IRRIGATION AND SOIL TEMPERATURE EFFECTS ON RUSSET BURBANK QUALITY[1]

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Abstract

Potato growers in the Pacific Northwest suffer large economic losses in seasons with above normal temperatures, due to excess reducing sugars in tubers, which cause dark-end French fries. Our objective was to study irrigation management effects on potato quality, particularly the factors causing dark-end French fries or sugar-end syndrome. Solid-set sprinkler irrigated plots were established on potatoes at Kimberly, Idaho during the 1987, 1988 and 1989 irrigation seasons, and at Parma, Idaho in 1987 and 1988. Irrigation treatments were high and low frequency (3/week and 1/week) and two or three water application amounts referenced to estimated evapotranspiration (ET, ET+20%, and ET-20%). Neither frequency nor amount significantly affected yields. Irrigation frequency had more influence on potato quality than application amount. More frequent irrigation produced slightly higher quality tubers and lower incidence of dark-ends when fried. Soil temperature was inversely related to tuber grade quality and directly related to percentage of sugar-end tubers. Soil temperature was about 0.5 C lower under the high frequency than under the low frequency irrigation regime. On these silt loam soils, allowing available soil water to decline to 50 percent had no adverse affect on yield or quality.

Compendio

Los productores de papa en el noroeste del Pacífico sufren grandes pérdidas económicas en las temporadas con temperaturas por encima de lo normal, debido a un exceso de azúcares reductores en los tubérculos, lo cual provoca un oscurecimiento en los extremos de las papas fritas a la francesa. El objetivo fue estudiar los efectos del manejo de la irrigación sobre la calidad de la papa, en especial de los factores que causan el oscurecimiento de los extremos de las papas fritas a la francesa o síndrome de azúcar terminal. Se establecieron parcelas irrigadas por un sistema sólido de aspersión, para papas en Kimberly, Idaho durante las temporadas bajo riego de 1987, 1988 y 1989, y en Parma, Idaho en 1987 y 1988. Los tratamientos de riego fueron de alta y baja frecuencia (3/semana y 1/sem-

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ana) y dos o tres cantidades de agua aplicada referidas a la evapotranspiración estimada (ET, ET + 20%, y ET-20 %). Ni la frecuencia ni la cantidad afectaron significativamente los rendimientos. La frecuencia de riego tiene mayor influencia sobre la calidad de la papa que la cantidad aplicada. Riegos más frecuentes dan lugar a tubérculos de calidad ligeramente superior y una menor incidencia de terminales oscuros cuando se les fríe. La temperatura del suelo estuvo inversamente relacionada al grado de calidad del tubérculo y directamente relacionada al porcentaje de tubérculos con el síndrome de azúcar terminal. La temperatura del suelo fue aproximadamente 0.5 C menor bajo alta frecuencia de riego comparada con aquella observada a baja frecuencia de riego. Los suelos de los lugares mencionados (migajones cenagosos) que permiten que el agua disponible disminuya hasta 50%, no tuvieron efecto adverso sobre el rendimiento o la calidad.

Introduction

Potato yield and quality can be adversely affected by water stress and high temperatures, or a combination of these, at certain stages of growth. Water or heat stress during early tuber development causes accumulation of reducing sugars in the basal or stem end of the tubers, resulting in "dark end" french fries, a major problem for processors [Owings *et al.* (14), Iritani and Weller (3, 4); Kleinkopf *et al.*, (6)]. Stark and McCann (16) found that irrigation deficits imposed during early to mid tuber bulking caused the highest percentages of sugar-ends. Little data is available on the effect of soil temperature during tuber growth on potato quality. Yamaguchi *et al.* (20), found that yield, specific gravity and starch content of Russet Burbank and White Rose tubers were highest, and the sugar content lowest when grown at soil temperatures between 15 and 24 C, compared with tubers grown at higher temperature.

