To the Graduate Council:

I am submitting herewith a thesis written by Jan Recia Jones entitled "Quantifying the Effects of Soil Erosion on Crop Productivity." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

John G. Graveel, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Vice Provost
and Dean of the Graduate School

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a Master's degree at The University of Tennessee, Knoxville, I agree that the library shall make it available to borrowers under the rules of the library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of the source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Head of Interlibrary Services when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Jan Rena Jones

Date 29 November 1990

QUANTIFYING THE EFFECTS OF SOIL EROSION ON CROP PRODUCTIVITY

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Jan Recia Jones

December, 1990

ACKNOWLEDGEMENTS

I am particularly indebted to the following inidviuals who assisted me through the trials and tribulations of this thesis:

Dr. John G. Graveel, for his guidance, encouragement, and patience—all in paramount proportions.

Dr. Donald D. Tyler, for allowing me the opportunity to work on this rather unique project.

Dr. Dennis R. West, for his comments and suggestions.

Reed Wade, my best friend, for his support, both emotional and technical, without which this work could not have been completed.

My family, for never giving up hope. Thanks, Mom.

Spike the cat, for just being.

ABSTRACT

The effects of soil erosion on yield and root development were determined for soybean (*Glycine max* (L.) Merr.) (1984) and corn (*Zea mays* L.) (1985) grown on Grenada silt loam (Glossic Fragiudalfs) in West Tennessee. Seven sites were selected in a cropped field where depth to the fragipan ranged from 0 to 107 cm below the soil surface. To verify the deep sites were relatively uneroded, selected physical and chemical properties of the 107 and 15 cm sites were compared to an area of Grenada silt loam in Crockett County, Tennessee with no history of cultivation. Across-the-site comparisons involving bulk density, soil color, exchangeable Na, and organic matter indicated that profile modification at the experimental sites had occurred as a result of soil erosion. Soils were sampled to either 90 or 120 cm depths in 15 cm increments at six points each within the row and 25 and 51 cm from the row; subsamples were composited by each depth increment. Four such samplings were made for each site. Roots were extracted and total root length was determined by the line-intercept method. Greater total root lengths were observed with increasing depth to the fragipan. Crop yields were correlated with total root length. Soybean yields ranged from 2.8 Mg ha^{-1} on the 107 cm site to 0.5 Mg ha^{-1} on the 0 cm site, whereas, corn yields ranged from 10.0 Mg ha^{-1} to 5.5 Mg ha^{-1} from the 107 cm site to the 0 cm site, respectively.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The Southern Loess Belt (Buol, 1973) is composed of loessially derived soils in Kentucky, Tennessee, Mississippi, and Louisiana. The soils in this region are predominately Alfisols (Springer and Elder, 1980; Langdale et al., 1985), which tend to be productive but easily eroded due to their high silt contents. Cropland erosion rates are among the nation's highest, ranging from 34 to over 56 Mg $ha^{-1}yr^{-1}$ (Langdale et al.,1985).

Erosion almost always reduces the productive potential of a soil, particularly when there are subsurface features that may impede plant rooting depths. This situation exists in the Tennessee portion of the Loess Belt, where approximately 55% of the uplands have fragipans. In addition, this region constitutes the largest acreage of cropland in the state (Springer and Elder, 1980).

Soil loss has reached a critical level on thousands of acres with root-restrictive fragipans in the Mississippi River Valley (Rhoton and Tyler, 1990). No practical reclamation program is currently available on these soils. This situation is particularly confounding since these soils are derived from loess; no more soil will be formed like that being lost to erosion.

Research quantifying the effects of soil erosion on soil productivity is somewhat limited. As a response to the need for more research in this area, a study was conducted in Fayette County in West Tennessee, where fragipans are present in approximately 70% of the uplands (Flowers et al., 1964). Experimental sites were located within a field with a wide range of depths to the fragipan. Data were collected with respect to crop rooting, crop yields, and soil characteristics. The objectives of the study were to quantify the effects of erosion on soil productivity using root length estimates and yield data and to investigate physical and chemical soil properties and determine how these change with degree of erosion.

CHAPTER 2

LITERATURE REVIEW

Soil Erosion and Productivity

Soil erosion influences the productivity of a soil via the modification of several soil properties important to plant growth; this effect is generally reflected as a reduction in crop yields. Researchers have consistently observed an increase in clay, less organic matter, lower available water- and nutrient-holding capacity, and a decrease in the thickness of the A horizon in eroded soils. A complex interrelationship exists between these changes and the resulting effects on plant growth and productivity; in the field these relationships are not easily separated (Rhoton and Tyler, 1990). Consequently, the experimental results are not always without contradictions due to the diversity of soils and the interaction of chemical, physical, and biological influences that may modify them over time (Crosson, 1983). As a result of this complexity the quantitative data needed to assess the erosion-productivity relationship remain relatively unavailable.

Yet, a uniform conclusion in erosion-productivity studies is that the loss of available soil water-holding capacity is often the most significant yield limiting factor (Rhoton and Tyler, 1990). Erosion reduces the effective rooting zone, particularly in soils with restrictive subfeatures, confining root development and decreasing the volume of soil from which plant roots can extract water. These losses increase the possibility of moisture stress which can culminate in reduced yields.

