it could have been related to a probable difference between the 2 trials in concentration of the chemicals in the root zone. Although this discrepancy does exist, the inbred 7B still was among the best in regard to tolerance indexes in both trials while 48B and 46B were the lowest in each case.

The combined data from the 2 trials indicate a detectable difference in herbicide tolerance exists among the onion inbreds tested. This is in agreement with previous reports (4, 13) and, in particular, with Alban (1) when it is noted that 36B is derived from 'Brigham Yellow Globe' and 46B is derived from 'Yellow Sweet Spanish'. It appears that this difference in tolerance should be large enough to permit breeders to develop onion inbreds that are highly tolerant to CIPC.

Since the data from the 2 trials do not correspond directly, the laboratory technique would be of most value as a preliminary screening method to eliminate the least tolerant inbreds. Subsequent field tests would be necessary to determine which inbreds have the highest tolerance under field conditions.

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Tolerance of Cranberry Plants to Manganese, Iron and Aluminum[1]

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Abstract. Cranberry cuttings grown in external solutions with several concentrations of Mn (0 to 1000 ppm), Fe (0 to 100 ppm) supplied as FeEDTA, and Al (0 to 150 ppm), showed tolerance to accumulations of high concentrations (8000 ppm from 1000 ppm in external solution) of Mn in the tissue and the ability to selectively exclude high level accumulation of Fe and Al from shoots. Root initiation by softwood cuttings was inhibited at high levels of Mn (275 ppm and above), Al (2.5 ppm and above) and Fe (2.5 ppm FeEDTA and above) in external solution.

THE cranberry plant, *Vaccinium macrocarpon*, L., grows successfully on bog soils too acid (pH near 4.0) for production of most other crop plants. This implies nutritional tolerances different from those shown by many other crop plants. An understanding of the soil-plant relationship under an acidic root environment would be helpful in establishing new approaches to a weed control program in cranberry bogs and also in providing information for a better characterization of the ecology of the cranberry bog environment.

Arnon and Johnson (1) reported direct phytotoxicity from H+ activity only at extremes of the physiological range. Gerloff (4) concluded that poor plant growth at pH levels as low as 4.5 was due to either the toxic effects of high concentrations of metals made soluble under highly acidic conditions or to the insolubility and thereby deficiency of nutrient elements. Hewitt (6) reported that the deleterious effects of high acidity were the result of a complex of factors of which Al and Mn toxicity were among the most important.

Rorison (13) showed that excess Al^{+3} was responsible for the lack of growth of *Scabiosa* sp. from certain acidic sand cultures. Excessive Fe absorption was responsible for the failure of hemp and mustard on acidic soils according to Olsen (12). Manganese toxicity to crops on acidic soils has been shown by several workers (2, 6, 9, 14). Morris and Pierre (11) reported differences in sensitivity of legume species to Mn toxicity. Lohnis (9) showed that oats and mustard tolerated high Mn levels by selective exclusion of the metal from the tissue, while tobacco and strawberry showed a tolerance to high concentrations in

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tissue. Among species of bog plants, Gerloff et al. (5) found a wide range of tolerance to Mn levels, with one species accumulating 3000 ppm in the shoots, an amount toxic for many other plant species. Gerloff (4) concluded that species with high Mn levels in the tissue showed tissue tolerance, while those species successfully growing in the same soil with low levels of Mn in the tissue showed selective exclusion of the metal.

Since acid soils are often associated with high levels of soluble Mn, Fe and Al, this experiment was carried out to demonstrate the nature of tolerance the cranberry plant can exhibit to high levels of these metals provided under the controlled conditions.

Materials and Methods

Accumulation of Mn, Fe and Al in tissues. The lowest 2 inches of hardwood cuttings of cranberry uprights, cv. 'McFarlin', were held in aerated deionized water for 4 weeks during which time root and shoot growth were initiated. At this time the deionized water in the containers was replaced with complete Hoagland's solution in which the plants continued growth for 4 weeks.

