DRY MATTER PRODUCTION AND LEAF ELEMENTAL CONCENTRATIONS OF COMMON BEAN GROWN ON AN ACID ULTISOL

R. Goenaga *; J. R. Smith *

* USDA-ARS, Tropical Agriculture Research Station, Mayaguez, Puerto Rico, U.S.A.

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Tolerance to soil aluminum (Al) differs greatly among grain legume species. However, there is insufficient information on the response of common bean (*Phaseolus vulgaris* L.) to Al stress under field conditions. A 2-yr field study was conducted to determine the effects of various levels of soil Al on dry matter production and mineral concentration in the leaves of five genotypes of common beans. Increasing the concentration of soil Al caused a significant decline in total, stem, pod, and grain dry weights in all genotypes. Increasing soil Al concentration from 0.68 cmol kg\(^{-1}\) to just 2.5 cmol kg\(^{-1}\) reduced the total dry weight of all genotypes between 25% and 31%. Increments in soil Al concentration up to 8 cmol kg\(^{-1}\) caused an increase in leaf potassium (K) and zinc (Zn) and an increase in nitrogen (N), iron (Fe), and Al. Leaf potassium (K) and zinc (Zn) increased up to a soil Al concentration of about 8 cmol kg\(^{-1}\) and then declined sharply. The results of this study demonstrate genotypic
differences for dry matter production in both dry beans and snap beans grown under Al stress. However, these differences may be of little practical value under the field conditions normally encountered in the humid tropics where the amounts of soil Al cause large reductions in yields.

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is grown extensively in most regions of the world and is an important source of dietary protein, vitamins, nutrients, and fiber (1,2). In 1999, worldwide production of common bean was 19,392,805 metric tons harvested in an area of 26,603,432 hectares (3). Worldwide increases in bean production have been insufficient to counter the continued rise in world population (1). Today, more people from under-developed countries are relying on beans to satisfy their basic nutritional needs, while more people from developed countries are increasing their intake of beans to increase the quality of their diets.

The most productive soils of the world are already under cultivation, and those available for agricultural expansion, particularly in Latin America and Africa, are often strongly acid, possessing toxic levels of soil Al saturation (4). In the tropical Americas, about 50% of the soils with potential for agricultural use have been diagnosed with Al toxicity problems (5). High Al subsoils are also a problem in the Southeastern United States (6).

The mechanism by which soil acidity reduces the yield of many crops has been studied extensively (7). Few studies have been conducted to screen common bean germplasm for acid soil tolerance under field conditions. Abruña et al. (8) found that yield of cultivar “Bonita” decreased to about 50% of maximum when the percent soil Al saturation was 50%. Under greenhouse conditions, Foy et al. (9) found that certain varieties of snap beans differed significantly in their tolerance to soil acidity when they were grown on a soil containing 5.6 cmol·kg⁻¹ Al.

The objectives of this investigation were to determine the critical soil Al concentrations that affect growth of *Phaseolus vulgaris* germplasm under field conditions and to identify potential sources of tolerance to this stress. The study is part of an effort designed to identify genetic markers with the potential for increasing selection efficiency and aiding in the release of Al-tolerant dry bean and snap bean germplasm.

MATERIALS AND METHODS

Field experiments were established 12 February 1998 and 4 February 1999 at the Corozal Research Station of the University of Puerto Rico. The study was
conducted on a deep, well-drained Ultisol in 3.65 × 3.65 m plots arranged in a randomized complete block design. The thirty plots used in the study differed in soil acidity because of differential applications of calcitic limestone over a period of years prior to these experiments. The soil in all plots was sampled before planting by taking 10 borings at a depth of 0–15 cm from each plot. The samples were air-dried and passed through a 20-mesh screen. Soil pH in water and 0.01 M CaCl₂ (1:2 soil:water) were measured with a glass electrode. K-Cl extractable Al was determined using an atomic absorption spectrophotometer, and exchangeable cations, extracted with neutral 1M NH₄OAc, were similarly determined.

All plots were planted to snap bean cultivars ‘Contender’ and ‘Tendercrop’ and dry bean lines ‘G18252,’ ‘XAN 201,’ and ‘BAT 477’. Contender and G18252 are considered to be Al-tolerant while XAN 201 and Tendercrop as Al-sensitive genotypes [(9) and unpublished data of the authors]. BAT 477 is considered to be as efficient in P uptake (10). To our knowledge, these genotypes have never been field-tested under a wide range of soil Al concentrations which, in this study, ranged from 0.6 to 16 cmol kg⁻¹. The pH_H₂O in these plots ranged from 5.18 to 3.76. Guard rows of cultivar ‘Dorado’ surrounded each plot. Rows were 56.0 cm apart with plants 10.2 cm apart within the row. Plants in each row were side-dressed with a 16–1.7–3.3 (N–P–K) commercial mixture applied at a rate of 753 kg ha⁻¹ two weeks after planting.

