PLANT VARIETIES AS INDICATORS OF ALUMINUM TOXICITY IN THE A_2 HORIZON OF A NORFOLK SOIL[1]

F. Leslie Long and Charles D. Foy[2]

ABSTRACT

Two varieties of barley (*Hordeum vulgare, L., emend, Lam.)* and two varieties of snapbeans *(Phaseolus vulgaris, L.)*, known to differ widely in their tolerance to aluminum, were used as biological indicators of aluminum toxicity in the A_2 horizon of an acid Norfolk soil (pH 5.2). Both top and root growth of the indicator varieties supported the conclusion that aluminum toxicity is an important growth-limiting factor in the Norfolk soil studied. Leaf rolling observed in aluminum-sensitive 'Kearney' barley (but not in aluminum-tolerant 'Dayton') grown on the unlimed soil, was attributed to aluminum-induced calcium deficiency.

Additional key words: Calcium deficiency, Acid soils, Barley *(Hordeum vulgare, L., emend, Lam.)*, Snapbean *(Phaseolus vulgaris, L.)*, Shallow rooting.

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[2] Research Soil Scientists, Florence, S. C. and Beltsville, Md.

SHALLOW rooting of row crops is a serious problem in the Coastal Plains Region of the southeastern United States. Because of poor root development in the A_2 and deeper soil horizons, plants cannot effectively use profile-stored moisture and nutrients. Consequently, crop yields may be drastically reduced by relatively short dry periods, especially if they occur during the critical stage of plant growth. Limited root growth may be due to chemical and/or physical factors.

In strongly acid soils (below pH 5.5), Al toxicity is a primary suspect as a growth-limiting factor. However, not even water-soluble Al is a reliable guide in predicting the toxicity in a given soil. For example, Adams and Lund (1) found that the toxicity of a given level of soluble Al in displaced soil solutions is influenced by the total salt concentration. The toxicity of Al in various soils was more closely related to its molar activity than to its solubility.

Plant varieties within a species differ widely in their specific tolerance to Al (2, 3). Because the ultimate test of toxicity is plant growth, such varieties should be useful tools in determining potential Al toxicities in acid soils. The objective of this study was to use a plant indicator approach to test the hypothesis that Al toxicity is a growth-limiting factor in an acid Norfolk A_2 soil horizon.

EXPERIMENTAL PROCEDURE

The Norfolk soil (A_2 horizon) used in this study had the following characteristics: pH 5.2, 0.13% organic matter, ammonium acetate cation exchange capacity (CEC) of 0.92 meq/100 g, and 0.38 and 0.14 meq of exchangeable Ca and Al per 100 g, respectively. Exchangeable Ca was displaced with 1 *N* ammonium acetate at pH 7.0 and determined in the filtrate by atomic absorption spectrophotometry. Exchangeable Al was displaced with 1 *N* KCl and determined colorimetrically.

In the fall of 1967 the surface soil (Ap horizon, 20 cm deep) was removed from the experimental area, and Al-tolerant 'Dayton' and Al-sensitive 'Kearney' barley varieties (3) were planted in prepared seedbeds of the limed and unlimed A_2 horizon. The limed plots received dolomitic limestone at the rate of 2,242 kg/ha (2,000 lb/acre). The barley was fertilized with 4-12-12 at 1,121 kg/ha (1,000 lb/acre), applied broadcast and incorporated with a rotary tiller prior to planting. The crop was also sidedressed with ammonium nitrate at a N rate of 112 kg/ha (100 lb/acre). In the spring of 1968 the barley was harvested in the milk stage, and selected leaf samples were dry ashed and analyzed for Ca, P, Cu, and Mn. Pegboard root samples (46 cm deep, 61 cm wide, and 18 cm thick) were taken from the barley planting to observe root density and distribution. After spring harvest of barley, the same limed and unlimed plots were fertilized with a second application of 4-12-12 at 1,121 kg/ha (1,000 lb/acre) and planted to Al-tolerant 'Dade' and Al-sensitive 'Romano' snapbean varieties (2). Snapbean plants were harvested at the early bloom stage.

RESULTS AND DISCUSSION

Forage yields of the two differentially Al-tolerant barley varieties grown on the Norfolk soil with and without lime are shown in Table 1. With no lime (soil pH 5.2) the Al-sensitive Kearney variety yielded significantly less than the Al-tolerant Dayton variety,

Table 1. Forage yields of two barley varieties and two snapbean varieties on the A_2 horizon of a Norfolk soil at different pH levels.

Barley variety	Forage yield, dry wt, kg/ha		Snapbean variety	Forage yield, dry wt, kg/ha	
	pH 5.2	pH 5.9		pH 4.8	pH 6.1
Dayton (Al-tolerant)	3,860	7,380	Dade (Al-tolerant)	3,830	9,350
Kearney (Al-sensitive)	1,730	6,460	Romano (Al-sensitive)	540	9,460
Diff.	2,130*	920ns		3,290*	-110ns

* Significant at 5% level.

