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Responses of Elephantgrass to Nutrient Solution pH Levels

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ABSTRACT

Seedlings of elephantgrass (*Pennisetum purpureum*, Schum.), cvs. Vruckwona and Napier, were grown in aerated nutrient solution and exposed to pH levels of 4.0, 5.0, 6.0, or 7.0. After 30 days under controlled conditions, the effects on growth were evaluated. Plants exposed to pH 5.0, as compared to those under pH 4.0, showed increases in total leaf area, plant height, number of leaves (NL), and leaf, root, and stem fresh weight. No significant differences were found in stubble fresh weight, maximum individual leaf area, leaf area ratio (LAR), leaf area:plant height ratio, and leaf, root, stem, and stubble dry weight and dry matter percentage. Seedlings exposed to pH 4.0, as compared to those under pH 5.0, exhibited higher leaf:stem ratio on a fresh weight basis (FWR) and a tendency for higher leaf:stem ratio on a dry matter basis (DWR). Cultivar Vruckwona yielded superior results than Napier for most studied parameters, except for NL, LAR, and DWR (in which there were no significant differences) and for stubble length and FWR (in which Napier performed better). The results suggest that reductions below 5.0 in the nutrient solution pH cause growth inhibition, affecting root, stem, and leaf FW to a greater extent. The magnitude of such effects varies among contrasting cultivars. In turn, pH increases above 5.0 induce no significant growth reduction or promotion.

INTRODUCTION

Plant growth is directly influenced by pH levels in the root medium (Islam et al., 1980; Tolley-Henry and Raper, 1986; Jariel et al., 1991). Optimal responses for many crop species tend to be achieved when pH varies from 4.0 to 6.5 (Kim et al., 1985; Findenegg, 1987; Siraj-Ali et al., 1987). Outside this range, growth inhibition occurs, and roots are reported to show detectable damage (Moore, 1984; Kasran et al., 1992).

Detrimental effects of extremes of pH on root growth are well documented. High pH levels reduce root expansion (Zieslin and Snir, 1989; Stoffella et al., 1991; Tang et al., 1993), and effects may be detected within the optimum pH range (Tang and Robson, 1993). Low pH levels, besides depressing root growth, exert direct toxicity, by excessively high hydrogen (H^+) ion concentration (Jariel et al., 1991), and may induce toxic levels of aluminum (Al) and manganese (Mn), and deficient levels of calcium (Ca), magnesium (Mg), and phosphorus (P) (Baligar et al., 1992). In some instances, low pH harmful consequences can be lessened if sufficient Ca is available in the root substratum (Vassileva et al., 1997).

Low pH levels are particularly important because acidic soils pose a major limitation for plant growth throughout the world, especially regarding Al toxicity (Wright, 1989). Studies on the effects of pH levels on crop growth may be useful in verifying the extent of growth inhibition and in identifying possible genetic sources of tolerance to acidic soil conditions (Jariel et al., 1991). Because the effects of pH on plants are frequently confounded with other chemical soil properties, most studies of pH effects have been conducted in nutrient solutions, where pH and other variables can be more precisely established and sustained (Moore, 1984).

Elephantgrass (*Pennisetum purpureum* Schum.) is a high yielding forage and biomass crop of increasing importance for animal production in tropical areas. The species is reported to tolerate soil pH of 4.5 to 8.2 (Duke, 1979). In field studies, no influence of soil pH variation was detected on elephantgrass dry matter production (Pieterse et al., 1992). However, pH effects on the species are still to be examined under more accurate approaches, as feasible by utilizing nutrient solution and controlled environment. Also, it remains unverified whether plant aerial parts might show differential responses to pH levels in relation to roots.

The purpose of this study was to verify pH effects on expansion and biomass production of roots, stems, and leaves of elephantgrass seedlings maintained in nutrient solution in growth chamber. An assessment of differential behavior of genotypes was attempted by studying two contrasting cultivars.

MATERIALS AND METHODS

Semi-herbaceous stem segments with one internode were harvested from field-grown elephantgrass plants and placed in aerated water. Two days after bud burst, eight uniform seedlings were selected, placed in supporting lids, and transferred to each of four 2-L plastic containers holding aerated nutrient solution. After 24 h, each seedling group was exposed to fresh aerated nutrient solution with pH level altered to 4.0, 5.0, 6.0, or 7.0. Subsequently, pH levels were checked twice a day and adjusted with 1N hydrochloric acid (HCl) or 1N sodium hydroxide (NaOH) when needed. Solutions were replaced every other day and brought to volume, whenever necessary, with distilled water.

