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Relationship of Sweetpotato Yield and Quality to Amount of Irrigation

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Abstract. **A line-source irrigation design was used to provide continuously increasing amounts of irrigation at each application to sweetpotato *[Ipomoea batatas* (L.) Lam]. Marketable yields increased with applied irrigation amounts until a total water application of 76% of pan evaporation (E_{pan}) was reached and then decreased rapidly with applied irrigation amounts. Weight loss and decay of roots during storage showed quadratic responses to irrigation amounts and were minimal at the irrigation level of maximum yields. Contents of dextrins and maltose increased with irrigation amounts. Glucose content was maximum at a total water amount of 94% E_{pan} and fructose content decreased with increased amounts of irrigation. Sensory ratings for appearance, flavor, texture, and preference, and objective color measurements of cooked flesh also reached their highest values near the irrigation amount of maximum yield.**

Yields of sweetpotatoes have been increased by irrigation in humid climates (Hammett et al., 1982; Hernandez et al., 1965; Jones, 1961; Lambeth, 1956; Peterson, 1961) in investigations designed to determine frequency of needed irrigation. Irrigation reduced percent dry matter, carotenoid content, and protein content of storage roots, but did not affect firmness, fiber content, or root splitting (Constantin et al., 1974; Hammett et al., 1982). Kattan et al. (1958) found maintaining available soil moisture above 50% increased enzymatic discoloration in canned roots.

Research on the effects of water application amounts at each irrigation is limited for sweetpotato. Lambeth (1956) irrigated to maintain available soil moisture above 40% of field capacity measured at 0.6, 0.9, or 1.2 m. The highest yield resulted from maintaining available moisture above 40% to a depth of 0.6 m. Weekly applications of 25 mm of water increased yields over no irrigation, but a weekly amount of 38 mm did not increase-yield further (Peterson, 1961). Evaporative demand was not reported in the experiments by Lambeth (1956) or Peterson (1961). To our knowledge, storage root quality responses to irrigation amounts have not been reported.

Response to higher amounts of irrigation might depend on increased fertilizer amounts, since N and K are used and lost more rapidly with increased moisture. Peterson (1961) compared amounts (in $kg{\cdot}ha^{-1}$) of 24N-31P-117K to 40N-53P-201K in combination with weekly irrigations of 25 and 38 mm and found no yield difference attributable to the amount of fertilizer applied.

Yields of various crops have been similar over a range of irrigation depths (Braunworth and Mack, 1987; Stewart et al., 1977; Vaux and Pruitt, 1983) and the same may be true for sweetpotatoes. There is a need to more precisely quantify the effects of irrigation amounts to determine the level of irrigation needed for optimum yields and quality. In this experiment, continuously increasing amounts of irrigation were applied with several levels of fertilizer at two locations. The objective was to determine optimum irrigation depths at each location for yield of sweetpotato and if increased amounts of fertilizer were needed. An initial estimate of storage and quality responses to the amount of irrigation was made at one location.

Experiments were conducted in 1987 on a Bude silt loam soil (fine, mixed, thermic, Glossaquic Fraguidalf) at Pontotoc, Miss., and on a Tifton loamy sand soil (fine loamy, siliceous, thermic, Plinthitic Paleuidult) at Tifton, Ga. Available water-holding capacities of the soils were 156 and 89 $mm{\cdot}m^{-1}$ at Pontotoc and Tifton, respectively. Optimum production practices most commonly used in the area near each experimental location were employed. Fertilizer was applied according to extension service recommendations based on soil test results. At Pontotoc, fertilizer was broadcast and incorporated at transplanting to supply 0, 50, and 186 kg of N, P, and K/ha, respectively. Plots at Tifton received 30, 26, and 75 kg of N, P, and K/ha, respectively, applied in a band to each side of the row at transplanting.

Cultivars used were those grown most extensively in each state. 'Centennial' plants were transplanted to field plots 20 May at Pontotoc in rows 1 m apart with plants spaced at 0.36 m. 'Jewel' plants were transplanted 1 June at Tifton to rows 1.4 m apart with plants also spaced at 0.36 m. Following transplanting, 13 mm of water was applied by sprinkler irrigation for plant establishment at both locations.

