High-frequency Trickle Irrigation and Row Spacing Effects on Yield and Quality of Potatoes[1]

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ABSTRACT

Soil water is a major limiting factor in the production and quality of potatoes (*Solanum tuberosum* L.). The objectives of this research were to determine the effects of trickle irrigation under controlled soil matric potential and two row spacings on the yield, quality, and nutrient contents of potatoes. Potatoes, trickle irrigated with nutrient solution and grown on 100-cm row spacing (CSI) on sandy loam (Typic Paleudult) soil, yielded 76% more marketable potatoes than those trickle irrigated under a plastic mulch and grown on twin row spacing (TRI) and 206% more than 100-cm spaced, nonirrigated potatoes (CSNI). Water deficit, calculated by subtracting rainfall from 80% of pan evaporation, was 14.0 cm. Soil matric potentials 15 cm from the soil surface were not different for the CSI and TRI treatments irrigated, respectively, with amounts of water equivalent to 60 and 43% of the water deficit. The N and Mg contents of tubers were increased by irrigation. Leaf petiole nitrate N of CSI and TRI potatoes was consistently greater than 16,000 ppm, a critical level for Russett Burbank potato production in Idaho, but fell significantly below that level for the CSNI potatoes after an extended drought.

Additional index words: **Water management, Soil water stress, Soil matric potential, Nutrient, Water use efficiency, Energy conservation.**

THE mean yield of spring-grown potatoes (*Solanum tuberosum* L.) for the USA and for seven southeastern states between 1971 and 1973 was 25,890, and 12,952 kg/ha, respectively, representing an average 50% production limitation in the southeast[3]. Factors such as soil water and aeration, high temperature, nutrient levels, and weed and insect infestations may combine to produce yield limitations in the southeast.

Soil water is a major limiting factor in the production and quality of potatoes. Epstein and Grant (4) have suggested that potato plants grown in northern Maine may suffer from water stress when the soil water potential is less than —0.25 bar. Mist irrigation on silty loam soils (13, 15) has been shown to reduce internal moisture stress in plant leaves and to keep plants more photosynthetically active, thus providing more of the sugars necessary for tuber growth. Shallow layered sandy loam soils have lower water storage capacity and lower water retention than silty loam soils and will desorb rapidly between rainfalls (8, 9, 10). Potatoes growing in these soils are subjected to a wide range of soil matric potentials which may decrease yield and lower the quality of tubers. Tuber shape defects during the tuber enlargement period can be decreased, and potato yields increased by maintaining a high and nonfluctuating soil matric potential in the root zone (1, 4, 6, 7, 12). Ideal conditions for potato growth include high and nearly constant soil matric potential, high soil oxygen diffusion rate, adequate incoming radiation, and optimal soil nutrients. High-frequency water-nutrient management by trickle irrigation minimizes soil as a storage reservoir for water and nutrients, provides at least daily requirements of water and nutrients to a portion of the root zone of each plant, and maintains a high soil matric potential in the rhizosphere to reduce plant water stress. Controlled high-frequency trickle irrigation has been used in the subhumid Coastal Plains to accurately regulate soil matric potentials in the root zone without inhibiting the oxygen diffusion rate in soil and to minimize plant water stress of sweetcorn (*Zea mays* L.) (8, 9). Yield and water use efficiency of trickle-irrigated sweetcorn were significantly greater than that of furrow and sprinkler-irrigated plants.

The objectives of this experiment were to evaluate the influence of high-frequency trickle irrigation on potato yield and quality grown on sandy loam soil and to study the effects of row spacings plus high-frequency trickle irrigation on potato production.

PROCEDURE

A. Experiment Design and Conditions

A field experiment was conducted at Florence, S. C. comparing: (a) 100-cm row spacing with high-frequency trickle irrigation (CSI) (Fig. 1a); (b) twin-row spacing with high-frequency trickle irrigation (TRI); and (c) 100-cm row spacing with no irrigation (CSNI) (Fig. 1a). Pairs of rows (35 cm apart) were spaced 130 cm in the TRI plots (Fig. 1b). Treatments were replicated three times. Plots were 30 m long and 6 rows wide, the two center rows of which were harvested. Tuber pieces ('Irish Cobbler') were planted about 25 cm apart in the row for all plots.

