Morphological Alterations of Corn (*Zea mays* L.) Plants in Response to Aluminum Toxicity in the Soil

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ABSTRACT

The objective of the experiment was to identify the morphological alterations in corn genotypes in response to aluminum toxicity in the soil. A complete randomized block design with five replications was used. The a factorial scheme was composed of two corn genotypes (C525M - tolerant, and HS701B - sensitive) and two neutralization levels (0% and 100% of aluminum saturation). The evaluations were performed at six leaf and 10-11 leaf growth stages, emergence of the "stigma-style", and the physiological maturity. The presence of toxic aluminum didn't significantly reduce diameter and height of stem, leaf area, dry matter of aerial parts, total dry matter and yield. Stem diameter, leaf area, dry matter of root, dry matter of aerial parts, total dry matter and yield did not allow the separation of genotypes in relation to aluminum toxicity in the soil.

Key words: Plant physiology, maize, soil acidity, plant growth

INTRODUCTION

Soils with pH from 4.0 to 7.0 are distributed throughout the tropical and subtropical regions of the world (Dudal, 1979). The presence of aluminum in acid soils harms both crop growth and yield (Olmos & Camargo, 1976; Foy *et al*., 1978; Foy, 1983). However, there are no reports of field studies to differentiate sensitive corn genotypes from tolerant ones to aluminum toxicity in the soil. According to Foy *et al.* (1978) and Alam & Adams (1979), aluminum toxicity symptoms are easily identified. Leaf symptoms of aluminum toxicity in some plants were considered similar to phosphorous deficiency or calcium induced deficiency in other plants (Foy, 1983). Foy & Flemming (1978) observed that aluminum interferes in plant cell division, reduced root respiration, and oxydative phosphorilation and interfered with the translocation, transport and use of various nutrients and water by the plants. Foy (1983) observed that the presence of aluminum in solutions caused the appearance of short, fragile, thick and bronze colored roots. Taylor (1988) found that the inhibition of root lengthening by aluminum was faster than the effect of aluminum toxicity on plant growth. The problem is aggravated on the sub-surface of acid soils because of the absorption of nutrients and water by the roots (Foy, 1983; Ritchley *et al*., 1983).

Experimental evidences indicated that aluminum tolerance differed among and within species (Brenes & Pearson, 1973; Furlani & Hanna, 1984; Furlani *et al*., 1986). These researchers found that sensitive and tolerant genotypes to soil acidity had different root system development. Studies by Lafever (1977), Camargo (1984), Mascarenhas *et al*. (1984), Lopes *et al*. (1987) and Llugany *et al*. (1995) showed irregular growth in the root systems in *Hordeum vulgare* (L.), *Oryza sativa* (L.), *Glycine max* (L.) Merril and *Zea mays* (L.) when cultivated in acid soils.

Sherchan *et al*. (1983), Mascarenhas *et al*. (1984) and Lopes *et al*. (1987) showed that seedling primary root length was a better indicator to assess varietal tolerance to the increase in the aluminum concentration in the nutritive solution than the accumulation of dry matter of the aerial part and roots.

The present experiment was carried out to identify the morphological parameters which best

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characterize the sensitivity of the corn crop and of corn genotypes to toxic aluminum in field soils.

MATERIAL AND METHODS

The experiment was carried out in a Dark Red Latossol with a clay texture at the Piraquara Experimental Farm of the Federal University of Paraná, State of Paraná, Southern Brazil, during the 1994/95 growing season. A randomized complete block design, with five replications was used in the experiment. The treatments were disposed in a factorial arrangement of two cultivars [C525M - acid tolerant and HS701B - susceptible to acidity, according to Llugany *et al*. (1995)] and two aluminum saturation levels 100% (no liming) and 0% (10.5 t/ha of lime). The amount of lime applied was determined by chemical soil analysis (Table 1) to reach saturation of 70% base. Calcitic-type lime was applied in 1993.

