restricted. Evidence that lateral dye movement is greatly restricted in blighted tree trunks has been reported (17). An examination of xylem vessels from blighted trees by electron microscopy has demonstrated not only vessel obstructions, but also the presence of plugging materials in vessel pits, which are part of the lateral water movement system (12). Xylem-vessel obstructions, which originate from paravascular parenchyma cells (6) or primary walls or middle lamella (12), may result from a natural phenomenon related to senescence or a host response to a pathogen. Toxins or enzymes from a pathogen may be involved. Presently, no evidence exists to relate xylem-vessel obstructions or reduced vessel size with incipient water-translocation dysfunction.

Studies currently underway on the mechanisms of above-normal zinc accumulation and water-translocation dysfunction are of prime importance in determining a cause of blight. The use of trees with early stages of blight where trees are sectored offers a valuable tool for the accomplishment of this reasearch.

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Drainage Requirements for Sweet Potato at Harvest[1]

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Additional index words. pH, potassium, soil texture, flood damage, *Ipomoea batatas*

Abstract. **Poor drainage resulting in high soil moisture causes wet soil injury in the fleshy roots of sweet potato (*Ipomoea batatas* (L) Lam). Sweet potato lines with varying resistance to flood damage were grown in a sandy loam and a silt loam soil and subjected to water table drawdown rates of 5, 20, 35 and 100 cm/day for 7 days prior to harvest. Decay increased with time after harvest and decreasing drawdown rate. 'Julian' had the longest postharvest keeping quality for the various drainage rates applied and there was no difference in keeping quality between soils. 'Centennial' was intermediate, showing wet soil damage with lower drainage rates and the damage was higher on the silt loam than on the sandy loam soil. NC 257 showed high wet soil injury for all drainage rates with greater injury in the finer textured soil. Decay of the roots was greater in 1976 than in 1975 for all genetic sources. pH, titratable acidity and soluble K were well correlated with decay in 1975 but not in 1976.**

In humid areas, where rainfall often occurs during the harvest season, lack of adequate drainage delays maturity of grain crops and induces flood damage in tuber and root crops. Furthermore, inadequate drainage for root crops such as sweet potato and yam produces conditions suitable for decay, thus reducing root quality and the length of time they may be stored. The amount of injury caused by excessive soil water during the harvest period depends on the plant species, soil, temperature and stage of plant development.

Plants respond differently to depth of free water in soil. The effect of wet soils on crops and the response of crops to drainage

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have been reviewed (1, 9, 10). The most common research approach is to determine the effect of constant water table depth on crop yields but the effect of water table drawdown rate and fluctuating water tables on crop yields has also been studied.

Generally, experiments with constant water tables have shown that yields increase with depth of water table until an optimum depth is reached and then decrease for deeper water tables (2, 3, 9, 10, 11). The optimum depth of water table depends on the soil type and the application of supplemental surface water (10) with maximum yields usually achieved for deeper water tables when surface water is applied.

Wesseling (9) showed that the optimum depth of the water table will shift depending on the prevailing climatological conditions. In dry years the optimum water table depth will be less than in wet years.

In field drainage, it is important to establish the optimum relation of the water table to root development and crop production. However, relatively little work has been done to determine the rate that the water table must be lowered to prevent crop injury or reduction in yields. Short periods of high water tables do not damage most crops (6, 9, 10). Hiler, et al. (4) noted that the effect of excessive soil water conditions on plants is dependent on the stage of growth and proposed the stress day index concept to evaluate the influence of fluctuating soil water conditions on crop yields. In humid regions, high intensity rainfall may cause the water table to rise to the surface even on well drained soils.

Van Hoorn (8) showed that optimum sweet potato yields were obtained when the water table depth was maintained at a 40 to 60 cm depth in a clay soil. In sweet potato, the root is harvested so any damage to the roots is directly reflected in the crop yield and quality. This is pointed out by the work of Kushman and Pope (5) who found significant decay of sweet potatoes due to wet and cold soil conditions prior to harvest.

When excessive soil water conditions occur during or immediately before harvest, biochemical processes may be initiated that have a detrimental effect on the storage qualities of sweet potato roots – effects which may not be obvious at harvest. The purpose of this study was to determine the effect of drainage rate on wet soil injury in sweet potatoes which were flooded immediately prior to harvest.