A line-source irrigation design with four replications was used (Hanks et al., 1976). The line-source system consisted of a single sprinkler irrigation line through the center of the experimental area and provided for a continuous decrease in the amounts of water applied to plots perpendicular to the irrigation line as distance from the line increased. Irrigation plots were two rows wide (1.0 m between rows) and 18 m long at Pontotoc, and single rows 1.4 m apart by 12 m long at Tifton. Due to plot width, there were eight levels of irrigation at Pontotoc and 11 at Tifton.

Irrigations were applied during periods of no wind movement to prevent distortion of water application patterns and were made mostly between 9:00 PM and 5:00 AM. Rain gauges were placed in the center of each irrigation level at six equidistant linear spacings to measure the amounts of water applied. Observations during irrigations confirmed that no water runoff occurred.

Irrigation was scheduled based on evaporation from a U.S. Weather Bureau Type A pan (E_{pan}). Beginning 11 days after transplanting, irrigation water was applied at Pontotoc and Tifton when E_{pan} exceeded rainfall by 50 and 25 mm, respectively. Since no information was available on irrigation amounts, the same levels were used at both locations and were selected to be certain to include amounts above and below a likely optimum. The quantity of water applied to the intermediate irrigation rate at both locations was 40% of E_{pan} beginning 11 days after transplanting and was increased 2.4% daily to 120% of E_{pan} on day 44. The amount of water applied in each irrigation was constant at 120% E_{pan} from day 44 until harvest.

Previous fertilization results (unpublished data) showed that only N was leached from the Pontotoc soil, but increased levels of all elements might be needed for maximum yields at Tifton. Split fertilizer applications were included to more uniformly supply needed elements and counteract leaching with higher water applications. Fertilizer treatments were 0, 45, and 90 kg N/ha at Pontotoc. The intermediate amount was applied in one application at transplanting. One-half of the 90 $kg{\cdot}ha^{-1}$ was applied at transplanting and the remaining half was sidedressed 60 days later. At Tifton, transplant fertilizer levels ($kg{\cdot}ha^{-1}$) of 30N-26P-75K were augmented by 0N-0P-0K, 30N-26P-75K, or 60N-52P-150K as sidedressed applications 30 days later. Investigations to determine needed amounts by element followed if yield responses to increased amounts of the complete fertilizer were observed. Fertilizer treatments were applied in randomized strips across irrigation levels and were 6 m long at both locations.

Storage roots were harvested and graded 15 Sept. at Pontotoc and 5 Oct. at Tifton.

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Table 1. Yield responses of sweetpotatoes to the amount of irrigation at Pontotoc, Miss., and Tifton, Ga.

Water supplied		Yield (t·ha⁻¹)			
Irrigation[z] (mm)	Total[y] (%)	Marketable	U.S. No. 1	Canner	Jumbo
		Pontotoc (Centennial)			
708	147	11.9	1.9	9.9	0.1
614	134	12.6	1.3	11.2	0.1
495[x]	118	16.4	2.7	13.6	0.1
381	103	17.7	3.1	14.5	0.1
277	89	21.8	6.7	14.7	0.4
178	76	32.8	16.0	16.0	0.8
84	63	30.1	12.9	16.6	0.6
0	52	26.7	11.0	15.2	0.5
Linear		**	**	**	**
Quadratic		**	**	**	**
		Tifton (Jewel)			
711	158	23.6	4.4	19.1	0.1
642	148	25.8	4.9	20.7	0.2
544	134	22.2	7.2	14.9	0.1
460	122	27.8	10.6	17.1	0.1
385[x]	111	24.5	9.1	15.1	0.3
325	103	27.7	11.8	15.7	0.2
266	94	29.6	16.6	11.9	1.1
193	84	32.6	21.3	9.3	2.0
127	74	36.6	24.0	7.8	4.8
68	66	34.7	22.6	5.2	6.9
4	57	22.3	13.6	3.4	5.3
Linear		**	**	**	**
Quadratic		**	**	**	**

[z]Irrigation water applied in nine and 13 applications at Pontotoc and Tifton, respectively. All plots received 13 mm of irrigation after transplanting plus 376 and 380 mm of rainfall at Pontotoc and Tifton, respectively.
[y]Total expressed as a percentage of pan evaporation.
[x]Amount based on pan evaporation, other rates due to gradient produced by the line-source irrigation system.
*,**Significant at $P = 0.05$ and 0.01, respectively.

