

Screening of tropically adapted genotypes of soybean (*Glycine max* (L.) Merrill) for aluminium stress tolerance in short-term hydroponics

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Keywords: aluminium activity, aluminium stress tolerance, nutrient solution, Tropically adapted genotypes

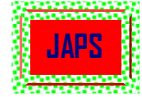
1 SUMMMARY

The screening of genotypes is a prerequisite for the identification of aluminium tolerant varieties. Four (4) levels of aluminium activity (0, 5, 50 and 300 μ MAI³⁺) were used to screen forty nine (49) genotypes of soybean in hydroponics at the Crop Science Laboratory of the University of Agriculture, Makurdi, Nigeria, with the objective of identifying aluminium tolerant genotypes. The four levels of aluminium activity constituted the main plots while the 49 soybean genotypes constituted the subplots in a split-plot design, with three replications. The soybean seedlings were germinated for 4 days and transferred to nutrient solutions containing the various levels of aluminium activity. The seedlings grew for 3 days (3D) in hydroponics, and data were taken on the primary root length, root dry weight, and shoot dry weight. Highly significant Al, genotype and Al x genotype effects were observed for all the traits studied. Four genotypes, namely TGX 1896–3F, TGX 1844–18E, TGX 1873–16E and TGX 1878–7E were identified as aluminium stress tolerant in hydroponics and recommended for field trial on acid soils of Nigeria.

2 INTRODUCTION

Aluminium is the third most abundant element in the earth crust and a major phytotoxic element in acid soils (Kochian, 1995). Toxic aluminium levels retard root growth causing various root deformations, and discolouration, that ultimately result in low grain yield in acid soils (Blum, 1986; Villagarcia, 2001). Liming has been used to ameliorate the problem of aluminium toxicity/low pH in soils. Liming the top soil however, remains a temporary solution due to subsoil acidity. Restriction in root growth due to subsoil acidity reduces plant nutrient acquisition and access to subsoil water, which culminates in the reduction of crop yield (Ferrufino *et al.*, 2000). Moreover, the cost of liming particularly in developing countries like Nigeria is high and does not justify such a huge investment given the return is low from grain

yield of soybeans. The development of aluminium tolerant cultivars of soybeans therefore remains a viable alternative. Various screening methodologies ranging from hydroponics, sand culture, to pot/field experiments at different stages of plant growth have been adopted in searching for aluminium tolerant genotypes of soybean (Campbell and Carter, 1990; Carter and Rufty, 1993; Spehar, 1994; Bianchi-Hall *et al.*, 1998; Bianchi-Hall *et al.*, 2000; Silva *et al.*, 2001; Villagarcia *et al.*, 2001). However, hydroponics screening has advantages of close observation of the roots as the experiment progresses and it can be regulated and reproduced. Hence, hydroponics has been used in the rapid screening of large numbers of germplasm and identification of



parental stock for soybean breeding (Villagarcia *et al.*, 2001).

The appropriate characterization of soybean genotypes for aluminium stress tolerance has often been compounded by limited published and often contradictory data (Villagarcia *et al.* 2001), and therefore remains a problem in breeding for aluminium stress tolerance. Previous effort at rating of soybean for aluminium stress tolerance in Nigeria have been concentrated on adaptive studies on the acid soils of South-East and South-South Nigeria

(Okpara and Ibiam, 2000; Yusuf and Idowu, 2001; Okpara *et al.*, 2002; Osedeke and Ojeniyi, 2003 and 2005) with inconsistent findings. There is therefore the need to generate reliable and reproducible information on the aluminium stress tolerance rating of tropically adapted varieties of soybean prior to any field trial.

The objective of the research therefore, was to identify aluminium tolerant tropically adapted genotypes of soybean in hydroponics that could be selected for field trials on acid soils of Nigeria.

3 MATERIALS AND METHODS

Four levels of aluminium activity (0, 5, 50 and $300\mu\text{MAl}^{3+}$) were used to screen forty-nine (49) IITA released TGX varieties of soybean for aluminium stress tolerance in hydroponics in 2004. The four levels of aluminium activity were arrived at after a preliminary screening through ten levels of aluminium activity in 2002 (Ojo, 2010; Ojo and Bello, 2010). The four levels of aluminium activity constituted the main plots in a split-plot design, while the forty-nine genotypes constituted the sub-plots. The 49 varieties included the six (TGX 923-2E, TGX 1740-2E, TGX 1805-31F, TGX 1802-1F, TGX 1485-1D, and TGX 1440- 1E) that were reported in previous adaptability studies in Nigeria (Okpara and Ibiam, 2000; Yusuf and Idowu, 2001) and the most popular genotype (TGX 1448-2E) currently in production in the major soybean producing areas of Nigeria. The Experiment was replicated three times. The experiment commenced on the 8th January 2004 and lasted until 18th March 2004. The experiment was conducted on the laboratory tables in the Crop Science Laboratory of the University of Agriculture, Makurdi, Nigeria. Seeds of the 49 genotypes were surface sterilized with ethanol for 1 minute and then with sodium hypochlorite for 3 minutes and rinsed 6 times with deionised water (Ramirez *et al.* 1997), prior to germination. Petri dishes were similarly sterilized. Thereafter, cotton wool was soaked with deionised water in Petri dishes and the seeds were placed on them for

