COMPARISON OF RUSSET BURBANK YIELD AND QUALITY UNDER FURROW AND SPRINKLER IRRIGATION

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Abstract

A survey of growers in the Treasure Valley of western Idaho/eastern Oregon indicated that Russet Burbank potato tends to produce better quality tubers under sprinkler irrigation than with furrow irrigation. Irrigation plot studies were carried out over 3 years on 2 sites to determine if these differences were a result of commonly-used management practices or inherent in the irrigation method. With good water management, irrigation method did not affect yields, but sprinkler irrigation produced tubers with slightly better visual quality and much lower incidence of sugar ends. The reasons for better quality with sprinkler-irrigation were projected to include: 1) less water stress since sprinklers can more uniformly apply the small, frequent irrigations that potato requires; 2) better nitrogen management since furrow applications often leach nitrogen from the root zone; and 3) lower soil temperatures due to sprinkler water evaporative cooling.

Compendio

Una encuesta de productores en el Valle del Tesoro (Treasure Valley) del oeste de Idaho y este de Oregón indicó que la papa Russet Burbank tendía a producir tubérculos de mejor calidad bajo irrigación por aspersión que bajo irrigación por surco. Se llevaron a cabo estudios de irrigación en parcelas durante tres años y dos lugares para determinar si estas diferencias eran el resultado de prácticas de manejo comunmente utilizadas o inherentes al método de irrigación. Con un buen manejo del agua, el método de irrigación no afectó los rendimientos, pero la irrigación por aspersión produjo tubérculos con una calidad visual ligeramente superior y una muy menor incidencia de azúcares terminales. Las razones de una mejor calidad con la irrigación por aspersión fueron estimadads e incluyeron: 1) menor estrés al agua desde que los aspersores pueden aplicar más uniformemente las irrigaciones pequeñas y frecuentes que la papa requiere; 2) un mejor manejo del nitrógeno desde que la irrigación por surco arrastra frecuentemente, por percolación, el nitrógeno de la zona de la raíz; y 3) menores temperaturas del suelo debido al enfri-

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amiento por evaporación del agua asperjada.

Introduction

Potato yield and quality can be decreased by plant stress during growth. Stress is caused by water deficiency, nutrient deficiency, and/or disease. High soil temperatures may also decrease tuber quality (25). Stress produces different results depending upon when it occurs (10). Russet Burbank potato occasionally suffers from a tuber quality problem called "sugar end" or "dark end" syndrome. The phenomena, in which one end of the tuber has higher levels of reducing sugars and fries darker than the remainder of the tuber, is believed to be caused by stress during tuber growth (8, 9, 10) and may be related to water management (18, 20).

In the semi-arid Pacific Northwest, irrigation management determines water availability, influences nutrient availability and may affect soil temperature. Potato is sensitive to water deficiency and has a shallow root zone. Wright and Stark (24) conclude, after reviewing past studies, that for optimum production of water stress-sensitive cultivars such as the Russet Burbank, soil water should remain above 65% of the available water holding capacity of the soil. Potato roots are not vigorous and seldom penetrate hard soil layers below plow depth. Even without restricting layers, they absorb most of their water from the surface 30 cm of soil (24). Thus, potato requires frequent irrigation to avoid water stress and small irrigations to avoid deep percolation loss of water and mobile nutrients.

The two primary irrigation methods for row crops are gravity (surface) irrigation in furrows and sprinkler irrigation. Gravity irrigation has been used since early agricultural development. Sprinkler irrigation came into common usage in the U.S. in the 1950s and 1960s. Potato was one of the first crops in the Pacific Northwest on which sprinkler irrigation was widely used. By 1980, over 90% of the Russet Burbank potato grown in the Pacific Northwest was sprinkler irrigated. The reasons for this trend include: 1) many growers feel potato is easier to manage and produces higher yields and quality under sprinkler irrigation, 2) potato is often grown on land not previously developed for gravity irrigation, and 3) potato generally produces sufficient gross income to allow use of capital-intensive irrigation methods.

Potato growers in the Treasure Valley in western Idaho and eastern Oregon did not follow this regional trend to convert to sprinkler irrigation. Farmers in the area grow potato in rotation with several other furrow-irrigated crops and generally felt that they could not afford the added cost of adopting unfamiliar and capital-intensive sprinkler irrigation. Sugar-end syndrome is a more frequent and serious problem in the Treasure Valley than in other areas.