Number of trifoliates and plant height (distance from ground level to end of longest stem) for each cultivar or line were determined each year at 45 days after planting (DAP). At this time, the third trifoliate was also taken from plants, washed with distilled water, and dried to constant weight at 70°C. The dry samples were ground to pass a 1.0-mesh screen and analyzed for N, P, K, Ca, Mg, Fe, Al, and Zn. Nitrogen was determined by the micro-Kjeldahl procedure (11), P by the molybdovanado-phosphoric acid method (11), and K, Ca, Mg, Fe, Al, and Zn by atomic absorption spectrometry (12).

Pods were harvested gradually in both years as they became fully matured. Once all pods were harvested, plants were pulled from the soil, washed, and separated into stems, pods, and seed. There were no trifoliates present on plants at this stage. Plant parts were dried at 70°C to constant weight for dry matter determination. Regression analyses were determined using the GLM procedure of the SAS program package (13). Only coefficients at p ≤ 0.05 were retained in the models.

RESULTS AND DISCUSSION

Dry Matter Production

Differences among soil Al treatments and genotypes were highly significant (p < 0.01) for total, stem, pod, and grain dry weight measured at the end of the
Increasing the concentration of soil Al caused a significant decline in total dry weight in all genotypes (Fig. 1A). Dry bean genotypes G18252, BAT 477, and XAN 201 showed significantly higher total dry weight than snap bean genotypes Tendercrop and Contender. The highest total dry weight (271 g m\(^{-2}\)) was obtained by genotype G18252 at a soil Al concentration of 0.68 cmol kg\(^{-1}\) (pH\(_{\text{CaCl}_2}\) = 4.5; pH\(_{\text{H}_2\text{O}}\) = 5.2). The lowest (116 g m\(^{-2}\)) total dry weight at this low Al concentration was obtained by genotype Tendercrop (Fig. 1A).

Increasing soil Al concentration from 0.68 cmol kg\(^{-1}\) to 2.5 cmol kg\(^{-1}\) (pH\(_{\text{CaCl}_2}\) = 4.3; pH\(_{\text{H}_2\text{O}}\) = 4.8) reduced the total dry weight of all genotypes between 25% and 31%. When the soil Al concentration was doubled to 5.4 cmol kg\(^{-1}\) (pH\(_{\text{CaCl}_2}\) = 3.9; pH\(_{\text{H}_2\text{O}}\) = 4.5), total dry weight of genotypes declined by an average of 63%. Total dry matter production of snapbeans Tendercrop and Contender did not differ by more than 10% when the concentration of soil Al ranged from 0.68 to 2.5 cmol kg\(^{-1}\). However, a higher Al concentration caused a greater decline in total dry matter production in Tendercrop than in Contender. A similar response was obtained by Foy et al. (9) who found Contender to be more Al-tolerant than Tendercrop. Still, both genotypes are severely affected by soil Al concentration exceeding 2.5 cmol kg\(^{-1}\), a relatively low concentration in soils of the humid tropics. Therefore, the greater total dry matter production of Contender over Tendercrop at low Al concentrations may be of little value under the higher soil Al concentrations found in the humid tropics (4).

At soil Al concentrations of 0.68, 2.5, and 5.4 cmol kg\(^{-1}\), stem, pod, and grain dry weights accounted for 15–20%, 18–21%, and 60–66%, respectively, of the total dry weight of each genotype. However, genotypes Contender and BAT 477 allocated more dry matter toward grains (66%) and less toward stems (15%) (Figs. 1A–D). The highest grain yield (172 g m\(^{-2}\)) among dry bean genotypes was obtained by G18252 when grown at a soil Al concentration of 0.68 cmol kg\(^{-1}\). At this soil Al level, G18252 outyielded BAT 477 and XAN 201 by 10% and 19%, respectively. At a soil Al concentration of 5.4 cmol kg\(^{-1}\), grain yield of G18252 was reduced to 73 g m\(^{-2}\). However, this yield was still 24% and 27% higher than that obtained by genotypes BAT 477 and XAN 201. Among snap beans, Contender attained a higher grain yield (82 g m\(^{-2}\)) than Tendercrop (70 g m\(^{-2}\)) when grown at a soil Al concentration of 0.68 cmol kg\(^{-1}\). Grain yield of Contender at soil Al levels of 2.5 and 5.4 cmol kg\(^{-1}\) was 59 g m\(^{-2}\) and 30 g m\(^{-2}\), respectively. These yields were 19% and 26% higher than those attained by Tendercrop at the above soil Al concentrations (Fig. 1B).