The restoration of productivity in eroded soils was the focus of a 4 year study by Batchelder and Jones (1972). Lime, fertilizers, irrigation, and the application of straw mulch were needed to restore corn yields on an artificially exposed Groseclose clay loam (Typic Hapludult) containing >50% clay. Initially, low fertility and pH were considered the principal limiting factors in the exposed subsoil. When these problems had been rectified by fertilization and liming the availability of soil water became the significant limiting factor. Mulching promoted increased water use efficiency through reduced surface runoff and improved water infiltration. Over the study period, corn yields increased from 3007 kg ha^{-1} to 9205 kg ha^{-1} on the mulched soil without irrigation.

A watershed study was used to evaluate corn yield reductions on eroded Southern Piedmont soils by Langdale et al. (1979). Corn yields were correlated to soil depth above the Bt horizon. On severely eroded, moderately eroded, and alluvial soils, corn yields averaged 2226, 4674, and 6429 kg ha^{-1}, respectively. In addition to the decrease in soil depth produced by erosion, other yield influencing soil modifications included increased clay and relatively low values of total Kjeldahl N, extractable P, and carbon for the eroded areas. Climatic variations possibly reduced yields on a short term basis, but soil erosion was stated to be the primary long-term cause of corn yield reduction in the Southern Piedmont.

In another Southern Piedmont study, White et al. (1983) similarly observed that crop yields were correlated to soil depth. Erosion had a marked impact on soybean production; yields averaged 2775 kg ha^{-1} for the slightly eroded sites decreasing to 1333 kg ha^{-1} on the severely eroded sites. Soil analyses indicated lower fertility in the eroded soils.

The effects of soil erosion on the properties and productivity of two Kentucky soils were investigated by Frye et al. (1982). Both the Maury and Crider soils (Typic Paleudalfs) had strongly developed profiles and were known to vary in degrees of past erosion. The Ap horizons of the eroded soils were observed to have higher clay content, increased bulk density, less organic matter, and decreased fertility status. Increased clay content was cited as the most obvious effect of erosion. Higher bulk density and lower available water-holding capacity were attributed to this increase. Results indicated that corn grain yields were lower on eroded soils, 12% on the Maury and 21% on the Crider soil. Yield reductions were largely attributed to a 4 to 5% decrease in the available water-holding capacity in the Ap horizon. Damage to a soil's physical properties, particularly soil water-holding capacity, was concluded to be the most injurious to productivity, usually resulting in long-term damage that is difficult to amend.

Soils with subsurface features that may restrict rooting depths comprise a significant portion of the cultivated land in the United States. Erosion may impose considerable damage to these soils over a relatively short period of time and hence pose a special research priority (Meyer et al., 1985) as the damage is difficult and expensive to mitigate. Continued erosion will eventually make crop production uneconomical.

Frye et al. (1983) studied the effects of soil erosion on a Zanesville silt loam (Typic Fragiudalf) containing a fragipan. Erosion from the surface of these soils can result in shallower depths to the pan, reducing the available water-holding capacity. Yet, this effect was not observed, rather available water-holding capacity was not significantly reduced due to the high silt (71%)—low clay content of the illuvial horizon. Instead, a decrease in the volume of soil available for root growth and water storage was the primary factor affecting the water-supplying capacity as demonstrated by lower grain yields associated with decreasing depth for three of the four years of the study. It was suggested that productivity losses would be relatively small on comparable soils without a fragipan, whereas erosion of a soil with a fragipan shallower than 40 to 50 cm would adversely affect productivity.

Erosion-induced changes in the properties of a fragipan soil were the focus of a study by Rhoton and Tyler (1990). Research sites in Mississippi were Grenada silt loam (Glossic Fragiudalfs) with varying degrees of erosion. To assess the changes in soil properties as fragipan depth decreased, these sites were compared to a virgin site in Tennessee. Depth to the fragipan accounted for a major percentage of the variability observed in the chemical properties considered to be unaffected by lime and fertilizer amendments (exchangeable Na, organic matter, extractable Fe and Mn). The modification of soil physical properties was attributed to increased clay content and declining organic matter with depth. Increased surface sealing, runoff, and crusting also contributed to productivity losses, however, decreased available water-holding capacity and available water content were the most yield limiting changes. It was concluded that a minimum depth of 60 cm above the fragipan should maintain productivity in most years.

A decrease in soil depth coupled with a loss of available water-holding capacity was responsible for yield reductions in a study by Olson and Nizeyimana (1988). The impact of soil erosion on corn yields and soil properties of seven soil series in Illinois was investigated; parent materials were either loess or loess overlying glacial till. Restrictive subsoil features, evidenced as either claypans or fragipans, were present in some of the soils. Comparisons of moderately and severely eroded phases were made for each soil, with sites located within the same field. Erosion was most detrimental on soils with root restricting features, a 24% reduction in corn yields as compared with a 5% reduction in soils with no restrictions.