germination. After four days, seedlings with poor vigour and twisted radicles were discarded, while ten vigorous healthy seedlings of each genotype were transferred to each of the continuously bubbling hydroponics tanks, fitted with aerators. Each tank was a 5-litre capacity plastic tank of 20cm diameter covered with a removable plastic lid. Each lid had holes of 0.6cm diameter in which single seedlings were fitted and held in place with cotton wool. The nutrient solution culture was composed following the procedures of Howell and Bernard (1961) with some modification (Table 1).

Each tank was filled with 3 litres of deionised water, and nutrients required for 5 litres were weighed and dissolved in it. The pH of the nutrient solution was then adjusted to 4.05 ± 0.05 by adding a few drops of concentrated sulphuric acid. The desired aluminium activity for each tank was prepared separately in one litre of deionised water adjusted to pH of 4.05 ± 0.05 . Thereafter, the one litre aluminium solution was poured into the nutrient solution, and the solution made up to 5-litre mark with deionised water ($\text{pH } 4.05\pm 0.05$). Aluminium treatments were in the form of $\text{Al}_2(\text{SO}_4)_3$. Aerators were then connected to the tank and the solution allowed to bubble continuously for two hours before transferring seedlings to it.

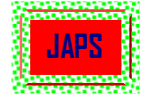


Table 1: Composition of nutrients in hydroponics

| Chemical | Concentration |
|---|-------------------------|
| KH_2PO_4 | 0.5mM L^{-1} |
| KCl | 0.5mM L^{-1} |
| $\text{NaH}_2\text{PO}_4 \cdot 2\text{H}_2\text{O}$ | 1.0mM L^{-1} |
| NH_4NO_3 | 0.8mM L^{-1} |
| $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ | 1.5mM L^{-1} |
| MgSO_4 | 1.00mM L^{-1} |
| $\text{Fe}(\text{NO}_3)_2$ | $80\mu\text{M L}^{-1}$ |
| H_3BO_3 | $20\mu\text{M L}^{-1}$ |
| $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ | $3\mu\text{M L}^{-1}$ |
| $\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$ | $3\mu\text{M L}^{-1}$ |
| $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ | $3\mu\text{M L}^{-1}$ |
| $(\text{NH}_4)_6\text{M}_{07}\text{O}_{24} \cdot 4\text{H}_2\text{O}$ | $0.8\mu\text{M L}^{-1}$ |

mM L^{-1} = Millimole per litre $\mu\text{M L}^{-1}$ = Micromole per litre The various levels of Al^{3+} were supplied in the form of $\text{Al}_2(\text{SO}_4)_3$. Adapted from Howell and Bernard (1961)

Each tank was filled with 3 litres of deionised water, and nutrients required for 5 litres were weighed and dissolved in it. The pH of the nutrient solution was then adjusted to 4.05 ± 0.05 by adding a few drops of concentrated sulphuric acid. The desired aluminium activity for each tank was prepared separately in one litre of deionised water adjusted to pH of 4.05 ± 0.05 . Thereafter, the one litre aluminium solution was poured into the nutrient solution, and the solution made up to 5-litre mark with deionised water (pH 4.05 ± 0.05). Aluminium treatments were in the form of $\text{Al}_2(\text{SO}_4)_3$. Aerators were then connected to the tank and the solution allowed to bubble continuously for two hours before

transferring seedlings to it. Seedlings grew for three days (3D) in the nutrient solution and were harvested at the age of seven days. On harvesting, five seedlings were randomly picked from each tank, and data taken on primary root length, root dry weight and shoot dry weight. Primary root length was defined as the distance from the root tip to the junction region between the root and the hypocotyls (Bianchi-Hall *et al.*, 1998). Roots and shoots were separated, air dried for three hours, and then oven dried at 70°C for 48 hours before taking their respective weights. The data were subjected to analysis of variance by the General Linear Model (GLM) and the Analysis of variance (ANOVA) procedures of SAS (1990).