Table 2. Curing and storage responses of 'Jewel' sweetpotatoes to total amount of water supplied at Tifton, Ga.

Total amount of water[z] (%)	Curing loss[y] (%)		Storage loss[x] (%)		Dry wt (%)	
	Wt	Decay	Wt	Decay	After harvest	After storage
158	11.7	19.3	21.4	33.5	25.6	26.8
134	13.0	25.2	21.5	24.8	23.6	25.3
111	10.3	0.0	13.9	6.6	23.2	24.4
94	8.6	14.4	10.1	5.2	22.6	23.3
74	8.0	0.0	10.5	2.5	22.6	22.7
57	8.0	5.4	14.8	4.1	21.2	22.2
Linear	**	*	**	**	**	**
Quadratic	NS	NS	**	**	*	*

[z]Total expressed as percentage of pan evaporation.
[y]Expressed as percentage of precured weight.
[x]Expressed as percentage of prestorage weight.
NS,*,**Nonsignificant or significant at $P = 0.05$ and 0.01, respectively.

Quality and weight loss measurements were made at Tifton. U.S. No. 1 roots from alternate irrigation treatments, beginning with the lowest level (see Table l), were cured for 7 days at 30C and 90% relative humidity (RH) and placed in storage at 16C and 80% RH. Flesh color and dry weights of raw 'Jewel' were determined before curing, after curing, and after 4 months of storage. Ten roots from each treatment were cut transversely immediately before color analyses with a colorimeter (Gardner x1-20 Tri-stimulus; Gardner/Neotec, Silver Spring, Md.) and standardized to a reference plate: L = 70.4, a = 23.9, b = 9.3. After color measurements, 10-mm slices from each root were peeled and cut into 10-mm dices before drying in a forced-air oven at 70C for 72 h.

A 30-mm transverse slice from each of the 10 roots was wrapped in aluminum foil and baked at 190C for 90 min and cooled. The baked flesh was macerated with a fork, mixed, and presented to a six-member trained sensory panel for evaluations of appearance, flavor, texture, and preference. About 75 g of the cooked tissue was placed in a 55-mm-diameter cup having an optical-glass bottom for color analyses. This sample was frozen for sugar analyses by high-pressure liquid chromatography (HPLC). For sugar analyses, 2.5 g of baked sweetpotato tissue was placed in a centrifuge tube, One gram of diatomaceous earth and 40 ml of distilled water were added, mixed thoroughly, heated at 60C for 30 min, cooled, and centrifuged at 11,000 × *g* to separate particulate material. A 10-ml aliquot of the supernatant was passed through a silica preparatory cartridge, with the first 5 ml being discarded. A 20-μl aliquot was used for analyses for glucose, fructose, maltose, and dextrins by HPLC.

The desired information from these experiments was the relationship of the amount of water to storage root yield and quality components. Therefore, yield and quality data were analyzed by regression (Chew, 1976; Little, 1978, 1981).

Amounts of water applied based on E_{pan} were similar for the two sites (Table l), since E_{pan} amounts were 747 and 700 mm during production of the sweetpotato crops at Pontotoc and Tifton, respectively. Nine irrigations were made at Pontotoc and 13 at Tifton. E_{pan} exceeded rainfall sufficiently for irrigations on days 11, 47, 56, 64, 69, 81, 90, 96, and 107 after transplanting at Pontotoc and on days 31, 36, 42, 46, 50, 55, 60, 67, 71, 83, 87, 91, and 110 at Tifton. Total rainfall was also similar at the two locations, 376 and 380 mm at Pontotoc and Tifton, respectively. Total water amounts (irrigation + rainfall) ranged from 52% to 147% of E_{pan} at Pontotoc and from 57% to 158% of E_{pan} at Tifton (Table 1).