Hairston et al. (1988) investigated the effect of soil depth on soybean yield in the Mississippi Blackland Resource Area where erosion has exposed the parent material, Selma chalk, on many upland sites and sideslopes. Research sites were selected with depths of chalk ranging from 100 to 1500 mm and were predominantly silty clay in texture. With regression analyses, the combination of decreasing soil depth, organic matter, and water storage capacity were determined to be the major factors affecting soybean yields. Yet, the variability observed between soil and climatic factors rendered it difficult to use depth to chalk as a consistent predictor of soil productivity.

Roots

On soils with restrictive subfeatures, such as fragipans, erosion reduces the depth of the rooting zone and decreases the availability of soil water. Additionally, the inherent properties of the fragipan may also influence root growth, particularly those of high bulk density and high soil acidity.

Soil acidity can adversely affect root development when the pH falls below 4.0 (Moore, 1974; Barber, 1984). Toxic metals, primarily aluminum and manganese, are brought into soil solution at this pH level. Generally, these two elements, rather than hydrogen, are the main factors influencing root growth in acid soils. Manganese toxicity is not observed frequently as plants can tolerate higher concentrations (Barber, 1984). Furthermore, manganese is usually more toxic to shoots than to roots (Bennett, 1974).

Aluminum is a common toxic element in soils with low soil pH values and may pose a particular problem in subsoils because their acidity is not easily corrected by liming. The aluminum levels resulting in inhibition of root growth vary with plant species, cultivar, and soil characteristics. Generally, excess soluble aluminum in the soil reduces root penetration and increases the possibility of drought stress (Foy, 1974; Barber, 1984).

Root growth may also be influenced by high bulk density within the soil profile.

Plant roots grow by penetrating through pore spaces and by moving soil particles aside from the root's path. Increases in soil bulk density are accompanied by a decrease in the size of pore spaces. Consequently, root elongation will be reduced, which, in turn, will alter the root's capacity to absorb water and nutrients (Taylor, 1974; Barber 1984).

When adverse soil conditions impose stress on the root system, growth may be reduced or stopped. Translocation of water and nutrients then becomes limited, and the equilibrium that exists between root and shoot growth is disrupted. Under these conditions the plant cannot reach optimum yield (Brown and Scott, 1984).

The absorption and translocation of water and nutrients are the primary functions of a plant's root system, making root density and distribution significant determinants of crop yield. When the environment is favorable the rooting pattern is genetically controlled. Whereas, in most field situations the physical and chemical properties of the soil determine root morphology (Pearson, 1974).

CHAPTER 3

MATERIALS AND METHODS

The study was conducted from 1984 to 1985 in a 94 ha field located in Fayette County in western Tennessee. The experimental area was classified Grenada silt loam (fine-silty, mixed, thermic Glossic Fragiudalfs). Six sites, with the addition of a seventh site in 1985, were established with fragipan depths of 0, 15, 38, 51, 56, 76, and 107 cm below the soil surface with slopes ranging from 0 to 5%. Determination of fragipan depth was achieved by averaging 6 separate depth measurements using a soil tube. Selected chemical characteristics of the top 15 cm for each site are shown in Table 1.

The deepest sites, 107 and 76 cm, were located within a previous homesite area that had been row cropped only 13 to 20 years, while the remainder had probably been continuously cropped for over 50 years. Conventional tillage consisting of moldboard plowing and discing were used in the experimental area. Soybeans (Asgrow 5475) were planted in early June 1984 following a previous crop of soybeans. Phosphorus (P) and potassium (K) were applied at recommended rates based on University of Tennessee soil test results with the exception of eroded areas where the rates were doubled or tripled by the farm operator. Corn (Pioneer 3147) was planted in mid-April of the 1985 growing season. At planting 392 kg of 17-17-17 was applied followed 4 weeks later by 224 kg of ammonium nitrate. For each crop the herbicides used for weed control were those recommended by the University of Tennessee.

Soil samples for root length estimates were collected three times for each crop during the growing season: 17 July, 8 August, and 6 September for soybeans and

Table 1. Selected chemical properties determined by averaging soil test results for samples (0–15 cm) collected at each of the seven sites in Fayette County, Tennessee.

Depth to fragipan	pH	P	K	Organic carbon
–cm–		——kg ha^{-1}——		g kg^{-1}
107	6.5	157V[†]	168M	13
76	6.6	107V	358V	14
56	6.1	45H	190H	9
51	5.7	58H	158M	7
38	5.7	54H	123M	7
15	5.4	49H	168M	5
0	5.1	22M	123M	3

[†]University of Tennessee plant nutrient status rating scale: V=very high, M=medium, and H=high.

6 June, 27 June, and 13 August for corn.

Six separate 6 m row length measurements were used to determine grain yield at each site. Samples were cut in the field, machine threshed, and weighed. Soybeans were adjusted to 13.5% moisture, corn 15.5%.

The soil samples were taken in 15 cm increments down to either 90 or 120 cm soil depths. At each site, four separate samples were taken in the row, and 25 and 51 cm from the row and composited for each 15 cm depth. Roots were separated from the soil by washing the sample through a 40-mesh screen. The remaining material was placed in a container of water, allowing the roots to float to the surface. The water was decanted onto a small 2 mm screen; the roots removed with tweezers and placed in a beaker of water.

