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Effect of Duration of Soil Saturation on Ethanol Concentration and Storage Loss of Sweet Potato Roots[1]

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Abstract. **The effect of 24, 48, and 72 hours of soil saturation on the ethanol concentration of roots at harvest and on post-harvest storage loss was investigated for sweet potato [*Ipomoea batatas* (L.) Lam. cvs. Jewel and Centennial]. Ethanol accumulated rapidly with increasing time of soil saturation for both cultivars. Ethanol concentration was greater in roots taken from soil with slow drainage rates following saturation than from roots grown in soil with a fast drainage rate. The ethanol concentration in 'Centennial' roots did not increase beyond 48 hour saturation in soil with good drainage following saturation, while ethanol accumulated in 'Jewel' roots up to 72 hours. Weight loss in storage due to shrinkage and rotting was greatest for Jewel when subjected to 72 hours of continuous saturation followed by poor drainage, but as little as 24 hours of soil saturation followed by poor drainage caused significant storage losses.**

Sweet potato roots are sensitive to high levels of soil moisture prior to harvest (1, 5, 6, 8). Although traditionally grown on coarse-textured soils, sweet potatoes may be exposed to low oxygen content in saturated or near-saturated soil because of excessive rainfall on soils with relatively impermeable subsoil horizons. These roots may exhibit accelerated weight loss and rotting both in the field and later in storage (1, 5, 6). Differences in total weight loss due to shrinkage and rotting during curing and storage were found between 'Jewel', 'Centennial', and many other genotypes (8), 'Jewel' is considered intolerant, and 'Centennial' is considered tolerant, to high soil moisture (9). There is strong evidence for a genotype by environment interaction (8).

In several plant species, metabolic differences have been found between species tolerant and susceptible to flooding damage (7). Species susceptible to flooding damage exhibited accelerated rates of glycolysis leading to increased levels of ethanol when exposed to anaerobic conditions (4, 7). Published data was not found linking ethanol concentration in roots exposed to anaerobic conditions and flooding damage in sweet potatoes.

The objectives of this study were: (a) to determine root ethanol concentration as a function of duration of soil saturation, soil drainage properties, and cultivar; (b) to ascertain whether ethanol concentration at harvest is correlated with storage loss of 2 differentially tolerant sweet potato cultivars; and (c) to assess the value of root ethanol concentration as a possible measurement to screen for flood tolerance.

Materials and Methods

The research was conducted at North Carolina State University, Raleigh, from May to Sept., 1979, using a $2^2 \times 4$ factorial experiment arranged in a split-plot design with 3 replications. Experimental units were 0.75 $m^2 \times 1.0$ m deep steel tanks equipped with drainage valves. The whole-plot factors of soil type and time of saturation were completely randomized. Soil types used in the study were Appling sandy loam (clay kaolinitic thermic typic hapludult) and Alamance silt loam (fine silty siliceous thermic typic hapludult) which differ widely with respect to moisture retention and drainage properties (2). The 4 levels of time of saturation were 0 (control), 24, 48, and 72 hr of continuous saturation. The sub-plot factor was comprised of the cultivars 'Jewel' and 'Centennial'.

Dolomitic lime and 15 g of fertilizer (8N-8P-8K) was incorporated into the top 17 cm of soil in all tanks. The Appling sandy loam received 75 g lime/tank and the Alamance silt loam received 100 g lime/tank in order to adjust the pH to 5.8. All tanks were topdressed with 5 g NH_4NO_3 and 8 g KCl 60 days from planting. The plants were transplanted on May 13, 1979, to form two rows (1 row per cultivar) spaced 25 cm apart. Three plants per cultivar were spaced 20 cm within the row. Flooding was initiated 126 days after planting by closing the drainage valves and maintaining about 15 cm of water ponded on the soil surface. Each tank was allowed to drain freely for 24 hr following the prescribed time of saturation and then the roots were harvested. Sweet potatoes were harvested from control tanks the same day as the 24 hr treatment. Soil moisture content was determined gravimetrically.

A 3-root sample in the size range of 3.8 to 5.0 cm diameter by 12.7 to 15.0 cm length was taken for ethanol determination. The extract for ethanol determination was prepared within 1 hr following harvest. A 1-cm-thick cross-sectional slice was taken from the center of each root and diced to give approximately 1- cm cubes. Six to 7 g were weighed from each root, and then a 20 g composite sample was homogenized at high speed for 45 sec in a half-pint blender jar with 100 ml 1.8% $Ba(OH)_2$ solution. One hundred ml of 2% $ZnSO_4$ solution was added and the mixture blended for an additional 15 sec. The raw extract was then placed in plastic vials and frozen.

