OPTIMAL ALLOCATION OF LIMITED WATER SUPPLIES FOR RUSSET BURBANK POTATOES[1]

J.C. Stark and I.R. McCann[2]

Abstract

Water shortages in many potato-producing regions have increased the demand for information on irrigating potatoes with limited water supplies. Field studies were conducted at Aberdeen, Idaho in 1988 and 1989 to determine the optimal allocation of limited water supplies for Russet Burbank potatoes. Irrigation amounts equal to 60 or 80% of estimated seasonal evapotranspiration (ET) were applied using various patterns of water allocation. Irrigation deficits were either partitioned evenly over the entire tuber bulking period, or were imposed during two of three designated growth stages (early, mid or late bulking) corresponding to the periods from 0 to 3, 3 to 6, and 6 to 9 weeks after tuber initiation, respectively. A well-watered, 100% ET check was included for comparison. Total yield reductions were greater when irrigation deficits were imposed during the early-mid and mid-late bulking sequences than when they were imposed evenly over the entire tuber bulking period or during the early-late bulking sequence. Results relating U.S. No. 1 yields to seasonal water allocation patterns were similar to those for total yield. However, U.S. No. 1 yield reductions were proportionately greater. Irrigation deficits imposed during the early-mid bulking sequence resulted in the lowest specific gravities and the highest percentages of dark ends.

Compendio

La escasez de agua en muchas de las regiones donde se produce papa ha originado que se incremente la demanda por información sobre la irrigación del cultivo en condiciones de un bajo abastecimiento de agua. En 1988 y 1989 se condujeron estudios en Aberdeen, Idaho, para determinar la distribución óptima de cantidades limitadas de agua para papas Russet Burbank. Al irrigar se aplicaron cantidades iguales al 60 u 80% de la evapotranspiración (ET) estimada para la temporada utilizando varios esquemas de distribución de agua. Los déficits de irrigación iguales a 20

---

[1]Approved for publication by the Director of the Idaho Agric. Expt. Station as research paper No. 91758.

[2]Associate Professor, Plant Science Division, University of Idaho Research and Extension Center, Aberdeen, Idaho 83210; Assistant Professor, Dept. of Agricultural Engineering, University of Idaho Research and Extension Center, Aberdeen, Idaho 83210.

Accepted for publication December 13, 1991.

ADDITIONAL KEY WORDS: Irrigation management, drought, water stress, *Solanum tuberosum* L.

o 40% de la ET estimada fueron distribuidos ya sea uniformemente durante todo el periodo de formación de tubérculos o fueron impuestos durante dos de tres etapas consideradas de crecimiento (producción temprana, media o tardía) correspondientes a periodos de 0 a 3, 3 a 6 y 6 a 9 semanas después de iniciada la tuberización, respectivamente. Con fines de comparación, se incluyó un testigo irrigado al 100% de la ET. Las reducciones en el rendimiento total fueron mayores cuando los déficits de irrigación fueron impuestos durante las secuencias de crecimiento o durante la secuencia temprano-tardía de crecimiento. Los resultados al relacionar los rendimientos en U.S. No. 1 con los esquemas de distribución fueron similares a aquellos para el rendimiento total. Sin embargo, las reducciones en el rendimiento de U.S. No. 1 fueron proporcionalmente mayores. Los déficits de irrigación impuestos durante la secuencia temprano-media de crecimiento resultaron en las gravedades específicas más bajas y los porcentajes más altos de extremos oscuros.

Introduction

With the advances in irrigation technology that have occurred during the past 30 years, there has been a shift in North American potato production to arid, temperate regions. The primary variety grown in many of these areas is Russet Burbank, which is well known for its high susceptibility to drought (11). Prolonged drought in a number of major potato-producing areas has increased the demand for information on irrigating Russet Burbank potatoes with limited seasonal water supplies.