Several studies in the past compared sprinkler and furrow irrigation of potato. Various studies measured effects of irrigation method such as higher occurrence of Verticillium wilt under furrow irrigation (6), early die of potato vines with furrow irrigation (17), lower soil temperature with sprinkler irrigation (15, 17), more efficient water use with sprinkler irrigation (5, 7) and concentrating nitrogen fertilizer in the upper hill with furrow irrigation (17). However, most studies did not find a significant effect on yield or external visual quality (5, 7, 14, 17). Exceptions were Agrawal *et al.* (1) who reported higher yield and larger tubers and Jensen *et al.* (11) who reported better visual quality with sprinkler irrigation. The only previous study which has evaluated the effect of irrigation method on fry color was Jensen *et al.* (11) who measured significantly lighter stem-end fry colors with sprinkler irrigation in eastern Oregon.

The objective of this study was to evaluate irrigation method effects on Russet Burbank yield and quality, both under commonly-followed farmer practices and with carefully controlled water management. This study was part of a larger project designed to determine causes for sugar-end syndrome and to develop management practices to prevent its occurrence.

Methods

Farmer sprinkler and furrow irrigation practices on Russet Burbank potato in the Treasure Valley area were determined from farmer responses to questionnaires distributed by a potato processing company. Sprinkler water applications were calculated from farmer logged irrigation schedules and details of the sprinkler system (nozzle size, spacing, and operating pressure). Furrow applications were estimated from irrigation schedules combined with average furrow infiltration rates measured by the inflow-outflow method on 15 fields in the area. Yield, grade, and tuber fry color information for the surveyed fields were supplied by the processor. In addition, net water application (field inflow minus runoff) was monitored on four furrow-irrigated farmer fields with automated flow measurement devices during the 1987 season.

Sprinkler and furrow irrigation of Russet Burbank potato were compared in side-by-side replicated plots for three years at Kimberly, in south-central Idaho, and two years at Parma, in southwestern Idaho. 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. The soil at Kimberly was Portneuf silt loam (coarse-silty, mixed, mesic Durixerollic Calciorthids). The Parma soil was a Greenleaf silt loam (fine-silty, mixed, mesic, Xerollic Haplargids). Both soils have a hard highcalcium layer at about 0.45 m below the surface which restricts root penetration but not water movement. The soils have similar infiltration and water holding characteristics. Field capacity (-33 kPa pressure) and wilting point (-1500 kPa) water contents were determined, on pressure plates, to be 32% and 14% (volumetric), respectively, for both soils, resulting in an available water holding capacity, AW, of 18%. Field measurements supported these limits.

The experimental design was a split plot replicated three times. Each replication block was approximately 50 m wide and 100 m long. Sprinkler irrigation was applied to half of each block from three solid set laterals. Sprinkler application amounts were calculated from sprinkler flow rates and verified with catch-cans. Furrow irrigation water was applied to the other half of each block through gated pipe from a constant-head reservoir so that constant flow could be maintained. Individual furrow inflow rates were measured volumetrically (bucket and stop watch), and runoff rates were measured with V-notch furrow flumes connected to automatic data loggers. Furrow application amounts were calculated as the difference between inflow and outflow volume divided by the irrigated area. Water application depths were based on daily crop water use as predicted by the modified Penman equation (12) using data from an automated weather station located in each field. Soil moisture status was monitored with tensiometers and gravimetric soil water samples during all years and with neutron meters in 1987 and 1988.

The two irrigation method blocks were subdivided into two irrigation amount treatments. The low amount treatment was designed to just replace predicted crop water use. An additional 15% of water was applied to the high amount treatment to maintain higher available water contents. In 1987, one week irrigation intervals were used. Observations of shallow rooting depth and the resulting 40 percentage point decreases in available water content in seven days convinced us to increase irrigation frequencies to twice per week for furrow applications and 2 or 3 times per week for sprinkler applications in 1988 and 1989. The irrigation treatments and seasonal water applications are listed in Table 1.