The soil was a shallow-layered Norfolk sandy loam (Typic Paleudult), with a pH of 6.1 and an organic matter content of less than 0.5 %. The A1 horizon has an average bulk density of 1.5 g/cm^3 and sand-silt-clay percentages of 76, 18, and 6%, respectively. The A2 horizon has an average bulk density of 1.7 g/cm^3 and sand-silt-clay percentages of 70, 20, and 10%, respectively. The B horizon has an average bulk density of 1.5 g/cm^3 and sand-silt-clay percentages of 61, 18, and 21%, respectively. Campbell et al. (2) have described the physical properties of this soil in detail. Fertilizer (10-10-10 analysis) was broadcast at the rate of 1,120 kg/ha over the entire test area. Herbicide, nematocide, and insecticide were applied as recommended by Clemson Univ. Extension Service.

B. Water-Nutrient Management

For the CSI and TRI treatments, porous irrigation tubes (Viaflo, E. I. DuPont de Nemours, Wilmington, DE 19898)[4] were installed as shown in Fig. 1a, b (9, 10). In the TRI plots, a strip of clear polyethylene plastic (0.01 cm thick and 20 cm

[1] Contribution from the Coastal Plains Soil and Water Conservation Research Center, Southern Region, ARS-USDA, Florence, SC 29501, and North Carolina State Univ., Dep. of Horticultural Science, Raleigh, NC 27602, in cooperation with the South Carolina Agric. Exp. Stn. Received 2 Sept. 1975.

[2] Soil scientist, ARS-USDA, Florence, S. C., and assistant professor, North Carolina State Univ., Raleigh, N. C., respectively.

[3] USDA Statistical Reporting Service Report, 1974.

[4] Trade names are used for identification purposes only and do not imply preference for this item by the USDA or by N. C. State Univ.

wide) was installed above the porous tube and partially covered with soil to reduce evaporation. In the CSI plots the porous tube was installed 5 cm to the right of the plants and 4 to 5 cm below the soil surface.

Tensiometers (Soil Moisture Model #2725)[4] were installed at a 15-cm soil depth, so that the ceramic cups of the instruments were in the row, equidistant from two potato hills (Fig. 1a, b). Soil matric potential was measured twice daily at 0800 and 1600 hours to determine the need for irrigation. The frequency and length of irrigations needed to replace the water lost by evapotranspiration was calculated as follows:

$$Q_1 = L_1 WET \qquad [1]$$

where

Q_1 = quantity of water lost by evapotranspiration from the area in cm^3/day
L_1 = length of row in cm
W = effective width of the soil surface in cm contributing to evapotranspiration
ET = evapotranspiration rate in cm/day

and

$$Q_2 = PFL_2\gamma \qquad [2]$$

where

Q_2 = quantity of water to be applied by irrigation to replace Q_1 in cm^3/day
P = period of irrigation in minutes/irrigation
F = frequency of irrigation in irrigation/day
L_2 = length of tube in cm
γ = flow rate of the tube in $cm^3/cm/min$.

By equating (1) and (2) and $L_1 = L_2$

$$PF = \frac{WET}{\gamma} \qquad [3]$$

Figure 2 shows a family of curves used for the CSI treatment and for various ET values when $\gamma = 8.62 \times 10^{-2}$ $cm^3/cm/min$ and W = 15 cm at the beginning of the season. A similar family of curves was derived for the TRI treatment using W = (165/100) ×15 cm. As the crop grew, W was increased to 80 and (165/100) × 80 cm, respectively. These curves indicate the range of frequencies and times available as management variables for different evapotranspiration rates. In this experiment, plots were irrigated, for 30 min at a water application rate of 0.08 ml/cm of tube/min, as many times daily as required if the tensiometer measured less than -200 mb (11).

The soil matric potential profile was measured at the end of some of the irrigated rows, 30 m from the lateral, with a portable soil water pressure probe. (Soil Moisture cat. no. 2900-C, P. O. Box 30025, Santa Barbara, CA 93105)[4]. Measurements were obtained on a 5 by 10 cm grid, starting 5 cm from the soil surface below the irrigation tube and extending to the 30 cm depth.

The soil matric potential was maintained between 0 and 200 mb with a nutrient solution which contained equal amounts of N (as 50% urea and 50% NH_4NO_3) and K (as KNO_3). The nutrient solution was supplied daily through the porous tube with a metering pump at a rate of 55 ml/min (Precision Control Product Corp., model 8301, 1396 Main St., Waltham, MS 02154)[4] to maintain 22,000 ppm plant NO_3-N level (5) as measured by tissue analysis. Fertilizer applications were quantified daily by recording the time the precalibrated metering pump operated. An equivalent of 336 kg/ha each of N and K was applied in solution throughout the growing season. After the weekly desired plant nutrient level was obtained, water alone was applied with the irrigation system. The nonirrigated potatoes were sidedressed four times with NH_4NO_3 and KNO_3 applied manually in a band 5 cm deep and 15 cm from the potatoes to supply the equivalent N and K amounts.