Soil type can affect optimum irrigation management. Potatoes grown on sandy soil required daily irrigation amounts near daily evapotranspiration (ET) to avoid reductions in yield and quality [Hang and Miller, (2)]. However, high yields were obtained on a loam soil with a daily irrigation considerably below ET during the bulking period if an early irrigation replenished the soil water to field capacity [Martin and Miller (7); Miller and Martin (9)].

Irrigation frequency and timing of stress can affect potato quality. Russet Burbank was much more sensitive to water stress with a 4 day irrigation interval, and more severely damaged by early or late season stress, than Nooksack or Lemhi varieties [Miller and Martin (10, 11)]. Wright and Stark (19) state that for the Russet Burbank variety, available soil water should be maintained above 65 percent. Miller and Martin (12) found three early varieties performed best with daily irrigation to replace evapotranspiration, and poorest when irrigation was interrupted during tuber bulking. Ojala *et al.* (13) found that yield and quality were greatest when the irrigation deficit occurred either early or late in tuber growth, if stress was minimized during the mid-bulking period. In the Columbia Basin of Oregon, Hane and Pumphrey (1) found optimum yields and quality of Russet Burbank require about 625 mm total water use, while in Eastern Idaho, Ojala *et al.* (13) found yields increase with up to 590 mm of water use.

Potatoes grown in the Pacific Northwest are primarily sprinkler irrigated, with either center-pivot systems, where irrigation frequencies of 1 to 3 days are common, or solid-set, side-roll, or hand-move sprinkler systems with frequencies of 4 to 7 days. The objective of this experiment was to study the effects of sprinkler irrigation frequency and amount on potato quality, particularly the tendency to produce sugar-end tubers resulting in dark-end french fries. A secondary objective was to study the interaction between irrigation regime and soil temperature.

Methods and Materials

The experiments were conducted for 3 years (1987-89) at Kimberly, in south-central Idaho and for 2 years (1987-88) at Parma, in southwest Idaho. The soil at Kimberly was Portneuf silt loam (coarse-silty, mixed, mesic Durixerollic Calciorthid), and the Parma soil was Greenleaf silt loam (fine-silty, mixed, mesic, Xerollic Haplargid). These soils are similar in water holding capacity, with a field capacity of 32 percent (volumetric) and wilting point of 14% (determined by pressure plate analyses), resulting in 18% available water or 81 mm of water in a 45 cm root zone.

Solid-set sprinkler plots were replicated 3 times. The sprinklers applied water at about 5 mm hr^{1}. Irrigation application times were set to apply the required amount for each treatment. Irrigation amounts were verified with catch cans. The daily crop water use was estimated by combining reference evapotranspiration, calculated with the modified-Penman method using data from an onsite weather station, and associated crop coefficient curves as described in Jensen *et al.* (5). Daily deep percolation was estimated as water applied which exceeded the soil water holding capacity of the 45 cm root zone. Soil water was also monitored by gravimetric soil sampling, neutron probe and tensiometers. Soil temperatures were recorded hourly from thermocouples placed 5 cm and 15 cm below the soil surface in the center of the potato hill. Average and maximum daily soil temperatures were computed.

The sprinkler irrigation treatments in 1987 and 1988 were high frequency (3/week) and low frequency (1/week) irrigation, coupled with two application amounts. The high amount replaced ET and maintained soil water at or above 60 percent of available, while the lower amount (about

15 percent less) produced gradually increasing water deficit. In 1989 one frequency (2/week), and 3 irrigation amounts (ET, ET+20 percent, and ET-20 percent) were used.

Potato seed pieces (60 g) were planted 20 cm deep and 23 cm apart in 91 cm rows, between 15 and 20 April at Parma and between 20 and 25 April at Kimberly. Plots were 14 rows wide but only the center 5 rows were used for sampling soil water and yields. Row lengths were about 60 m. Preplant fertilizer applications followed recommended rates to produce optimum yields [McDole *et al.*, (8)]. Plant nutrient status was monitored with petiole samples during tuber bulking.