The average number of trifoliates among dry bean genotypes grown at a soil Al concentration of 0.68 cmol kg\(^{-1}\) was 7.0 leaves m\(^{-2}\) (Fig. 2A). However, when genotypes XAN 201 and BAT 477 were grown at a soil Al concentration of...
Figure 1. Dry weight of plant organs of five dry bean genotypes as influenced by soil aluminum.
2.5 and 5.4 cmol kg\(^{-1}\), the number of trifoliates was reduced in both by 22% and 50%, respectively. Plants of genotype G18252 grown at soil Al levels of 2.5 and 5.4 cmol kg\(^{-1}\) had a reduction in the number of trifoliates of 13% and 34%, respectively. The greater number of trifoliates in plants of G18252 probably explains the higher yields obtained by this genotype. The number of trifoliates in snap beans Contender and Tendercrop grown at 0.68 cmol kg\(^{-1}\) was 4.6 and 4.4 leaves m\(^{-2}\), respectively. However, at a soil Al concentration of 5.4 cmol kg\(^{-1}\), plants of genotypes Tendercrop and Contender had a decline in the number of trifoliates of 42% and 30%, respectively. Increases in soil Al significantly reduced plant height of all genotypes (Fig. 2B). Among dry beans, plants of G18252 grew taller than XAN 201 and BAT 477 at levels of soil aluminum above 2.0 cmol kg\(^{-1}\). Among snap beans, plants of Contender grew taller than those of Tendercrop.

**Figure 2.** Number of trifoliates (A) and plant height (B) of five dry bean genotypes as influenced by soil aluminum. All symbols as in Figure 1; BA, BAT477; CO, Contender; G1, G18252; TE; Tendercrop; XA, XAN 201.
Leaf Nutrient Concentration

Figures 3A–H shows the concentration of various nutrients in trifoliates collected from each genotype at 45 DAP. In general, increments in soil Al resulted in a significant increase in leaf N (Fig. 3A). In genotypes Tendercrop and XAN 201 leaf N increased until a soil Al concentration of about 8 cmol kg$^{-1}$ and then declined. Leaf N in genotypes BAT 477 and G18252 grown at a soil Al concentration of 16 cmol kg$^{-1}$ was 40% and 25% greater, respectively, than when grown at a concentration of 0.68 cmol kg$^{-1}$. The increase in leaf N with increments in soil Al was unexpected since it is known that high levels of soil Al represent a limiting factor for root growth as well as for nodulation and N fixation (14). Increased leaf N concentration in young trifoliates at high soil Al may be explained in part by an induction of premature senescence of older trifoliates, increased proteolytic activity and, hence, remobilization of soluble N from older to younger leaves.

As expected, increments in soil Al resulted in significant reductions in the concentration of leaf P, Ca, and Mg (Figs. 3B, D, and E). Adaptation of crops to acid soils requires highly efficient uptake and utilization of these nutrients (14). Only genotype Contender showed higher value of leaf Ca and this response was only apparent at low soil Al concentration (Fig. 3D).

In general, leaf K increased and then declined rapidly with increases in soil Al (Fig. 3C). An exception was genotype Tendercrop in which leaf K declined sharply as soil Al increased. In sorghum, Al toxicity has been associated with increased concentration of K in plant tops (15). As with K, leaf Zn increased with increases in soil Al and then declined (Fig. 3G). Significantly higher leaf Zn concentration was attained by G18252. Even at a soil Al concentration of 8.0 cmol kg$^{-1}$, the concentration of this nutrient was 20% higher than the average for the other genotypes. Increments in soil Al resulted in significant increases in leaf Fe and Al (Figs. 3F and H). Genotypes Tendercrop and Contender showed significantly higher concentrations of these nutrients at all soil Al levels.

CONCLUSIONS

The results of this study demonstrate genotypic differences for dry matter production in both dry beans and snapbeans grown under Al stress. However, these differences may be of little practical value under the conditions normally encountered in the humid tropics where the amounts of soil Al cause large reductions in yield. This was the case even in genotypes Contender and G18252, which presumably have some degree of tolerance to Al. It is noteworthy, however, that leaf concentrations of P, K, Mg, and Zn increased until soil Al reached about 8 cmol kg$^{-1}$. However, leaf Ca declined sharply at low soil Al concentrations.
Figure 3. Leaf nutrient concentration of five dry bean genotypes as influenced by soil aluminum. Absence of a genotype denotes lack of a significant response. All symbols and abbreviations as in Figures 1 and 2.
Perhaps future studies should be directed toward the identification of Ca-efficient genotypes as a mean to find Al-tolerant genotypes. The authors are presently screening approximately 100 common bean genotypes in a continued effort to identify Al-tolerant germplasm for this important crop.

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REFERENCES


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