Irrigation water was measured daily with flowmeters. Rainfall and pan evaporation were measured daily with standard U. S. Weather Bureau instruments. Based on previous experiments, water deficit was calculated by subtracting all rainfall from 80% of pan evaporation (9, 10, 11).

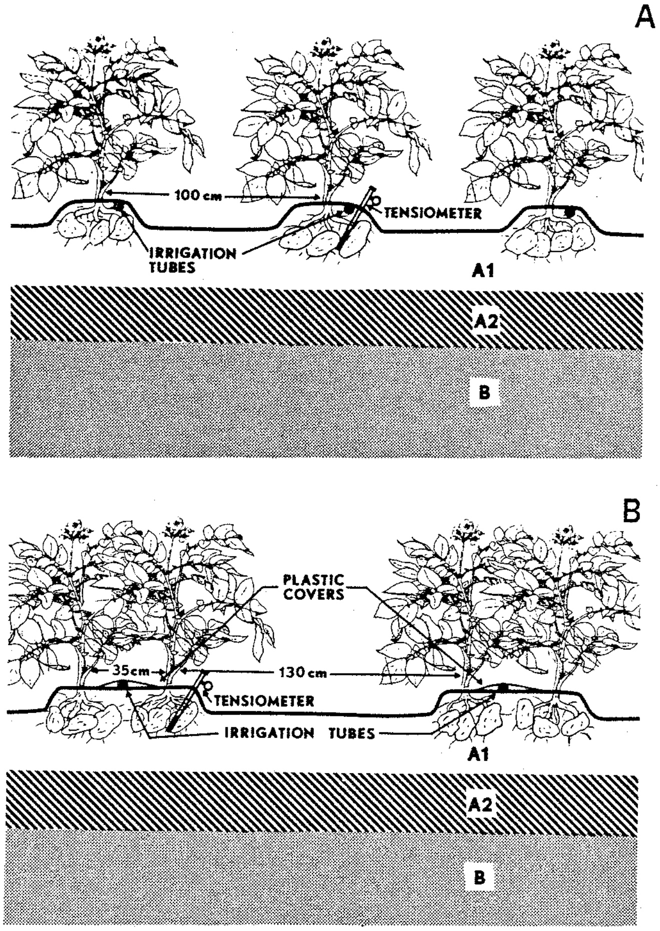

Fig. 1. Schematic of soil profile, Norfolk sandy loam (Typic Paleudult), and potatoes, trickle irrigation tube and tensiometer position for (a) CSI treatment and (b) TRI treatment.

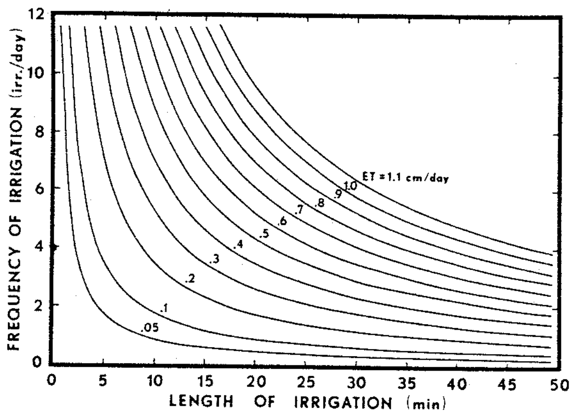

Fig. 2. Irrigation frequency and time requirements for porous tube irrigation system under different evapotranspiration rates.

C. Plant and Soil Measurements

Potatoes were planted on 6 March (day 66) and emerged on 27 March (day 87). Plant heights were determined by measuring the tallest portion of haulm in each of 10 hills at different locations on each yield row. The mean of these measurements was used for statistical analyses.

The NO_3-N contents of potato leaf blade, petiolule, and petiole were measured several times during the growing season. The first mature leaf from the top of the plant was sampled for NO_3-N. The petiole, petiolule, and leaf blades were sepa-

Table 1. Factors influenced by three irrigation treatments of potatoes.†

Treatment	Total wt.§	Wt. of U.S. No. 1 (d > 5 cm)	Wt. of Jumbo (d > 9 cm)	Wt. of 2nd growth	Cracked potatoes	Specific gravity	Marketable wt.‡
	kg/ha				no./ha		%
Trickle irrigated Conventional spacing (CSI)	34,269 a**	28,054 a	228	847	4,485	1.069	83 a
Trickle irrigated Twin row spacing (TRI)	20,258 b	16,283 b	375	391	1,202	1.075	82 a
Nonirrigated Conventional spacing (CSNI)	13,351 c	9,237 c	0	33	305	1.085	69 b

** Column values followed by the same letter are not significantly different at the 99% confidence level. † CSI and CSNI yields adjusted for rwo spacing from 100 cm to 91.4 cm. ‡ Marketable weight is the total of U.S. No. 1 and Jumbo potatoes. § Total weight includes weight of undersized potatoes not shown in the table.

