ROOT PENETRATION OF ARTIFICIALLY COMPACTED HARD LAYERS

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Introduction

Greater soil penetration resistance can affect plant shoot as well as root growth. Increased resistance has been shown to decrease leaf size and seedling growth (Beemster *et al.*, 1996; Arvidsson *et al.*, 1996) and to decrease root growth and yield (Costantini *et al.*, 1996; Misra *et al.*, 1996). Tillage can reduce soil penetration resistance and improve root growth, though this is a temporary solution and recompaction takes place over time (Busscher, *et al.*, 1995).

For a more permanent solution, Kasperbauer *et al.* (1991) examined the abilities of different cultivars to penetrate hard soil layers. They were able to distinguish between a good and a poor rooting cotton cultivar. However, they used only one hard layer and depended on its strength to separate good from poor rooting cultivars.

Addition of gypsum to soils has aided in root penetration of hard layers. Sumner *et al.* (1986) and other researchers reported reduced acidity and improved physical characteristics with gypsum amendment.

We hypothesized that a column with increasing penetration resistance with strength could be more easily used to separate cultivars that might not be separated by a single hard layer. It would be more flexible because it would have a range of hard layers to more closely filter out the poor and good rooting varieties. We further hypothesized that addition of gypsum to the hard layers would aid in root growth.

Methods

We grew soybean in soil columns in a growth chamber in 1994 and repeated the experiment in 1996. Temperatures in the chamber were controlled between 28 and 29°C with an air conditioner running continuously and a heater on a thermostat. Columns were illuminated with four Grow-Lux bulbs that irradiated the tops of the columns at 72 to 75 $\mu E\ m^{-2}\ s^{-1}$, on for 12 hrs/day and off for 12 hrs/day.

We obtained soil from the edge of a field of Norfolk sandy loam, a typic Kandiudult (a fine loamy Acrisol), near Florence, SC, USA. Soil was taken from the Ap horizon and sieved through a 2-mm screen before it was packed into columns. Soil was poured loosely into the top layers of the columns to a depth of 4.5 cm. Succeeding layers were 2.5-cm deep. They were compacted to bulk densities of either 1.4 g/cm^3 for all depths (non-variable with depth) or 1.4, 1.55, 1.65, and 1.75 g/cm^3 increasing with depth (variable with depth). Columns were 7.5-cm diameter. Soils were compacted at water contents of 6%. Plants were not watered during the experiment. We terminated the experiment when the plants died.

Two soybean genotypes, PI416937 and Essex, were grown in the columns. PI 416937 was maturity group V variety, tolerant of drought and Al. Essex was a maturity group V older public variety, susceptible to Al and drought. Seeds of the same size were germinated, planted into moist peat pots, and placed on top of the columns.

Soils were treated with either 0 or 1 g/kg gypsum. All combinations of treatments (variable or non-variable compaction with depth, two genotypes, and gypsum or none) were arranged in a completely random design in four replicates.

A duplicate set of cores was compacted for measurement of soil strength with a 3-mm-diameter, stainless-steel flat-tipped probe. The probe was attached to a strain gauge and a motor geared to penetrate soil at a constant rate of 0.28 mm/s. Microvolt output from the strain gauge was captured in a computer. Data were obtained after about 3- to 4-mm depth of probing where the recorded penetration resistance with depth leveled off. Calibration data (not shown) related strain gauge microvolt output (v) to soil penetration resistance as pr = 0.313 v - 0.013 (r^2 = 0.99).

During the experiment, we measured plant height daily, leaf area (mid experiment), and root growth at the end of the experiment. Leaf area was measured by tracing the leaves on pieces of paper, cutting out the traces, and measuring their area on an area meter. Root growth was measured at the end of the experiment after cutting the cores apart. Roots were separated from the soil in a root washing machine (Smucker *et al.*, 1982). Root length was measured with a modified area meter as counts based on digitization of the root image.

Data were analyzed as a split plot with the gypsum, compaction, and plant type as main plots and depth within the column or dates of measurement as subplots. Differences were significant at the 5% level unless otherwise specified.

Results and discussion

Bulk density and penetration resistance: The measured bulk densities of the duplicate set of cores were the same as the targeted values (Table 1). The set compacted for the columns would be as accurate. Penetration resistances of the duplicate set of compacted cores increased with depth and/or bulk density.

Table 1. Measured bulk densities and penetration resistances for the duplicate set of cores as they vary with column depth.

	Bulk Density		Penetration Resistance	
Depth	1994	1996	1994	1996
	----- g/cm^3 -----		----- MPa -----	
1	1.40*	1.40	0.78d**	0.79d
2	1.55	1.55	1.06c	1.07c
3	1.65	1.65	1.42b	1.49b
4	1.74	1.74	2.11a	2.17a

*Standard error < 0.009 for both years and all depths.
** Means within columns with the same letter are not different by the LSD test.

Root growth: There were no differences in root growth between treatments with and without gypsum. The top core of each column had the highest root count. Averaged over all other treatments, root counts for the non-variable bulk density columns were 8.74, 5.63, 4.61, and 4.97 for depths 1, 2, 3, and 4, respectively. For the variable bulk density columns, they were 9.89, 4.34, 3.53, and 1.90 with an LSD=1.28 at 5%. Except for the top core, columns with variable bulk density had decreasing root growth with depth while columns with non-variable bulk density did not.