4 RESULTS

Mean squares for primary root length, root dry weight and shoot dry weight are summarized in Table 2. Aluminium levels showed highly significant effects on the primary root length, root dry weight and shoot dry weight. Highly significant differences were observed between the control ($0\mu\text{MAl}^{3+}$) and the three levels of aluminium treatment (5, 50, & $300\mu\text{MAl}^{3+}$) for

the primary root length, root dry weight and shoot dry weight. Aluminium activity at $5\mu\text{MAl}^{3+}$ was highly significantly different from the $50\mu\text{MAl}^{3+}/300\mu\text{MAl}^{3+}$ levels for all the three traits. Highly significant differences were also observed between the $50\mu\text{MAl}^{3+}$ and the $300\mu\text{MAl}^{3+}$ levels of aluminium activity for the three traits.

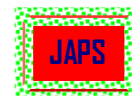


Table 2: Mean squares for root and shoot traits of 49 soybean genotypes grown at 4 levels of aluminium activity (0, 5, 50, & 300 μ MAI³⁺) in hydroponics for 3 days (3D)

| Source of Variation | Df | Primary root Length (cm) | Root dry weight (g) | Shoot dry weight (g) |
|------------------------|-----|--------------------------|---------------------|----------------------|
| Reps | 2 | 0.3354 | 0.000001 | 0.0002 |
| Aluminium (Al) | 3 | 928.6982** | 0.00203** | 0.010267** |
| 0Al Vs Others | 1 | 1393.0473** | 0.00554** | 0.0154** |
| 5Al Vs 50/300Al | 1 | 835.8284** | 0.00033** | 0.009255** |
| 50Al Vs 300Al | 1 | 557.2189** | 0.00022** | 0.00615** |
| Genotype (Gen.) | 48 | 41.05115** | 0.000045** | 0.00165** |
| Gen. X Al | 144 | 7.36715** | 0.00005** | 0.0007** |
| Gen. X 0Al Vs Others | 48 | 11.0507** | 0.000025** | 0.00105** |
| Gen. X 5Al Vs 50/300Al | 48 | 6.63045** | 0.000015** | 0.00065** |
| Gen. X 50Al Vs 300Al | 48 | 4.4203** | 0.00001** | 0.0004** |
| Error | 390 | 0.30645 | 0.000001 | 0.0002 |

Significant at $P < 0.05$ and $P < 0.01$ level respectively, 0Al = 0μ MAI³⁺ 5Al = 5μ MAI³⁺ 50Al = 50μ MAI³⁺ 300Al = 300μ MAI³⁺

Genotypic effects and the genotype \times aluminium interaction were highly significant for all the traits. The genotype \times 0μ MAI³⁺ versus others, genotype \times 5μ MAI³⁺ Vs $50/300\mu$ MAI³⁺ and genotype \times 50μ MAI³⁺ Vs

300μ MAI³⁺ interaction effects were highly significant for all the three traits studied. Primary root length growth inhibition increased as aluminium activity increases for most of the genotypes (Table 3).

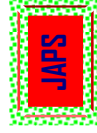


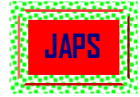
Table 3: Character means and coefficients of variation for root and shoot traits of 49 soybean genotypes grown at 4 levels of aluminium activity (0, 5, 50, & 300 μMAl^{3+}) in hydroponics for 3 days (3D)