After the 8-week growing period, the rooted cuttings were placed in solutions with the treatment levels of Mn, Fe and Al. The solutions were held in 2 liter black plastic culture pots. Fifteen cuttings per pot with 2 replicates of each treatment were used. Because Vlamis and Williams (15) had shown that Mn absorption was enhanced by concentrations of nutrients below those in Hoagland's solution, the treatment solutions were made at half strength Hoagland's to provide the following concentrations of nutrients: Ca 100 ppm; P 15.5 ppm; K 117 ppm; Mg 24 ppm; N (as NO_3-) 105 ppm; S 32 ppm; Cl 0.88 ppm; B 0.13 ppm; Mn 0.12 ppm; Zn 0.06 ppm; Cu 0.015 ppm; Mo 0.005 ppm and Fe 1.13 ppm. This solution was modified by addition or deletion of FeEDTA, Mn SO_4 and Al $(SO_4)_3 \cdot 18\ H_2O$ to provide ranges of concentrations as follows: Mn from 0.0 to 1000 ppm; Fe from 0.0 to 100 ppm; and Al from 0.0 to 150 ppm. On alternate days, solutions were adjusted to pH 4.5 except in the Al treatment solutions which were adjusted to pH 3.5 in order to maintain Al in the ionic state. The pH change never exceeded 0.5 units. Preliminary work indicated that pH 3.5 *per se* was not injurious to cranberry plants. Deionized water was added once a day as required to maintain a constant volume in the container. All solutions were renewed weekly during the experimental period. Plants were grown in a greenhouse maintained at 21 ± 2°C under natural daylight supplemented by low intensity tungsten filament light to provide a 16-hr light period.

After 5 weeks of growth under the experimental treatments, new roots and shoots were harvested separately, dried in a forced draft oven for 48 hr at 75°C, weighed, ground, pre-digested with concentrated HNO_3 and wet digested with ternary acid mixture. The digestates were analyzed by the following colorimetric methods: Mn by the permanganate method (8); Fe by the *o*-phenanthroline method (8); P by the vanadate method (7); and Al by means of "aluminon" (3). The P analyses were made to reveal any possible deficiencies that could occur from interactions with Mn, Fe and Al at the low pH levels used.

Influence of Mn, Fe and Al on root initiation. Actively growing softwood cuttings of uprights cv. 'Howes' were rooted directly in solutions containing the various concentrations of Mn, Fe and Al as described above. Other nutrient elements were supplied at twice the concentrations of external solutions listed above. The pH was adjusted on alternate days to pH 4.5 except in Al solutions where the pH was adjusted to 3.5. Temperature and light conditions were the same as in the previous experiment.

Root length was measured 3 weeks after "sticking" the cuttings, and shoot growth was harvested, dried and weighed 5 weeks later.

Results and Discussion

Accumulation of Mn, Fe and Al. The data for growth and composition of plants grown for 5 weeks at several concentrations of Mn in the external solution are shown as a log-log relationship in Fig. 1. Dry weight and Fe and P concentrations of shoots were not affected by Mn concentration in the external solution. Accumulation of Mn in shoots was directly related to the Mn concentration in the external solution. Manganese concentration in the shoots reached over 8000 ppm with 1000 ppm of Mn in the external solution. With this very high tissue concentration of Mn, the plants maintained active vegetative growth as shown by the curve of dry weight production. No plant damage was observed at these concentrations of Mn in the tissues or in the external solution.

The data for dry weight and Mn, Fe and P concentrations in plants grown with different levels of Fe are presented as a log-log relationship in Fig. 2. Differences in Fe concentration in the external solution from 0.0 to 100 ppm had no effect on shoot growth; Fe absorption was independent of external solution concentration of Fe from 0.0 to 10.0 ppm, but further increases in concentration of Fe in the external solution resulted in increased uptake by the plants. The P concentration in the shoots was apparently independent of Fe concentration in the external solution. The absence of an interaction between P and Fe was likely due to the use of chelated Fe in the

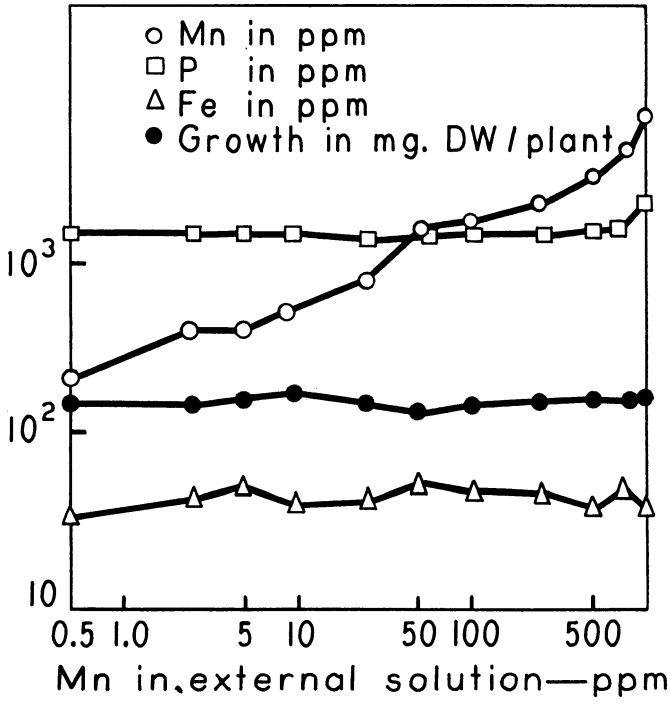

Fig. 1. Log-log relationship of Mn in external solution to the growth and to the concentration of Mn, Fe and P in cranberry shoots.