Two 15 m long row segments from each treatment (3 reps) were harvested in early October and graded by size and visible quality [USDA, (18)]. Tuber specific gravity was calculated from sample weights measured in air and water. Fry color shortly after harvest and after three months storage at 6 C were determined on subsamples. Fry color was determined by a Photovolt reflectance meter on 13 mm thick stem and bud-end slabs after frying in vegetable oil at 190 C for 2.5 minutes. The meter used a green tristimulus filter, a black cavity at 0.00, standard white enamel reflectance plaques, and was visually calibrated to a USDA fry color standard chart [USDA, (17)]. This procedure is similar to that recently reported by Shock *et al.*(15). Chart colors 3 and 4 are dark brown and are objectionable to consumers. Processors can reject potato lots which exceed a contract-specified percentage (#3+#4).

Results

Soil Water Level and Evapotranspiration

Total water applied (TOT), total deep percolation (DP) for the complete season, yield, grade and harvest stem-end fry color rating are presented in Table 1 by location and year, for each irrigation treatment. The average percent available soil water and soil temperature for June 15 to July 15 is also listed.

Evapotranspiration (ET) was near normal during the 1987 season while the 1988 ET was slightly higher than normal. Calculated daily soil water as a percent of available water through the 1988 season at Kimberly for the high and low frequency sprinkler treatments is shown in Figure 1. The soil was allowed to dry down initially to ensure stress in the low amount plots, but the high amount plots were brought up to at least 60 percent of available water when tuber initiation began about June 15. The low frequency plots experienced as much as 40 percentage point variations in available water between irrigations, while the high frequency plots had much less short term variation. Soil water measurements indicated that the calculated soil water contents were reasonably accurate.

TABLE 1.—*Results by location, year and irrigation treatment.*[1]

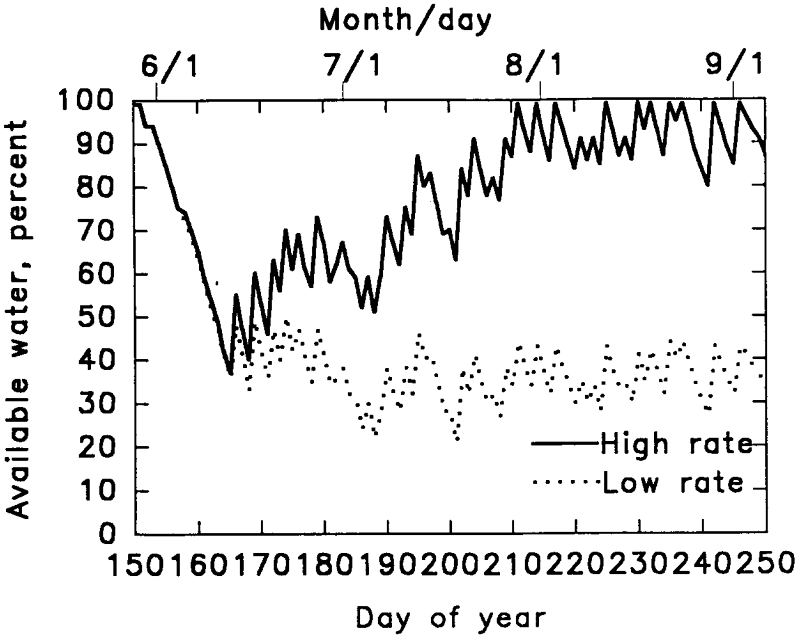
YEAR[2]	LOC	INT Days	AMT	TOT mm	DP mm	YIELD Mg/ha	GRADE	COLOR %	H_2O %	TEMP C
87	PARM	7	H	527	45	54 a	75 a	56 a	82	18.4 a
		7	L	459	5	47 a	71 a	41 a	79	18.3 a
		3	H	535	50	49 a	78 a	53 a	78	18.4 a
		3	L	481	6	49 a	68 a	40 a	61	18.8 a
87	KIMB	7	H	530	28	47 a	70 a	31 bc	79	18.4 b
		7	L	455	0	40 a	69 a	41 c	74	18.5 b
		3	H	532	2	44 a	66 a	14 a	70	17.4 a
		3	L	466	0	44 a	65 a	25 ab	4	17.4 a
88	PARM	7	H	633	99	32 a	49 a	87 b	76	20.0 a
		7	L	488	0	37 a	43 a	73 b	66	20.8 b
		3	H	625	87	39 a	54 a	54 a	90	19.8 a
		3	L	480	0	40 a	52 a	72 b	78	19.8 a
88	KIMB	7	H	60	31	54 a	67 a	29 a	65	19.8 a
		7	L	511	0	53 a	62 a	36 b	45	20.6 b
		3	H	624	12	56 a	69 a	27 a	62	19.8 a
		3	L	520	0	49 a	70 a	49 b	37	19.6 a
89	KIMB	3	H	629	26	43 a	67 a	17 a	66	17.1 a
		3	M	556	0	43 a	74 b	17 a	43	18.0 b
		3	L	445	0	41 a	67 a	18 a	31	17.7 ab
AVEAMT			H	576	46	46.9 a	66.0 a	43.9 a	75	19.0 a
			L	483	1	44.9 a	62.5 a	47.1 a	61	19.2 a
AVEINT		3DA				46.3 a	65.3 a	41.8 a	66	18.9 a
		7DA				45.5 a	63.3 a	49.3 b	71	19.4 b