Table 2. Content of major elements in potato tubers as influenced by three irrigation treatments and as measured in Minnesota.

Treatment	Elements				
	N	P	K	Ca	Mg
	%				
Trickle irrigated Conventional spacing (CSI)	1.75 a*	0.31 a	2.09	0.056	0.08 a
Trickle irrigated Twin row spacing (TRI)	1.75 a	0.27 a	2.03	0.058	0.09 a
Nonirrigated Conventional spacing (CSNI)	1.48 b	0.24 b	2.13	0.042	0.10 b
Range of values obtained in Minnesota					
Low	1.30	0.47	2.37	0.040	0.10
High	1.50	0.60	4.28	0.110	0.14

* Element values for each column followed by the same letter are not significantly different at the 95% level of confidence.

Table 3. Content of minor elements in potato tubers as influenced by three irrigation treatments and as measured in Minnesota.

Treatment	Elements				
	Mn	Cu	Zn	Fe	Al
	ppm				
Trickle irrigated Conventional spacing (CSI)	28 a**	4	28 a	64	44
Trickle irrigated Twin row spacing (TRI)	15 b	4	24 b	65	29
Nonirrigated Conventional spacing (CSNI)	8 b	5	18 c	54	29
Range of values obtained in Minnesota					
Low	30	7	16	40	30
High	90	26	55	280	250

** Element values for each column followed by the same letter are not significantly different at the 99% level of confidence.

rated and hermetically sealed in polythylene plastic bags. Fresh and dry weights of each part were measured and recorded, and the water content of the sample separates was calculated. The NO_3-N in water extracts was measured with a specific ion electrode.

Each hill was harvested individually on 25 June (day 177), the potatoes were washed, air dried, and manually separated into U. S. No. 1 (diam. > 5 cm) and jumbo (diam. > 9 cm) by passing them through screens. Tuber weight and number for each plant were recorded. Second growth, hollow heart, cracked, and undersized potatoes were separated, weighed, counted, and only included in the total weights. Marketable potatoes were U. S. No. 1 and jumbo grades. The mean weight of U. S. No. 1 tuber per unit of row length was calculated. Specific gravity of potatoes was measured by weighing potatoes in air and in water (1).

Tuber samples were diced and dried to constant weight in an air oven at 80 C. Samples were ground in a Wiley mill to pass through a 20-mesh screen. The major and minor element contents of tubers were measured by atomic absorption spectrographic methods.

RESULTS AND DISCUSSION

Trickle irrigation with nutrient solution improved yield and quality of potato tubers. Yields shown in Table 1 were proportionally adjusted to 91.4 cm spacing by multiplying with a factor of 1:1 to permit comparison with yields obtained with conventional spacing. The total weight, the weight of U.S. No. 1, and the marketable weight were significantly different for each treatment. The marketable weight of CSI potatoes was 76% greater than that of the TRI potatoes and 206% greater than that of the CSNI potatoes. The mean weights per tuber of U.S. No. 1 potatoes for the CSI, TRI, and CSNI treatments were 296, 241, and 208 g, respectively.

The specific gravity values (Table 1) tended to increase as water applied decreased. The percent marketable weights of the irrigated potatoes (Table 1) were the same, but that of the nonirrigated potatoes was 13.5% less than that of those irrigated.

Table 2 shows the major and Table 3 the minor elemental contents of tubers for this test and for similar tests conducted in Minnesota and shown here for comparison purposes only. Generally, all values of major and minor elements were either within the range or lower than those obtained in Minnesota (14), possibly because of the higher leaching rate of the sandy soils in the Coastal Plains. The N and P content of trickle- irrigated tubers was significantly greater than that of those nonirrigated. The N contents of potatoes for all treatments were within the range of that for potatoes grown in Minnesota (14). The Mg content of trickle- irrigated tubers was lower than that of the nonirrigated tubers, and lower than the range of values obtained in Minnesota (14). The Ca and K contents of tubers for all treatments were not different.

Of the minor elements, only the Mn and Zn content of tubers decreased as soil moisture decreased.