Root length was estimated using the line-intercept method (Tennant, 1975). For length estimates a specially designed box was used—characterized by a "box within a box" design. The root sample was poured into the inner box, which had a bottom composed of nylon fabric. The roots were positioned so that no overlapping occurred. After positioning, the inner box was placed into the outer box onto which a $1/2 \times 1/2$ cm grid had been attached. The number of X-Y intercepts between the roots and the grid lines were counted manually. Length estimates were calculated using the following formula:

$$\text{Root Length} = \text{Number of Intercepts} \times \text{Length Conversion Factor } (0.3928)$$

One soil sample from each site was reserved for soil analysis from the first soybean sampling to describe the upper 90 cm of soil. Samples were collected to 120 cm during the second corn sampling. Therefore, one sample was reserved from the additional 30 cm of soil to further characterize the soil profile.

All soil samples were air dried, ground, and sieved to <2 mm. Soil pH was measured both in a 1:1 soil/water suspension and in 0.01 M $CaCl_2$ (McLean, 1982). Exchangeable cations were extracted with 1 M NH_4OAc and then measured by atomic spectroscopy (Thomas, 1982). The potassium chloride method was used to determine exchangeable acidity (Thomas, 1982). Extractable Fe and Mn were determined by atomic absorption spectroscopy following double acid extraction (Gambrell and Patrick, 1982). Particle size analysis was completed using the pipet method (Gee and Bauder, 1986). The saran-coated clod method was used to estimate bulk density (Blake and Hartge, 1986). Total C was determined by dry combustion on a Leco Model CR-12 Carbon Analyzer (Nelson and Sommers, 1982).

Root length data was analyzed by site (depth to the fragipan) to determine the effect of soil depth on root development using the general linear model (GLM) procedure (SAS Institute, 1985).

CHAPTER 4

RESULTS AND DISCUSSION

Sites

To verify the deep sites were relatively uneroded based on depth to the fragipan, selected physical and chemical properties of the 107 and 15 cm sites were compared to an area of Grenada silt loam in Crockett County, Tennessee (Table 2). Dendrological studies established that this 35 ha wooded area was uncultivated, as evinced by the presence of 300 year old trees. Fragipan depth over this area was relatively uniform and averaged approximately 90±10 cm (Rhoton and Tyler, 1990).

Generally, fragipans have inherently high bulk densities, which subsequently serve as diagnostic criteria for these horizons. Increases in bulk densities were observed in the Btx horizons at each site. Upon comparison, bulk densities below the Ap at the 15 cm site correspond to those approximately 90 cm below the surface on the 107 cm site. The virgin A1 and A2 horizons exhibit low bulk density values (1.08 Mg m^{-3}) as compared to the Ap1 and Ap2 horizons of the relatively uneroded 107 cm site. The values observed in these horizons, 1.37 and 1.56 Mg m^{-3}, respectively, occur as a result of tillage compaction. However, the high bulk density of the Ap2 horizon, though comparable with those observed in the fragipan, did not appear to significantly influence root growth. This effect may be attributed to the absence of other characteristics normally associated with fragipans.

The physical property of soil color was also indicative of topsoil removal by erosion. The dark brown color (7.5YR 4/4) of the fragipan horizons (Btx1 and Btx2) could be compared across the sites. However, an increase in the amount of yellow

Table 2. Selected physical and chemical properties of the virgin, deep (107 cm), and shallow (15 cm) sites.

Horizon	Depth	Color (moist)	Bulk density	Exchangeable Na	Organic matter
	—cm—		Mg m^{-3}	$cmol_c$ kg^{-1}	g kg^{-1}
		Virgin			
A1	0-10	10YR 3/2	1.08	0.02	49.8
A2	10-20	10YR 3/3	1.08	0.01	13.7
BA	20-36	10YR 4/4	1.28	0.02	7.3
BW	36-48	10YR 5/6	1.44	0.02	4.4
Bt1	48-64	10YR 5/6	1.51	0.04	2.7
E/Btx	64-74	10YR 6/2	1.54	0.06	2.1
Btx1	74-127	7.5YR 4/4	1.58	0.18	1.5
Btx2	127+	7.5YR 4/4	1.60	0.62	1.0
		Deep (107 cm)			
Ap1	0-11	10YR 4/4	1.37	0.02	16.3
Ap2	11-18	10YR 4/4-5/4	1.56	0.06	6.6
BA	18-30	10YR 5/4	1.45	0.10	4.4
BW	30-47	10YR 5/4	1.41	0.13	2.4
Bt1	47-59	10YR 5/4	1.40	0.15	1.9
E/Btx	59-70	10YR 6/4	1.40	0.15	1.4
Btx1	70-101	7.5YR 4/4	1.55	0.29	1.1
Btx2	101+	7.5YR 4/4	1.56	0.37	0.8
		Shallow (15 cm)			
Ap	0-12	10YR 5/4	1.46	0.04	8.6
E/Btx	12-50	10YR 6/2	1.54	0.13	1.0
Btx1	50-130	7.5YR 4/4	1.50	0.32	1.1
Btx2	130+	7.5YR 4/4	1.51	0.39	0.9

color was observed in the surface horizons of the cultivated sites as compared to the very dark grayish brown (10YR 3/2) color of the virgin A1 horizon. As the depth to the fragipan was reduced by erosion, the incorporation of subsurface material and a decrease in organic matter content resulted in the lighter color of these horizons.

