ROOT PENETRATION OF A COMPACTED SUBSOIL AS A POTENTIAL COMPONENT OF COTTON GENOTYPE SELECTION FOR CULTIVAR DEVELOPMENT

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Abstract

Cotton production soils of the southeastern Coastal Plain are sandy and often overlie a subsurface hardpan that restricts the root zone. This can be a serious problem in years with insufficient rainfall. Mechanical disruption of the hardpan, most frequently by subsoiling, is widely recommended to increase the root zone. The process is expensive and the effects are temporary. Cotton cultivars with roots able to penetrate a subsoil hardpan would have the potential to decrease the need for subsoiling and significantly reduce production costs. Our objective is to identify germplasm with greater ability to penetrate compacted soil. Twenty-four cotton genotypes of diverse ancestry including 14 cultivars and 10 Pee Dee germplasm lines were evaluated in field plots without irrigation over a naturally-compacted subsoil near Florence, SC. At the end of the season, plants were dug to examine roots and then rated on a 1-5 scale based on magnitude of the taproot penetration of the hardpan. Among the 14 cultivars, PD-1 performed best (3.46 rating) while CB 407 (2.21 rating) had the poorest penetration of the hardpan. Of the 10 germplasm lines, PD 5529 performed best (3.35 rating) while PD 695 (1.79 rating) was least able to penetrate the subsoil hardpan. These data clearly demonstrate genotypic variation for rooting ability through a subsoil hardpan. We conclude that ability to penetrate a subsoil hardpan should be part of the evaluation process before using germplasm lines for development of new cultivars for use in geographic regions that have subsoil hardpans.

Introduction

Cotton production costs must be reduced if U.S. cotton is to remain competitive in the world market. In some areas, subsoiling is a significant production cost for equipment and fuel (Sistler and Zimmerman, 1980; Tompkins and Wilhelm, 1981; Garner et al., 1989). Soils of the southeastern Coastal Plain of the U.S. are typified by a sandy surface layer and the presence of a hardpan about 20 cm below the soil surface. The presence of the hardpan restricts the root zone, which when combined with surface soil low in water retention capacity, requires either irrigation to meet water needs of a restricted root zone or mechanical disruption of the hardpan to achieve a larger root zone. In South Carolina, only a minor fraction of the cotton area has access to irrigation. Thus, under-the-row subsoiling is a recommended production practice for practically the entire cotton area of the Coastal Plain of South Carolina (Roof et al., 1994). Mechanical disruption is generally applied each crop season as studies have shown that the hardpan will reform in a short period of time if not practiced frequently (Busscher et al., 1986). Eliminating or reducing this energy-intensive field operation would significantly ameliorate cotton production costs.

Our study of cotton root penetration of a soil hardpan was motivated in 1985 during an extended drought by the observation that some weed species remained turgid and growing while many crop plants wilted in the same fields. Roots of the turgid weed plants were found to have penetrated the hardpan while few, if any, roots of the wilted crop plants had penetrated the hardpan. In ensuing laboratory study, Kasperbauer and Busscher (1991) demonstrated genotypic differences in the ability of cotton roots to penetrate a compacted layer of soil. The purpose of this report is to summarize root penetration ability of a sample of cotton cultivars and Pee Dee germplasm lines grown in a field during a droughty season and one with abundant rainfall.

Materials and Methods

Genotypes with a range of ancestry were selected from the USDA Cotton Breeding Program. The different genotypes were grown without irrigation in field plots of Norfolk loamy sand near Florence, SC. A hardpan was present about 20 cm below the surface and the plots had not been subsoiled for at least 5 years. Mid-July planting dates were used each year to increase the probability that plants would be exposed to water stress during the hot summer days if roots were limited to the sandy layer above the hardpan.

Plant Responses During a Droughty Season

Ten-meter-long rows were overseeded on 18 July 1986 and seedlings were thinned to about 15-cm spacing soon after emergence. Soil moisture was adequate for quick germination and emergence. However, a severe drought occurred after the plants were 20 to 25 cm tall. The plants were evaluated for shoot and root characteristics 80 days after planting.