Previous potato irrigation research has emphasized the development of guidelines for managing irrigation when water supplies are adequate for maximum yield (1, 5, 16, 18). Some investigators have also evaluated potato response to reduced water application (2, 4, 9, 10, 14, 17). However, most of these studies have been conducted to evaluate effects of uniformly varying water application rates during a major portion of the growing season. The remainder have compared effects of transient drought during specific growth stages. Additional research is needed to specifically address the problem of determining the optimal allocation of limited water supplies during tuber development.

The study reported here was designed to compare the effects of varying the amount and seasonal distribution of water application on Russet Burbank yield and quality and to determine the optimal sequencing of irrigation deficits.

Materials and Methods

Experiments were conducted at the University of Idaho Research and Extension Center, Aberdeen, Idaho in 1988 and 1989 on a Declo silt loam soil (coarse-loamy, mixed, mesic Xerollic Calciorthid) with an available water holding capacity of approximately 17.5 cm in the top meter of soil. In both experiments, 180 kg N/ha and 100 kg P/ha were broadcast and incorporated with a disk prior to planting. All other nutrients were determined to be adequate for maximum yield (8). Russet Burbank potatoes were planted on 11 May, 1988 and on 9 May, 1989 in 0.91 m wide rows with a 0.25 m interrow spacing. Weeds were controlled with metribuzin applied at 0.45 kg/ha. Insects were controlled with aldicarb applied with the seedpiece at 3.0 kg a.i/ha.

The experimental design used in the two experiments was a randomized complete block with 9 irrigation treatments and 4 replications. Irrigation treatment plots were 5 rows (4.55 m) wide x 12 m long. All plots were irrigated with a solid set sprinkler system prior to tuber initiation to maintain available soil moisture in the top 30 cm above 65%. Tuber initiation was defined as the time when 50% of the stolons had tubers with diameters >1 cm. During the 9 weeks following tuber initiation, water was applied with drip irrigation tape that was laid along the surface of the hills adjacent to the base of the plants. This procedure uniformly wetted the surface of the hills and enabled precise control of water application.

During the 1988 and 1989 tuber bulking periods, irrigation amounts equal to 60, 80, or 100% of the estimated, long-term average evapotranspiration (ET) rate for the corresponding 9 week period at Aberdeen were applied using various water allocation patterns (Table 1). An average of 45 cm ET for the 9 week tuber bulking period was estimated from weather data for 1982-1987 using a modified Penman equation (3, 18). The predetermined irrigation deficits were either partitioned evenly over the entire 9 week period, or were imposed during two of three designated growth

TABLE 1.—*Seasonal water allocation patterns used for the 1988 and 1989 limited irrigation treatments.*

Treatment	Percent ET	Stress sequence	Water applied			
			E[1]	M	L	Total
			cm			
1.	100	—	15.0	15.0	15.0	45.0
2.	80	EML	12.0	12.0	12.0	36.0
3.	80	EM	10.5	10.5	15.0	36.0
4.	80	ML	15.0	10.5	10.5	36.0
5.	80	EL	10.5	15.0	10.5	36.0
6.	60	EML	9.0	9.0	9.0	27.0
7.	60	EM	6.0	6.0	15.0	27.0
8.	60	ML	15.0	6.0	6.0	27.0
9.	60	EL	6.0	15.0	6.0	27.0

[1]Early (E), mid (M) and late (L) bulking refer to the periods from 0 to 3, 3 to 6, and 6 to 9 weeks after tuber initiation, respectively.

periods. Early-bulking (E), mid-bulking (M), and late-bulking (L) refer to the periods from 0 to 3 weeks, 3 to 6 weeks, and 6 to 9 weeks after tuber initiation. Predetermined irrigation deficits were used to provide a uniform experimental design in which water allocation patterns could be varied while holding the total amount of water applied at constant levels. The differential irrigation treatments began on 30 June, 1988 and 3 July, 1989. The 100% ET check treatment received a 2.5 cm irrigation each Monday and Thursday. Deficit irrigation treatments received proportionately less irrigation on the same days to adjust for designated reductions in water application. Precipitation during the tuber bulking period was only 9 mm in 1988 and 18 mm in 1989.