Marketable, U.S. No. I, canner, and jumbo root yields showed strong quadratic changes with irrigation amounts at both locations (Table 1). Yields at Pontotoc were highest when total water applied to the 'Centennial' sweetpotatoes was 76% of E_{pan}. Marketable root yield was reduced slightly with total water amounts <76% of E_{pan}, whereas total water amounts >76% of E_{pan} substantially reduced marketable yield. Most of the change in marketable yield of 'Centennial' roots was due to variations of U.S. No. 1 yield. Total water application at 76% of E_{pan} produced U.S. No. 1 yields that were 45% higher than without irrigation, but irrigation applications that resulted in total water amounts of 147% of E_{pan} produced only 17% of the U.S. No. 1 yield produced without irrigation.

Yields of 'Jewel' sweetpotatoes at Tifton showed response trends to water application amounts that were similar to the Mississippi experiment, although marketable and U.S. No. 1 yield reductions with high irrigation amounts were not as great at Tifton as at Pontotoc. The greatest sensitivity to excess irrigation at Pontotoc is not attributable to the cultivar because 'Jewel' has been reported to be more sensitive to flood damage than 'Centennial' (Collins and Wilson, 1988).

Weight loss and decay during curing and storage of 'Jewel' roots showed strong responses to the total amount of water applied (Table 2). Weight loss and decay were high when total water received was 134% to 158% of E_{pan}. They were minimal at total water amounts of 74% to 94% of E_{pan} and then increased at totals of 57% of E_{pan}. Dry weight increased with increased water quantities.

Glucose, fructose, maltose, and dextrins (three to five glucose units) represented 6%, 4%, 65%, and 25% of the total sugars, respectively, in baked 'Jewel' sweetpotatoes.

Table 3. Effect of total amount of water supplied during production (at Tifton, Ga.) on sugar content and sensory evaluations of baked 'Jewel' sweetpotatoes after curing and storage.

Total amount of water[z] (%)	Sugars (%)					Sensory rating[x]			
	Dextrins[y]	Maltose	Glucose	Fructose	Total	Appearance	Flavor	Texture	Preference
158	5.3	15.5	1.1	0.75	22.6	4.5	3.9	4.3	4.1
134	5.8	14.7	1.2	0.80	22.5	5.6	4.7	5.1	4.9
111	5.8	14.2	1.3	0.80	22.1	6.2	5.7	5.6	5.6
94	5.3	13.1	1.5	0.89	20.8	6.5	5.9	6.2	5.9
74	4.5	12.4	1.4	0.88	19.1	6.0	5.7	6.0	5.8
57	5.1	12.4	1.4	0.98	19.8	5.6	5.6	5.8	5.7
Linear	*	**	*	**	*	*	**	**	**
Quadratic	NS	NS	*	NS	NS	**	**	**	**

[z]Total expressed as percentage of pan evaporation.
[y]Dextrins composed of three, four, and five glucose units.
[x]Sensory rating on a hedonic scale of 1 to 7; 1 = disliked extremely and 7 = liked extremely.
NS,*,**Nonsignificant or significant at $P = 0.05$ and 0.01, respectively.

Table 4. Effect of total amount of water applied during production (at Tifton, Ga.) on flesh color of fresh, stored, and baked 'Jewel' sweetpotatoes.

Total amount of water[z] (%)	Flesh color[y]				Cooked color[x]	
	After harvest[w]		After storage			
	L	a	L	a	L	a
158	68.3	29.3	69.0	29.2	39.8	16.3
134	68.6	28.9	67.8	30.8	40.1	17.3
111	67.4	29.1	67.5	31.5	40.1	18.2
94	67.9	30.3	66.5	32.0	43.1	19.7
74	68.1	29.6	67.1	31.0	45.8	19.4
57	68.0	29.2	67.4	30.0	46.7	18.0
Linear	*	NS	*	NS	*	**
Quadratic	NS	*	*	**	NS	**

[z]Total water amount expressed as a percentage of pan evaporation.
[y]Color measurement of sliced raw tissue.
[x]Color measurement of mashed cooked tissue after storage of roots.
[w]L and a = colorimeter measurements of reflectance and red pigmentation, respectively.
NS,*,**Nonsignificant or significant at $P = 0.05$ and 0.01, respectively.

