ is the slope of the saturation vapor pressure-temperature curve at average air temperature, 0.67 is the psychrometric constant, a and b are emperically determined constants that depend on crop characteristics, W is the total wind travel per day in miles, measured at a height of 2 meters (6 feet) above the ground, e_s is the mean saturation vapor pressure, and e_a is the actual vapor pressure of the air.

To determine E we need values for all of the variables in equation (1). Values of $\Delta/(\Delta + 0.67)$, $0.67/(\Delta + 0.67)$, and e_s all depend only on air temperature. Average air temperature can be taken as the average of the maximum and minimum daily air temperature. Average saturation vapor pressure is the average of e_s at T_{max} and e_s at T_{min}. Table 1 gives values of these variables as a function of temperature. A value for e_a is obtained with a sling psychrometer. The wet and dry bulb temperatures from the sling psychrometer are used to obtain e_a from Figure 2. Vapor pressure is usually quite constant over the period of a day.

Net radiation is obtained by measuring incoming total solar radiation and average temperature. If we assume that the average crop surface temperature is about the same as the average air temperature, then the net longwave radiation can be calculated, (Table 1). The net radiation is 0.77 times the incoming solar radiation plus the net infrared radiation from Table 1.

Total daily wind travel is measured with a totalizing anemometer. Table 2 gives values of the wind factor for various values of daily wind run using the values of a and b from Wright and Jensen (1972).

Table 1. Temperature dependent quantities used in Equation 1 to calculate evapotranspiration.

T - °F.	Δ / Δ + 0.67	0.67/Δ + 0.67	e_s -mb	$R_{L\,net}$ -mmH_2O
32	0.40	0.60	6.11	-3.7
34	0.41	0.59	6.62	-3.7
36	0.43	0.57	7.17	-3.7
38	0.45	0.55	7.76	-3.6
40	0.47	0.53	8.39	-3.6
42	0.48	0.52	9.06	-3.6
44	0.50	0.50	9.79	-3.5
46	0.52	0.48	10.6	-3.5
48	0.53	0.47	11.4	-3.5
50	0.55	0.45	12.3	-3.4
52	0.56	0.44	13.2	-3.4
54	0.58	0.42	14.2	-3.3
56	0.60	0.40	15.3	-3.3
58	0.61	0.39	16.4	-3.3
60	0.62	0.38	17.6	-3.2
62	0.64	0.36	19.0	-3.2
64	0.65	0.35	20.3	-3.1
66	0.67	0.33	21.8	-3.1
68	0.68	0.32	23.4	-3.1
70	0.69	0.31	25.0	-3.0
72	0.70	0.30	26.8	-3.0
74	0.72	0.28	28.7	-2.9
76	0.73	0.27	30.6	-2.9
78	0.74	0.26	32.7	-2.8
80	0.75	0.25	35.0	-2.8
82	0.76	0.24	37.3	-2.7
84	0.77	0.23	39.8	-2.7
86	0.78	0.22	42.4	-2.7
88	0.79	0.21	45.2	-2.6
90	0.80	0.20	48.1	-2.6
92	0.81	0.19	51.3	-2.5
94	0.82	0.18	54.5	-2.5
96	0.82	0.18	58.0	-2.4
98	0.83	0.17	61.6	-2.4
100	0.84	0.16	65.5	-2.3