Materials and Methods

Sweet potatoes were grown in 14-gauge steel, 0.75 × 0.75 × 1.0 m deep tanks on the campus of North Carolina State University, Raleigh. The tanks were treated with red oxide and asphalt-abestos paint inside and outside to reduce corrosion. The outside of each tank was further insulated with a 2.5 cm sheet of polyester foam to reduce heat transmission to the soil. A 2.5 cm diameter drain was placed in the bottom of each tank with a control valve on the outlet to regulate the drainage rate. A piezometer was installed in the bottom of each tank to determine the water table position with time.

Two soil types, Appling sandy loam and Alamance silt loam were used in the study (Table 1). The drainage branch of the soil water characteristic was determined for each soil at 0.15 m and 0.45 m below the surface by using a standard pressure plate apparatus (Fig. 1). The average of effective vertical, saturated hydraulic conductivities of the soil was determined by ponding water on the surface and measuring the flow rate under a unit hydraulic gradient for a 12 hr period. The values obtained were 0.09 and 0.07 m/hr for the sandy loam and silt loam respectively.

The soils were sampled in 1975 and 1976 and were limed and fertilized prior to planting in accordance with the recommendations of the North Carolina Soil Testing Laboratory. Two cultivars and one experimental selection were used in this study: 'Julian' very tolerant, 'Centennial' moderately tolerant, and NC 257 very susceptible to flood damage.

Table 1. Physical properties of an Appling sandy loam and Alamance silt loam soils.

Soil properties	Appling sandy loam	Alamance silt loam
Bulk density (g/cm^3)	1.50	1.48
Particle density (g/cm^3)	2.54	2.63
Saturated hydraulic conductivity (m/hr)	.091	0.07
Water content at wilting point (15 atm) (cm^3/cm^3)	.089	0.162
Available water holding capacity (cm^3/cm^3)	0.165	0.223

Sweet potatoes were transplanted into the soil tanks on May 18, 1975 and May 29, 1976. The sweet potatoes were grown in accordance with recommended horticultural practices. In order to maintain vigorous growth during dry periods, irrigation water was applied. Soil water tension was monitored at 30 cm and 15 cm depths by tensiometers placed in 2 tanks of each soil type. Irrigation was applied when the soil water content dropped to 50% of the available water holding capacity in the top 30 cm. This corresponded to soil water tensions of 3 m and 2 m of water for the silt loam and sandy loam, respectively.

The control valves were open throughout the growing season to insure adequate drainage. Seven days prior to harvesting, October 3, 1975, and October 4, 1976, the valves were closed and the tanks were flooded for 24 hrs to simulate high intensity, long duration precipitation. After 24 hr the control valves were opened to predetermined settings to drain the flooded tanks at water table drawdown rates of 5 cm/day, 20 cm/day, 35 cm/day and full drainage which was about 100 cm/day.

After 6 days of drainage, sweet potato roots were harvested, washed, dried, weighed and immediately transferred to the laboratory for analysis. Total titratable acidity and pH were determined on subsamples of 4 roots from each treatment. A 1 cm thick cross-sectional slice was taken from the center of each root and a composite sample was prepared. These 4 slices were cut into 0.5 cm cubes and a 100 g sample was blended with 200 ml of distilled water for 3 min. 100 ml of the resulting puree was used to determine pH and titrated to an end point of

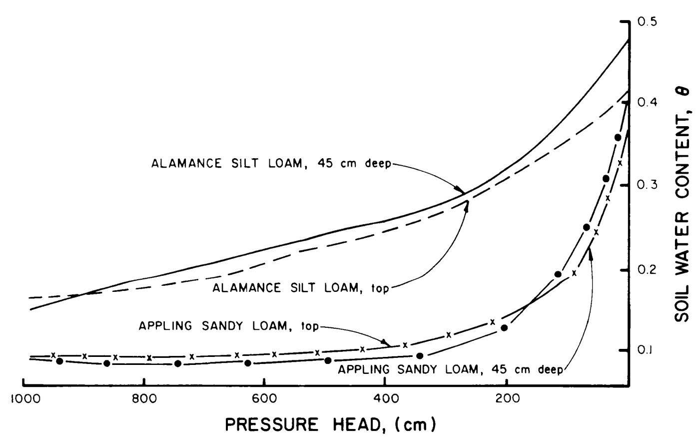

Fig. 1. Drainage branch of soil-water characteristic curves for Appling sandy loam and Alamance silt loam determined at surface and 45 cm depths.