Preplant, banded fertilizer applications followed recommended rates to produce optimum yields (16). Plant nutrient status was monitored with petiole samples. Soil temperatures were measured with thermocouples located 5 and 15 cm below the soil surface in the center of the potato hill. Temperatures were recorded every hour throughout the season.

Two 15-m long row segments from each treatment were harvested in early October. Tubers were graded by size and visible quality (3), and fry color and specific gravity were determined on subsamples. Fry color was measured, after one month storage at 16 C, on 13-mm thick stem- and bud-end slabs after frying in vegetable oil at 190 C for 2.5 minutes. Fry color was

TABLE 1.—*Irrigation treatments, predicted seasonal crop water requirements (CWR) and seasonal water applications.*

Location	Year	Treatment Frequency (per week)	Treatment Amount	Predicted CWR (mm/season)	Irrigation Application[1] (mm/season) Furrow	Irrigation Application[1] (mm/season) Sprinkler
Kimberly	1987	`1	Med	490	503	455
			High		594	530
Kimberly	1988	2-3[2]	Med	620	1230[3]	520
			High		1200[3]	624
Kimberly	1989	2	Med	590	582	556
			High		673	629
Parma	1987	1	Med	460	518	459
			High		549	527
Parma	1988	2-3[2]	Med	530	551	480
			High		678	625

[1]Including precipitation during the growing season which ranged from 5 to 67 mm.
[2]Two per week for furrow irrigation and three per week for sprinkler irrigation.

determined by a Photovolt[2] model 577 reflectance meter visually-calibrated to a USDA fry color standard chart (2). The meter used a green tristimulus filter and was standardized with black cavity and standard white enamel reflectance plaques. This procedure is similar to that recently reported by Shock (20). Dark ends were defined as those with #3 and #4 color. Data from research plots were analyzed with MEAN, ANOVA, or GLM procedures of SAS (19).

Results

Farmer Field Survey

The surveyed sprinkler-irrigated fields produced slightly higher average tuber yields with significantly (P=.05) lower incidence of dark-end tubers than furrow-irrigated fields (Table 2). Visual quality was not affected by irrigation type.

Most sprinkler irrigators applied water for either 8 or 12 hours (25 to 50 mm application depth) every 4 to 7 days during early to mid-season (June 15 - July 15). Mean calculated gross water application to the 85 surveyed sprinkler-irrigated farmer fields was 17% greater than the estimated crop water use (Table 2). If 5% of the sprinkler applications were assumed lost to evaporation and wind losses, the excess net application would be

[2]Use of trademarks does not constitute a guarantee or warranty of the procuct by the USDA-ARS and does not imply its approval to the exclusion of other products.

TABLE 2.—*Estimated water application and crop-water use, and measured yield and quality for surveyed Treasure Valley farm fields.*

	Sprinkler	Furrow
Number of Fields Surveyed	85	38
Mid-season Water Application (June 15 - July 15)		
Median irrigation interval (days)	5	6
Median Individual Irrigation Amount (mm)	35	60
Average Daily Water Application (mm/day)	7	10
Average Daily Crop Water Use (mm/day)	6	6
Excess Daily Application (%)	17	67
Seasonal Water Application		
Average Water Application (mm)	690	900
Estimated Crop Water Use (mm)	580	580
Excess Seasonal Application (%)	19	55
Estimated Deep Percolation (mm)	75	320
Yield and Quality		
Total Yield (Mg/Ha)	41	38
USDA #1 Grade Tubers (%)	69	68
Specific Gravity	1.082	1.083
Dark Ends (%)	5	8*

*Significantly different at $P < 0.05$.

12%, which is a reasonable allowance for non-uniform water distribution. Estimated deep percolation loss of water below the root zone averaged 75 mm for the season under sprinkler irrigation.

Furrow irrigation intervals tended to be about one day longer than sprinkler intervals. However, most farmers irrigated alternate furrows each irrigation, which resulted in 10- to 14-day intervals on each furrow. Irrigation times were generally 12 or 24 hours and estimated applications varied from 25 mm to greater than 100 mm net applications. Seasonal water application (deducting runoff) to the 38 furrow-irrigated farmer fields was highly variable and averaged about 55% greater than estimated crop water use, resulting in an average deep percolation loss of 320 mm. On the four seasonally-monitored fields seasonal water application varied from slightly below estimated crop water use to 200% of water use. Three of the four fields received excessive amounts of irrigation water.