Soil water content in the surface 90 cm of each plot was determined gravimetrically at the beginning and end of the 9 week tuber bulking periods. Evapotranspiration during tuber bulking was determined from the sum of irrigation + precipitation and changes in soil water storage. No additional irrigation was applied after the 9 week tuber bulking period.

A 10 m section from the center row of each plot was harvested on 27 September, 1988 and 3 October, 1989. Total yield and grade were determined from the harvested samples. Specific gravities were determined from a 5 kg sample of U.S. No. 1 tubers using the weight-in-air/weight-in-water method. Percentages of dark-end tubers were determined after 3 months of storage at 8 C by frying ten 228 to 342 g tubers (5 fries per tuber) from each plot at 190 C for 3 min. Yield and quality data were analyzed using analysis of variance procedures (6).

Results

Potato ET estimates were developed for the 1988 and 1989 growing seasons for comparison with the different irrigation treatments using a modified Penman equation to estimate potential ET (3) and appropriate crop coefficients to adjust for seasonal changes in crop water use (18). Evapotranspiration estimates for the E, M, and L periods were 14.4, 15.1, and 13.8 cm in 1988, and 13.3, 14.0 and 12.7 cm in 1989, respectively. As a result, actual irrigation deficits were smaller in 1989 than in 1988. Temperatures were also more moderate during the 1989 growing season, resulting in conditions that were more favorable for tuber growth.

Total tuber yields averaged 29.40 t/ha in 1988 and 39.89 t/ha in 1989 (Tables 2 and 3). Compared to the 100% ET treatment, the 80 and 60% ET treatments reduced total yields by an average of 3.55 and 9.05 t/ha in 1988, and 5.21 and 10.29 t/ha in 1989, respectively. The greatest reductions in total yield generally occurred when irrigation deficits were imposed during the EM and ML bulking sequences. Spreading irrigation deficits evenly over the entire tuber bulking period or imposing irrigation deficits during the EL sequence generally produced smaller total yield reductions.

TABLE 2.—*Irrigation treatment effects on tuber yield distributions in 1988.*

Treatment	Percent ET	Stress sequence	Tuber Yield <114 g	114-284 g	>284 g	U.S. No. 1	Malformed	Total
			t/ha					
1.	100	–	11.09	18.89	2.96	21.85	2.05	34.99
2.	80	EML	11.54	16.90	2.92	19.82	1.60	32.96
3.	80	EM	11.84	15.20	2.02	17.22	1.17	30.23
4.	80	ML	12.24	15.73	1.53	17.26	1.26	30.76
5.	80	EL	10.72	16.94	2.96	19.90	1.25	31.87
6.	60	EML	11.83	12.97	0.85	13.82	1.32	26.97
7.	60	EM	10.44	7.64	0.64	8.28	5.70	24.42
8.	60	ML	12.76	9.95	0.81	10.76	1.13	24.65
9.	60	EL	10.64	12.87	1.48	14.35	2.75	27.74
$LSD_{0.05}$			NS	2.75	1.92	2.41	1.99	2.52

TABLE 3.—*Irrigation treatment effects on tuber yield distributions in 1989.*

Treatment	Percent ET	Stress sequence	Tuber Yield <114 g	114-284 g	>284 g	U.S. No. 1	Malformed	Total
			t/ha					
1.	100	–	11.28	30.21	2.52	32.73	2.77	46.78
2.	80	EML	13.12	24.54	2.91	27.45	2.11	42.68
3.	80	EM	12.82	22.91	2.64	25.55	2.28	40.65
4.	80	ML	10.55	23.38	3.48	26.86	2.98	40.39
5.	80	EL	13.02	23.83	3.04	26.87	2.67	42.56
6.	60	EML	13.54	19.65	2.41	22.06	2.24	37.84
7.	60	EM	12.58	18.36	2.54	20.90	1.93	35.41
8.	60	ML	11.79	19.95	1.83	21.78	1.81	35.38
9.	60	EL	11.96	20.08	2.70	22.78	2.57	37.31
$LSD_{0.05}$			1.62	2.05	NS	2.89	NS	2.14

