# Genotypic Variation for Root Penetration of a Soil Pan

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**ABSTRACT.** Cotton production has increased dramatically on the Coastal Plain of the southeastern USA since eradication of the boll weevil (*Anthonomus grandis* [Boh.]) in the late 1980s. Most of the cotton production in this area occurs on soils possessing subsoil pans. Soil pans limit root growth, requiring mechanical disruption to increase the root zone and facilitate cotton growth. Mechanical amelioration of a soil pan has several disadvantages including expenses for equipment and energy, equipment to break up the pan may not be available, and the effects of mechanical disruption are temporary and contribute to soil erosion. The need for soil pan disruption might be eliminated or reduced with cotton germplasm capable of rooting through high strength soil. Our objective was to identify germplasm with superior rooting ability and thereby initiate breeding efforts incorporating this trait into cultivars. Cultivars and Pee Dee germplasm lines were evaluated at Florence, SC for 2-yr without irrigation for root penetration of a naturally occurring soil pan. Roots were excavated at maturity and rated on a 1-5 scale based on magnitude of the root penetration of the pan. Combined analysis of variance over years revealed significant genotypic variation and a genotype × yr interaction for root penetration of the pan. Despite the genotype × yr interaction, we identified germplasm that could partially root through the pan. Additionally, we were able to eliminate those genotypes with poor rooting characteristics from further consideration as parents in the breeding program. Cultivars with ability

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to penetrate a soil pan would make a valuable contribution to sustainable cotton production systems for the USA and developing countries.
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## *INTRODUCTION*

Cotton hectarage has increased in the southeastern USA in response to reduction of boll weevil densities to subeconomic pest levels. Cotton production costs have decreased with boll weevil eradication, yet they still remain high compared with other row crops (Lege et al., 1996). Production costs must be reduced if USA grown cotton is to remain competitive in a global economy. A significant cost for cotton production is amelioration of subsoil pans by mechanical disruption (Sistler and Zimmerman, 1980; Tompkins and Wilhelm, 1981; Garner et al., 1989). For example, Khalilian et al. (1991) reported that the cost in fuel alone to operate a commonly used four-row subsoil implement was about 11 L $ha^{-1}$. The effect of the soil pan is to restrict the root zone and when combined with a shallow surface layer of soil low in water retention capacity, results in the need for pan disruption or irrigation to supplement erratic rainfall. Soil pans are ubiquitous in soils of the southeastern USA (Campbell et al., 1974; Busscher et al., 1995), consequently under-the-row subsoiling to break the pan and increase the rooting area is recommended annually (Lege et al., 1996), since its effect is not permanent (Busscher et al., 1986). Irrigation or equipment to mechanically disrupt the pan is not available to all cotton growers, particularly in developing countries. Cotton germplasm with ability to root through high strength pans could eliminate or reduce the need for pan disruption, and would contribute positively to environmentally and economically sustainable cotton production systems.

The junior author was initially motivated to study root penetration of soil pans after observing during a severe drought non-wilted weed species such as Palmer Amaranth (*Amaranthus palmeri*) growing in the same field with wilted crop plants. Roots of the turgid Palmer Amaranth had penetrated the pan to extract water, while those of the wilted crop plants could not. In a subsequent laboratory study, Kasperbauer and Busscher (1991) found two cotton genotypes that differed for root penetration of artificially compacted soil cores. This finding motivated us to assay an expanded array of germplasm for rooting ability through a naturally compacted soil pan.

Plant breeding has a role in fostering sustainable agricultural systems.

Cotton germplasm that is economically productive without irrigation and subsoiling is a desirable breeding objective to enhance grower competitiveness and the sustainability of cotton production. The purpose of our study was to assess a genetically diverse array of potential parents available to the cotton breeding program for ability of the taproot to penetrate a soil pan. In this manner, genotypes with inferior rooting characteristics could be excluded from the breeding program.