Research Plots

There were no significant or consistent effects of irrigation amount on any yield or quality parameters. The low application amounts apparently did not create sufficient water stress to affect yield. Consequently, irrigation amount treatments are combined in Table 3.

Irrigation methods did not affect total or marketable yield in any of the five site/years for the experimental studies (Table 3). Sprinkler irriga-

TABLE 3.—*Yield and quality results for research plots.*

	Total Yield (Mg/ha)	(Mg/ha)	Marketable Yield		USDA #1 Grade (percent)		Specific Gravity		#3 & #4 Fry Color (percent)		#4 Fry Color[1] (percent)	
	Sprinkler	Furrow	Spr	Fur	Spr	Fur	Spr	Fur	Spr	Fur	Spr	Fur
Kimberly												
1987	44	47	37	41	68	54	1.082	1.083	29	58**	10	21*
1988	53	54	50	50	69	51*	1.085	1.086	26	47*	5	15**
1989	43	41	36	36	71	68	1.079	1.076*	14	57**	2	19**
Parma												
1987	50	50	39	42	73	75	1.082	1.081	43	58	7	13
1988	37	33	31	25	51	37**	1.071	1.068**	53	80*	18	47*
Average	45	45	38	39	66	57	1.080	1.079	33	60	9	23

[1]Stem end fry color one month after harvest.
* Significant differences between irrigation method at P < 0.10.
**Significant differences between irrigation method at P < 0.01

tion produced significantly higher tuber specific gravity in 1988 at Parma, and in 1989 at Kimberly, with no consistent differences for the other three cases. The percent of total yield graded as USDA #1 tubers was higher with sprinkler irrigation than with furrow irrigation in 4 of 5 cases and significantly higher at both sites in 1988. Sprinkler irrigation produced fewer dark-end tubers in all years with significant differences in 4 of the 5 cases. Average percentage stem-end dark-end tubers was 33% with sprinkler irrigation and 60% with furrow irrigation. Bud ends fried much lighter than stem ends (less than 5% dark ends) and showed no effect of irrigation method.

The high amount treatments of both the sprinkler and furrow irrigated plots generally successfully maintained water contents above 65% of available water holding capacity. The 1989 data (Fig. 1) show that, although the plots were allowed to dry out early in the season, beginning the last week of June (day 177), water contents were maintained in the desirable range. The low amount treatments, designed to match crop water use, generally kept levels above 50% of available water holding capacity. Furrow irrigation applications were consistently 5 to 15% larger than sprinkler applications except in 1988 at Kimberly where high infiltration rates caused excessive furrow applications (Table 1). Projected seasonal deep percolation losses (based on uniform water applications) were generally less than 100 mm for the furrow-irrigated plots (except Kimberly, 1988) and less than 50 mm from sprinkler-irrigated plots.

Soil temperatures at the 15-cm depth in the sprinkler-irrigated plots averaged between 0.5 C and 1.0 C lower than in the furrow-irrigated plots