[1]Significant difference (Pr>F=0.05) within a year/location shown by different letters using Duncan's multiple range test. For averages, AOV was based on a pooled analysis.

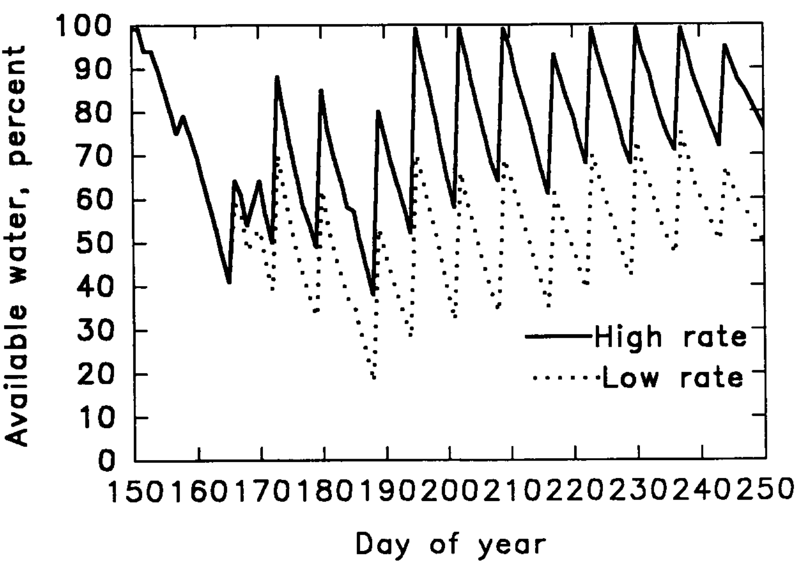
[2]YEAR Year of study
LOC Location: Parma or Kimberly, ID
INT Irrigation interval, days.
AMT Irrigation amount, High, Medium, or Low (see text).
TOT Total irrigation and rainfall, mm.
DP Total seasonal deep percolation, mm.
YIELD Total marketable yield, Mg/ha.
GRADE Percent of total yield in U.S. No. 1 tubers.
COLOR Harvest fry color rating, stem end, percent (#3+#4).
H_2O Soil water, average percent available from 6/15 to 7/15.
TEMP Soil temperature, average at the 150 mm depth, 6/15 - 7/15.
AVEAMT Average for High and Low amounts, 1987 and 1988 only.
AVEINT Average for 3 and 7 day intervals.

Fry Color and Sugar Ends

Harvest fry color ratings (higher %3+%4 indicates higher percentage of dark ends) are for tubers fried within one month after harvest. The second (January) fry had much higher percentages of dark ends due to an increase in reducing sugars in storage. The ratios of Storage to Harvest fry



a. High frequency, 3 irrigations per week.



b. Low frequency, 1 irrigation per week.