Effects of water allocation patterns on U.S. No. 1 yields were similar to those for total yield. Actual reductions in U.S. No. 1 yield for the various stress sequences were close to the corresponding reductions in total yield. However, proportional reductions in U.S. No. 1 yields were greater.

Water deficits imposed during the EM and ML stress sequences in 1988 produced the lowest U.S. No 1 yields at both the 60 and 80% ET irrigation levels. The differential effect of stress timing was quite pronounced at the 60% ET irrigation level. Effects of stress timing on U.S. No 1. yields were considerably smaller in 1989, although the trends were similar to those observed in 1988.

Water allocation patterns had relatively little effect on the yield of tubers <114 g. The primary effect of irrigation amount and timing was on the yield of tubers in the 114 to 284 g range. Small differences in yield of large (>284 g) tubers occurred in 1988 but not in 1989. The only notable increase in the yield of malformed tubers occurred with the 60% EM treatment in 1988.

Relative yields (Y/Y_{max}) for the limited irrigation treatments were determined by dividing the treatment yields by the check yield (Tables 4 and 5). Relative ET (ET/ET_{max}) for each treatment was determined in a similar manner. Relative ET values were 3 to 13% higher than the corresponding relative irrigation (I/I_{max}) values of either 0.60 or 0.80. This primarily resulted from the fact that actual ET was slightly lower than anticipated ET in both years of the study. In addition, soil water depletion in the limited irrigation plots was usually greater than in the check plots.

A stress sensitivity index (SSI) was used to normalize potato response to ET deficits over the two years of the study (Tables 4 and 5). The SSI expresses the ratio of the relative reduction in yield to the relative reduction in ET as follows:

$$SSI = \frac{(1 - Y/Y_{max})}{(1 - ET/ET_{max})}$$

The terms Y and Y_{max} refer to the treatment and check yields, while ET and ET_{max} refer to corresponding evapotranspiration totals. The higher

TABLE 4.—*Irrigation treatment effects on relative evapotranspiration (ET/ET_{max}), relative total yield and US No. 1 yield (Y/Y_{max}) and corresponding stress sensitivity index (SSI) values in 1988.*

Treatment	Percent ET	Stress sequence	ET/ET_{max}	Total yield Y/Y_{max}	Total yield SSI[2]	U.S. No. 1 yield Y/Y_{max}	U.S. No. 1 yield SSI
1.	100	–	1.00	1.00	–	1.00	–
2.	80	EML[1]	0.87	0.94	0.46	0.91	0.69
3.	80	EM	0.83	0.86	0.82	0.79	1.23
4.	80	ML	0.85	0.88	0.80	0.79	1.40
5.	80	EL	0.88	0.91	0.75	0.91	0.75
6.	60	EML	0.68	0.77	0.72	0.63	1.15
7.	60	EM	0.63	0.70	0.81	0.38	1.68
8.	60	ML	0.66	0.70	0.88	0.49	1.50
9.	60	EL	0.70	0.79	0.70	0.66	1.13

[1]Early (E), mid (M) and late (L) tuber bulking.
[2]$SSI = (1-Y/Y_{max})/(1-ET/ET_{max})$.

SSI values indicate a greater reduction in yield for a given reduction in ET and, hence, a greater sensitivity to ET deficits. In nearly every case, potatoes were more sensitive to ET deficits imposed during either the EM or ML sequences. Stress sensitivity index values were usually much higher for U.S. No. 1 yield than for total yield.