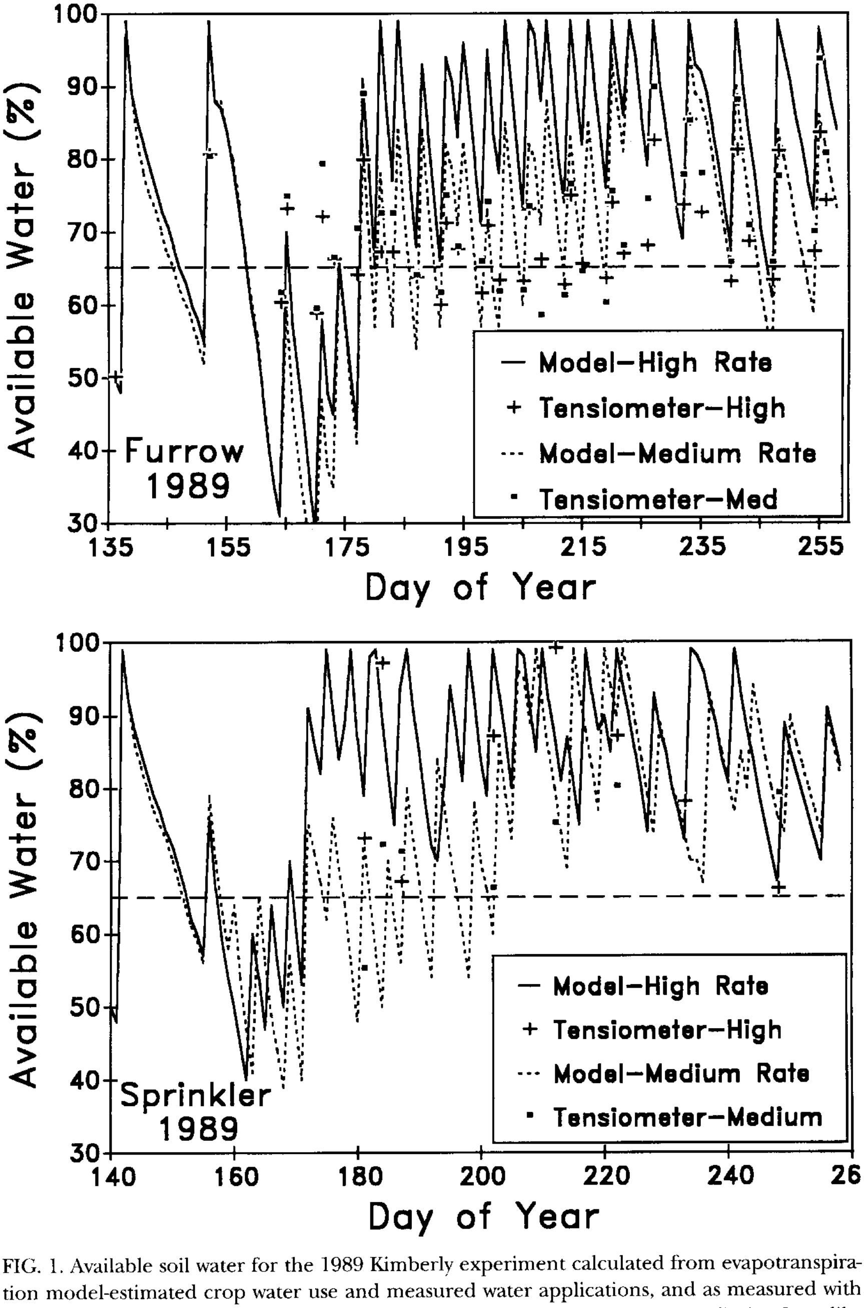

FIG. 1. Available soil water for the 1989 Kimberly experiment calculated from evapotranspiration model-estimated crop water use and measured water applications, and as measured with tensiometers (at 30 cm depth). The horizontal dashed line indicates lower limit of readily-available water.

a. Furrow irrigation b. Sprinkler irrigation

TABLE 4.—*Daily average and maximum soil temperature (Deg C) 15-cm below the center of the potato row.*

	Daily average					Daily Maximum				
	1987 Parm	1987 Kimb	1988 Kimb	1989 Kimb	Avg.	1987 Parm	1987 Kimb	1988 Kimb	1989 Kimb	Avg.
Early Season[1]										
Furrow	19.0	19.1	21.0	20.4	19.9	21.1	21.3	23.0	21.6	21.8
Sprinkler	18.7	18.6	19.9	18.4	18.9	20.8	21.2	22.4	19.4	21.0
Difference	0.3	0.5	1.1	2.0	1.0	0.3	0.1	0.6	2.2	0.8
Total Season[2]										
Furrow	19.5	18.3	17.4	18.0	18.3	21.7	20.2	18.9	20.0	20.2
Sprinkler	19.0	17.3	16.9	16.5	17.4	21.5	19.8	19.0	18.6	19.7
Difference	0.5	1.0	0.5	1.5	0.9	0.2	0.3	0.0	1.5	0.5

[1]Tuberization to canopy cover.
[2]Tuberization to canopy die.
Note: 1988 Parma temperature data were incomplete due to equipment failure.