| GENOTYPE | Primary Root Length (cm) | | | | Root Dry Weight (g) | | | | Shoot Dry Weight (g) | | | |
|---------------|--------------------------|--------|-------|-------|---------------------|-------|-------|-------|----------------------|-------|-------|-------|
| | 0 | 5 | 50 | 300 | 0 | 5 | 50 | 300 | 0 | 5 | 50 | 300 |
| TGX 1740-2E | 6.583 | 3.167 | 2.667 | 2.017 | 0.019 | 0.011 | 0.010 | 0.009 | 0.153 | 0.058 | 0.048 | 0.046 |
| TGX 1897-17F | 9.250 | 4.117 | 2.500 | 2.308 | 0.018 | 0.013 | 0.009 | 0.007 | 0.132 | 0.061 | 0.051 | 0.048 |
| TGX 1485-1D | 10.700 | 4.350 | 2.617 | 2.517 | 0.018 | 0.012 | 0.011 | 0.009 | 0.130 | 0.061 | 0.051 | 0.048 |
| TGX 1805-8F | 7.083 | 5.000 | 2.133 | 2.083 | 0.019 | 0.014 | 0.008 | 0.008 | 0.115 | 0.059 | 0.049 | 0.048 |
| TGX 1830-20E | 2.733 | 2.833 | 2.300 | 2.208 | 0.013 | 0.012 | 0.009 | 0.008 | 0.123 | 0.058 | 0.048 | 0.048 |
| TGX 1835-10E | 10.083 | 9.017 | 2.608 | 2.583 | 0.017 | 0.013 | 0.009 | 0.008 | 0.123 | 0.057 | 0.046 | 0.045 |
| TGX 1876-4E | 8.417 | 5.500 | 2.200 | 2.117 | 0.018 | 0.016 | 0.009 | 0.008 | 0.131 | 0.061 | 0.051 | 0.049 |
| TGX 1895-33F | 6.167 | 3.300 | 2.483 | 2.408 | 0.019 | 0.011 | 0.009 | 0.008 | 0.114 | 0.060 | 0.050 | 0.050 |
| TGX 1831-32E | 9.667 | 8.050 | 2.517 | 2.400 | 0.024 | 0.012 | 0.008 | 0.008 | 0.141 | 0.056 | 0.049 | 0.048 |
| TGX 1871-12E | 10.667 | 6.833 | 2.517 | 2.508 | 0.027 | 0.014 | 0.008 | 0.008 | 0.114 | 0.062 | 0.056 | 0.055 |
| TGX 1895-23F | 7.667 | 4.683 | 2.717 | 2.617 | 0.018 | 0.013 | 0.008 | 0.008 | 0.127 | 0.056 | 0.048 | 0.048 |
| TGX 1892 -10F | 6.500 | 6.133 | 2.717 | 2.692 | 0.020 | 0.015 | 0.008 | 0.008 | 0.124 | 0.065 | 0.057 | 0.056 |
| TGX 1895-19F | 8.083 | 6.833 | 2.800 | 2.717 | 0.025 | 0.014 | 0.009 | 0.009 | 0.110 | 0.054 | 0.046 | 0.045 |
| TGX 1895-49F | 9.667 | 3.967 | 2.517 | 2.500 | 0.021 | 0.012 | 0.009 | 0.008 | 0.151 | 0.056 | 0.046 | 0.045 |
| TGX 1895-22F | 6.167 | 2.683 | 2.517 | 2.408 | 0.018 | 0.011 | 0.009 | 0.008 | 0.141 | 0.059 | 0.050 | 0.049 |
| TGX 1805-31F | 9.333 | 5.100 | 4.767 | 3.133 | 0.018 | 0.013 | 0.012 | 0.012 | 0.111 | 0.063 | 0.059 | 0.057 |
| TGX 1895-50F | 10.083 | 7.150 | 3.781 | 3.000 | 0.019 | 0.016 | 0.009 | 0.008 | 0.158 | 0.075 | 0.068 | 0.065 |
| TGX 1888-15F | 10.083 | 7.083 | 3.233 | 3.117 | 0.020 | 0.017 | 0.009 | 0.009 | 0.096 | 0.083 | 0.074 | 0.071 |
| TGX 1873-16E | 6.583 | 6.956 | 4.642 | 4.041 | 0.018 | 0.017 | 0.016 | 0.013 | 0.102 | 0.106 | 0.098 | 0.089 |
| TGX 1802-3F | 12.000 | 6.533 | 3.517 | 3.442 | 0.020 | 0.015 | 0.012 | 0.010 | 0.137 | 0.078 | 0.068 | 0.064 |
| TGX 1878-7E | 9.450 | 12.183 | 8.517 | 8.083 | 0.022 | 0.026 | 0.018 | 0.016 | 0.112 | 0.084 | 0.080 | 0.078 |
| TGX 1893-7F | 7.167 | 4.000 | 2.517 | 2.508 | 0.020 | 0.016 | 0.010 | 0.009 | 0.158 | 0.068 | 0.059 | 0.056 |
| TGX 1894-3F | 7.250 | 4.500 | 2.717 | 2.508 | 0.020 | 0.015 | 0.011 | 0.009 | 0.121 | 0.079 | 0.068 | 0.064 |
| TGX 1882-2F | 5.000 | 2.700 | 2.317 | 2.317 | 0.018 | 0.016 | 0.009 | 0.009 | 0.151 | 0.069 | 0.069 | 0.065 |
| TGX 1019-2EN | 7.667 | 6.167 | 3.517 | 3.117 | 0.020 | 0.013 | 0.009 | 0.008 | 0.140 | 0.083 | 0.075 | 0.073 |
| TGX 1890-7F | 9.833 | 4.450 | 3.617 | 3.608 | 0.021 | 0.015 | 0.010 | 0.009 | 0.130 | 0.066 | 0.058 | 0.055 |
| TGX 1802-1F | 13.250 | 5.417 | 3.000 | 2.908 | 0.023 | 0.012 | 0.009 | 0.008 | 0.101 | 0.051 | 0.044 | 0.040 |
| TGX 1886-33F | 6.833 | 5.333 | 2.817 | 2.808 | 0.020 | 0.015 | 0.011 | 0.009 | 0.161 | 0.059 | 0.049 | 0.045 |
| TGX 1869-31E | 7.500 | 5.133 | 3.108 | 3.000 | 0.017 | 0.016 | 0.009 | 0.009 | 0.151 | 0.080 | 0.072 | 0.070 |
| TGX 1880-3E | 7.667 | 6.200 | 3.583 | 3.508 | 0.020 | 0.017 | 0.009 | 0.009 | 0.137 | 0.077 | 0.070 | 0.065 |
| TGX 1891-3F | 10.583 | 5.000 | 3.633 | 3.492 | 0.026 | 0.015 | 0.009 | 0.006 | 0.162 | 0.094 | 0.088 | 0.086 |