Lime and fertilizer amendments to the cultivated sites modified several soil chemical properties, but exchangeable Na and organic matter were considered unaffected by past amendments and were used for site comparisons. Values for exchangeable Na were higher throughout the profile on the 107 cm site as compared to the virgin site, with the exception of the Btx2 horizon. Closely corresponding values were observed in the E/Btx, Btx1, and Btx2 horizons of the 107 and 15 cm sites, however, a slight increase was noted in the fragipan horizons of the severely eroded site. This data suggests that subsurface horizons with greater Na concentrations have gradually moved toward the surface as erosion has reduced soil depth.

As would be expected, the virgin A1 horizon had a high organic matter content. Whereas, a significantly lower content was observed in the surface horizon of the 107 cm site, indicating that cultivation had resulted in organic matter decomposition. Further organic matter reductions were seen in the Ap horizon of the 15 cm site. Organic matter contents in the fragipan horizons of the 15 cm site parallel those approximately 90 cm below the surface of the 107 cm site. Consequently, it may be assumed that root growth did not advance into the fragipan horizons of the shallow site as no increase in organic matter was observed in these horizons above those recorded at the deep site.

Root development may be adversely affected by the strongly acidic conditions that are generally characteristic of fragipan horizons. Exchangeable acidity levels (Table A.1) observed in the fragipan horizons of the 107 cm site were comparable to those in the BW and Bt1 horizons above the pan. Root length data indicates that elongation was not restricted in horizons above the fragipan at this site. Therefore, acidity does not appear to be a primary factor in root restriction in the fragipan at the experimental sites.

Soybean Root Distribution as Affected by Fragipan Depth

Soybeans were initially sampled on 17 July 1984, following planting in early June. Total root lengths, as measured in 15 cm increments, for the deep (107 cm), intermediate (51 cm) and shallow (15 cm) sites are shown in Figure 1. Although the plants are in an early vegetative phase of growth, the fragipan has begun to influence root development on the shallow site. Measurements from this site were significantly lower in the 0–15, 30–45, and 60–75 cm increments as compared to the deep site, while intermediate site measurements were not significantly different as compared to the deep site at any depth increment.

The second sampling date for soybeans was 8 August, which represented the peak blooming and pod setting stage of development. This is a critical point in the growing season as water stress during this period can result in yield reductions (Doss et al., 1974). Total root lengths for the deep (107 cm), intermediate (51 cm) and shallow (15 cm) sites are shown in Figure 2. Measurements on the shallow site were significantly lower at all depths except the 60 to 75 and the 75 to 90 cm increments as compared to the deep site. Whereas, the intermediate site measurements were significantly lower only at 45–60 cm, the location of the fragipan, when compared to the deep site. This data is most demonstrative of the restrictive nature of the fragipan to root development.

Total root lengths and soybean yields for the six experimental sites relative to fragipan depth are shown in Figure 3. Root length values decreased significantly