The linear increase in total sugar concentration with increased water amounts was due to an increase of maltose and dextrin concentration from 17.5% of fresh weight with total water of 57% E_{pan} to 20.8% of fresh weight with total water of 158% E_{pan} (Table 3). The concentration of simple sugars, glucose and fructose, decreased from 2.4% of fresh weight with total water of 57% E_{pan} to 1.8% with 158% E_{pan}.

The baked roots were rated highest for appearance, flavor, texture, and overall preference when total water applied was 94% of E_{pan} (Table 3). Sensory ratings of sweetpotatoes receiving the most water were particularly low due to discoloration, poor flavor, and a sticky texture of the roots. Increased enzymatic discoloration has been observed upon heating sweetpotatoes from high-irrigation regimes (Kattan et al., 1958). In the objective color analyses, total reflectance (L) decreased for baked roots grown with increased amounts of water, and less intensity of red pigmentation (a) resulted with either high or low amounts of water (Table 4).

In contrast to most plants injured by flooding (Cannel1 et al., 1979; Letey et al. 1962a, 1962b; Wadman-van SchravendijK and van Andel, 1985), the plants receiving the highest amounts of water in these experiments appeared vigorous. This observation agrees with results reported by Chua and Kays (1981) that top growth was enhanced and storage root growth was retarded by low root-zone O_2 concentration. However, low root-zone O_2 concentration cannot be assigned as the cause of reduced root growth in this experiment, because soil O_2 content was not measured.

None of the yield or quality characteristics of 'Centennial' or 'Jewel' were affected by application of a fertilizer. These results indicated that adequate nutrients are supplied by the basic fertilization level of 0, 50, and 186 kg of N, P, and K/ha to a Bude silt loam and 30, 26, and 75 kg of N, P, and K/ha to a Tifton loamy sand when these soils are used for intensive crop production.

We have shown that yield and quality of sweetpotatoes are influenced by the amount of irrigation. Irrigation to supplement rainfall in providing total amounts of water equivalent to ≈ 75% of E_{pan} produced maximum yields of sweetpotatoes grown on silt loam and loamy sand soils at Pontotoc and Tifton, respectively. Irrigation to provide total amounts of water equivalent to 75% to 95% of E_{pan} resulted in minimum loss during storage and maximum quality of cooked sweetpotatoes after storage. The silt loam soil was more susceptible to excessive water application than the loamy sand.

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Two Putative Cryoprotectants do not Provide Frost and Freeze Protection in Tomato and Pepper

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Abstract. **A commercially available cryoprotectant (50% propylene block copolymer of polyoxyethylene, 50% propylene glycol; trade name FrostFree) and an antitranspirant (96% di-1-p-menthene, i.e., pinolene, a terpenic polymer, 4% inert; trade name Vapor Gard) were evaluated for their ability to protect 'Pik Red' tomato *(Lycopersicon esculentum* Mill.) and 'Keystone Resistant Giant #3' pepper *(Capsicum annuum* L.) plants during frost and freeze occurrences in the field. Tests were conducted during four spring and two fall seasons. Protection from these products was not observed under field conditions when minimum air temperature reached -3.5C and -l.0C on separate occasions. Yields for treated and untreated plants were similar. Neither cryoprotectant injured the foliage in the absence of cold events.**

High prices for early season produce encourage vegetable growers to plant as soon as soils have warmed. Although knowledge of the average last frost or freeze date and the short-term temperature forecast can be used in making planting decisions to avoid frost or freeze damage, instances do occur when temperatures drop to damaging levels after transplanting. Irrigation systems designed to meet drought needs are not always suitable for frost protection, and traditional heating systems cannot be justified economically. Therefore, economically feasible alternative frost protection options are needed. Several chemical products have been marketed and promoted as inexpensive and effective in preventing crop damage from frost or freeze.