Figure 3 shows the soil matric potential near the potato row and 15 cm from the surface for each treatment. Rainfall and irrigation are shown in the lower portion of Fig. 3, and these data indicate two droughts during the growing season. The first was severe, extending 21 days, between Julian days 113 and 134, before the flowering stage. The soil matric potential in the nonirrigated (CSNI) plots was lower than —0.8 bar during half of the drought period, and plants were

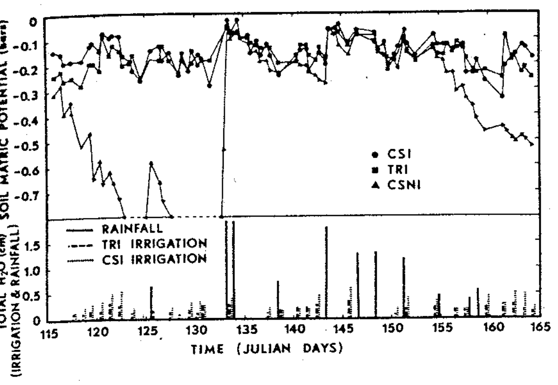

Fig. 3. Soil matric potential 15 cm from the soil surface as influenced by three irrigation treatments, and rainfall and water application by high-frequency trickle irrigation during the 1974 growing season.

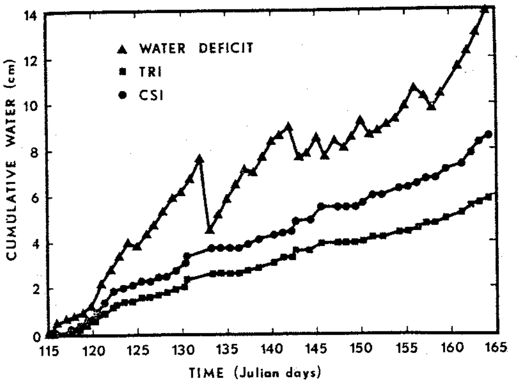

Fig. 4. Cumulative water deficit and amounts of irrigation water for CSI and TRI irrigation treatments.

continually wilted during daylight hours. The second drought, partially shown in Fig. 3, was late in the season, before harvest.

The effect of drought during the last 9 weeks of potato growth has been reported (1). Yield of U.S. No. 1 potatoes could be decreased more than 50%, if the minimal soil water potential decreased below —1.0 bar during the last 9 weeks of growing period. The yield decrease may also be a function of the duration of the drought and the time of the drought during this 9-week period (1).

Either of the two droughts observed was severe enough to significantly decrease yield for nonirrigated U.S. No. 1 potatoes. The mean and standard deviation of the soil matric potential during the growing period was —0.17 ± 0.06 bar, —0.18 ± 0.05 bar, and —0.36 ± 0.21 bar for the CSI, TRI, and CSNI plots, respectively. The lower part of Fig. 3 shows the total water supplied daily. The total rainfall for the period was 11.7 cm and the pan evaporation was 32.1 cm. Irrigation water supplied to the CSI and TRI plots was 8.4 and 6.0 cm, respectively. Althouugh 29% less water was applied to the TRI plots, there is no apparent difference between soil matric potentials of the CSI and the TRI plots. This may have been due to the clear plastic mulch covering the tube in the TRI plots, which caused some decrease in evaporation.

Figure 4 shows the cumulative irrigation water applied to the CSI and TRI plots and a water deficit

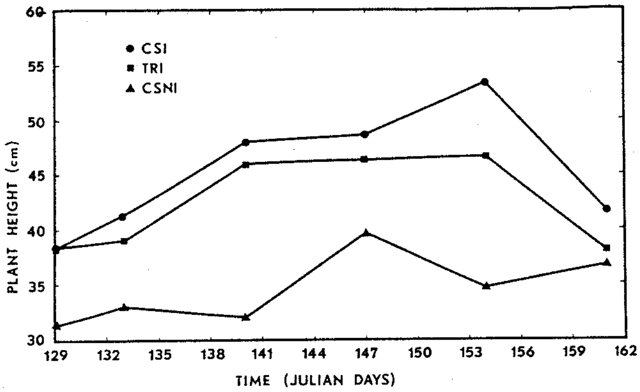

Fig. 5. Mean potato plant heights as influenced by three irrigation treatments for a period beginning before flowering stage until full maturity.

of 14.0 cm during the growing season. The use of controlled high- frequency trickle irrigation implied that a potential water saving of 40 and 57%, respectively, for the CSI and the TRI plots could be achieved over irrigation systems which would apply water to meet the deficit of 14.0 cm. Earlier experiments comparing water use efficiency of sweetcorn irrigated with high-frequency surface and trickle irrigation systems have demonstrated greater water conservation with high-frequency trickle irrigation than with other systems (9, 10).