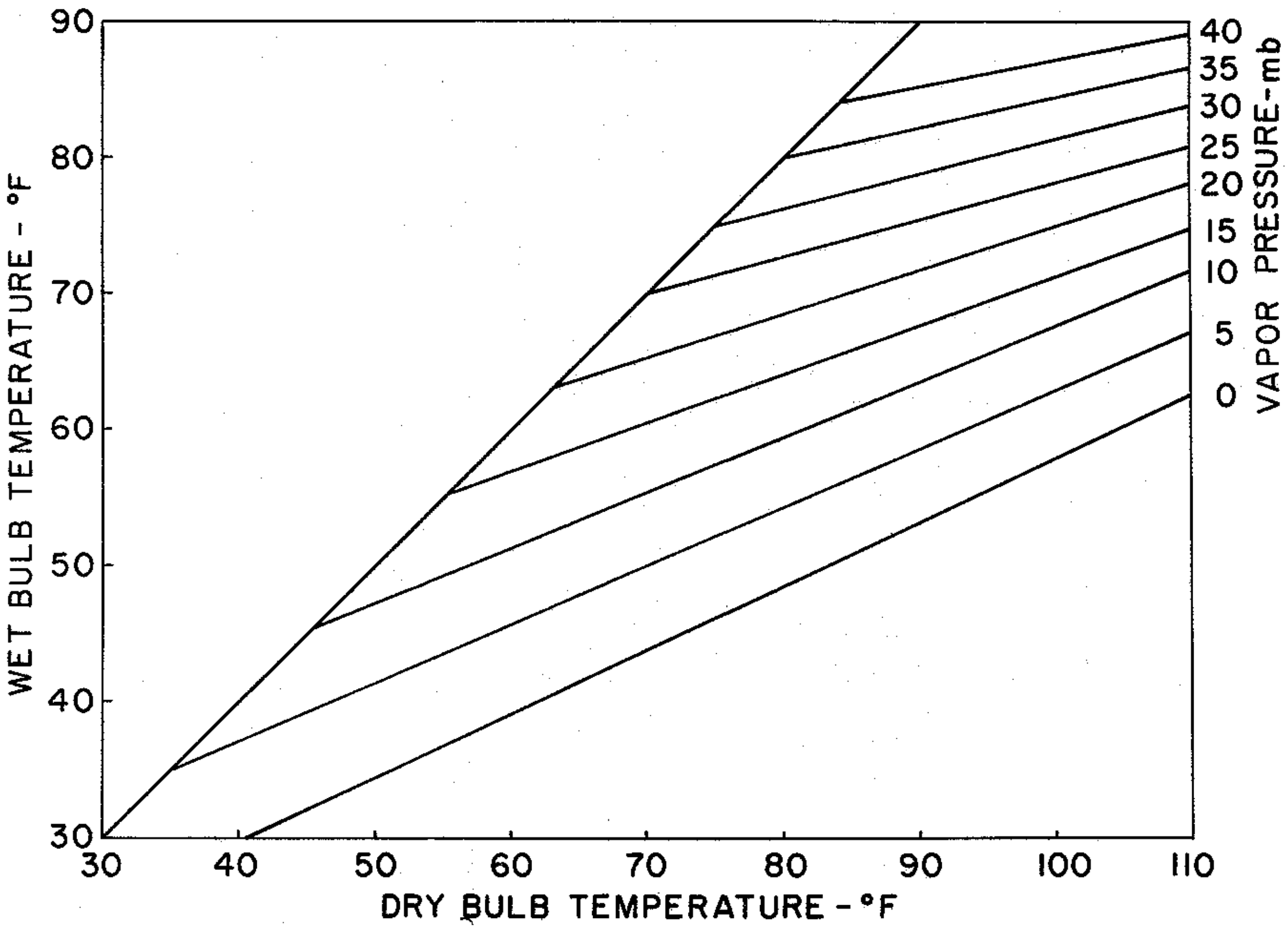

Figure 2. Graph for determining vapor pressure from wet and dry bulb temperature measurements.

Table 2. Wind factor for various values of total daily wind run. Calculated from equations of Wright and Jensen (1972).

Wind	Wind factor
0	0.2
10	0.25
20	0.30
30	0.35
40	0.40
50	0.45
60	0.50
70	0.55
80	0.60
90	0.65
100	0.70
110	0.75
120	0.80
130	0.85
140	0.90
150	0.95
160	1.00
170	1.05
180	1.10
190	1.15
200	1.20
210	1.25
220	1.30
230	1.35
240	1.40
250	1.45
260	1.50
270	1.55
280	1.60
290	1.65
300	1.70
310	1.75
320	1.80
330	1.85
340	1.90
350	1.95
360	2.00
370	2.05
380	2.10
390	2.15
400	2.20
410	2.25
420	2.30
430	2.35
440	2.40
450	2.45
460	2.50
470	2.55
480	2.60
490	2.65
500	2.70

Scheduling irrigation for center pivot and solid set sprinklers: We now have the theory we need to schedule high frequency irrigations. The next step is to specify the actual measurements to be made, the equipment to be used, and the use of the measurements in determining when to turn the water on and off.

Daily late evening or early morning meteorological measurements are needed, but need not be made at the potato field. Some other more convenient location, if properly selected for wind, temperature, and solar radiation, is adequate. Obviously, this data could be used to schedule irrigation for a large area surrounding the observation site. Maximum and minimum temperatures are determined with a standard max-min thermometer which is properly shielded from the sun. The totalizing anemometer is mounted 2 meters above the ground. The anemometer shows the total number of miles of wind which passed that day. Vapor pressure and humidity need to be measured once daily at the time of the other observations. A silicon solar cell measures the sun's intensity. Evapotranspiration is calculated from recorded data on a budget sheet similar to that shown as Table 3. An example calculation is shown in Table 3.