The frozen samples were thawed within 2 days and a 20 ml aliquot of the extract was centrifuged at 27000*g* for 10 min. The supernatant was filtered through Whatman #1 paper and the clear filtrate stored at approximately −20°C for 2 days. Ethanol was as-

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sayed with reagent kits (Ethyl Alcohol Reagent Set) purchased from Worthington Diagnostics, Freehold, N.J.

Results and Discussion

Soil moisture. The moisture content for the control soil at harvest was similar for both soil types and for all treatments prior to saturation. The saturated water contents were also similar for both soil types. A difference of 42.7% of the saturated values was found between the 2 soil types. The sandy loam soil drained rapidly as evidenced by the post-drainage soil moisture content of 40.5% of the saturated value. The silt loam soil was very poorly drained, retaining 83.2% of its moisture-holding capacity. Only a small amount (17%) of the total porosity was present as free gas and hence gas exchange in the root zone may have been limited. Roots exposed to the saturated treatments on the silt loam soil were subjected to conditions unfavorable for aerobic respiration for a longer time than on the sandy loam.

Ethanol concentration. Ethanol concentration increased with increasing time of saturation for all treatment combinations (Fig. 1). Ethanol levels for both cultivars on the silt loam were higher than those from the sandy loam. Low air porosity in the silt loam during drainage resulted in a higher concentration of ethanol due to a further accumulation of the fermentation product, lowered rate of aerobic metabolism of ethanol, or lowered rate of volatilization.

Cultivar differences. The increase in ethanol concentration in response to duration of soil saturation was similar for cultivars grown in Alamance silt loam but differed for those grown in Appling sandy loam (Fig. 1). 'Jewel' displayed a greater rate of increase in root ethanol concentration than 'Centennial' up to 48 hr and then the 2 curves converged near the limit of the data. There was a notable difference in the cultivar response on the sandy loam. The curves are not markedly different until the 48 hr time at which ethanol concentration of 'Centennial' roots reached a plateau. This suggests the possibility that 'Centennial' roots may possess the biochemical means to rapidly metabolize a portion of the accumulated ethanol when given favorable aeration following saturation. Cossins and Beevers (3) reported that numerous plant species are capable of rapidly consuming added ethanol under aerobic conditions. Differences in the rate and means of aerobic metabolism of accumulated ethanol following high soil moisture may explain differences in cultivar tolerance.

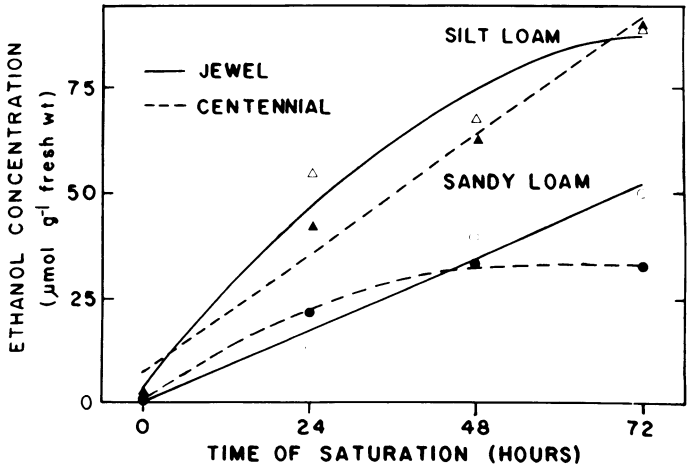

Fig. 1. Ethanol concentration in sweet potato roots at harvest as affected by duration of soil saturation. Each data point is the mean of 3 replications. LSD (5%) for comparing soil types and times is 8.0. LSD (5%) for comparing cultivars is 9.9.
Regression equations:
Jewel-silt loam: $y = 3.72 + 2.11x - 0.01x^2$; $R^2 = 0.91$
Jewel-sandy loam: $y = 0.20 + 0.73x$; $r^2 = 0.94$
Centennial-silt loam: $y = 7.18 + 1.18x$; $r^2 = 0.96$
Centennial-sandy loam: $y = 0.59 + 1.13x + 0.01x^2$; $R^2 = 0.95$