Each experimental plot was composed of seven 10m lines, with 0.90m interspaces. The central 5.0m lenght of the third, fourth and fifth line of each plot were used for the assessments. From each sampling row, two plants were randomly collected, totaling six plants per plot. The plants were collected by removing a 0.20m deep block of soil. The following parameters were assessed: stem diameter, plant height, leaf area, root dry matter, aerial part dry matter, total dry matter and yield. The samples were collected at the following stages: 1) six leaves; 2) 10-11 leaves; 3) emergence of the stigma-style; and 4) physiological maturity. Stem diameter and plant height were determined by paquimeter and measuring tape, respectively. The stem diameter was measured at soil level. The plant height was considered as the distance between the soil surface and the last visible leaf sheath. The leaf area was determined by using a leaf area gauge LICOR, model LI 3.1000. After these data collection, the leaf blades, roots and other parts of the plants were separately transferred to paper bags and allowed to dry in an air circulating chamber, at 60°C, until constant weight was achieved. Yield data were assessed at harvest.

All data were submitted to ANOVA and the F test was applied for significance. The means were compared by the Tukey test at 5% probability level.

RESULTS AND DISCUSSION

Liming resulted in a significant increase in the stem diameter of the corn plants. Although no significant differences were found between the two genotypes within each dosage (Table 2). Neutralization of soil acidity resulted in greater plant height. The HS701B genotype benefited most from the aluminum neutralization of the soil and remained the tallest up to the “stigma-style” stage (Table 3).

Table 1. Physical and chemical characteristics of the soil used to carry out an aluminun toxicity experiment in corn, at the Piraquara Experimental Farm of the Federal University of Paraná, State of Paraná, South Brazil, during the 1994/95 growing season.

Depth	pH	Al	H+Al	Ca	Mg	K	CTC (pH=7)	P	V	CTC efective	MO	Sand	Silt	Clay
cm	$CaCl_2$	--g.dm^{-3}	----------cmol$_c$ dm^{-3}-----				cmol$_c$.dm^{-3}	-...	--%--.	—cmol$_c$.dm^{-3}---	g.dm^{-3}-	-- g 100cm^{-3}--		
00-20	4.4	4.4	12.8	1.3	1.3	0.13	15.5	1	61.7	2.73	9.4	16.8	27.2	56.0
00-40	4.4	4.7	13.9	0.7	0.5	0.06	15.2	1	76.9	1.26	4.9	18.4	21.6	60.0

Table 2. Stem diameter (mm) of two corn genotypes (H1= C525M and H2= HS701B), grown in soils with 0% (D0) and 100% (D1) neutralization of toxic aluminum measured at four growth stages. Piraquara, PR. 1994/95.

Treatments	Stages			
	6 Leaves	10-11 Leaves	Stigma-Style	Physiologica Maturity
D0	11,74 b[1]	15,55 b	14,70 b	14,99 a
D1	14,21 a	17,93 a	16,38 a	16,63 a
H1 x D0	11,50 a	15,52 a	15,00 a	14,78 a
H2 x D0	11,98 a	15,58 a	14,40 a	15,20 a
H1 x D1	13,65 a	17,22 a	16,45 a	16,92 a
H2 x D1	14,78 a	18,65 a	16,30 a	16,35 a
m.s.d.[2] D	0,84	1,84	1,529	2,14
m.s.d. HxD	1,19	2,61	2,15	3,03
c.v. (%)	5,75	9,73	8,64	11,98

[1] - Means followed by the same letter are not statistically different by the Tukey test, at a level of 5% probability.
[2] - l.s.d. Least Significant Difference.

Leaf area significantly increased with the neutralization of soil acidity (Table 4). No significant differences were found between the two genotypes within each lime dose, except for plants at six leaf stage. At this growth stage, soil acidity neutralization significantly reduced root dry matter (Table 5). No further significant differences were found in root dry matter from the 10-11 leaf stage onwards in the areas with and without lime (Table 5). Significantly lower values were found for root dry matter for the C525M genotype at the 10-11 leaf stage in the areas without lime. In contrast, the C525M tolerant genotype had a greater ability to overcome the adverse soil conditions, with greater deepening of the root system and area of light capture (Tables 4 and 5). The methodology used to assess the root system of the C525M genotype became faulty after the second assessment, but for the HS701B genotype, the methodology used was shown to be adequate

Table 3. Plant height (cm) of two corn genotypes (H1= C525M and H2= HS701B) grown in soils with 0% (D0) and 100% (D1) neutralization of toxic aluminum measured at four growth stages. Piraquara, PR. 1994/95.