Table 3 WATER BUDGET

date July 7

Radiation	
1. Total short wave radiation	9.0
2. Net short wave radiation (0.77 x line 1)	7.6
3. Net longwave radiation (from line 8 and table 1)	-2.8
4. Net radiation (line 2 + line 3)	4.8
5. Water lost by radiation (line 4 x line 16)	3.6
Temperature and vapor pressure	
6. Maximum temperature	97
7. Minimum temperature	65
8. Average temperature ((T_{max} + T_{min}) / 2)	81
9. Maximum saturation vapor pressure (from line 6 and table 1)	60
10. Minimum saturation vapor pressure (from line 7 and table 1)	21
11. Average saturation vapor pressure (line 10 + line 9 divided by 2)	41
12. Wet bulb temperature	62
13. Dry bulb temperature	78
14. Vapor pressure of the air (from line 12, line 13, and figure 2)	13
15. Vapor pressure difference (line 11 - line 14)	28
16. $\Delta / (\Delta + 0.67)$ (from line 8 and table 1)	.76
17. $0.67 / (\Delta + 0.67)$ (from line 8 and table 1)	.24
Wind	
18. Today's anemometer reading	5480
19. Yesterday's anemometer reading	5322
20. Today's total wind (line 18 - line 19)	158
21. Wind factor (from line 20 and table 2)	1.0
22. Water lost by wind (line 21 x line 17 x line 15)	6.7
Water budget	
23. Balance from yesterday	-3.1
24. Water lost since last measurement [(line 22 + line 5) x 1.00 *]	10.3
25. Water applied since last measurement (rain + irrigation)	0
26. New water balance (line 23 - line 24 + line 25)	-13.4

Tensiometer readings

6" depth	____	____	____	____	____	____	average ____
18" depth	____	____	____	____	____	____	average ____

plot average tensions on figure 3

* The ET adjustment factor is placed in this blank space. It should begin as 1.00. If the 6" tensions from figure 3 are increasing, increase the factor by 0.05 at each irrigation until they stabilize. If the tensions at 18" are too low or are decreasing, decrease the factor by 0.05 at each irrigation until the proper value is maintained.

Each time a specified amount of water is added to the field, that depth is added to the budget sheet. The amount of water (rain or irrigation) reaching the crop is determined by placing gallon cans about even with the crop surface at various locations in the field. This may need only occasional checking during the season. Evenness of water distribution over the field is extremely important since adequate water for all parts of the field is needed.

The "new balance" line on the budget sheet shows the water excess or deficit in the soil. When sufficient evapotranspiration has occurred to use up about one irrigation depth of water, the crop needs to be irrigated. The irrigation is recorded and ET measurements continue until another irrigation depth is required.

Soil moisture tension measurements are used to adjust the evapotranspiration predictions to assure that the moisture tension in the root zone is maintained at the proper level. If water is applied in excess of that used for ET the excess will be lost to deep percolation. If too little water is applied the tension in the root zone increases beyond the optimum value and transpiration rate and growth are reduced. If tensions tend to increase the ET adjustment factor (Table 3) should be increased about 5%. If the tensions below the root zone become too low the adjustment factor would be reduced by about 5%.

The moisture tension at various locations in the field can be sampled with a portable tensiometer (Soil Moisture Equipment Co.). A number of locations should be sampled, and measurements at 6 and 18 inch depths should be made. The 6 inch depth should represent the water tension in the root zone, and the 18 inch depth should represent the tension below the root zone. Tensions should be measured just prior to irrigation (driest area) and plotted as in Figure 3 to show increasing or decreasing trends. The root zone water potential should be kept lower than 0.5 to 0.6 bar for a loam or sandy loam soil (when temperatures are high) and should be less than this for sandy soil. The tension below the root zone should be kept at a value required for proper leaching of salts. Figure 4 shows leaching rate as a function of tension for soils at the Othello farm. Leaching rates may require seasonal adjustment to obtain maximum benefit from fertilizer.