Root Development During a Season of Abundant Rainfall

Twenty-four cotton genotypes including 14 cultivars and 10 Pee Dee germplasm lines were evaluated in 1994. Cultivars and germplasm lines were selected for study based on diversity in pedigree (Calhoun et al., 1994) and 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 design with 4 replications. Plots were single rows, 6.5 m long with 1 m spacing between plots. Plots were overseeded by hand on 17 July 1994 and thinned to about 15 cm between plants soon after emergence. No irrigation was applied during the growing season, but abundant rainfall kept the soil moist above the hardpan. In early November, 12 consecutive plants per plot were dug to determine rooting patterns. Each of the 12 roots was scored on a 1-5 scale (Figure 1) for penetration of the hardpan. Roots were scored as follows: 1) roots did not penetrate the hardpan and the entire root mass developed above the compacted layer; 2) taproot entered, but neither the taproot nor lateral roots penetrated through the compacted soil layer; 3) taproot did not penetrate, but one or more lateral roots penetrated through the hardpan; 4) taproot turned at the hardpan surface, travelled laterally until it found a weak spot, and then penetrated through the compacted soil layer; 5) the taproot entered vertically and penetrated the compacted soil layer into the subsoil, resembling root growth in mechanically disrupted subsoils or in soils lacking a hardpan. Since the data consisted of small whole numbers, ANOVAS were conducted using the raw data and transformed data [$(x + 0.5)1/2$; Gomez and Gomez, 1984]. The ANOVAS were conducted using plot means derived from the mean of the 12 roots. Essentially equivalent results were obtained with the raw and transformed data (not shown), thus the raw data were used in the ANOVA and computation of means. Means were separated with Fisher's protected LSD test (Steele and Torrie, 1981).

Results and Discussion

Plant Responses During a Droughty Season

An extended drought during the 1986 season allowed a good test of rooting ability through the hardpan because the soil above the hardpan became very dry. Of the seven cultivars and lines used, four (Acala SJC-1, Coker 201, Coker 315, and PD-1) remained turgid, one (PD-2) exhibited slight wilting, and two (PD 695 and SC-1) wilted severely. Although the rating scale shown in Figure 1 was not in place during this season, review of the descriptive notes taken 80 days after planting indicates that most of the turgid plants would have scored 3 or 4 with a few at 5. That is, lateral and/or taproots penetrated through the hardpan into moist soil below the hardpan. The severely wilted plants had their entire root masses above the hardpan, and they would have received scores of 1 or 2. The next logical step was to study in more detail a sample of commercial cultivars and germplasm from the Pee Dee Cotton Breeding Program to determine the magnitude of variation available for root penetration of a soil hardpan.

Root Development During a Season of Abundant Rainfall

Cotton roots of the 24 genotypes were rated for ability to penetrate a naturally compacted subsoil layer based on whether or not the taproot or any lateral roots were able to penetrate the hardpan (Figure 1). In this manner, we were able to assess genotypic differences in ability of roots to penetrate a compacted subsoil layer during a year with adequate rainfall.

We observed significant differences among genotypes in the ability to penetrate the soil hardpan (Table 1). None of the genotypes had a mean rating between 4 and 5, indicating that root growth of all genotypes was restricted to a degree. The cultivar PD-1 possessed the greatest ability to penetrate the hardpan, while the cultivar SC-1 and germplasm line PD 695 were least able to penetrate the soil hardpan (Table 1). Plants of PD-1 had lateral or taproots that penetrated through the hardpan (rating of 3 or 4 with an occasional 5), while roots of SC-1 or PD 695 were restricted to growing above the hardpan as was observed during the dry season described above. These observations are consistent with an earlier laboratory study by Kasperbauer and Busscher (1991), which demonstrated that roots of PD-1 seedlings could penetrate a compacted soil core and utilize moisture in soil below the compacted core, while roots of PD 695 seedlings could not penetrate cores with the same penetration resistance. As a result, seedlings of PD 695 had more restricted root zones and were dependent on moisture in the soil above the compacted layer. Additionally, PD-1 was determined to have greater root weight per unit length than PD 695 when grown over artificially compacted soil cores (Kasperbauer and Busscher, 1991, and unpublished data). Among cultivars currently recommended for planting in South Carolina, Georgia King penetrated the hardpan best while CB 407 was least able to penetrate the hardpan (Table 1). All of the cultivars and germplasm lines, however, exhibited some restriction of root development when grown over the hardpan.