Irrigation deficits during the EM period resulted in the lowest specific gravities in both years of the study (Table 6). Otherwise, the different water allocation patterns had comparatively little effect on specific gravity. The timing of irrigation deficits also had a significant effect on the percentage

TABLE 5.—*Irrigation treatment effects on relative evapotranspiration (ET/ET_{max}), relative total yield and US No. 1 yield (Y/Y_{max}) and corresponding stress sensitivity index (SSI) values in 1989.*

Treatment	Percent ET	Stress sequence	ET/ET_{max}	Total yield		U.S. No.1 yield	
				Y/Y_{max}	SSI[2]	Y/Y_{max}	SSI
1.	100	–	1.00	1.00	–	1.00	–
2.	80	EML[1]	0.87	0.91	0.69	0.84	1.23
3.	80	EM	0.85	0.87	0.87	0.78	1.47
4.	80	ML	0.86	0.86	1.00	0.82	1.29
5.	80	EL	0.84	0.91	0.56	0.82	1.12
6.	60	EML	0.73	0.81	0.70	0.67	1.22
7.	60	EM	0.69	0.76	0.77	0.64	1.16
8.	60	ML	0.71	0.76	0.83	0.66	1.17
9.	60	EL	0.72	0.80	0.71	0.70	1.07

[1]Early (E), mid (M) and late (L) tuber bulking.
[2]$SSI = (1-Y/Y_{max})/(1-ET/ET_{max})$

TABLE 6.—*Specific gravities and percent dark ends for the 9 water allocation treatments in 1988 and 1989.*

Treatment	Percent ET	Stress sequence	Specific gravity		Dark ends	
			1988	1989	1988	1989
					------- % -------	
1.	100	–	1.073	1.083	8	8
2.	80	EML	1.069	1.081	18	8
3.	80	EM	1.068	1.079	25	10
4.	80	ML	1.073	1.082	13	7
5.	80	EL	1.074	1.080	22	10
6.	60	EML	1.068	1.079	25	8
7.	60	EM	1.060	1.078	48	16
8.	60	ML	1.068	1.081	20	5
9.	60	EL	1.070	1.080	38	7
$LSD_{0.05}$			0.004	0.002	8	NS

of dark ends in 1988. Large irrigation deficits during the EM or EL stress sequences produced the highest percentages of dark ends. There was no significant effect of irrigation treatment on the percentage of dark ends in 1989.

Discussion

The results of this study show that limited water supplies should be allocated in a manner that minimizes potato water stress during the early- and mid-bulking periods. Water deficits during early-bulking produced the greatest reductions in tuber quality, while water deficits during mid-bulking produced the greatest reductions in total tuber yield.

Several investigators have reported that interruptions in the water supply during tuber initiation and early development usually produce the greatest reductions in U.S. No. 1 yield and tuber quality (5, 11, 15). The reductions in quality associated with the early-mid bulking stress sequence in this present study are consistent with these findings. However, the effects of water deficits on U.S. No. 1 yields in this study were relatively small compared with studies in which short periods of severe drought were imposed during early tuber development.

In our study, water deficits were spread evenly over either a 6 or 9 week period during tuber bulking. This approach provided an opportunity for the plants to adapt to developing water deficits. The high water holding capacity of the silt loam soil used in this study also allowed water stress to develop at a relatively slow rate. As a result, malformed tuber development was minimized and reductions in U.S. No. 1 yield were primarily caused by reductions in tuber size associated with mid-bulking stress.

A large photosynthetically-active leaf surface is necessary to maintain high tuber bulking rates for extended periods (12). Water stress can reduce tuber bulking rates by reducing leaf area and photosynthetic efficiency (7). In addition, water stress during tuber bulking hastens the senescence of potato leaves and inhibits new leaf formation, thereby reducing leaf area duration (13, 19).