Storage loss. The percentage of initial weight lost from shrinkage and rotting is plotted over time in storage for the 72-hr saturation treatment and the control (Fig. 2). Within all 4 cultivar × soil type combinations the 72-hr saturation treatment resulted in greater storage loss than the control as shown by the regression curves. After 42 days in storage, 25% of the initial weight of 'Jewel' roots from the sandy loam was lost due to shrinkage and rotting compared with only 8% for the control. Similarly, 'Centennial' roots lost about 21% of their weight after 42 days in storage from the 72-hr saturated sandy loam. However, differential cultivar tolerance is clearly shown on the higher stress conditions of the silt loam where nearly 60% of the initial weight of 'Jewel' was lost after 42 days in storage from the 72-hr saturated treatment compared to only 21% for 'Centennial'. Differences in tolerance between 'Jewel' and 'Centennial' were not detected under conditions of good drainage (sandy loam) following a 3-day period of continuous saturation. The additional 24 hr of unfavorable aeration (drainage period) in the poorly drained silt loam was severe enough to be well beyond the tolerance limit of the susceptible cultivar 'Jewel', resulting in a storage loss of 35% above the sandy loam for the 72-hr saturation treatment after 42 days in storage (Fig. 2). Soil type made little difference in storage loss for the tolerant cultivar 'Centennial'.

Relationship of storage loss to duration of saturation and ethanol concentration. Percentage weight loss of 'Centennial' roots after 42 days in storage from the silt loam was linearly related to duration of saturation (Fig. 3). Each 24-hr increase in duration of saturation above the control reduced root weight of 'Centennial' only 3.6% (Fig. 3). In contrast, more than 24-hr of continuous saturation followed by 24-hr of poor drainage caused substantial storage loss to the flood susceptible cultivar 'Jewel' (Fig. 3).

The relationship of weight loss after 42 days in storage to the root ethanol concentration at harvest from the silt loam shows that only 1.5% increase in weight loss is associated with a uniform increase of 10 μmol of ethanol g^{-1} fresh wt for 'Centennial' (Fig. 4). In contrast, the weight loss for 'Jewel' rises sharply at about 60 μmol g^{-1} fresh weight, suggesting a threshold level of ethanol concentration in 'Jewel' that may be in part responsible for triggering a latent souring response in storage. An ethanol content of 100 μmol g^{-1} fresh weight at harvest in 'Jewel' was associated with the loss of about 70% of the initial weight after 42 days in storage. The same ethanol level in 'Centennial' was associated with only 25% weight loss. Hence, ethanol levels at harvest do not necessarily indicate the extent of damage that occurs in storage. Results indicate that tolerant cultivars such as 'Centennial' may be able to rapidly reduce root ethanol levels in response to aeration following a period of near or complete anaerobiosis.

Weight loss during storage due to shrinkage and removal of soured roots and ethanol concentration of roots at harvest are dependent on the duration of saturation, relative cultivar tolerance, and soil drainage properties. Increasing duration of soil saturation increased root ethanol concentration for both cultivars. The recovery exhibited by 'Centennial' roots may be a characteristic of flood-tolerant cultivars. A demonstration of reduced ethanol levels at periodic intervals in storage following a saturated treatment for a number of cultivars and breeding lines would provide further support to this hypothesis.