Figure 5 shows potato plant heights, measured at intervals during the growing season. Plant heights for the last measurements were decreased by plant redaction with maturity. The measurements taken on day 154 of the growing season indicated 34.9% difference between mean plant heights of CSI and CSNI plots (significant at the 99% confidence level).

The leaf blade, petiolule, and petiole NO_3-N content are shown in Table 4. Leaf blade NO_3-N content varied between 0.8 and 4.5 ppt with the CSI and CSNI treatments having the highest and the lowest NO_3-N contents, respectively. Petiolule and petiole NO_3-N showed similar trends with a wider range of values. Petiole NO_3-N content fluctuated with fertilization and rainfall for the CSNI plots but was higher and more constant for the CSI and TRI plots. The decline in plant NO_3-N contents from days 123 to 130 occurred during a period of rapid growth rate for the CSI and TRI plots and water stress for the CSNI plots. These data indicate the magnitude of the NO_3-N measurement sensitivity for each of the three components. Since the NO_3-N content of potato tubers is directly proportional to the NO_3-N in the leaves at blooming time and increases with fertilization rate (3), which was presumed adequate for all treatments, the yield differences may have resulted either from fertilizer application methods or from irrigation, but not from fertilization rate. Except for the early measurements, there was no difference in the NO_3-N content of the petiole for the CSI and TRI plots during the remainder of the growing season. Data by Painter[5] showed that 13,500 ppm of NO_3-N in the petiole was adequate for maximal yield. Similarly, data by Gardner and Jones (5) suggested that at stolon formation

[5] Painter, Charles G., Parina, Idaho, unpublished data.

Table 4. NO_3-N content of potato leaf blades, petiolule, and petiole influenced by three irrigation treatments and time.

Time	NO_3-N content of leaf blades			NO_3-N content of petiolule			NO_3-N content of petiole		
	Irrigation treatments			Irrigation treatments			Irrigation treatments		
(Julian days)	CSI	TRI	CSNI	CSI	TRI	CSNI	CSI	TRI	CSNI
	ppt								
116	1.8	0.9	1.0	23.1	16.0	15.3	36.3	25.0	26.3
123	4.5	4.3	1.8	31.3	22.5	19.8	42.5	33.8	29.8
130	2.9	3.5	0.8	21.3	24.0	7.8	35.0	33.8	14.1
137	2.7	3.0	3.3	16.5	21.3	13.4	29.8	32.3	19.8
144	2.4	3.2	1.5	16.8	20.6	9.5	32.3	33.8	18.1
151	1.2	2.3	1.3	14.8	18.1	13.1	26.3	27.3	22.5
158	1.4	3.5	0.9	16.0	20.0	8.1	28.1	25.0	15.3
165	3.0	3.8	2.4	20.0	16.9	13.0	33.8	34.8	31.6
Mean	2.5	3.1	1.6	20.0	19.9	12.5	33.0 a**	30.7 a	22.2 b
S.D.	±1.1	±1.1	±0.9	±5.4	±2.8	±4.0	±5.2	±4.2	±6.5

** NO_3-N values for each column followed by the same letter are not significantly different at the 99% level of confidence.

stage, a petiole NO_3-N level lesser than 16,000 ppm was deficient and that a level greater than 22,000 ppm was sufficient to produce maximal potato yield. The petiole NO_3-N content for the CSNI treatment was lowest following the first drought on day 130 (14,100 ppm) but was never lower than 13,500 ppm.

Figure 6a, b shows cross sections of the soil profile, soil matric potential measurements taken on a grid, and the equipotential lines drawn in the A1 soil horizons for a CSI and TRI representative plot row on day 119. These data characterize the depth and thickness-variable shallow compacted A2 horizon, ranging in depth from 10 to 15 cm and 15 to 25 cm for the CSI and TRI rows, respectively. Zones of high soil matric potential are present near the irrigation tube and plants and in the A2 and B1 soil layers. These data were obtained 5 days after the 15-cm soil matric potential of the nonirrigated plots began to decrease below the control level of the irrigated plots, and zones of dry soil were developing between the rows and beds. For all practical purposes, potatoes grown with both row spacing were subjected to similar soil matric potential profiles, so that it can be assumed that the difference in water application for the CSI and TRI plots resulted from lower evaporation in the TRI plots. Soil between pairs of twin row beds in the TRI plots was slightly dryer than that between the rows of the CSI plots. This was caused by the greater distance between porous tubes in the TRI plots (Fig. 1a, b) and by plants intercepting water in the TRI plots. During precipitation this dry zone of soil becomes a sink and storage reservoir for water; infiltration of water is increased; runoff is decreased, and nutrients applied through the porous tube are less likely to be leached or lost with runoff.