Plants were allowed to grow for 30 days. They were then harvested and measured regarding the following parameters: total leaf area (cm^2); maximum individual leaf area (cm^2); plant height (stem length, cm); number of leaves (NL); stubble diameter (cm) and length (cm); leaf, root, stem and stubble fresh weight (FW, g), dry weight (DW, g) and dry matter (DM) content (%), leaf area ratio (LAR - leaf area per plant dry weight, $cm^2\ g^{-1}$), leaf area:plant height ratio (cm); and leaf:stem ratio on a dry weight (DWR) and on a fresh weight (FWR) basis. Leaf area measurements were performed with LI-3000A portable area meter (LI-COR). For dry weight evaluations, plant materials were dried in a forced-air oven (Thelco 130DM laboratory oven, Precision Scientific, Chicago IL) at 65°C for 72 h. Weighing measurements were performed in a digital balance-analytical (Mettler AE200, Mettler-Toledo AG, Greifensee, Switzerland).

The nutrient solution had the following composition on a per liter basis: 1.5 mL 1M calcium nitrate [$Ca(NO_3)_2 \cdot 4H_2O$], and 1 mL each of 1M potassium hydrogen phosphate (K_2HPO_4), 1M potassium dihydrogen phosphate (KH_2PO_4), 1M magnesium sulfate ($MgSO_4 \cdot 7H_2O$), and 0.5M ammonium nitrate (NH_4NO_3), and micronutrients solution [0.08 g copper sulfate ($CuSO_4 \cdot 5H_2O$), 3.75 g boric acid (H_3BO_3), 0.075 g molybdenum trioxide (MoO_3), 2.25 g manganese chloride ($MnCl_2 \cdot H_2O$), and 0.33 g zinc sulfate ($ZnSO_4 \cdot 7H_2O$) per liter of stock]. FeEDTA was supplied according to Passos (1996). The pH measurements were performed with an Orion 520A pH-meter (Orion, Boston, MA).

Elephantgrass cvs. Napier and Vruckwona were studied in two separate experiments in which the described procedures were utilized. Each experiment was carried out in a completely randomized design with one plant per plot and eight replications. Data were statistically analyzed through ANOVA and mean contrasts for pH levels compared by Student-Newman-Keuls test. Data for cultivars were pooled for all pH levels and mean contrasts compared by F test.

Manipulations were carried out under controlled conditions (Biotronette Mark III environmental chamber, LAB-LINE Instruments, Melrose Park IL), set at 26°C, 60% RH, 16 h photoperiod, and 180 (mol $m^{-2}\ s^{-1}$ photosynthetically active radiation (PAR, measured with LI-190SA quantum sensor and LI-189 quantum meter, LI-COR,

TABLE 1. Growth attributes of elephantgrass seedlings at different nutrient solution pH levels.

Variable	pH level			
	4	5	6	7
Leaf area:plant height ratio (cm)	12.33 A	15.44 A	14.94 A	14.21 A
Leaf area ratio ($cm^2.g^{-1}$)	402.55 A	460.44 A	382.06 A	453.33 A
Leaf:stem ratio on a DW basis	2.14 A	1.69 A	1.81 A	1.68 A
Leaf:stem ratio on a FW basis	1.27 A	1.00 B	1.12 AB	1.07 AB
Plant height (cm)	18.07 B	23.50 A	20.94 AB	21.21 AB
Maximum individual leaf area (cm^2)	58.13 A	75.69 A	72.00 A	70.20 A
Number of leaves	6.33 B	7.75 A	7.00 AB	7.33 AB
Stubble diameter (cm)	1.26 A	1.31 A	1.50 A	1.50 A
Stubble length (cm)	7.27 A	6.94 A	8.06 A	7.71 A
Total leaf area (cm^2)	238.07 B	374.69 A	326.38 AB	331.60 AB

For each variable, means followed by the same letter are not significantly different ($P>0.05$) by Student-Newman-Kuels test.

Lincoln NE). All reagents were provided by SIGMA (St. Louis, MO), except NH_4NO_3 which was furnished by E. Merck (Frankfurt, Germany).

RESULTS AND DISCUSSION

Nutrient solution pH level significantly affected several growth-related parameters of elephantgrass seedlings. Regarding tissue expansion (Table 1), plants exposed to pH 5.0 exhibited higher total leaf area, plant height, and NL than the ones exposed to pH 4.0. Plant architecture, however, showed lesser effects. Seedlings kept under pH 5.0, compared to those under pH 4.0, yielded a non-significant trend for higher means of LAR, leaf area:plant height ratio and maximum individual leaf area while plants under pH 4.0 exhibited significantly higher FWR and a tendency for higher DWR than those under pH 5.0. No significant differences for stubble diameter and length were detected.

Results relative to biomass production (Table 2) showed significantly higher means with pH levels 5.0 and 6.0 for stem FW; 5.0, 6.0, and 7.0 for root FW; and 5.0 for leaf FW, in relation to pH 4.0. No significant differences were found in stubble FW, and leaf, root, stem, and stubble DW and DM content.