Treatments	Stages			
	6 Leaves	10-11 Leaves	Stigma-Style	Physiologica Maturity
D0	12,61 b[1]	24,74 b	126,98 b	128,45 b
D1	20,20 a	54,79 a	183,16 a	178,91 a
H1 x D0	11,07 b	22,55 a	126,80 a	116,00 a
H2 x D0	14,15 a	26,92 a	127,15 a	140,90 a
H2 x D1	18,10 b	44,40 b	167,47 b	158,65 a
H2 x D1	22,30 a	65,17 a	198,85 a	199,17 a
m.s.d. [2] D	1,98	3,62	21,06	31,27
m.s.d. HxD	2,80	5,12	29,78	44,22
c.v. (%)	10,68	8,05	12,0	17,99

[1] - Means followed by the same letter are not statistically different by the Tukey test at a level of 5% probability.
[2] - l.s.d. Least Significant Difference.

Table 4. Leaf area (dm^2) of two corn genotypes (H1= C525M and H2= HS701B) grown in soils with 0% (D0) and 100% (D1) neutralization of toxic aluminum, at four growth stages. Piraquara, PR. 1994/95.

Treatments	Stages			
	6 Leaves	10-11 Leaves	Stigma-Style	Physiologica Maturity
D0	2280 b[1]	3274 b	8472 b	10254 a
D1	4245 a	7180 a	10434 a	11916 a
H1 x D0	2548 a	3089 a	9222 a	11302 a
H2 x D0	2012 a	3458 a	7723 a	9207 a
H1 x D1	4697 a	6862 a	10616 a	13055 a
H2 x D1	3793 b	7498 a	10252 a	10776 a
m.s.d. [2] D	448	702	1401	2000
m.s.d. HxD	821	1015	2142	3395
c.v. (%)	12	12	13	16

[1] - Means followed by the same letter are not statistically
diferent by the Tukey test at a level of 5% probability.
[2] – l.s.d. Least Significant Difference

because of the greater accumulation of roots occurring in the first 10cm of the soil profile.

According to Mascarenhas *et al* (1984), the length of the seedling primary roots is a better parameter than the accumulation of the root dry matter to assess soybean crop tolerance to toxic aluminum. The result of the experiments showed that the accumulated root dry matter can be used to differentiate genotypes sensitive to toxic aluminum in the field up to the 10-11 leaf stage.

Table 5. Root dry matter weight (g) of two corn genotypes (H1= C525M and H2= HS701B) grown in soils with 0% (D0) and 100% (D1) neutralization of toxic aluminum, at four growth stages. Piraquara, PR. 1994/95.

Treatments	Stages			
	6 Leaves	10-11 Leaves	Stigma-Style	Physiologica Maturity
D0	43,6 a[1]	31,0 a	93,4 a	96,2 a
D1	38,3 b	31,7 a	79,5 a	97,4 a
H1 x D0	46,1 a	26,1 b	90,4 a	89,6 a
H2 x D0	41,1 a	35,9 a	96,2 a	102,7 a
H1 x D1	39,0 a	30,0 a	86,5 a	125,6 a
H2 x D1	37,6 a	33,3 a	72,6 a	69,2 b
m.s.d.[2] D	4,5	5,4	39,01	30,5
m.s.d. HxD	6,3	7,6	55,1	43,1
c.v. (%)	9,6	15,2	39,9	27,8

[1] - Means followed by the same letter are not statistically
different by the Tukey test at a level of 5% probability.
[2] – l.s.d. Least Significant Difference

Neutralization of toxic aluminum in the soil promoted a significant increase in dry matter of the aerial part of the maize plants for all the growth stages assessed (Tables 6 and 7). In areas without lime the genotypes C525M and HS701B did not show significant differences in dry matter accumulation for the total or aerial part of the plants during the whole crop development cycle (Tables 6 and 7). The neutralization of the toxic aluminum caused a significant increase in the accumulation of dry matter of the aerial and total plant parts in the C525M and HS701B genotypes, respectively, at the six and 10-11 leaves stages.

Table 6. Aerial part dry matter weight (g) of two corn genotypes (H1= C525M and H2= HS701B) grown in soils with 0% (D0) and 100% (D1) neutralization of toxic aluminum, at four growth stages. Piraquara, PR. 1994/95.