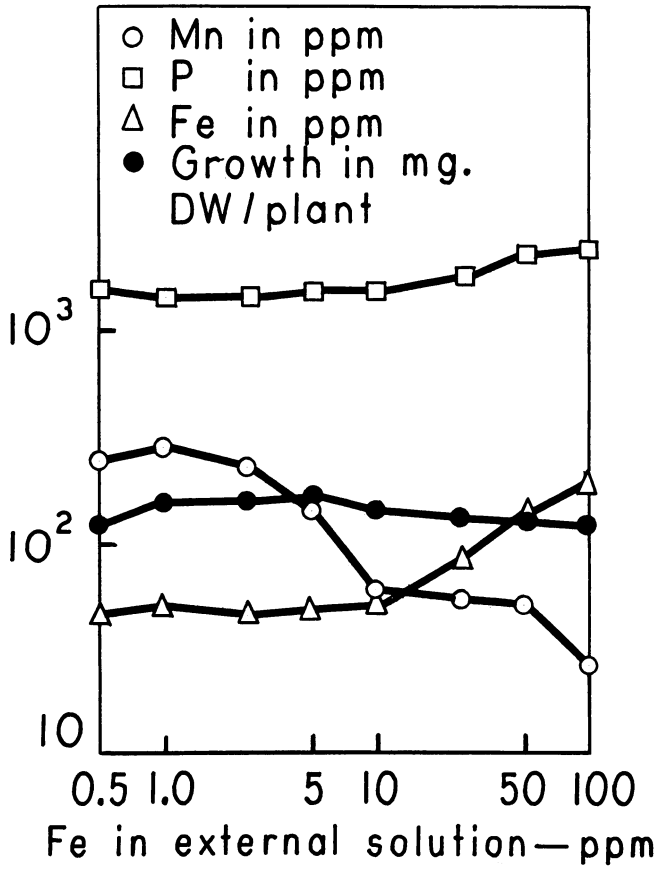

Fig. 2. Log-log relationship of Fe in nutrient solution to growth and concentration of Mn, Fe and P in cranberry shoots.

external solution. A different response could have been anticipated with Fe SO_4. Manganese concentration in the shoots was inversely related to the Fe concentration in the external solutions.

With 100 ppm of Fe in the external solutions the plants developed black spots on the oldest leaves. These spots remained small, and the plants continued to develop new growth. Whether or not the spots were the toxic result of high concentrations of Fe or of the chelating agent used (EDTA) or were symptoms of Mn deficiency remains unknown.

The ratios of Fe:Mn were calculated for the several external solutions, and the comparable Mn and Fe accumulations for these treatments are plotted as a log-log relationship in Fig. 3. The concentration of Mn in tissues was inversely related to the ratio of Fe:Mn from .0025 to 200 in the external solution. The concentration of Fe in the foliage was influenced by Fe in the external solution only when the concentration reached 10 ppm and above and when the ratio Fe:Mn was 20 or higher. At lower concentrations in the external solution the plant was able to selectively exclude Fe. However, if Fe had been supplied in the nonchelated form as might be the case in acid soils, the uptake of Fe might have been different.

Data for growth and Al and P concentrations in the tissues grown 5 weeks in solutions are shown in Table 1. Dry matter yields of new growth of cranberry shoots were not affected until the external solution contained 150 ppm of Al. No Al was found in the shoots or roots with no Al in the external solution. From 0.5 to 100 ppm in external solution, the Al concentration in shoots varied from 35 to 48 ppm and increased to 65 ppm when the

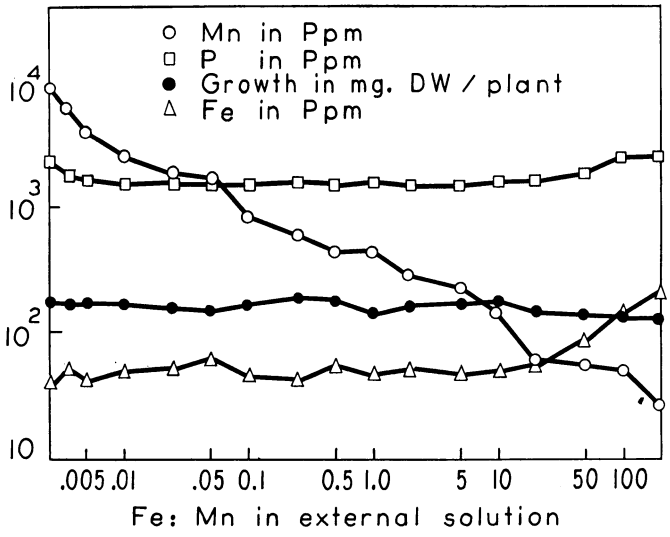

Fig. 3. Log-log relationship of Fe:Mn in external solution to growth and concentration of Mn, Fe and P in cranberry shoots.