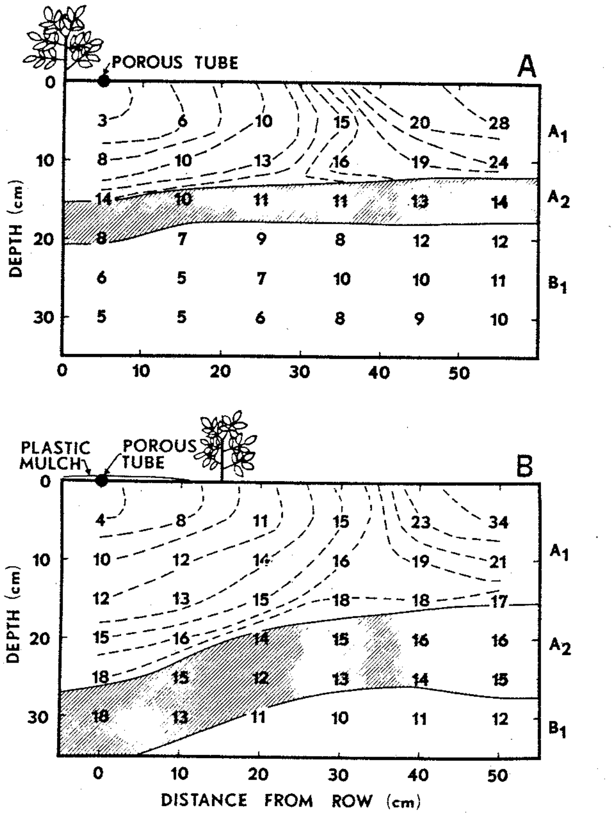

Fig. 6. Soil matric potential profile (cb). (a) under a row of potatoes irrigated by a high-frequency trickle irrigation system (CSI) on day 119. (b) under a twin row of potatoes irrigated by a high-frequency trickle irrigation system (TRI) on day 119.

SUMMARY AND CONCLUSION

High-frequency trickle irrigation with nutrient solution using conventional row spacing (CSI) increased the yield of marketable potatoes by 206% over nonirrigated potatoes (CSNI) and by 76% over potatoes trickle- irrigated with nutrient solution and grown on twin row spacing (TRI). Yield of U.S. No. 1 potatoes from the CSI plots was 8% greater than the 3-year U.S. average and 117% greater than the 3-year Southeast average. Yield of U.S. No. 1 potatoes from the TRI plots was 37% less than the 3-year U.S. average and 26% greater than the 3-year Southeast average.

Soil matric potential 15 cm from the surface was not different for the CSI and TRI treatments. Water deficit, calculated by subtracting rainfall from 80% of pan evaporation, was 14.0 cm during the growing season. Measurement of water applied indicated that 60% of the water deficit was supplied for the CSI treatment and 43% for the TRI treatment. Mean petiole NO_3-N for the three treatments was 33,000, 30,700, and 22,200 ppm, respectively, for the CSI, TRI, and CSNI plots and consistently above 13,500 ppm, a standard value for maximum yield production in Idaho. Weekly measurements of petiole NO_3-N for the CSI and TRI plots were consistently above the sufficient level reported for Russet Burbank cultivar, but were below that level for 4 weeks in the CSNI plots.

Potato production in the Southeast is highly dependent on soil matric potential control. High-frequency trickle irrigation with nutrient solution can more than double present yields and stabilize the economic position of the farming community. Adaptation of twin row beds (TRI) for trickle irrigation will reduce the cost of porous tube needed by 39% and the amount of water used by 17% when compared to CSI. Although irrigation water is readily available in the southeast, pumping and delivery cost of water to the irrigation system in the field can be decreased significantly by adopting high-frequency trickle irrigation-nutrient management techniques.

ACKNOWLEDGMENT

The authors express their gratitude for the cooperation and support received from Mr. Richard C. Bergman and E. I. DuPont de Nemours & Co. and to Dr. Morris Watson (NCSU), Mr. Jimmie D. Vaught, Mr. Jerry R. Brock, Mr. Mark Fisher, and Mrs. Debbie Browder for their participation in the project.