Treatments	Stages			
	6 Leaves	10-11 Leaves	Stigma-style	Physiologica Maturity
D0	71,2 b[1]	75,7 b	194,0 b	492,9 b
D1	84,5 a	133,8 a	263,6 a	709,3 a
H1 x D0	73,0 a	72,7 a	206,8 a	551,0 a
H2 x D0	69,5 a	78,8 a	181,2 a	434,8 a
H1 x D1	88,6 a	114,9 b	260,5 a	723,8 a
H2 x D1	80,3 b	152,7 a	266,8 a	694,9 a
m.s.d.[2] D	2,5	16,8	35,6	207,5
m.s.d. HxD	3,6	23,8	50,3	293,5
c.v. (%)	2,9	14,2	13,7	30,5

[1] - Means followed by the same letter are not statistically diferent by the Tukey test at a level of 5% probability.
[2] - l.s.d. Least Significant Difference.

Table 7. Total dry matter weight (g) of two corn genotypes (H1= C525M and H2= HS701B) grown in soils with 0% (D0) and 100% (D1) neutralization of toxic aluminum, at four growth stages. Piraquara, PR. 1994/95.

Treatments	Stages			
	6 Leaves	10-11 Leaves	Stigma-style	Physiological Maturity
D0	114,9 b[1]	107,0 b	299,8 a	589,0 b
D1	122,8 a	165,6 a	343,2 a	806,7 a
H1 x D0	119,1 a	99,0 a	297,2 a	640,6 a
H2 x D0	110,6 a	115,0 a	302,3 a	537,5 a
H1 x D1	127,7 a	145,0 b	347,3 a	849,4 a
H2 x D1	117,9 b	186,2 a	339,1 a	764,1 a
m.s.d.[2] D	6,3	20,5	60,5	213,5
m.s.d. HxD	9,0	29,0	85,5	301,9
c.v. (%)	4,7	13,3	16,6	27,0

[1] - Means followed by the same letter are not statistically different by the Tukey test at a level of 5% probability.
[2] -l.s.d. Least Significant Difference.

A significant 139% increase was found in corn grain yield with the neutralization of the toxic soil aluminum (Table 8). The C525M genotype yielded 26% higher than the HS701B one in areas without lime, but this difference was not statistically significant. The negative effects on crop development and yield caused by the presence of toxic levels of Al in the soil were also reported by Olmos & Camargo (1976), Foy *et al*. (1978) and Foy (1983).

Table 8. Grain yield (kg/ha) of two corn genotypes (H1= C525M and H2= HS701B) grown in soils with 0% (D0) and 100% (D1) neutralization of toxic aluminum, obtained at harvest. Piraquara, PR. 1994/95.

Treatments	Yield (kg.há$^{-1}$) (kg/há)Produtividade
D0	2306,8 b[1]
D1	5511,9 a
H1x D0	2572,4 a
H2x D0	2041,2 a
H1x D1	5876,3 a
H2x D1	5147,5 a
m.s.d.[2] D	928,1
m.s.d. HxD	1312,5
c.v. (%)	21,0

[1]- Means followed by the same letter are not statistically different by the Tukey test at a level of 5% probability.
[2] - l.s.d. Least Significant Difference.

Sherchan *et al* (1983), Mascarenhas *et al*. (1984) and Lopes *et al*. (1987) showed that corn seedling primary root length was the best toxic plants were the most sensitive parameters to asses the presence of Al in the soil. The presence of toxic aluminum in the soil reduced the development of the corn plants in the field for the stem diameter, height, leaf area, accumulation of aerial part dry matter, total and yield. These parameters should not be used to identify germoplasm sensitive to toxic aluminum in the soil.

RESUMO

O presente experimento teve por objetivo de identificar as alterações morfológicos nos genótipos de milho em resposta a toxicidade do alumínio a campo. O delineamento experimental utilizado foi o de blocos casualizados com cinco repetições. O arranjo experimental foi um fatorial 2 x 2, dois genótipos de milho (C525M - tolerante e HS701B - sensível) e dois níveis de neutralização (0% e 100% de saturação de alumínio). As avaliações foram realizadas nos estádios de desenvolvimento de 6 folhas e 10-11 folhas, emergência do “estilo-estigma” e maturidade fisiológica das plantas de milho. A presença do alumínio tóxico não reduziu significativamente o diâmetro e a altura do colmo, área foliar, matéria seca de parte aérea, matéria seca total e produção. O diâmetro do colmo, área foliar, matéria seca de raiz, matéria seca de parte aérea, matéria seca total e produção são características que não podem ser empregadas para diferenciar genótipos de milho com relação a presença de alumínio tóxico no solo.

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