Table 2. Decay of sweet potato roots from 3 cultivars and 4 drainage rates in 1975. Data averaged over 2 soil types.

Cultivar	Drawdown rate (cm/day)	Decay (%)				
		Days after harvest				
		2	9	12	16	23
Centennial	5	1	15	25	42	54
	20	2	9	18	38	48
	35	0	9	29	51	60
	100	0	9	11	28	40
Julian	5	0	1	9	25	34
	20	0	2	6	24	27
	35	0	5	12	31	34
	100	0	2	12	21	31
NC 257	5	50	60	88	96	97
	20	41	68	78	85	89
	35	35	58	70	81	85
	100	6	15	31	43	54
LSD 5%		13	14	17	17	16

pH 8.1 with 0.1 N NaOH to determine titratable acidity. Finally, 50 ml of the sample puree was filtered and a 20 ml aliquot used for soluble K determination by atomic absorption spectrophotometry.

The remaining roots in the samples were held at room temperature (about 26°C) for 3 weeks. Although curing at 29°C and 95% R.H. is recommended, a significant portion of the crop is not cured in practice. The roots were not cured in this experiment. The degree of decay was evaluated at 2, 9, 12, 16 and 23 days after harvest by taking a weighted average of the decay in each of the roots from a plot.

The plots were arranged in a split plot design with 3 replicates. The main plots were soil and drainage rate combinations. Cultivars were subplots. Analyses of variance were performed and, where F-test warranted, the LSD was calculated.

Results and Discussion

Flooding sweet potatoes prior to harvest was detrimental to the keeping quality of the roots. 'Julian' showed the least decay while 'Centennial' was intermediate and NC 257 showed the greatest postharvest decay (Tables 2 and 3). NC 257 exhibited the least decay at 100 cm/day drawdown during both years. This trend began at 9 days after harvest and continued through the storage period. In 1975, drawdown rates of 100 cm/day produced better keeping quality than the 5 cm/day rate for 'Centennial' from the 12th day after harvest unitl termination of storage. Decay in 'Julian' was not appreciably influenced by drainage rate in either year. There was no difference in root decay rates between the 2 soil types for 'Centennial' and 'Julian' in either year (Tables 4 and 5). However, there was less decay in NC 257 roots from the sandy loam soil for most of the observation periods during both years.

Table 3. Decay of sweet potato roots of 3 cultivars from 4 drainage rates in 1976. Data averaged over 2 soil types.

Cultivar	Drawdown rate (cm/day)	Decay (%)				
		Days after harvest				
		2	9	12	16	23
Centennial	5	0	5	30	42	64
	20	1	4	14	20	48
	35	1	2	12	18	41
	100	0	4	15	27	50
Julian	5	0	3	20	29	57
	20	1	10	21	27	43
	35	1	2	9	17	47
	100	0	4	12	28	31
NC 257	5	5	40	87	91	98
	20	0	16	37	54	66
	35	1	20	45	58	80
	100	1	9	25	40	56
LSD 5%		2	8	17	15	20

Table 4. Storage decay of sweet potato roots from 3 cultivars and 2 soil textures during 1975.

Cultivar	Soil texture	Decay (%)				
		Days after harvest				
		2	9	12	16	23
Centennial	Sandy loam	0	5	13	39	44
	Silt loam	2	12	28	47	56
Julian	Sandy loam	0	2	9	23	27
	Silt loam	0	3	10	26	35
NC 257	Sandy loam	24	49	59	71	76
	Silt loam	41	60	74	81	86
	Significant difference	*	NS	NS	NS	NS

During 1975, root pH decreased and titratable acidity increased with increasing drawdown rate (Table 6). During 1976 this pattern of pH and titratable acidity change was not distinct. Part of the year to year variation in pH and titratable acidity is mirrored in decay being less severe in 1976. These changes in pH and titratable acidity between the drawdown extremes correspond to decay data and indicate wet soil injury of the roots. Only in 1975 were differences in pH and titratable acidity sufficiently consistent to indicate the usefulness of these tests in studying response of sweet potato roots to different drainage rates. These changes are similar to those observed by Kushman and Pope (5) for roots that were exposed to cold weather prior to harvest. Apparently, pH and titratable acidity changes comparable to those that take place in chilled roots during storage take place prior to harvest if either wet or cold soil conditions develop.