FIG. 1. Soil Water, 1988 Kimberly.

color ratings were nearly constant within each location and year, indicating that the harvest fry ratings alone could be used to compare treatment effects. The stem-end fry colors gave the best correlation with tuber quality and were used in this analysis. The bud-end samples gave much lighter color ratings (<5 percent (#3+#4)) and were not good indicators of treatment effects.

Differences between frequency treatments were not significant for the 1987 season, except that the high frequency at Kimberly tended to improve the color ratings slightly. The fry data showed high percentages of sugar-ends at Parma for both years. The 1988 Parma data showed higher sugar-end percentages and larger differences between treatments than in 1987. Tuber handling and storage procedures in 1988 may have increased harvest fry color rating (#3+#4) 15 percent-20 percent (Personal comm., G. E. Kleinkopf) compared to 1987 data. In 1988, more frequent irrigation at the high application rate reduced dark-ends at Parma compared to low frequency irrigation.

Soil Temperature Effects

Average daily mean and maximum soil temperatures for June and all season (June-August) periods are given in Table 2. Due to equipment malfunction, data for Parma in 1988 was incomplete. Daily mean and maximum soil temperatures for the 1988 season at Kimberly are shown in Figures 2 and 3, respectively. The high frequency irrigation treatment maintained a lower soil temperature than the low frequency treatment (measured at 15 cm depth from the top of the hill, Figure 2). The gradual decrease in soil temperatures through the season is probably due to increased crop cover and decreased direct solar radiation being absorbed

TABLE 2.—*Average daily (AV) and average daily maximum (MAX) soil temperatures, for early and all season periods, by year and location.*

			DEPTH			
			5 cm		15 cm	
YEAR	LOCATION	PERIOD	AV C	MAX C	AV C	MAX C
1987	PARMA	JUNE	18.7	23.2	18.7	20.8
		ALL	19.4	25.2	19.0	21.5
1987	KIMBERLY	JUNE	18.5	24.1	18.6	21.2
		ALL	17.4	23.1	17.3	19.8
1988	KIMBERLY	6/22 - 7/15	19.7	23.4	19.9	22.4
		ALL	16.8	20.4	16.9	19.0
	KIMBERLY	JUNE			16.2	19.4
		ALL			16.5	18.6

Note: Standard Error of Estimated Mean varied between 0.2 and 0.6 C.