(Table 4). Sprinkler irrigation reduces soil temperatures both by reducing air temperatures and because the temperature of the water droplets is near the wet bulb temperature when they reach the ground. Evaporation from the wet soil surface also removes heat from the soil. Consequently, sprinkler irrigation cools the soil more than furrow irrigation.

Discussion

Farmer Irrigation Practices

For the silt loam soils prevalent in the study area, the surface 30 cm of soil holds only 19 mm of readily available water (that above 65% available) ([1-0.65] · 0.18 · 300 mm = 19 mm). In southern Idaho, potato, during mid-season, uses an average of 6 mm of water per day or 19 mm in about three days. Since these soils can hold additional water above field capacity for about one day, the irrigation interval can be increased to four days before depleting the readily-available water in the top 30 cm. Only 15% of the Treasure Valley irrigators used 4 day or shorter intervals. The median interval was 5 to 6 days which requires extracting water down to 60% available to 40 cm below the surface. Both sprinkler and furrow irrigators in the area use longer than optimum intervals.

In southern Idaho, potato consumes an average of 24 mm of water in four days and 36 mm in six days during mid-season. Uniformly applying such small amounts with furrow irrigation is very difficult unless fields are small and infiltration rates are low. On the average furrow-irrigated farmer field, applications exceeded water use by more than 50%, resulting in large amounts of water deep percolating beyond the root zone, potentially carrying with it a portion of the plant-available nitrogen. By comparison, the surveyed sprinkler irrigators applied 30 to 40 mm per irrigation which would produce much smaller deep percolation losses. The longer furrow irrigation intervals and probable nitrogen deficiencies caused by large amounts of deep percolation could contribute to the higher incidence of dark end tubers produced under furrow irrigation (9). It is surprising that this large difference in water application did not significantly affect yields and visual quality.

Sprinkler irrigation also facilitates improved cultural practices. On many soils, potato benefits from nitrogen applied during plant growth (23). Although nitrogen fertilizer is commonly applied during the season through sprinkler systems, nitrogen application with furrow irrigation is not common because of non-uniform distribution and the loss of nitrogen with the runoff water. Pre-emergent herbicides and some insecticides are also commonly applied and incorporated with sprinkler water. With furrow irrigation, they must be applied and incoroporated with ground equipment which increases soil compaction.

Best Achievable Irrigation Management Practices

On the research plots in 1988 and 1989, both furrow and sprinkler irrigation were applied every 3 to 4 days during peak water use to maintain soil water in the readily available range, and excessive applications were generally avoided (except as noted earlier). Soil water content and nutrient concentrations were generally maintained a little higher under sprinkler irrigation, but were within acceptable ranges with both methods. However, even with the carefully-scheduled irrigations, furrow irrigation still produced lower quality tubers.

High soil temperature during critical growth stages may be a contributing factor to sugar-end development in Russet Burbank potato (13, 18). Soil temperatures were only slightly higher with furrow irrigation than with sprinkler irrigation, although this difference would likely be increased if sprinkler irrigation frequencies were shorter than with furrow irrigation (13).

We believe these small measured differences in soil water status and soil temperature with irrigation method are not sufficient to explain the large differences in fry color. Since explicit causitive factors were not determined, we project that the quality differences were a result of non-uniform furrow water distribution and its impact both on water deficits and nitrogen availability.

Because small irrigation amounts are difficult to apply with furrows, alternate furrows are irrigated each irrigation. Consequently, only about 15% of the soil surface is wetted and the water would have to move 0.8 m laterally through the soil to wet the whole root zone. The potato hill is above the water level in the furrow so water must also move upward to wet