If roots of a cultivar exhibited decay, the amount of soluble K tended to increase with the drainage rate (Table 7). Soluble K concentration of 'Julian' was not influenced by greater drainage rates in sandy loam, but the 5 cm/day drawdown rate caused decreased soluble K when these cultivars were grown in a silt loam soil during both years. When drawdown rate decreased from 35 to 5 cm/day, 'Centennial' roots decreased

Table 5. Storage decay of sweet potato roots from 3 cultivars and 2 soil textures during 1976.

Cultivar	Soil texture	Decay (%)				
		Days after harvest				
		2	9	12	16	23
Centennial	Sandy loam	0	3	20	29	56
	Silty clay loam	0	4	15	24	45
Julian	Sandy loam	1	6	18	30	57
	Silty clay loam	1	2	12	20	44
NC 257	Sandy loam	1	25	40	54	71
	Silty clay loam	2	15	53	64	76
	Significance	NS	*	*	*	NS

Table 6. The pH and total titratable acidity of sweet potato roots at harvest for 1975 and 1976, as influenced by cultivar, soil texture and drainage rate.

Cultivar	Soil texture	Drawdown rate (cm/day)	1975 pH	1975 Titratable acidity (meq/100 g)	1976 pH	1976 Titratable acidity (meq/100 g)
Centennial	Sandy loam	5	6.62	1.25	6.18	2.42
		20	6.39	1.60	6.30	2.22
		35	6.28	1.77	6.23	2.45
		100	6.37	1.53	6.13	2.55
	Silt loam	5	6.75	1.12	6.37	2.07
		20	6.60	1.45	6.34	2.30
		35	6.37	1.55	6.24	2.32
		100	6.32	1.46	6.38	2.00
Julian	Sandy loam	5	6.38	1.70	6.24	2.12
		20	6.19	1.97	6.06	2.87
		35	6.18	2.10	6.09	2.57
		100	6.30	1.42	6.07	2.75
	Silt loam	5	6.44	1.75	6.36	2.52
		20	6.30	1.97	6.35	2.47
		35	6.22	2.12	6.34	2.22
		100	6.32	1.75	6.44	2.00
NC 257	Sandy loam	5	6.42	1.47	6.09	2.62
		20	6.28	2.05	6.21	2.47
		35	6.20	2.15	6.17	2.55
		100	6.35	1.00	6.06	2.70
	Silt loam	5	6.49	1.51	6.28	2.30
		20	6.41	1.77	6.25	2.50
		35	6.27	1.97	6.24	2.57
		100	6.21	1.70	6.30	2.67
LSD 5%	Cultivar		.09	.01	.08	.01
	Drawdown rate		.16	.01	.09	.01

Table 7. Potassium concentration of sweet potato roots for 1975 and 1976 as influenced by cultivar, drainage rate and soil texture.

Cultivar	Soil texture	Drawdown rate (cm/day)	K (ppm) 1975	K (ppm) 1976
Centennial	Sandy loam	5	941	963
		20	989	1097
		35	1019	1106
		100	1018	1112
	Silt loam	5	901	930
		20	1009	1111
		35	1081	1159
		100	1079	1184
Julian	Sandy loam	5	936	989
		20	944	951
		35	888	947
		100	882	933
	Silt loam	5	986	997
		20	1083	1109
		35	959	1051
		100	1130	1143
NC 257	Sandy loam	5	762	801
		20	743	799
		35	844	878
		100	924	960
	Silt loam	5	819	832
		20	816	829
		35	941	967
		100	941	974
LSD 5%	Cultivar		49	52
	Drainage rate		75	91

in soluble K in sandy loam soil in 1975 and silt loam soil in 1976. Similarly, soluble K of 'Centennial' decreased when drawdown rate decreased from 20 to 5 cm/day in sandy loam soil in 1976 and silt loam soil in 1975. However, the NC 257 breeding line decreased in soluble K as drawdown rate decreased from 35 to 20 cm/day in both soil textures. Even though