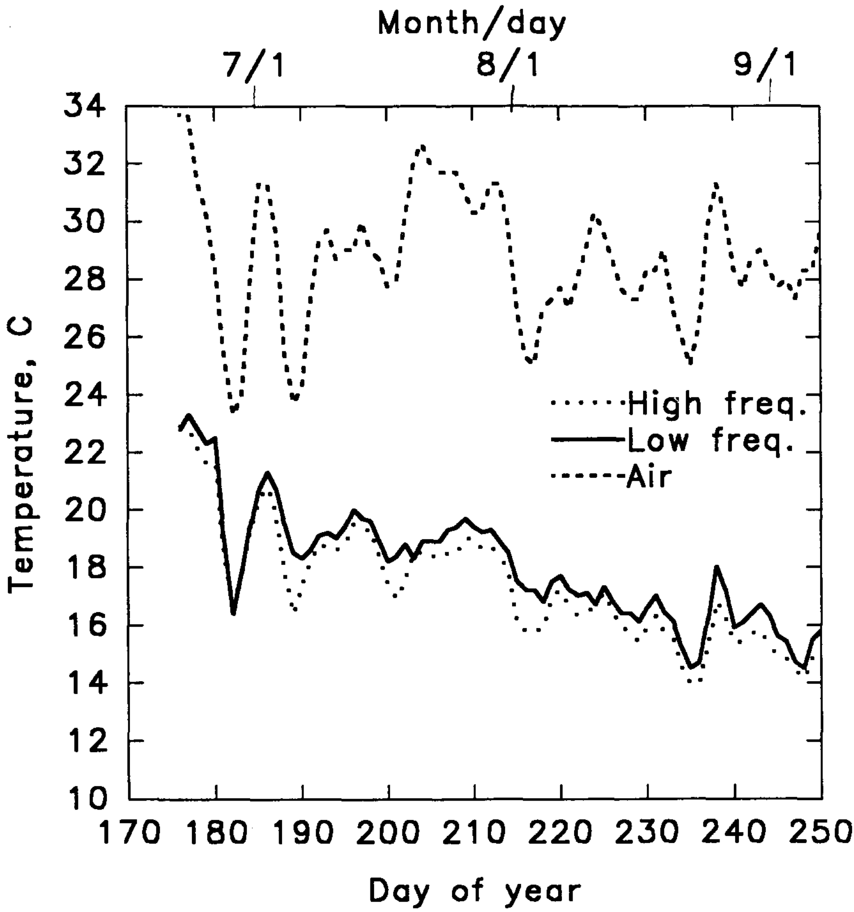


FIG. 2. Soil temperature at 15 cm depth, and 3-day mean air temperature, 1988 Kimberly.

by the soil. The 3-day moving average air temperature at Kimberly in 1988 (Figure 2) correlated well with soil temperature, and could be used as an indicator of daily current soil temperature. Maximum daily soil temperature at the 5 cm depth at Kimberly in 1988 was 1 to 2 degrees lower in the high frequency plots (Figure 3).

Soil temperatures were highest between mid-June and mid-July at Kimberly all three years. The 1987 early season soil temperatures at Parma (Table 2) showed the reverse trend due to a cool, wet June and early crop development. Overall, temperatures were higher at Parma than at Kimberly in 1987, which may partially account for the higher percentages of dark-end fries. At both locations, temperatures were reduced by both

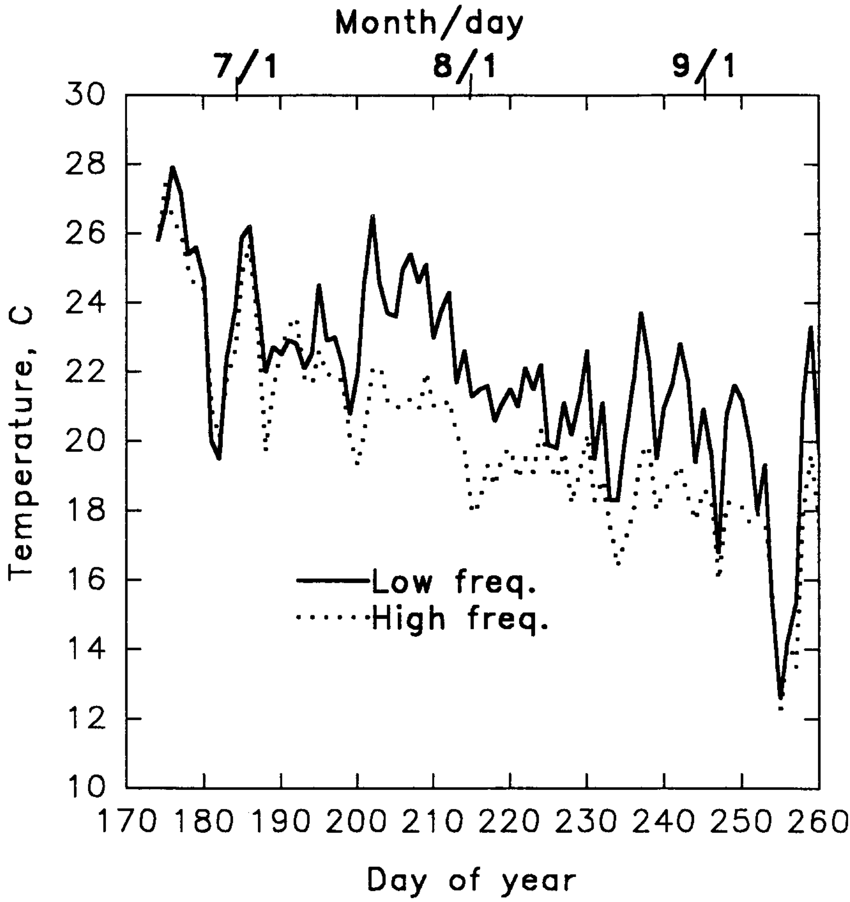


FIG. 3. Maximum daily soil temperature at 5 cm depth, Kimberly, 1988.