## *MATERIALS AND METHODS*

Twenty-three cotton genotypes including 13 cultivars and 10 Pee Dee germplasm lines were evaluated in 1994 and 1995 at the USDA-ARS Coastal Plains, Soil, Water, and Plant Research Center, Florence, SC. The cultivars and germplasm lines were possible parents for the cotton breeding program that we wished to screen for rooting ability before they were used in crosses. Pee Dee germplasm developed by the USDA-ARS, Florence, SC over the past 50 years has been used by public and private cotton breeding programs to produce numerous cultivars (Bowman et al., 1996). The genotypes in our study included 11 of the 12 cultivars recommended for commercial planting in South Carolina (May et al., 1993). The experimental design was a randomized complete block with four replications. Cotton was produced on a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudult). A pan was present about 20 cm below the soil surface (Campbell et al., 1974; Busscher et al., 1986), which had not been disturbed by tillage for at least five years. The previous cropping history of the land used in our study included cotton production, but without tillage that would have disrupted the pan. Also, only one cotton cultivar was produced on the land prior to 1994; and based on our findings in this study, the prior cotton production had little or no effect on ability of subsequent cotton crops to penetrate the soil pan. Plots were single rows, 6.5 m long with 1-m spacing between plots. Plots were seeded by hand on 17 July 1994 and 14 July 1995, and they were thinned to about 15 cm between plants soon after emergence. Although Porter et al. (1992) found that planting date has little effect on cotton taproot development, we chose Mid-July planting dates each year to decrease the chance that the soil pan would be overly softened by unusually high off-season rains. Plots were not irrigated. In early November of both years, roots from 10 consecutive plants per plot were assessed for penetration of the pan. We had to devise a method of obtaining representative samples of root development, yet still allow many genotypes to be screened as is necessary in a breeding program. Consequently, shovels were employed to carefully excavate soil from around the plants, endeavoring in the process that neither the taproot nor lateral roots were damaged. Rooting response to the soil pan was assigned the following ratings: Rating = 1, no roots penetrated the pan; rating = 2, taproot entered, but neither the taproot nor lateral roots penetrated through the compacted soil layer; rating = 3, taproot did not penetrate, but one or more lateral roots grew through the pan; rating = 4, taproot deflected at the surface of the pan, travelled laterally until it found an apparent weak spot and then penetrated through the compacted soil layer; rating = 5, taproot entered vertically and penetrated the compacted soil layer into the subsoil.

The data consists of small whole numbers; thus, ANOVAs were conducted using the raw data and square root transformed data [$(x + 0.5)^{1/2}$; Gomez and Gomez, 1984]. The ANOVAs were conducted on plot means calculated from the 10 plants per plot. Equivalent results (e.g., significance levels for genotypic differences and rank of genotype means) were obtained from ANOVA of the raw and transformed data; consequently, the raw data were used in the ANOVA. Means were separated with Fisher's protected LSD test (Steele and Torrie, 1981).

## *RESULTS AND DISCUSSION*

The ANOVA of root penetration of the soil pan indicated significant genotypic differences ($P < 0.05$), plus a genotype × yr interaction ($P < 0.05$). Despite the genotype × yr interaction, we could still delineate the germplasm into groups representing those with best rooting response to the pan and those with roots essentially limited to development above it (Table 1). The germplasm lines PD 5529 and PD 5358 were examples of genotypes that consistently exhibited the best rooting ability, while SC-1 and PD 695 had roots least able to penetrate the pan. Unfortunately, we did not identify any germplasm that could root unimpeded through the pan. Examination of the nature of the genotype × yr interaction indicated mostly minor rank and magnitude changes (Table 1). An exception, however, was the performance of CB 407. We hypothesize that its anomalous performance between years and the genotype × yr interaction, in general, may be related to seasonal variation in precipitation because moisture content of soil alters its strength, and consequently its resistance to root penetration (Campbell et al., 1974). January through November precipitation totals for 1994 and 1995 were 114 cm and 130 cm, respectively. Two-thirds (about 10 cm) of the precipitation difference between years fell between July and November of 1995, during which root development would have occurred. Not all genotypes, however, responded to the increased precipitation and possibly reduced soil pan penetration resistance. The key finding is that despite differences of about 10 cm in rainfall during plant development, the expression of rooting ability was mostly consistent over years.

TABLE 1. Cotton cultivar (denoted by quotes) and germplasm line pedigrees and mean rating (1-5 scale) for ability to penetrate a soil pan at Florence, SC.