Rieger (1989) conducted an extensive review of chemicals used to increase cold hardiness and delay spring budbreak in horticultural crops. Previous work has shown that antitranspirants did not decrease freeze damage to developing peach *(Prunus persica* Batsch) fruits (Matta et al., 1987; Rieger and Krewer, 1988), young citrus trees (Burns, 1970, 1973) or tropical foliage plants (Fitzpatrick et al., 1986). Rieger and Krewer (1988) reported that Protec (Delacar Corp., Tavares, Fla.), an antitranspirant, increased mortality of almond and plum blossoms exposed to -4.4C. Call and Seeley (1989) reported that the antitranspirant Wilt-Pruf (Wilt Products, Greenwich, Conn.) significantly reduced the T50 for 'Johnson Elberta' peach flower buds, but through delay of dehardening, which could not be applied to vegetable transplants. Previous work on the croyoprotectant FrostFree (Plant Products, Vero Beach, Fla.) found it ineffective in increasing survival of ovaries of various *Prunus* spp. (Matta et al., 1987; Rieger and Krewer, 1988). Vapor Gard (Miller Chemical and Fertilizer, Hanover, Pa.), an antitranspirant, is sold to retard transpiration and maintain healthy foliage, but the label also specifies that it can be used to protect from cold dessication. However, we found no refereed results of using these materials on vegetable crops.

The objective of this study was to evaluate these two commercially available materials for frost and freeze protection of pepper and tomato transplants under field conditions. FrostFree is 50% propylene block copolymer of polyoxyethyene, 50% propylene glycol, and Vapor Gard is 96% di-l-p-menthene (i.e., pinolene, a terpenic polymer, 4% inert). Use of a field study over one in a controlled environment was justified because antitranspirants are hypothesized to act as barriers to external nucleators (Levitt, 1980). The antitranspirant film on the surface of the leaves is thought to impede the frost that forms on the surface from providing a nucleator for water inside the plant. Inability to make frost form on the plants in a controlled chamber negates the use of such a chamber in testing the Vapor Gard material.

'Pik Red' tomatoes and 'Keystone Resistant Giant #3' peppers were seeded in the greenhouse and grown to transplant stage (two true leaves). The plants were fertilized twice in the greenhouse with 20N-20P-20K fertilizer (3.75 g/liter Peters Fertilizer Products, W.R. Grace, Fogelsville, Pa.), No preconditioning by water or fertilizer reduction was carried out.

Plants were transplanted at the Central Crops Research Station near Clayton, N.C., on a Typic Paleudult with 0.3% humic matter and pH 5.3. A randomized complete-block design with four replicates was used. Transplanting occurred as early as possible in advance of the average last frost date for Clayton (7 Apr., SD = 12 days). Pepper plants were spaced 30 cm and tomato plants 45 cm in 1.5-m-wide ridges. Each plot consisted of one row 4.5 m long. The Fall 1987 test was initiated when a frost was forecast within the next 5 days. The Fall 1988 test was initiated to precede the average first fall frost by one SD (25 Oct., SD = 10 days).

FrostFree was evaluated in the springs of 1987-90 and in Fall 1987 and 1989. Six treatments were imposed during 1987-89, with applications to the plants of ($kg \cdot ha^{-1}$): 1) 0.7 one day before transplanting, 2) 0.7 immediately after transplanting, 3) and 4) 0.7 or 1.3 when a frost or freeze was imminent (usually the day before), 5) 0.3 immediately after transplanting and 0.3 repeated when a frost or freeze was imminent and 6) no cryoprotectant (left dry). In 1990, a control or one of two treatments, 1.1 $kg \cdot ha^{-1}$ applied to the plants either 1 day before transplanting or when frost or freeze was immiment, was used. Vapor Gard was evaluated in Spring 1989 and 1990 and Fall 1989. The two treatments consisted of a pretransplant application to the plants at 1.0 $kg \cdot ha^{-1}$ and a 1.0 $kg \cdot ha^{-1}$ application when a frost or freeze was imminent and a control that was left dry. Manufacturer's guidelines for FrostFree specify reapplication every 10 days. This necessitated multiple applications in Fall 1989. FrostFree and Vapor Gard were applied with a CO_2 backpack sprayer pressurized at 276 kPa to deliver 375 liters of spray solution/ha.

Air temperature in the field was measured by three Taylor maximum-minimum self-

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