high amount and high frequency irrigation but frequency had the largest effect (Table 1). Soil temperatures at the 15 cm depth in the high frequency plots were about 0.5 C lower than in the low frequency plots.

Temperatures at the 15 cm depth within the hill gave the best correlation among the measured input parameters with potato quality. Early season temperature data to July 15, and the average temperatures for the entire season correlated similarly with tuber quality. In general, as average soil temperature increased, the percent of number one tubers decreased and the percent #3+%#4 fry color rating increased, indicating more sugar-end tubers (Figures 4 and 5, the high frequency irrigation data is indicated by the solid points).

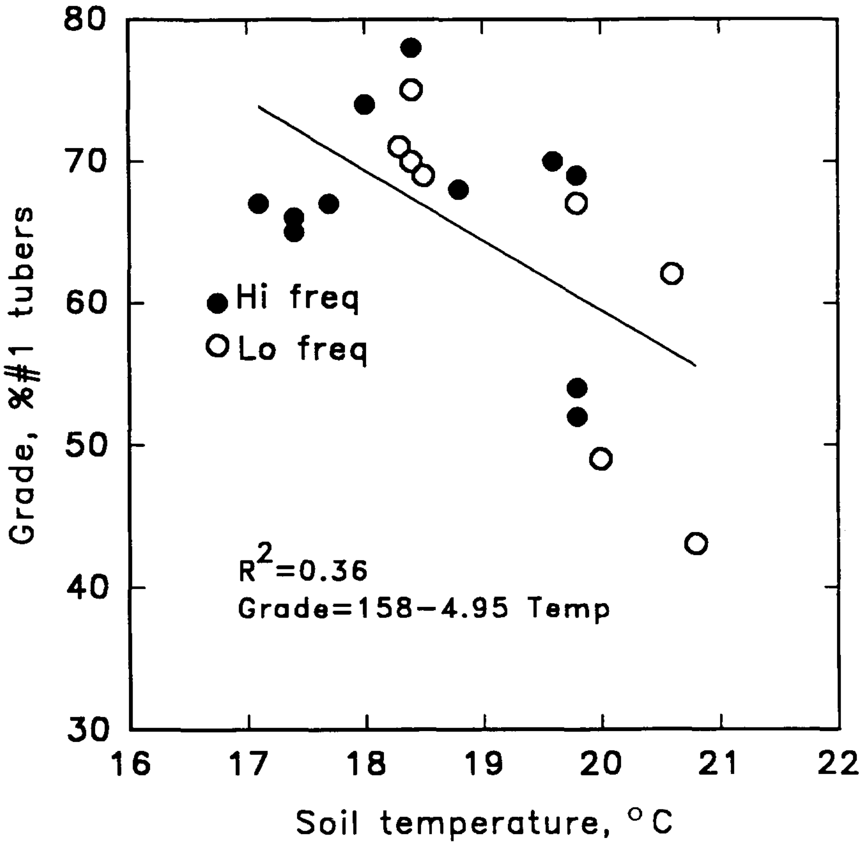


FIG. 4. Effect of soil temperature (15 cm depth, 6/15-7/15) on percent USDA number one tubers.

Intuitively, soil temperature should be inversely related to soil water due to increased opportunity for surface evaporation. The data showed little correlation between soil temperature and average percent available water (6/15-7/15). Apparently, high frequency irrigation maintained lower soil temperatures at the same or lower average soil water than the low frequency treatments. This is probably due to increased evaporation from the soil surface with more frequent irrigation, particularly early in the season.