| | | | | | | | | | | | | |
|--------------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| TGX 1893-10F | 7.833 | 4.967 | 3.517 | 3.400 | 0.021 | 0.017 | 0.012 | 0.011 | 0.111 | 0.077 | 0.075 | 0.073 |
| TGX 1842-1E | 8.850 | 6.167 | 3.717 | 2.417 | 0.012 | 0.013 | 0.012 | 0.011 | 0.084 | 0.087 | 0.076 | 0.073 |
| TGX 1838-5E | 11.167 | 9.500 | 7.133 | 7.083 | 0.025 | 0.012 | 0.012 | 0.008 | 0.135 | 0.063 | 0.053 | 0.049 |
| TGX 1893-6F | 10.167 | 9.167 | 3.617 | 3.608 | 0.020 | 0.018 | 0.011 | 0.009 | 0.120 | 0.081 | 0.073 | 0.073 |
| TGX 1896-3F | 9.583 | 14.330 | 9.617 | 9.181 | 0.020 | 0.026 | 0.020 | 0.014 | 0.105 | 0.094 | 0.093 | 0.092 |
| TGX 1869-13E | 7.417 | 4.500 | 3.817 | 3.608 | 0.020 | 0.017 | 0.013 | 0.011 | 0.124 | 0.077 | 0.067 | 0.064 |

| GENOTYPE | Primary Root Length (cm) | | | | Root Dry Weight (g) | | | | Shoot Dry Weight (g) | | | |
|--------------|--------------------------|--------|-------|-------|---------------------|-------|-------|-------|----------------------|-------|-------|-------|
| | 0 | 5 | 50 | 300 | 0 | 5 | 50 | 300 | 0 | 5 | 50 | 300 |
| TGX 1844-18E | 10.917 | 15.208 | 9.500 | 7.067 | 0.020 | 0.025 | 0.020 | 0.014 | 0.125 | 0.096 | 0.090 | 0.089 |
| TGX 1886-38F | 8.167 | 7.033 | 3.000 | 2.408 | 0.021 | 0.017 | 0.013 | 0.011 | 0.098 | 0.088 | 0.057 | 0.057 |
| TGX 1440-1E | 7.750 | 4.283 | 3.517 | 3.508 | 0.018 | 0.013 | 0.012 | 0.010 | 0.092 | 0.074 | 0.065 | 0.063 |
| TGX 1844-4E | 9.167 | 4.450 | 3.417 | 3.417 | 0.017 | 0.014 | 0.011 | 0.010 | 0.096 | 0.078 | 0.065 | 0.063 |
| TGX 1448-2E | 9.667 | 3.267 | 3.217 | 3.000 | 0.025 | 0.014 | 0.011 | 0.010 | 0.155 | 0.086 | 0.075 | 0.072 |
| TGX 1864-17F | 10.883 | 8.167 | 3.333 | 3.183 | 0.020 | 0.016 | 0.012 | 0.011 | 0.080 | 0.072 | 0.062 | 0.061 |
| TGX 1889-12F | 9.167 | 6.150 | 3.017 | 3.000 | 0.030 | 0.020 | 0.012 | 0.011 | 0.135 | 0.062 | 0.050 | 0.044 |
| TGX 1866-7F | 10.967 | 4.475 | 3.633 | 3.417 | 0.020 | 0.011 | 0.010 | 0.010 | 0.136 | 0.071 | 0.062 | 0.060 |
| TGX 1846-10E | 8.917 | 4.083 | 3.517 | 3.500 | 0.022 | 0.019 | 0.012 | 0.011 | 0.101 | 0.059 | 0.048 | 0.044 |
| TGX 1866-12F | 9.483 | 3.150 | 2.433 | 2.117 | 0.030 | 0.015 | 0.010 | 0.009 | 0.120 | 0.071 | 0.062 | 0.060 |
| TGX 1895-35F | 4.750 | 4.017 | 3.808 | 3.680 | 0.023 | 0.018 | 0.014 | 0.010 | 0.110 | 0.074 | 0.067 | 0.057 |
| TGX 923-2E | 14.500 | 5.017 | 4.517 | 4.080 | 0.020 | 0.018 | 0.012 | 0.011 | 0.120 | 0.046 | 0.040 | 0.035 |
| GRAND MEAN | 8.702 | 5.937 | 3.600 | 3.294 | 0.017 | 0.015 | 0.011 | 0.010 | 0.125 | 0.070 | 0.062 | 0.061 |
| LSD (0.05) | 0.850 | 0.460 | 0.320 | 0.280 | 0.002 | 0.001 | 0.001 | 0.001 | 0.004 | 0.004 | 0.004 | 0.010 |
| C.V. (%) | 6.000 | 4.800 | 5.500 | 5.200 | 6.800 | 3.600 | 5.600 | 4.900 | 2.000 | 3.500 | 3.800 | 10.1 |