external solution concentration reached 150 ppm. In the roots, Al concentration increased from 0.0 to 578 ppm as the external solution concentration increased from 0.0 to 2.5 ppm. Changes in external solution concentration of Al from 2.5 to 150 ppm caused no trend of change in tissue concentration. Phosphorus concentration of the shoots and roots was unaffected by the concentration of Al in the external solution. However, elsewhere we reported (10) that a high Al concentration in the external solution during the experimental period interfered with the net ^{32}P accumulation in the cranberry tissue. The high levels of P found in the root analyses could possibly be the result of phosphates that precipitated in and on the surface of the roots.

Over the short term of this experiment the cranberry plant was shown to have tolerance to high levels of Mn in the tissue and to selectively exclude Fe (as FeEDTA) and Al from the tissues when present at high levels in the external solution. These metals, Mn, Fe and Al are all more soluble at pH's common to cranberry soils (pH 4.0–5.0) than at higher pH's. Manganese and Al may be toxic to some plant species when the metals are available in high concentrations. The tolerance to heavy metals may be necessary for cranberry survival in its native habitat, and the toxicity of these metals to other species may be a major factor limiting the vegetative competition to the cranberry.

Table 1. Dry weight and Al and P concentration of cranberry plants (new growth only) in relation to the concentrations of Al in the external solution.

Al in the external solution	Shoots			Roots		
	Avg dry wt per plant	Al	P	Avg dry wt per plant	Al	P
ppm	mg	ppm	%	mg	ppm	%
0.0.....	164	0	0.15	19.2	0	.87
0.5.....	156	41	0.16	17.5	270	.88
2.5.....	164	39	0.16	18.5	578	1.17
5.0.....	155	47	0.16	16.2	442	1.29
10.0.....	151	48	0.17	14.0	500	1.14
25.0.....	177	36	0.17	17.9	541	1.09
50.0.....	141	38	0.17	14.5	451	1.06
100.0.....	157	35	0.17	14.9	468	1.03
150.0.....	123	65	0.15	9.5	536	1.09

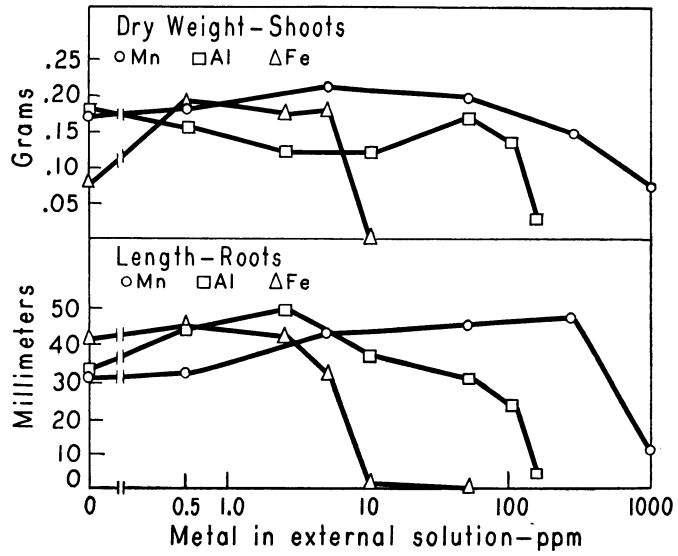

Fig. 4. Semi-log relationship between heavy metal concentration in nutrient solution and the root and shoot growth of softwood cuttings of cranberry.

Influence of Mn, Fe and Al on root development. The average dry weight of shoots per plant and the root length of cranberries rooted and grown in external solutions with several concentrations of heavy metals are shown in Fig. 4. A growth stimulation, as shown by the increase in average length of roots, occurred when Mn and Al concentrations in the external solutions were increased from 0.0 to 2.75 and 0.0 to 2.5 ppm, respectively. Manganese at 1000 ppm, Al at 10, 50, 100 and 150 ppm and Fe at 5, 10, 50 and 100 ppm suppressed root growth. Shoot growth patterns were similar to those observed for roots except that shoot growth was less sensitive to metal ions than was root growth. Plants did not survive solutions with Fe concentrations of 50 ppm and above. It is possible that plant death was a result of interactions with the chelating agent (EDTA) rather than a direct effect of Fe concentration.

Cranberry cuttings rooted at wide ranges in the external solution concentrations of Mn, Fe and Al. Root growth was restricted only at concentrations beyond those that would be expected in soils. It is unlikely that cranberry rooting in the field is ever adversely affected by metal ion concentration. However, other species may well be excluded from this environment because of toxicity of one or more metals to rooting of propagules and seed germination.

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