Yield and Grade Quality

Total yields and grade quality for the two locations and three years of data are given in Table 1. There was no effect of irrigation frequency or

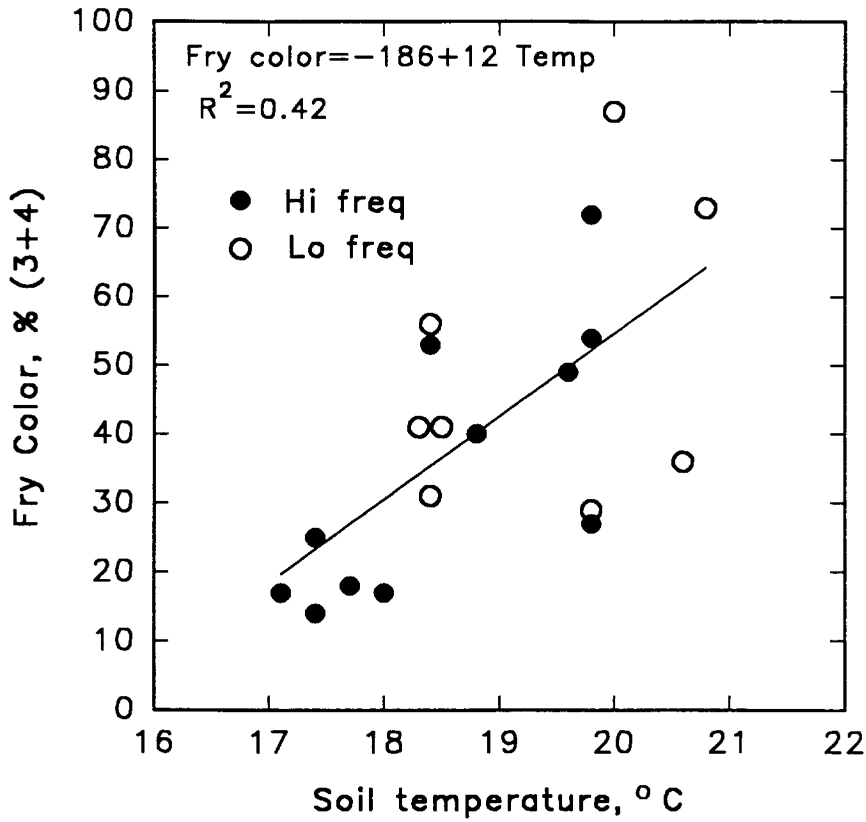


FIG. 5. Effect of soil temperature (15 cm depth, 6/15-7/15) on fry color rating.

amount on total yield or tuber quality as measured by percent No. 1's at either location in 1987 or 1988.

In 1989 the medium amount of water had higher percent No. 1's, indicating that the high amount was overirrigated. Although the high amount plots received about 17 percent more total water than the low amounts, when deep percolation is considered, the actual difference in water use was only about 13 percent. This may explain the lack of differences in yield and grade between the high and low amount plots.

Summary

Solid set sprinkler irrigated plots were used to study the effects of irrigation frequency and amount on potato quality for 3 years at two locations in Southern Idaho. Increasing the frequency of sprinkler irrigation tended

to increase the percent number one tubers and reduce the sugar ends, although the differences were non-significant.

The critical period for tuber quality appears to be from mid-June to mid-July, based on measured soil temperature differences. Increased mid-season soil temperature increased sugar-end tubers. Although soil temperature is primarily controlled by air temperature and radiation, this study shows that by using more frequent sprinkler irrigation, soil temperatures can be reduced, along with the incidence of sugar-end tubers. Crop management practices which produce higher percentages of U.S. number one tubers also tend to reduce the incidence of sugar-end tubers.

The lack of effects of reduced irrigation amount on yield and grade quality indicates that, on silt loam soils, water levels can be allowed to decline to approximately 50 percent of available without detrimental effects.

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