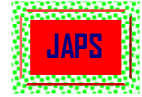


Primary root length in the control ($0\mu\text{MAI}^{3+}$) ranged from 2.733cm for TGX 1830-20E to 14.500cm for TGX 923-2E with 55.1% of the genotypes recording means higher than the population mean (8.702cm). Imposition of aluminium treatment at $5\mu\text{MAI}^{3+}$ aluminium activity inhibited growth in most of the genotypes with >60% of them recording lower primary root length than the population mean. The least growth in the primary root length (2.683cm) at the $5\mu\text{MAI}^{3+}$ aluminium activity was observed for TGX 1895-22F while the best growth (15.208cm) was observed for TGX 1844-18E. Primary root length growth at the $5\mu\text{MAI}^{3+}$ aluminium activity however, compares favourably with that of the control ($0\mu\text{MAI}^{3+}$) in many of the genotypes. Primary root length in fourteen genotypes was significantly different from population mean at the $5\mu\text{MAI}^{3+}$ level of activity with TGX 1873-16E, TGX 1878-7E, TGX 1896-3F, TGX 1830-20E, TGX 1844-18E, and TGX 1842-1E producing longer primary root lengths at $5\mu\text{MAI}^{3+}$ than in the control ($0\mu\text{MAI}^{3+}$). Primary root length of TGX 1896-3F at the $5\mu\text{MAI}^{3+}$ aluminium activity was 149.5% of its length in the control ($0\mu\text{MAI}^{3+}$). The $50\mu\text{MAI}^{3+}$ and the $300\mu\text{MAI}^{3+}$ levels of aluminium activity produced the greatest inhibition in the growth of the primary roots. Primary root length at these two levels of aluminium activity ranged between 2.000cm and <4.000cm in most of the genotypes with only 7 and 10 genotypes recording significantly longer lengths than population mean at the $50\mu\text{MAI}^{3+}$ and $300\mu\text{MAI}^{3+}$ levels of aluminium activity respectively. A few genotypes were however exceptional, experiencing little or no inhibition due to aluminium treatment at these levels (50 & $300\mu\text{MAI}^{3+}$). Primary root lengths of TGX 1896-3F, TGX 1844-18E, TGX 1873-16E, TGX 1878-7E and TGX 1895-35F at the $50\mu\text{MAI}^{3+}$ and $300\mu\text{MAI}^{3+}$ levels of aluminium activity were in the range of 70 – 100% of their respective control ($0\mu\text{MAI}^{3+}$) conditions. Coefficient of variations of 6.0%, 4.8%, 5.5% and 5.2% were observed for

primary root length at 0, 5, 50 and $300\mu\text{MAI}^{3+}$ levels of aluminium activity respectively.

A progressive decline in root dry weight was generally observed with increasing aluminium activity as the percentage of genotypic means higher than the population mean declined from 89.8% in the control to as low as 26.5% at the highest ($300\mu\text{MAI}^{3+}$) level of aluminium activity. Root dry weight ranged from 0.012g plant⁻¹ for TGX 1842-1E to 0.030g plant⁻¹ for TGX 1866-12F and TGX 1889-12F in the control. Four genotypes, namely, TGX 1740-2E, TGX 1895-33F, TGX 1895-22F and TGX 1866-7F maintained the least root dry weight of 0.011g plant⁻¹ while TGX 1896-3F and TGX 1878-7E maintained the highest weight of 0.026g plant⁻¹ at the $5\mu\text{MAI}^{3+}$ level of aluminium activity. Root dry matter accumulation at the $5\mu\text{MAI}^{3+}$ level of aluminium activity was the same or higher than that of the control ($0\mu\text{MAI}^{3+}$) for some genotypes, namely TGX 1805-31F, TGX 1873-16E, TGX 1878-7E, TGX 1842-1E and TGX 1896-3F. Root dry matter accumulation in TGX 1873-16E, TGX 1878-7E, TGX 1838-5E, TGX 1844-18E and TGX 1896-3F at the $50\mu\text{MAI}^{3+}$ and $300\mu\text{MAI}^{3+}$ levels of aluminium activity was also significantly higher than their respective population means. The C.V. for root dry weight at 0, 5, 50 and $300\mu\text{MAI}^{3+}$ levels of activity were 6.8%, 3.6%, 5.6% and 4.9% respectively.