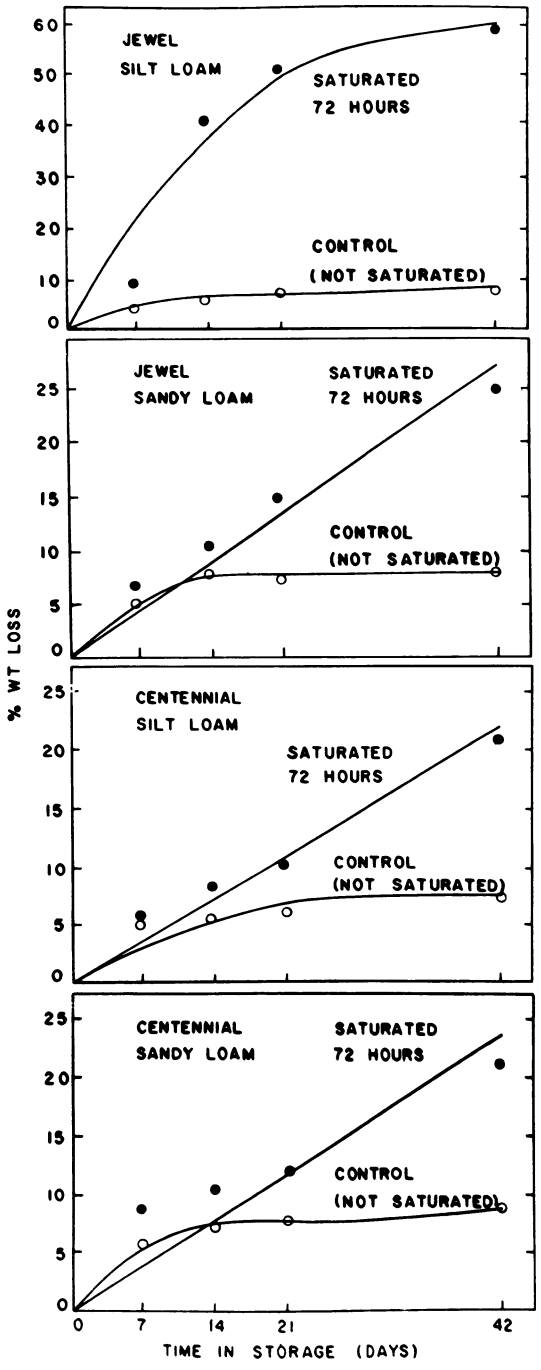

Fig. 2. Cumulative percent weight loss over time in storage due to shrinkage and rotting from the 72-hour and control treatments for 2 cultivars and 2 soil types. Each data point is the mean of 3 replications. LSD (5%) for comparing saturated and non-saturated means for all treatments are 1.7 for 7 days, 13.7 for 14 days, 13.6 for 21 days, and 16.3 for 42 days.
Regression equations:
Jewel-silt loam-72 hrs: $y = 3.31x - 0.045x^2$; $R^2 = 0.88$
Jewel-silt loam-control: $y = 0.10x - 0.046x^2 + 0.0006x^3$; $R^2 = 0.99$
Jewel-sandy loam-72 hrs: $y = 0.65x$; $r^2 = 0.94$
Jewel-sandy loam-control: $y = 0.10x - 0.044x^2 + 0.0006x^3$; $R^2 = 0.97$
Centennial-silt loam-72 hrs: $y = 0.52x$; $r^2 = 0.88$
Centennial-silt loam-control: $y = 0.49x - 0.0074x^2$; $R^2 = 0.96$
Centennial-sandy loam-72 hrs: $y = 0.56x^2$; $r^2 = 0.86$
Centennial-sandy loam-control: $y = 1.08x - 0.048x^2 + 0.0006x^3$; $R^2 = 0.99$

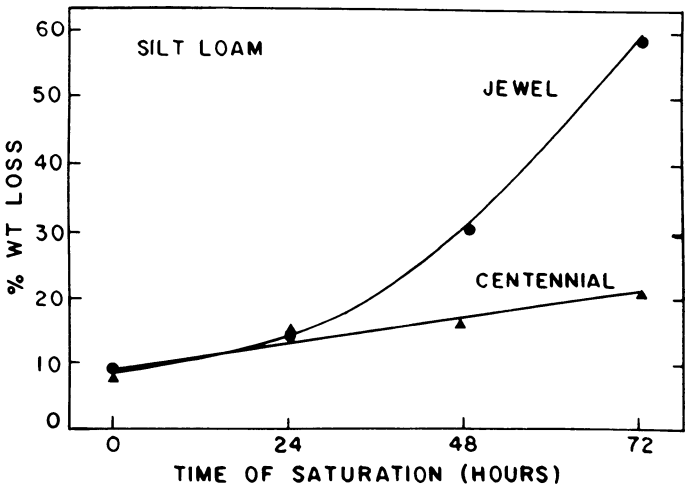

Fig. 3. The effect of duration of soil saturation prior to harvest on the cumulative percent weight loss of sweet potato roots from the silt loam soil after 42 days in storage. Each data point is the mean of 3 replications. LSD (5%) for comparing times is 16.3.
Regression equations:
Jewel: $y = 9.64 - 0.46x + 0.01x^2$; $R^2 = 0.84$
Centennial: $y = 7.72 + 0.15x$; $r^2 = 0.51$