| Cultivar or Line | Pedigree[a] | 1994 Rating | 1995 Rating | 2-Yr Mean Rating |
|---|---|---|---|---|
| 'PD-1' | PD 4381/PD 8623 | 3.5 | ----b | ---- |
| PD 5529 | Deltapine 41/PD 6133 | 3.4 | 3.1 | 3.2 |
| PD 5358 | Delcot 311/PD 5657 | 3.4 | 3.4 | 3.4 |
| 'Stoneville Ga King' | Tifcot 56/McNair 235 | 3.3 | 3.0 | 3.1 |
| PD 5363 | Delcott 311/PD 6131 | 3.3 | 3.3 | 3.3 |
| 'Stoneville LA 887' | DES 119/LA 434-RKR | 3.2 | 3.2 | 3.2 |
| 'Deltapine 5415' | DP 50/DP 90 | 3.2 | 2.8 | 3.0 |
| PD 5256 | McNair 220/AC 241 | 3.1 | 3.2 | 3.2 |
| 'Coker 320' | Coker 315/McNair 220 | 3.1 | 3.3 | 3.2 |
| PD 93001 Light Brown | PD-3/Dark Brown | 3.1 | 3.3 | 3.2 |
| 'PD-3' | PD 9363/PD 9240 | 3.1 | 3.2 | 3.1 |
| PD 93002 Dark Brown | PD-3/Dark Brown | 3.1 | 3.5 | 3.3 |
| PD 93004 Light Brown | PD-3/Dark Brown | 3.1 | 2.9 | 3.0 |
| PD 5472 | McNair 235/PD 6184 | 3.1 | 3.4 | 3.2 |
| 'Deltapine 90' | DP 6516/DP 6582 | 3.0 | 3.2 | 3.1 |
| 'DES 119' | DES 24/DES 2134-047 | 3.0 | 3.0 | 3.0 |
| 'Acala 1517-88' | Acala 1517-77br/DP 70 | 3.0 | 3.2 | 3.1 |
| PD 93003 Light Brown | PD-3/Dark Brown | 3.0 | 2.9 | 2.9 |
| 'CB 1233' | N/A | 2.9 | 3.2 | 3.0 |
| 'SG 1001' | McNair 235/DP 90 | 2.9 | 2.8 | 2.8 |
| 'Stoneville KC 311' | DP 90/McNair 235 | 2.6 | 2.5 | 2.5 |
| 'CB 407' | N/A | 2.2 | 3.1 | 2.7 |
| 'SC-1' | Coker 421/PD 4398 | 1.9 | 2.3 | 2.1 |
| PD 695 | La Frego 2/2*PD 8562 | 1.8 | 2.3 | 2.0 |
| | LSD 0.05 | 0.3 | 0.4 | ----c |

[a]Calhoun et al. (1994).

[b]Not included in 1995 test.

[c]LS for 2-yr mean not presented due to genotype $\times$ yr interaction.

N/A = not available.

Consistent with results of the study conducted by Kasperbauer and Busscher (1991) that employed artificially compacted soil, we found that PD-1 exhibited superior rooting over a natural soil pan. PD-1 was determined to have greater root weight per unit length in the laboratory study (Kasperbauer and Busscher, 1991, and unpublished data), possibly contributing to its ability to partially root through the pan. We can also hypothesize that the rooting ability of PD-1 may be related to structural idiosyncracies, such as aerenchyma, that facilitate oxygen uptake and thus, root cell growth. We intend to investigate further root structural characteristics of germplasm exhibiting moderate ability to root through compacted soil. Though agronomically obsolete, PD-1 has value as a source of moderate rooting ability through compacted soil. Much of the germplasm in this study exhibited similar rooting performance, suggesting commonality of genes conditioning this trait. This finding could reflect a narrow genetic base (Van Esbroeck et al., 1998), or that root development is controlled by only a few loci that have become homozygous through selection.

Subsoiling and irrigation were not production practices utilized in the Pee Dee cotton breeding program until after 1970 (T.W. Culp, personal communication). It is possible that in seasons with low or poorly distributed precipitation, identification of superior plant types in breeding populations prior to 1970 may have coincidentally selected for the ability to partially penetrate the pan or tolerate a restricted root zone. Some current Pee Dee germplasm (e.g., PD 5529 and PD 5358) may retain genes conferring ability to partially penetrate a soil pan that were inherited from germplasm developed prior to the advent of subsoiling. Despite attaining cultivar status, SC-1 apparently did not inherit genes conferring rooting ability through compacted soil.

In summary, this study found some current germplasm with the ability to root through the pan similar to that of obsolete PD-1. The germplasm lines PD 5529 and PD 5358 have a desirable combination of moderate rooting ability, excellent fiber quality, and high yield potential (Green et al., 1991a, 1991b). Fiber quality must be improved simultaneously with rooting ability and yield potential to meet the needs of producers and the textile industry. PD 695 and the cultivar SC-1 with poor rooting characteristics could be excluded as parents of new populations in our breeding program. Much of the germplasm exhibited similar rooting ability, suggesting that more diverse germplasm be screened. Another germplasm source that could be sampled is wild *Gossypium hirsutum* accessions, where fitness has not been dependent on human activities, thus, genes for superior root characteristics might be found.

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