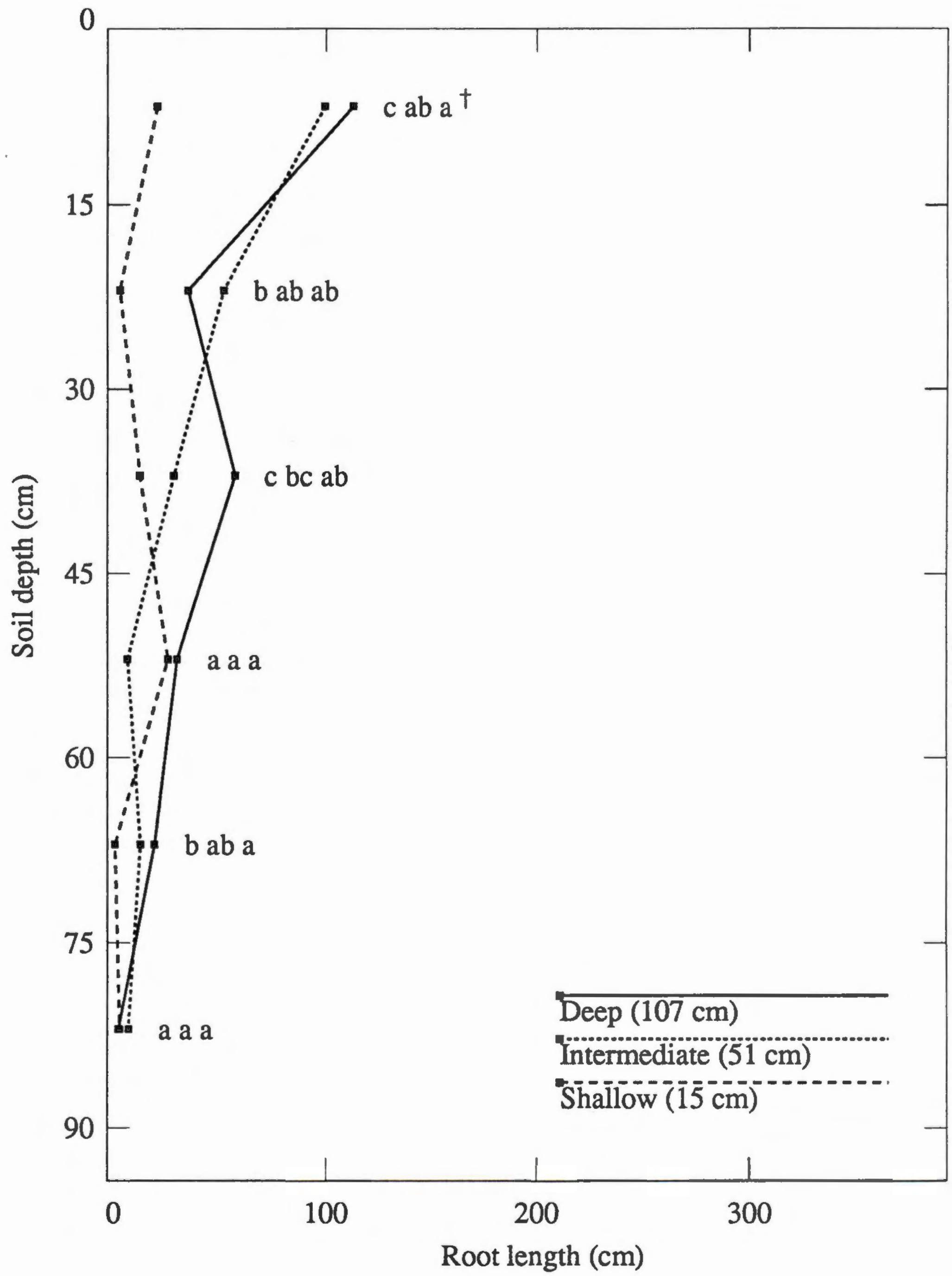

Figure 1. Soybean root length for sites with deep, intermediate, and shallow depths to the fragipan on 17 July 1984.

†Data shown are for three of the six sites. Refer to Table A.2 for the 38, 56, and 76 cm sites. For each depth in Figure 1 values followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range test.