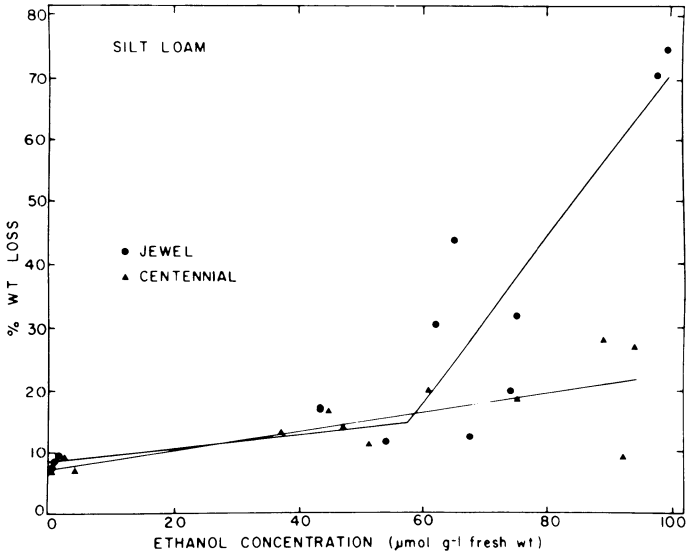

Fig. 4. The relationship of root ethanol content at harvest with cumulative percent weight loss from the silt loam soil after 42 days in storage.
Regression equations:
Jewel: $y = 8.67 + 0.11x_1 + 1.19(x_1 - 57.52)x_2$; $r^2 = 0.83$
where $x_2 = 0$ if $x_1 < 57.52$
1 if $x_1 > 57.52$
Centennnial: $y = 7.72 + 0.15x$; $r^2 = 0.51$

This study suggests the possible value of ethanol measurements at some time in storage as a screening device for sweet potato breeding programs. Testing of cultivar sensitivity to increasing time of soil saturation and the use of different post-saturation drainage rates could serve as useful tools in the selection of tolerant breeding lines. This would enable the determination of critical durations of stress induced by high soil moisture for moderately

tolerant cultivars that are otherwise desirable. The information also could be used to determine the most desirable time of harvest in order to minimize crop losses when use of field equipment is not limiting.

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Effect of Cultivar, Strain, and Growth Regulator Treatments on Shoot Development and Ethylene Evolution in Apple Trees[1]

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Additional index words. Malus domestica, flowering, ethephon, daminozide

Abstract. **'Miller Sturdeespur Delicious' apple (*Malus domestica* Borkh.) trees made less extension growth than 'Imperial Red Delicious' (non-spur) under controlled conditions. No differences in extension growth were measured between 'MacSpur' and 'Imperial McIntosh' (non-spur) trees. Development of the spur-type morphology was determined by the number of lateral buds which grew into spurs during the second growing season. Application of (2-chloroethyl)phosphonic acid (ethephon) alone, or in combination with butanedioic acid mono-(2, 2- dimethylhydrazide) (daminozide) decreased extension growth and increased shoot ethylene evolution in growth chamber studies, and promoted flowering in the field. Application of daminozide plus ethephon was more effective than ethephon alone. Daminozide alone did not affect shoot ethylene. No change in ethylene evolution or shoot development was detected following applications of gibberellin 4/7 (GA) or 2, 3, 5-triiodo benzoic acid (TIBA) to spur or non-spur type trees. Bark scoring had no effect on shoot ethylene. However, this treatment also promoted flowering of young trees in the field. It is suggested that while some manipulations can increase shoot ethylene evolution and also promote flowering, the ethylene evolved following treatment operates indirectly by retarding growth, rather than by directly stimulating flower bud initiation.**

With the trend toward planting compact apple trees at close spacings, the costs of orchard establishment have risen dramatically. To offset these increased costs, trees which rapidly reach a level of sustained annual production are needed. Frequently, excessive vegetative growth by young trees delays their flowering and fruiting (7, 23, 24). This problem is especially severe in 'Delicious', the major apple cultivar in the United States.

Numerous management techniques are used by fruit growers to suppress shoot growth and induce flowering of young trees. Branching bending, summer pruning, ringing, and the application of growth regulators have been used effectively (7, 15, 23, 24). Increased ethylene evolution follows bending, pruning, and the application of some growth retardants (7, 9, 11, 16, 17). While these treatments can increase ethylene evolution, it is not known what role this hormone actually plays. Studies of ethylene evolution in field-grown apple trees have shown that no difference exists between the cultivars 'McIntosh' and 'Delicious', despite differences in their precocity (20). In that study, the greatest factor affecting ethylene evolution in the field was date of sampling. Endogenous ethylene was primarily influenced by tissue age and development and the weather conditions at the time of sampling.

A second option available to increase production in young apple plantings is the use of spur strains. Comparisons of spur and non-spur strains of 'Delicious' have shown that spur strains make less extension growth, more spurs per unit shoot length, and fewer branches (5, 14, 21). These trees are consequently smaller

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[2]Former Graduate Assistant. Currently: Assistant Professor, Department of Horticulture, University of Maryland, College Park, MD 20742. Growth regulators used in this study were applied as the following proprietary products: daminozide (Alar-85, Uniroyal); ethephon (Ethrel, Amchem); GA (gibberellin component of Promalin, Abbott); and TIBA (Floraltone, Amchem).

[3]Professor. The authors wish to thank R. Melious and R. Musselman for their assistance in the growth chamber studies.