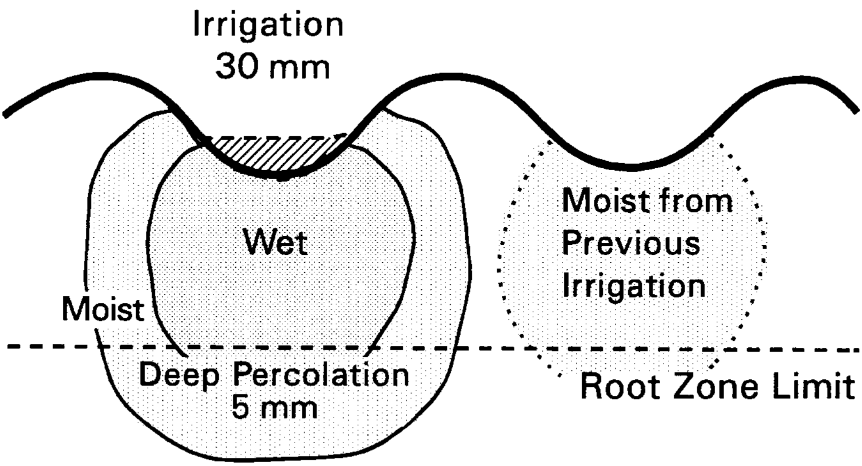

FIG. 2. Depiction of soil water distribution below alternately-irrigated potato furrows after an irrigation equal to pre-irrigation storage capacity.

the hill. Unless a dense soil layer restricts downward water movement, water moves downward in soil faster than laterally. Thus, attempts to wet the complete root zone causes large amounts of deep percolation loss (Fig. 2). Detailed soil water content measurements before and after irrigation showed that, even when furrow water applications were 20% less than the available soil water storage, only 85% of the applied water was stored in the root zone (the remainder being lost to deep percolation). Water application 20% greater than available storage produced 35% deep percoloation loss but still failed to wet all the potato hill. This lateral water distribution problem is the reason the measured soil-water contents shown in Figure 1a are less than those predicted by crop-water use. Although the average water content in the root zone can be maintained within acceptable limits, potato roots near each furrow experience widely varying soil water contents and the upper potato hills remain dry. The dry portions of potato hills effectively reduce the water storage capacity of the root zone. Sprinkler irrigation, by comparison, wets the whole soil surface and re-quires only vertical water movement to replenish the root zone.

The distribution of irrigation water along furrows is dependent upon the water infiltration rate. Infiltration is a highly variable phenomena with coefficients of variation often exceeding 30% (4, 21). As a result, water applications to individual plants would be expected to vary from about half to double the field average. This variability is in addition to non-uniform water application created by the irrigation process (*i.e.*, greater application to the head or inflow end than the tail end of the field). Because water from sprinklers is usually applied at rates below the infiltration rate, infiltration does not affect water distribution and applications are generally more uniform. Yield samples from a series of 3 m long row segments showed that tuber visual quality (but not yield) was more variable with furrow than with sprinkler irrigation (data not shown). One stressed plant in twenty is sufficient to affect a quality parameter such as fry color which has a low threshold of acceptability.

A consequence of the non-uniform water distribution between and along furrows is non-uniform availability of nitrogen due both to dry soil regions and leaching losses. In spite of adequate nitrogen appications and well-managed water applications, petiole nitrogen concentrations tended to be lower in the furrow-irrigated plots, especially late in the season (22). Soil sampling at maturity showed that a substantial portion of pre-plant broadcast nitrogen accumulated in the dry, upper portion of the potato hills where it was unavailable due to lack of water. Banding the nitrogen near the seed piece during planting improved the availability of nitrogen under furrow irrigation (23).

With these differences in water and nitrogen availability due to irrigation method, and the previously proposed sensitivity of potato to these factors, it is surprising that yield and quality differences were not larger than measured, especially on farmer fields where both long furrow irrigation intervals (considering alternate furrow application) and sizeable overirrigation were documented. The lack of yield and quality differences forces consideration of the possibilities that potato is not as sensitive to water availability as previously thought (the 65% available water limit may be too high for most soils), and that farmers apply extra nitrogen to compensate for nitrogen leaching losses.

The economic advantages of sprinkler irrigation include higher gross income and reduced risk due to higher tuber quality, higher water use efficiency and easier cultural practices. These are certainly sufficient to justify use of sprinklers for potato production on land not previously developed for surface irrigation, and will usually justify use of sprinklers for potato production on otherwise surface-irrigated land.

Summary and Conclusions

Sprinkler irrigation produced better Russet Burbank tuber quality and fry color than furrow irrigation, even with well-scheduled furrow water applications. Definitive causes for the irrigation method effects were not identified. Possible reasons for lower potato quality with furrow irrigation include water stress due to non-uniform water application, nitrogen deficiency due to deep percolation losses, and higher soil temperatures.

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