LITERATURE CITED

1. Burton, W. G. 1966. The potato. H. Veenman and Zonen N. V., Wageningen, Holland, p. 66-74.
2. Campbell, R. B., D. C. Reicosky, and C. W. Doty. 1974. Physical properties and tillages of Paleudults in the southeastern Coastal Plains. J. Soil Water Conserv. 29:220-224.
3. Carter, J. N., and S. M. Bosma. 1974. Effect of fertilizer and irrigation on nitrate-nitrogen and total nitrogen in potato tubers. Agron. J. 66:263-266.
4. Epstein, E., and W. J. Grant. 1973. Water stress relations of the potato plant under field conditions. Agron. J. 65 400-404.
5. Gardner, B. R., and J. P. Jones. 1975. Petiole analyses and the nitrogen fertilization of Russett Burbank potatoes. Am. Potato J. 52 195-200.
6. Jones, St. T., and W. A. Johnson. 1958. Effect of irrigation at different minimum levels of soil moisture and of imposed droughts on yield of onions and potatoes. Proc. Am. Soc. Hort. Sci. 71:440-445.
7. Kunkel, R. 1957 Factors affecting the yield and grade of Russett Burbank potatoes. Colorado Agric. Exp. Stn. Tech. Bull. 62.
8. Phene, C. J., G. J. Hoffman, and R. S. Austin. 1973. Controlling automated irrigation with a soil matric potential sensor. Trans. ASAE 16:773-776.
9. ———. 1974. High-frequency porous tube irrigation for water-nutrient management in humid regions. International Drip Irrigation Congr. Proc. 2nd. (San Diego, Calif.). p. 166-171. Dep. of Soil Sci. and Agric. Eng., Univ. of Calif., Riverside.
10. ———. 1974. Subsurface irrigation in the humid Southeastern Coastal Plains. p. 267-303. *In*: M. C. Blount (ed.) Proc. symp. on water resources: Utilization and conservation in the southeastern environment, The Fort Valley State College, Fort Valley, Ga.
11. ———, and R. B. Campbell. 1975. Automating pan evaporation measurements for irrigation control. Agric. Meteorol. 15:181-191.
12. Ruf, R. H., Jr. 1964. Shape defects of Russett Burbank potato tubers as influenced by soil moisture, temperature and fertility level. Proc. Am. Soc. Hort. Sci. 84:441-445.
13. Sanders, D. C., and R. E. Nylund. 1972. The influence of mist irrigation on the potato. II. Growth and development. Am. Potato J. 49:187-195.
14. ———, ———, and E. C. Quisumbing. 1972. The influence of mist irrigation on the potato. III. Nutrients content of leaves. Am. Potato J. 49:218-226.
15. ———, ———, ———, and K. V. P. Shetty. 1972. The influence of mist irrigated on the potato. IV. Tuber quality factor. Am. Potato J. 49:243-254.

An Evaluation of a Resistance Form of the Energy Balance to Estimate Evapotranspiration[1]

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ABSTRACT

Evapotranspiration (ET) models that use the air-diffusion resistance to momentum (r_D) have been unsatisfactory under certain conditions. A field study was conducted in soybean [*Glycine max* (L.) 'Williams'] and sorghum [*Sorghum bicolor* (L.) 'Pioneer 846'] to evaluate an ET model that uses the diffusion resistance to heat transport (r_H) in the energy-balance equation and to assess the effect of replacing the resistance for heat with that for momentum.

Resistances were determined using wind speed and temperature profiles. Model estimates of latent-heat flux (LE) were compared with lysimetric measurements of LE. When using r_H, model estimates of LE were within 4% and 15% of lysimetric measurements for soybean and sorghum, respectively. When using r_D, estimates of LE for soybean were 25% greater, but for sorghum only 10% greater than when using r_H. Results indicated that the resistance form of the energy balance can be useful for estimating ET if the proper resistance is used. Significant errors may occur if the momentum resistance is used in the model instead of the resistance for heat.

Additional index words: Boundary layer, Diffusion resistance to momentum transport, Diffusion resistance to heat transport, Canopy temperature.

ACCURATE estimates of evapotranspiration (ET) have become increasingly important in recent years. Models for estimating ET that use a form of the energy-balance equation and an air-diffusion resistance to momentum transport in the turbulent boundary layer have been developed and tested (Black et al., 1970; Brown and Rosenberg, 1973; Brun et al., 1972). Generally, estimates of ET using such models have compared favorably with lysimetric measurements.

Under certain conditions, however, it has been found that the models can significantly overestimate ET (Hanks et al., 1973; Stone and Horton, 1974). Such deviations may be directly related to using the mo-

[1] Contribution no. 1514, Agronomy Dep., Evapotranspiration Laboratory, Kansas Agric. Exp. Stn., Kansas State Univ., and contribution no. 167, Kansas Water Resources Research Institute. The U. S. Dep. of Interior, Office of Water Research and Technology provided partial support for this research. Received 7 July 1975.

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