Comparisons between the two genotypes showed that cv. Vruckwona yielded superior results than Napier for most studied parameters, except for NL, LAR, and DWR, in which there were no significant differences, and for stubble length and FWR, in which Napier performed better (Table 3). Neither genotype showed tissue damage in response to pH variation.

The data overall trends indicate that pH 5.0 is best suited for elephantgrass growth in the absence of nutritional limitations. In fact, this level caused the

TABLE 2. Biomass attributes of elephantgrass seedlings at different nutrient solution pH levels.

Variable	pH level			
	4	5	6	7
Leaf dry matter (%)	10.35 A	9.65 A	10.06 A	9.60 A
Root dry matter (%)	8.00 A	7.12 A	6.94 A	7.33 A
Stem dry matter (%)	6.86 A	6.25 A	7.56 A	7.13 A
Stubble dry matter (%)	28.87 A	26.06 A	27.81 A	28.73 A
Leaf fresh weight (g)	5.00 B	9.00 A	8.00 AB	8.26 AB
Root fresh weight (g)	1.20 B	3.19 A	2.75 A	2.60 A
Stem fresh weight (g))	4.33 B	8.75 A	7.50 A	7.13 AB
Stubble fresh weight (g)	9.73 A	11.81 A	12.56 A	11.60 A
Leaf dry weight (g)	0.50 A	0.75 A	0.81 A	0.73 A
Root dry weight (g)	0,01 A	0.25 A	0.12 A	0.07 A
Stem dry weight (g)	0.14 A	0.37 A	0.37 A	0.33 A
Stubble dry weight (g)	2.93 A	3.43 A	3.68 A	3.60 A

For each variable, means followed by the same letter are not significantly different (P>0.05) by Student-Newman-Keuls test.

highest means for most studied parameters and effected significant reduction only in leaf:stem ratio on a FW basis when compared to pH 4.0 (an averaged 21.25% drop). These results confirm the maximum growth peak observed at nutrient solution pH 5.0 in potatoes (*Solanum tuberosum* L.) maintained under controlled conditions (Cao and Tibbitts, 1994).

The trends also indicate that reductions in nutrient solution pH levels below 5.0 depress growth of elephantgrass seedlings as observed in other species (Moore, 1984; Cao and Tibbitts, 1994). No significant growth promotion or inhibition was observed with pH above 5.0, despite the tendency for higher stem DM content and leaf DW at pH 6.0. These results suggest that elephantgrass show a differential behavior than other genera, such as *Lupinus*, in which pH above 6.0 depress root and shoot FW and taproot length (Tang and Robson, 1993). Apparently, the reduced availability of metal micronutrients that tend to occur in such conditions (Moore, 1984) did not influence growth of elephantgrass.

Growth expressed on a FW basis was the parameter mostly affected by pH reduction from 5.0 to 4.0 (averaged decreases of 62.38, 50.51, and 44.44%, for root, stem, and leaves, respectively). Reductions on a DW basis were not significant, causing DM content to show slight increases as pH was lowered. Total leaf area, plant height and NL also showed reductions of great magnitude (averaged decreases of 36.5, 23.10, and 18.53%, respectively), indicating that the total plant size was depressed.

The results in this study are not in agreement with field observations in which elephantgrass was not influenced by pH variation (Duke, 1979; Pieterse et al.,

TABLE 3. Growth and biomass attributes of elephantgrass cvs. Vruckwona and Napier seedlings as pooled for different nutrient solution pH levels (4, 5, 6, and 7).

Variable	Vruckwona	Napier
Leaf area:plant height ratio (cm)	16.71 **	11.73
Leaf area ratio ($cm^2.g^{-1}$)	413.22	437.68
Leaf:stem ratio on a DW basis	1.68	2.10
Leaf:stem ratio on a FW basis	1.00	1.23 **
Plant height (cm)	22.45 *	19.43
Maximum individual leaf area (cm^2)	80.97 *	56.57
Number of leaves	7.31	6.90
Stubble diameter (cm)	1.71 **	1.07
Stubble length (cm)	6.03	9.00 *
Total leaf area (cm^2)	401.06 **	230.93
Leaf dry matter (%)	11.47 **	8.17
Root dry matter (%)	10.00 **	4.38
Stem dry matter (%)	7.78 *	6.03
Stubble dry matter (%)	35.56 **	20.67
Leaf fresh weight (g)	9.37 **	5.70
Root fresh weight (g)	3.40 **	1.43
Stem fresh weight (g))	34.56 **	20.67
Stubble fresh weight (g)	15.97 **	6.63
Leaf dry weight (g)	1.00 **	0.38
Root dry weight (g)	0.21 *	0.01
Stem dry weight (g)	0.53 **	0.07
Stubble dry weight (g)	5.37 **	1.33

*Significant difference by F test ($P<0.05$).
**Significant difference by F test ($P<0.01$).