Essex had more roots than PI416937 (Table 2). Essex had greater root growth in non-variable columns while PI416937 did not. When the high strength restriction of root growth was released (when the cores were non-variable), root growth of Essex increased. Root growth of PI416937 did not.

Use of any one hard layer may or may not have distinguished root sensitivity differences of the genotypes to penetration resistances. The use of multiple hard layers gave us

several chances to separate the differences. In this experiment, differences could be seen between depths 1 and 2 in 1994 and depths 1 and 3 in 1996.

Increased penetration resistance (increased bulk density) generally led to lower root growth. The best regresstion equation for predicting root count (rc) with penetration resistance (pr) was $rc=6pr^{-1.9}$ ($r^2=0.69$). More root count variability for Essex was explained by penetration resistance ($r^2=0.72$) than PI416937 ($r^2=0.65$).

Table 2. Root count for the two varieties grown in the variable and non-variable bulk densities within the columns.

	1994			
	Essex		PI416937	
Depth	Non-variable	Variable	Non-variable	Variable
	----- digitized root count -----			
1	14.41a*	12.93a	8.40a	11.82a
2	9.47b	5.21b	6.09a	5.11b
3	7.21b	4.06b	5.58a	5.47b
4	7.34b	2.32b	5.06a	5.47b
Mean	9.61a**	6.13b	6.28b	6.72b
	1996			
1	6.66a*	6.93a	5.46a	7.51a
2	4.91ab	3.63b	2.03b	3.34b
3	3.66b	2.89b	2.01b	1.62bc
4	4.28b	0.40c	3.21b	0.23c
Mean	4.87a**	3.46b	3.18b	3.18b

* Means within columns for depth with the same letter are not different by the LSD test.
** Means within rows with the same letter are not different by the LSD test.

Table 3. Leaf area.

	1994			1996		
Genotype	Non-variable	Variable	Mean	Non-variable	Variable	Mean
			----- cm^2 -----			
Essex	43	32	37a*	57	53	55a*
PI416937	30	25	28b	58	51	54a
Mean	37a**	27b		57a**	52b	

* Means within columns with the same letter are not different by the LSD test.
* Means within rows with the same letter are not different by the LSD test.

Leaf area: There were no differences in leaf area between treatments with and without gypsum. In 1994, Essex had more leaf growth than PI416937 (Table 3). In 1996, there were

no differences between genotypes. For both years, there was more leaf area for columns without variation in bulk density than for columns with bulk density increasing with depth.

Plant height and days to plant death: We used the maximum measured value to analyze plant heights. In 1994, the genotype Essex not treated with gypsum had taller plants than with gypsum (Table 4). Gypsum did not affect the height of PI416937. Gypsum did not influence the height of either genotype in 1996. In both years, Essex was taller than PI416937. Variation of bulk density with depth did not affect maximum plant height.

For the two years taken together, Essex lived longer (34 days) than PI416937 (31 days, LSD=1 day). Plants also lived one day longer in columns without variable bulk density (33 days) than columns with variable bulk density (32 days, LSD=1 day).

Table 4. Plant height.

	1994			1996		
Genotype	No gypsum	Gypsum	Mean	No gypsum	Gypsum	Mean
			----- cm -----			
Essex	29a**	26b	28a*	31	32	32a*
PI416937	20	20	20b	24	25	24b
Mean	25a	23a		28a**	28a	

* Means within columns with the same letter are not different by the LSD test.
** Means within rows with the same letter are not different by the LSD test.

Conclusions

Increased penetration resistance reduced root growth in the columns with variable bulk density layers. Plant roots grew better in the columns that did not have high strength layers, mainly because Essex had better root growth in those columns. Plants also lived longer in the columns without the high strength layers.

Essex generally grew better than PI416937. It had taller plants, greater leaf area (in one of the two years), and lived longer than PI416937.

The addition of gypsum to the soil did not increase plant top growth. The only difference with gypsum was taller plants for Essex in 1994 in columns not treated with gypsum.

Columns without the high strength layers had lower penetration resistance and deeper penetration of roots, while plants grown in them had greater leaf area and lived slightly longer.

Columns with multiple hard layers enabled us to distinguish between genotypes in cases where only one hard layer would not have been sufficient.

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References

Arvidsson, J. *et al.*, 1996. Soil and Tillage Research 39(3-4): 175-197.
Beemster, G.T.S. *et al.*, 1996. Journal of Experimental Botany 47(304): 1651-1662.
Busscher, W. J. *et al.*, 1995. Soil and Tillage Research 35: 115-123.
Costantini, A. *et al.*, 1996. Australian Journal of Experimental Agriculture 36(7): 847-859.
Kasperbauer, M. J. *et al.*, 1991. Crop Science 31: 1376-1378.
Misra, R.K. *et al.*, 1996. Plant Soil 182(1): 1-11.
Smucker, A.J. *et al.*, 1982. Agronomy Journal 74: 500-503.
Sumner, M.E. *et al.*, 1986. Soil Science Society of America Journal 50: 1254-1258.