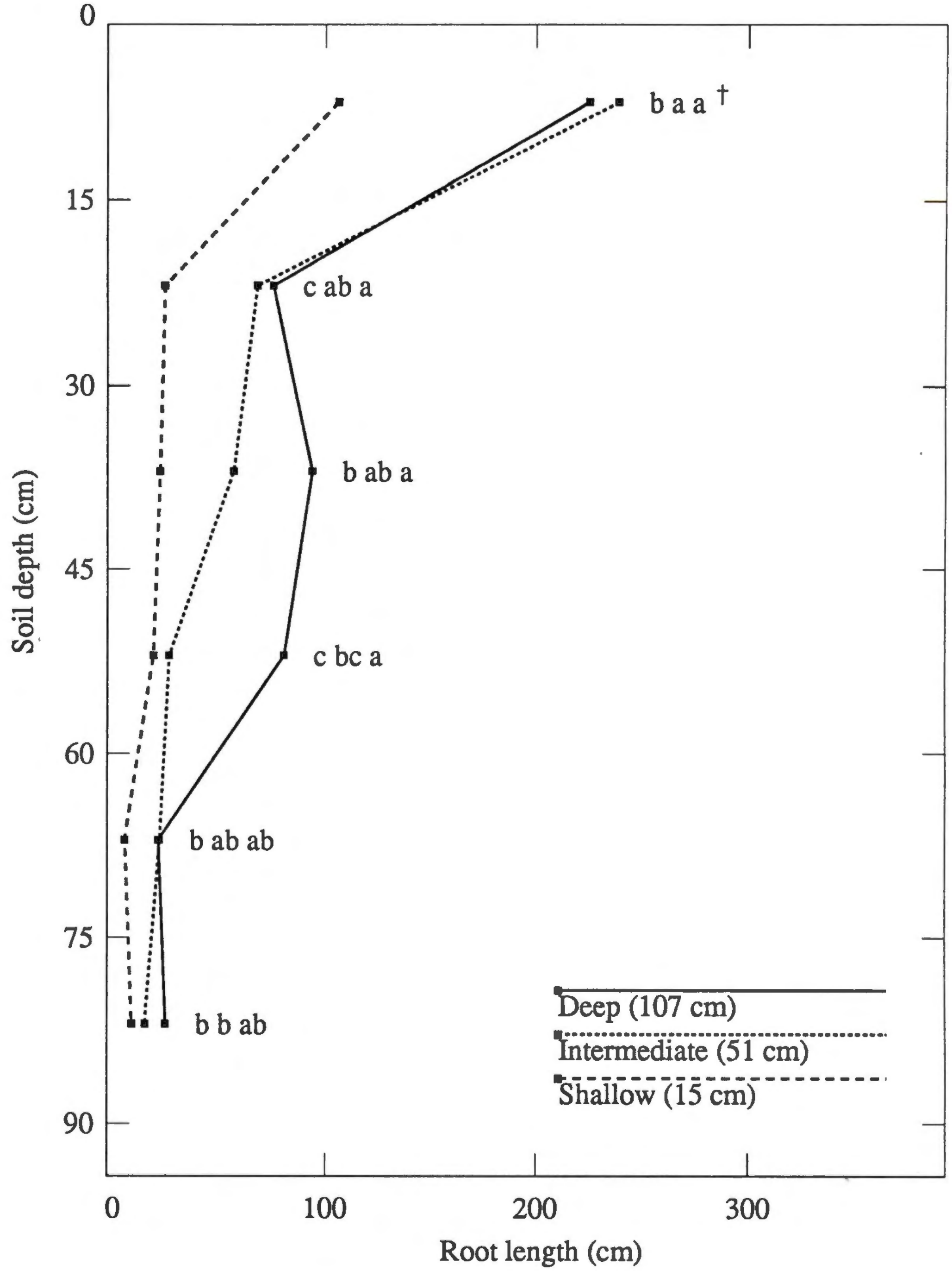

Figure 2. Soybean root length for sites with deep, intermediate, and shallow depths to the fragipan on 8 August 1984.

†Data shown are for three of the six sites. Refer to Table A.3 for the 38, 56, and 76 cm sites. For each depth in Figure 2 values followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range test.

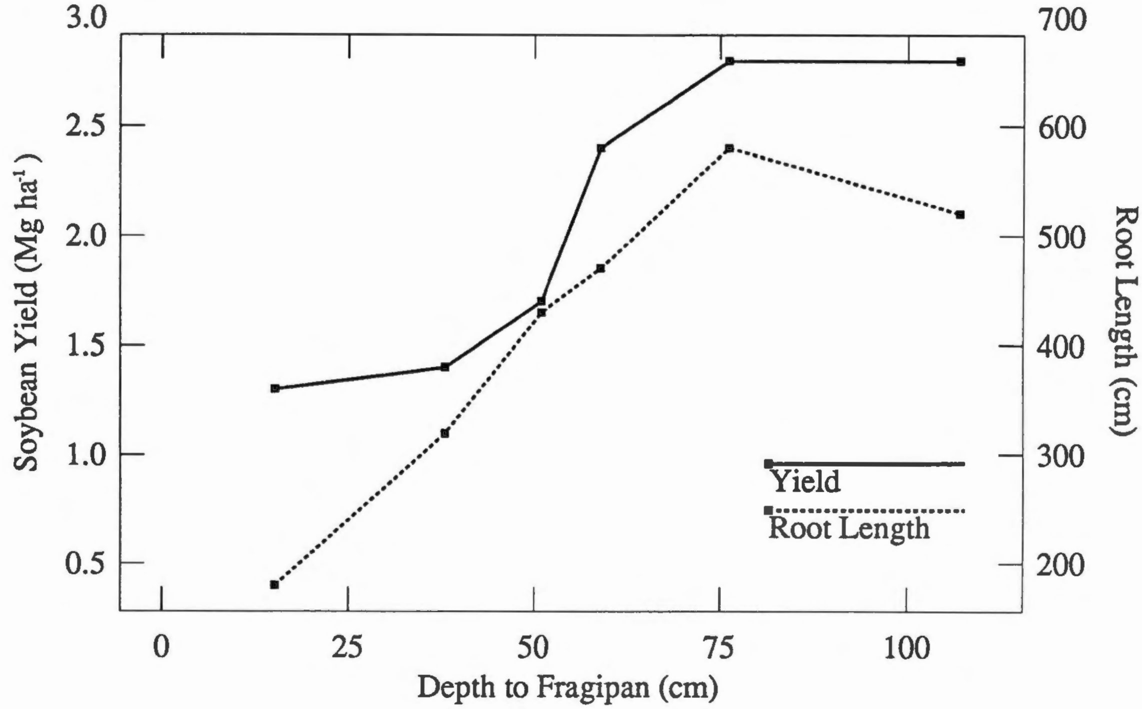

Figure 3. Soybean yield and total root length (8 August sampling) for the six sites relative to the depth of the fragipan.

from the deep sites to the shallow site, between 500 and 600 cm to less than 200 cm, respectively. Soybean yields maintained a similar pattern. Yields of 2.7 Mg ha^{-1} were observed on the deepest site and dropped to 1.3 Mg ha^{-1} on the shallow site. As expected, the yield for the intermediate site falls between these values. Yields on the 0 cm site were 0.5 Mg ha^{-1} (Table 3).

Total root length measurements for the three sites on the final sampling date, 6 September, are shown in Figure 4. The plants at this growth stage are at physiological maturity. Soybean roots were concentrated in the top 30 centimeters of soil. No significant differences in root lengths were observed beyond this depth. However, root lengths were significantly different in the 0–15 cm depths for both the intermediate and shallow sites as compared to the deep site.

Corn Root Distribution as Affected by Fragipan Depth

Corn was planted in the experimental area in mid-April 1985 and was initially sampled on 6 June. Total root lengths, as measured in 15 cm increments, for the deep (107 cm), intermediate (51 cm), and shallow (15 cm) sites are presented in Figure 5. Measurements from the shallow site were significantly lower when compared to the deep site at the 15–30 and 30–45 cm increments. As with soybeans, early corn root growth is restricted by the decreased depth to the fragipan on the shallow site. Intermediate site measurements were significantly lower at the 30–45 cm increment as compared to the deep site.