1992). However, field approaches in general lack controlling capabilities over variables such as the mineral composition of the substratum, temperature, R.H. and PAR, hence being prone to have soil properties confounding with pH effects (Moore, 1984). In our procedure, other sources of variation, such as differences in plant vigor, were also unlikely, since the non-significant mean contrasts observed for stubble diameter, length, DW, FW, and DM content suggest that the materials initially selected for the study were homogenous.

The superior performance of cv. Vruckwona over Napier for most studied attributes was probably influenced by its higher vegetative vigor. However, the lack of significant differences regarding NL, LAR, and DWR, and the greater values of FWR obtained with Napier, suggest that distinct genotypes are likely to show differential depressed growth in response to inadequate pH levels in the growing medium. This possibility merits further research.

CONCLUSIONS

The results suggest that elephantgrass plants show optimal growth at pH 5.0, in the absence of other nutritional restraints. The pH reductions below 5.0 cause growth inhibition, affecting root, stem, and leaf FW to a greater extent. The magnitude of those responses appears to be genotype-dependent. The pH increases above 5.0, in turn, do not cause significant growth inhibition or promotion.

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REFERENCES

Baligar, V.C., R.J. Wright, and K.D. Ritchey. 1992. Soil acidity effects on wheat seedling root growth. J. Plant Nutr. 15:845-856.

Cao, W. and T.W. Tibbitts. 1994. Responses of potatoes to solution pH levels with different forms of nitrogen. J. Plant Nutr. 17:109-126.

Duke, J.A. 1979. Ecosystematic data on economic plants. Quart. J. Crude Drug Res. 17:91-110.

Findenegg, G.R. 1987. A comparative study of ammonium toxicity at different pH of the nutrient solution. Plant Soil 103:239-243.

Islam, A.K.M.S., D.G. Edwards, and C.J. Asher. 1980. pH optima for crop growth. Results of a flow solution culture experiment with six species. Plant Soil 54:339-357.

Jariel, D.M., S.U. Wallace, U.S. Jones, and H.P. Samonte. 1991. Growth and nutrient composition of maize genotypes in acid nutrient solutions. Agron. J. 83:612-617.

Kasran, R., Z.H. Shamsuddin, and D.G. Edwards. 1992. Effect of toxic H^+ and Al on nonsymbiotic growth of groundnut in solution culture. Pertanika 15:189-197.

Kim, M.K., D.G. Edwards, and C.J. Asher. 1985. Tolerance of Trifolium sub-terraneum cultivars to low pH. Aust. J. Agric. Res. 36:569-578.

Moore, D.P. 1984. Physiological effects of pH on roots. pp. 131-151. In: E.W. Carson (ed.), The Plant Root and its Environment. University Press of Virginia, Charlotteville, VA.

Passos, L.P. 1996. Métodos Anallticos e Laboratoriais em Fisiologia Vegetal. pp. 101-105. EMBRAPA-CNPGL, Coronel Pacheco, Brazil.

Pieterse, P.A., R.S. Van Heerden, and N.F.G. Rethman. 1992. Influence of soil acidity and fertilizer application on the productivity of Bana grass during the establishment phase. Appl. Plant Sci. 6:77-80.

Siraj-Ali, M.S., J.C. Peterson, and H.K. Tayama. 1987. Influence of nutrient solution pH on the uptake of plant nutrients and growth of *Chrysanthemum morifolium* 'Bright Golden Anne' in hydroponic culture. J. Plant Nutr. 10:2161-2168.

Stoffella, P.J., M.L. Dipaola, A. Pardosi, and F. Tognoni. 1991. Rhizosphere pH influences early root morphology and development of bell peppers. HortScience 26:112-114.

Tang, C. and A.D. Robson. 1993. pH above 6.0 reduces nodulation in *Lupinus* species. Plant Soil 152:269-276.

Tang, C., J. Kuo, N.E. Longnecker, C.J. Thomson, and A.D. Robson. 1993. High pH causes disintegration of the root surface in *Lupinus angustifolius* L. Ann. Bot. 71:201-207.

Tolley-Henry, L. and C.D. Raper, Jr. 1986. Effects of ambient acidity on growth and nitrogen accumulation by soybean. Plant Phys. 82:54-64.

Vassileva, V., G. Milanov, G. Ignatov, and B. Nikolov. 1997. Effect of low pH on nitrogen fixation of common bean grown at various calcium and nitrate levels. J. Plant Nutr. 20:845-856.

Wright, R.J. 1989. Soil aluminum toxicity and plant growth. Commun. Soil Sci. Plant Anal. 20:1479-1497.

Zieslin, N. and P. Snir. 1989. Responses of rose plants cultivar 'Sonia' and *Rosa indica* major to changes in pH and aeration of the root environment in hydroponic culture. Sci. Hort. 37:339-349.