Shoot dry weight ranged from 0.084g plant⁻¹ for TGX 1842-1E to 0.162g plant⁻¹ for TGX 1891-3F in the control ($0\mu\text{MAI}^{3+}$). Aluminium stress on the shoot was generally severe. Shoot dry matter accumulation was least in TGX 923-2E (0.046g plant⁻¹) and highest in TGX 1844-18E (0.106g plant⁻¹) at the $5\mu\text{MAI}^{3+}$ level of aluminium activity with about 50% of the genotypes accumulating higher dry matter than the population mean. Shoot dry matter accumulation was also least in TGX 923-2E at both the $50\mu\text{MAI}^{3+}$ and $300\mu\text{MAI}^{3+}$ levels of aluminium activity, while TGX 1896-3F maintained the highest shoot dry weight at both levels. Seven genotypes (TGX 1896-3F, TGX



1842–1E, TGX 1844–18E, TGX 1864–17E, TGX 1873–16E TGX 1878–7E and TGX 1888–15F) were however outstanding in their performance, with shoot dry matter accumulation at the 50 and 300 μ MAI³⁺ levels of aluminium activity >70% of that accumulated in their respective controls

5 DISCUSSION

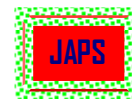
The highly significant genotypic effects observed for all the traits (primary root length, root dry weight and shoot dry weight) studied are indications that the soybean genotypes are genetically diverse in response to aluminium stress. The highly significant genotype \times aluminium and its various components of interaction (genotype \times 0 μ MAI³⁺ versus others, genotype \times 5 μ MAI³⁺ Vs 50/300 μ MAI³⁺ and genotype \times 50 μ MAI³⁺ Vs 300 μ MAI³⁺) observed for all the traits was due to changes in genotypic ranking in response to changes in the levels of aluminium activity. The increasing growth inhibition in the primary root length and the decreasing dry matter accumulation observed with increasing level of aluminium activity, is an indication that tender seedlings are highly sensitive to aluminium treatment at all levels. Tender seedlings are highly sensitive to changes in the levels of aluminium activity and experience heavy root damage in hydroponics (Ermolayev *et al.*, 2003) than older plants. Similar observations in previous studies have led to the conclusion that differential aluminium tolerance is better expressed in

(0 μ MAI³⁺) conditions. Shoot dry weights of ten genotypes were significantly higher than their respective population means at the 50 and 300 μ MAI³⁺ levels of aluminium activity. The highest C.V. of 10.1% was observed at 300 μ MAI³⁺ level of aluminium activity for shoot dry weight.

young seedlings than in older plants (Mugwira *et al.*, 1976; Blum, 1986; Villagarcia *et al.*, 2001; Ermolayev *et al.*, 2003). The ability of some genotypes to root vigorously and accumulate higher dry matter than other genotypes both in the presence and in the absence of aluminium had been previously observed and attributed to constitutive morphological characteristic (Urrea-Gonzalez *et al.*, 1996; Villagarcia *et al.*, 2001) which could be advantageous in the breeding of aluminium tolerant cultivars. In the current study, an aluminium stress tolerant genotype was considered as any genotype whose growth and dry matter accumulation is significantly higher than their respective population mean at the 5, 50 and 300 μ MAI³⁺ levels of aluminium activity. Root growth and dry matter accumulation at these three levels of aluminium activity (5, 50 and 300 μ MAI³⁺) should also be \geq 70% of the aluminium control conditions in such genotypes. Only TGX 1896–3F, TGX 1844–18E, TGX 1873–16E and TGX 1878–7E met these criteria and were appropriately identified as aluminium stress tolerant.