In this present study, water allocation patterns that minimized water deficits during periods of maximum leaf development and tuber bulking produced the smallest reductions in yield. This suggests that optimal distributions of limited water supplies for Russet Burbank potatoes should include conserving adequate water for the mid-bulking period. This may necessitate allowing water deficits to develop during early and/or late tuber bulking. The preference, of course, would be to limit water deficits during early bulking because of the likelihood of increased quality problems. Alternatively, limited water supplies could be distributed evenly over the entire tuber bulking period to minimize the severity of drought stress during any specific phase of tuber growth. Adjustments in the number of acres planted to potatoes could also be made according to the anticipated water supply to avoid the need to make choices concerning water allocation.

Literature Cited

1. Curwen, D. and L.R. Massie. 1984. Potato irrigation scheduling in Wisconsin. Am Potato J 61:235-241.
2. de Lis, B.R., I. Ponce and R. Tizio. 1964. Studies on the water requirement of horticultural crops. I. Influence of drought at different growth stages on the tuber's yield. Agron J 56:377-381.
3. Doorenbos, J. and W.O. Pruitt. 1977. Guidelines for predicting crop water requirements. FAO Irrig. Drain. Pap. 24. FAO, Rome.
4. Hang, A.N. and D.E. Miller. 1986. Yield and physiological responses of potatoes to deficit, high frequency sprinkler irrigation. Agron J 78:436-440.
5. Larsen, D.C. 1984. Simplifying potato irrigation scheduling - the Idaho program. Am Potato J 61:215-227.
6. Little, T.M. and F.J. Hills. 1978. Agricultural experimentation. Wiley, New York.
7. Loon, C.D. van. 1981. The effect of water stress on potato growth, development, and yield. Am Potato J 58:51-69.
8. McDole, R.E., D.T. Westermann, G.D. Kleinschmidt, G.E. Kleinkopf and J.C. Ojala. 1987. Idaho fertilizer guide - potatoes. Univ of Idaho Curr Info Ser No 261.
9. Miller, D.E. and M.W. Martin. 1983. Effect of daily irrigation rate and soil texture on yield and quality of Russet Burbank potatoes. Am Potato J 60:745-757.
10. Miller, D.E. and M.W, Martin. 1985. Effect of water stress during tuber formation on subsequent growth and internal defects in Russet Burbank potatoes. Am Potato J 62:83-89.
11. Miller, D.E. and M.W. Martin. 1987. Effect of declining or interrupted irrigation on yield and quality of three potato cultivars grown on a sandy soil. Am Potato J 64:109-117.
12. Moorby, J. and F.L. Milthorpe. 1975. Potato. p. 225-257. *In:* L.J. Evans (Ed.) Crop physiology. Cambridge Univ. Press, London.
13. Munns, R. and C.J. Pearson. 1974. Effect of water deficit on translocation of carbohydrate in *Solanum tuberosum*. Aust J Plant Physiol 1:529-537.
14. Shalhevet, J., D. Shimshi and T. Meir. 1983. Potato irrigation requirements in a hot climate using sprinkler and drip methods. Agron J 75:13-16.
15. Stark, J.C. and R.B. Dwelle. 1989. Antitranspirant effects on yield, quality and water use efficiency of Russet Burbank potatoes. Am Potato J 66:563-574.
16. Vitosh, M.L. 1984. Irrigation scheduling for potatoes in Michigan. Am Potato J 61:205-213.
17. Wolfe, D.W., E. Fereres and R.E. Voss. 1983. Growth and yield response of two potato cultivars to various levels of applied water. Irrig Sci 3:211-222.
18. Wright, J.L. and J.C. Stark. 1990. Potato. p. 859-888. *In:* B.A. Stewart and D.R. Nielson (Eds.). Irrigation of agricultural crops. Agronomy 30. Am Soc of Agron, Madison, WI.
19. Zaag, D.E. van der and W. G. Burton. 1978. Potential yield of the potato crop and its limitations. p 7-22. *In:* Survey papers, 7th Triennial Conf European Assoc Potato Res, Warsaw Poland. 26 June-1 July. Instytut Ziemniaka, Bonin, Poland.