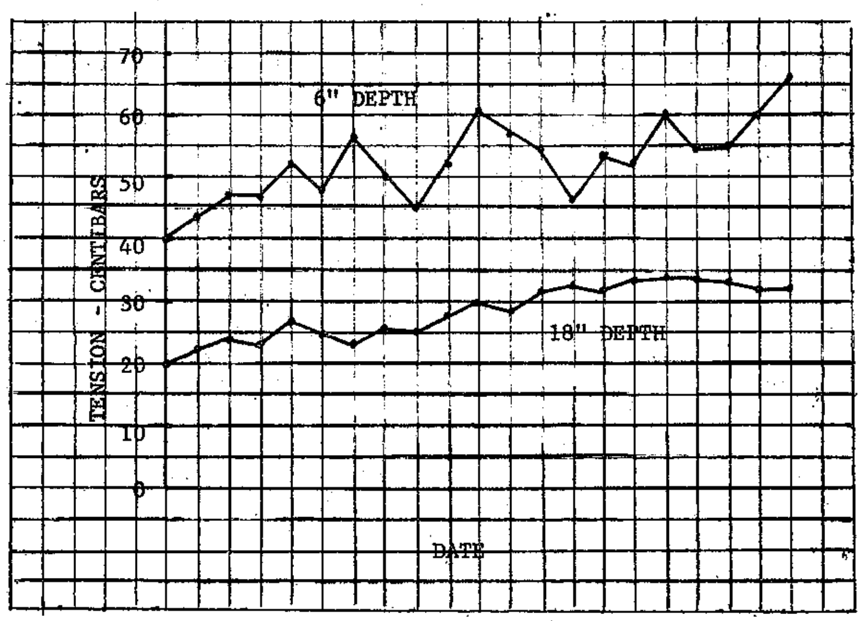

Figure 3. Hypothetical example of water tensions at 6 and 18 inch depths as they would be plotted to determine changes in the evapotranspiration adjustment factor.

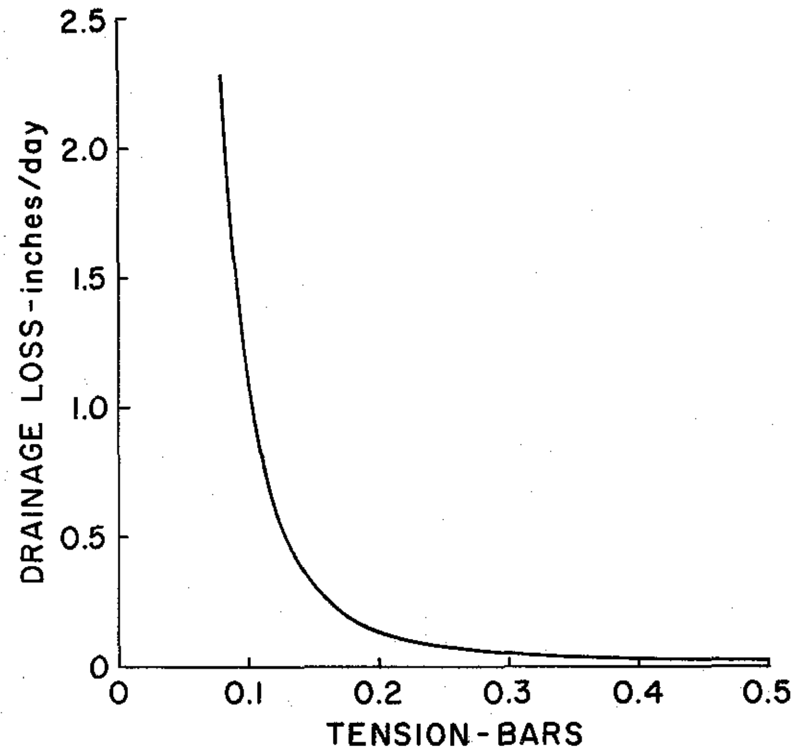

Figure 4. Drainage loss as a function of soil water tension for soils at the Othello experiment farm.

Expected benefits from frequent light irrigations: Maximum yield, good tuber quality, greater water efficiency and less nitrogen leaching are obvious benefits from irrigation scheduling. A less obvious benefit from precise irrigation scheduling is reduced ground water pollution. If the water tension below the root zone is kept high, movement of water and nutrients out of the root zone can be kept negligibly small when nitrate levels are high.

Why are both the evapotranspiration method and the tensiometer method used to schedule irrigation? If sufficient water is applied to replace the water lost, it should not be necessary to measure moisture tension because it would always be at the proper level. On the other hand, if water were applied every time the soil water potential reached its upper limit, then no measure of evapotranspiration should be required. Actually, both methods have been used by themselves to schedule irrigation. The weakness in the evapotranspiration method is that a slight underestimate or overestimate of daily ET could result in a large water excess or deficit by the middle or end of the season because there are no corrections for size of plant and other secondary variables in the equation. Tensiometer measurements require frequent and extensive sampling to obtain sufficient data to schedule irrigation, but when used with the ET measurements the sampling is done less frequently. One method therefore serves as a check on the other and the use of both assures proper irrigation scheduling.

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