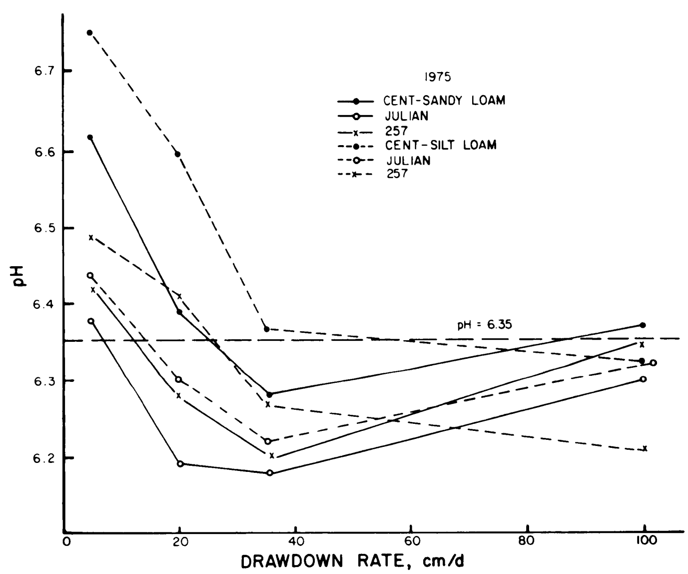

Fig. 2. The pH of sweet potato versus water table drawdown rate for a sandy loam and silt loam soil during 1975.

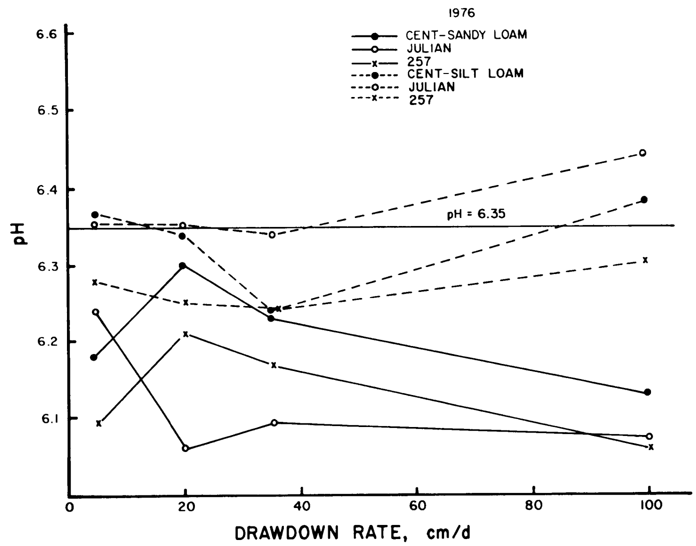

Fig. 3. The pH of sweet potato versus water table drawdown rate for a sandy loam soil and silt loam soil during 1976.

soluble K was lower in cultivars which exhibited more injury and when injury within a cultivar was greater, relatively high soluble K concentration was not consistently an indication of low level of injury.

From our results, both soil type and sweet potato cultivar should be considered in determining drainage requirements for areas where high water tables are likely at harvest time. To determine the necessary drainage rate to insure sound roots with good postharvest qualities, the pH of the roots should not exceed 6.35 as suggested by the National Sweet Potato Collaborators (7). As we have also observed that the pH of the roots increases with decreasing drainage rates, we can determine the drawdown rate that will give a pH of 6.35 (Fig. 2 and 3). In 1975, to obtain healthy sweet potato roots at harvest with pH 6.35 in a sandy loam, the drawdown rate should be 14 cm/day for NC 257, 7 cm/day for 'Julian' and 25 cm/day for 'Centennial'. In a silt loam, these values should correspond to 15 cm/day, 26 cm/day and 55 cm/day for 'Julian', NC 257 and the 'Centennial' respectively. The use of root pH to determine wet soil injury is highly variable but correlates with earlier findings and it can be a useful tool. But at times as in 1976 the root pH seldom exceeds 6.35 yet injury was noted in the breeding line NC 257.

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