6 REFERENCES

- Bianchi-Hall CM, Carter TE Jr., Rufty TW, Arellano C, Boerma HR, Ashley DA, Burton JW, 1998. Heritability and resource allocation of aluminium tolerance derived from soybean PI416937. *Crop Science* **38**: 513 – 522.
- Bianchi-Hall CM, Carter TE Jr., Bailey MA, Mian MAR, Rufty TW, Ashley DA, Boerma HR, Arellan C, Hussey RS, Parrott WA: 2000. Aluminium tolerance associated with quantitative traits loci derived from soybean PI416937 in hydroponics. *Crop Science* **40**: 538 – 545.
- Blum A: 1986. Plant Breeding for Stress Environments. CRC Press, USA. 223Pp.
- Campbell KAG and Carter TE Jr.: 1990. Aluminium tolerance in soybean: 1. Genotypic correlation and repeatability of solution culture and green house screening methods. *Crop science* **30**: 1049



- 1054.
- Carter TE Jr. and Rufty TW: 1993. Soybean plant introductions exhibiting drought and aluminium tolerance. P. 335 – 346. In Kuo CG (ed.). Proceedings of an international symposium on: Adaptation of food crops to temperature and water stress. Taiwan. 13 – 18 Aug. 1992. Asian Vegetable Research and Development Center, Shanhua, Taiwan.
- Ermolayev V, Weschke W, Manteufel R: 2003. Comparison of Al-induced gene expression in sensitive and tolerant soybean cultivars. *Journal of Experimental Biology* **54** (393): 2745 – 2756.
- Ferrufino A, Smyth TJ, Israel DW, Carter TE Jr.: 2000. Root elongation of soybean genotypes in response to acidity constraints in a subsurface solution compartment. *Crop Science* **40**:413 – 421.
- Howell RW and Bernard RL: 1961. Phosphorus response of soybean varieties. *Crop Science* **1**: 311 – 313.
- Kochian LV: 1995. Cellular mechanisms of aluminium toxicity and resistance in plants. *Annual Rev. Plant Physiol. Plant Mol. Biol.* **46**:237 – 260.
- Mugwira LM, Patel KL, Rao PV :1976. Lime requirement for triticale in relation to other small grains. *Acta Agronomica Academiae Scientiarum Hungaricae, Tomus* **25**: 365-380.
- Okpara DA and Ibiem B :2000. Evaluation of soybean varieties for adaptability to a humid tropical environment in South Eastern Nigeria. *Journal of Sustainable Agricultural Environment* **2**(1): 26 – 31.
- Okpara DA, Nwajiugo EC, Ibiem B :2002. The response of soybean to nitrogen and potassium fertilization in the forest Belt of South Eastern Nigeria. *Tropical Oil Seeds Journal* **7**: 53 – 61.
- Ojo GOS: 2010. Genotypic variation and diallel analysis for aluminium stress tolerance in soybean (*Glycine max* (L.) Merrill). PhD Diss., University of Agriculture, Makurdi, Nigeria.
- Ojo GOS and Bello LL: 2010. Determination of appropriate level of aluminum activity in hydroponics for the screening of tropically adapted soybean varieties. *Journal of Animal and Plant Science* **8** (2): 971 – 980.
- Osedeke VE and Ojeniyi SO: 2003. Nitrogen requirement of some promiscuous soybean cultivars in the acid soil of the forest zone of South Eastern Nigeria. *Nigerian Journal of Soil Science* **13**: 1 – 6.
- Osedeke VE and Ojeniyi SO: 2005. Evaluation of the Forest Zone of Southeast Nigeria for Soybean Production. *Nigerian Journal of Soil Science* **15**: 129 – 132.
- Spehar CR: 1994. Aluminium tolerance of soybean genotypes in short term experiments. *Euphytica* **76**: 73 – 80.
- Ramirez ME, Israel DW, Wollum AG :1997. Phenotypic characterization of soybean *Bradyrhizobia* in two soils of North Carolina. *Soil Biology and Biochemistry* **29**: 1547 – 1555.
- Silva IR, Smyth TJ, Israel DW, Rufty TW: 2001. Altered aluminium inhibition of soybean root elongation in the presence of magnesium. *Plant Soil* **230**: 223 – 230.
- Urrea-Gomez R, Ceballos H, Pandey S, Bahia-Filho AFC, Leon LA: 1996. A greenhouse screening technique for acid soil tolerance in maize. *Agron. J.* **88**: 806 – 812.
- Villagarcia M, Carter TE Jr., Rufty TW, Niewoehner AS, Jennette MW, Arellano C: 2001. Genotypic rankings for aluminium tolerance of soybean roots grown in hydroponics and sand culture. *Crop Science* **41**(5): 1499 – 1507.
- Yusuf IA and Idowu AA: 2001. Evaluation of four soybean varieties for performance under different lime regimes on the acid soil of Uyo, Nigeria. *Tropical Oilseeds Journal* **6**: 65 – 70.