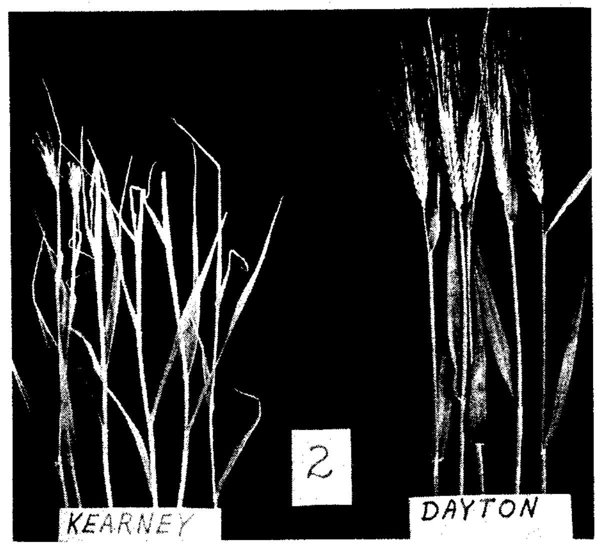

Fig. 1. Leaf roll symptoms in Al-sensitive Kearney barley (left) but none in Al-tolerant Dayton barley (right) grown on the unlimed A_2 horizon of a Norfolk soil at pH 5.2.

but with lime added (soil pH 5.9), forage yields of the two varieties were not significantly different. Soil pH values were determined in a 1:1 soil to water suspension at the time of harvest. Pegboard samples of the Al-sensitive Kearney root system showed that with no lime the roots were sparse, brown, and had a general unthrifty appearance. With lime added the Kearney roots were extensive, yellow to white, had an overall healthy appearance, and were essentially equal in growth to those of the Al-tolerant Dayton variety which showed very little lime response. Thus, both top and root growth of these two differentially Al-tolerant barley varieties strongly suggest Al toxicity as a growth-limiting factor.

Forage yield data for Dade and Romano snapbean varieties on this Norfolk soil also support the Al toxicity hypothesis (Table 1). On the unlimed soil (pH 4.8) the Al-sensitive Romano variety yielded significantly less than the Al-tolerant Dade variety, but on the limed plots (pH 6.1) the yields of the two varieties were essentially the same. Soil pH values were determined at the time of harvest.

Previous studies have shown that one characteristic of Al toxicity in barley is a marked interference in Ca uptake and translocation to plant tops (3). In the unlimed soil the Al-sensitive Kearney barley developed Ca-deficiency symptoms (rolling and eventual collapse of youngest leaves), but none appeared in Al-tolerant Dayton when the two varieties were grown side by side in 30-inch rows (Fig. 1). Liming the soil to pH 5.9 prevented the symptoms in the Kearney variety. The Ca concentration in the rolled leaves of Kearney (0.17%) was only about one-half that in the unrolled leaves (0.28%), indicating a true Ca deficiency in the affected leaves. The Ca concentration in the Dayton leaves (0.69%) was more than double that in the unrolled leaves of Kearney.

Absolute Ca deficiency is not considered a growth-limiting factor in this soil for several reasons. First, the exchangeable Ca in the unfertilized soil represented 40% of the CEC. Coastal Plain soils with much lower Ca saturations normally supply adequate Ca for plant growth. For example, Howard and Adams (4) reported that a Norfolk subsoil having a pH of 5.0 and a Ca saturation of only 12% contained sufficient Ca for the growth of primary cotton roots. The Ca requirement of barley is probably lower, or certainly no higher, than that of cotton. Secondly, 46 ppm Ca were added to the soil in the 4-12-12 fertilizer. Thirdly, only the Al-sensitive variety showed Ca deficiency symptoms. Leaf rolling in the Kearney variety was not associated with excesses or deficiencies of P, Cu, or Mn in the affected tissues.

Adams and Lund (1) reported that the critical KCl-extractable Al level for primary cotton root penetration in a Norfolk subsoil was about 0.10 meq/100 g, representing 2.7% of the NH_4OAc CEC value. Both cotton and barley are classified as Al-sensitive species, so this evidence for cotton is pertinent.

The Norfolk soil used in our experiment contained 0.14 meq of KCl-extractable Al/100 g, representing 15.2% of the NH_4OAc CEC value. Therefore, the Ca and Al evidence indicates that the Norfolk soil we used contained sufficient Ca to reduce the likelihood of Ca deficiency, *per se*, and sufficient Al to cause toxicity in Al-sensitive plants. The Ca deficiency observed in the Kearney barley variety apparently was induced by Al.

Results of these studies, based on the growth of indicator plants known to differ widely in Al tolerance, plus soil chemical evidence suggest that Al toxicity is a primary growth-limiting factor for some plants in the acid Norfolk soil (A_2 horizon) studied.

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