Given the diversity in pedigree of the genotypes in this study (Calhoun et al., 1994), it is tempting to relate varietal origin to ability of roots to penetrate a soil hardpan. For example, in-row subsoiling was not practiced in the Pee Dee Cotton Breeding Program until after 1970 (T.W. Culp, personal communication). Thus it is possible that during years in which precipitation was marginal and no irrigation was applied that selection of superior plant types in the Pee Dee Cotton Breeding Program prior to 1970 may have been indirectly selected for the ability to penetrate the hardpan or tolerate a restricted root zone. As a result, some Pee Dee germplasm (e.g., PD-1) could retain genes conferring ability to penetrate a soil hardpan that were inherited from Pee Dee germplasm developed prior to the advent of subsoiling. Lines such as SC-1 and PD 695 apparently did not inherit ancestral genes conferring rooting ability through compacted subsoil. In contrast, germplasm developed in areas where soils may not necessarily form hardpans or hardpans with penetration resistances similar to those of the southeastern Coastal Plain of the USA might not have been directly or indirectly selected for ability to penetrate a soil hardpan (e.g., KC 311, parents of the F2 from hybrid CB 407). Grimes et al. (1975) reported that some soils of the central valley of California do not have subsoil hardpans. Presumably there are other soils in cotton-producing areas around the world that may not form hardpans or may not have hardpans with penetration resistances as high as those of the southeastern Coastal Plain.

This study, which utilized a large sample of cultivars and germplasm, demonstrated genotypic differences in rooting ability through a subsoil hardpan. All of the genotypes, however, exhibited some degree of restricted root growth ranging from a slight detour of the taproot at the hardpan surface to the blockage of root penetration of the hardpan by other lines. We plan to further investigate the primary gene pool of G. hirsutum to determine if levels of rooting ability greater than PD-1 exist. Perhaps some of the race stock germplasm derived from tropical and subtropical origin where the climate is characterized by wet/dry cycles may possess genes for root growth through compacted soil. We plan to also study the mode of inheritance of cotton root penetration of a soil hardpan. Once the mode of inheritance is known, we can then more effectively exploit sources of variation in our cotton breeding program to develop high-yielding cotton germplasm with good fiber quality that can be grown less expensively with less dependence on mechanical subsoiling and/or frequent irrigation.

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Table 1. Cotton cultivar and germplasm line pedigrees and mean rating (1-5 scale) for ability to penetrate a naturally compacted subsoil layer at Florence, SC.

Cultivar or Line	Pedigree	Rating
PD-1	PD 4381/PD 8623	3.46
PD 5529	DeltaPine 41/PD 6133	3.35
PD 5358	Delcot 311/PD 5657	3.35
ST Ga King	Tifcot 56/McNair 235	3.29
PD 5363	Delcott 311/PD 6131	3.27
ST LA 887	DES 119/LA 434-RKR	3.17
DP 5415	DP 50/DP 90	3.17
PD 5256	McNair 220/AC 241	3.13
ST Coker 320	Coker 315/McNair 220	3.13
PD 93001 Light Brown	PD-3/Dark Brown	3.13
PD-3	PD 9363/PD 9240	3.10
PD 93002 Dark Brown	PD-3/Dark Brown	3.08
PD 93004 Light Brown	PD-3/Dark Brown	3.06
PD 5472	McNair 235/PD 6184	3.06
DeltaPine 90	DP 6516/DP 6582	3.04
DES 119	DES 24/DES 2134-047	3.02
Acala 1517-88	Acala 1517-77br/DP 70	3.02
PD 93003 Light Brown	PD-3/Dark Brown	3.00
CB 1233	N/A	2.92
SG 1001	McNair 235/DP 90	2.88
ST KC 311	DP 90/McNair 235	2.56
CB 407	N/A	2.21
SC-1	Coker 421/PD 4398	1.94
PD 695	La Frego 2/2*PD 8562	1.79

LSD 0.05=0.28

Figure 1. Cotton roots rated 1, 3, and 5 (L to R) on the scale used to evaluate root development over a hardpan in the field.