Corn had entered the silking stage when the second sampling was completed on 27 June. Total root lengths for the site are shown in Figure 6. Sensitivity to moisture stress is greatest during this developmental phase, resulting in a reduction in kernel number (Claassen and Shaw, 1970). Significant differences in root lengths

Table 3. Soybean yield and total root length (8 August sampling) for the seven sites relative to the depth of the fragipan.

Average Depth to Fragipan	Root Length	Yield
cm		$Mg\ ha^{-1}$
107	520.3	2.8±0.2[†]
76	579.9	2.8±0.1
56	473.5	2.4±0.2
51	425.8	1.7±0.1
38	318.0	1.4±0.2
15	184.2	1.3±0.1
0[‡]	—	0.5±0.03

[†]95% confidence interval
[‡]No root length measurement

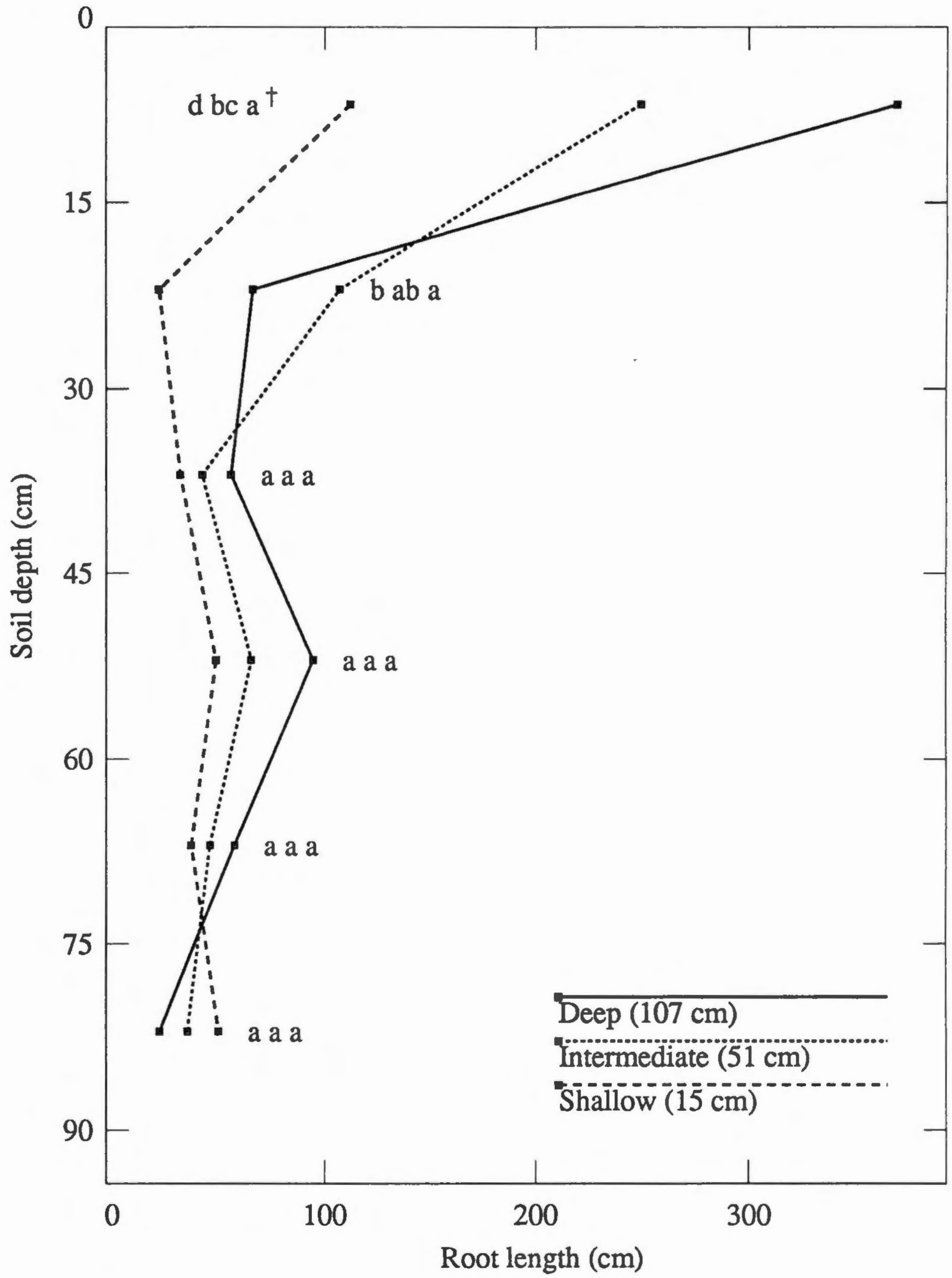

Figure 4. Soybean root length for sites with deep, intermediate, and shallow depths to the fragipan on 6 September 1984.

†Data shown are for three of the six sites. Refer to Table A.4 for the 38, 56, and 76 cm sites. For each depth in Figure 4 values followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range test.

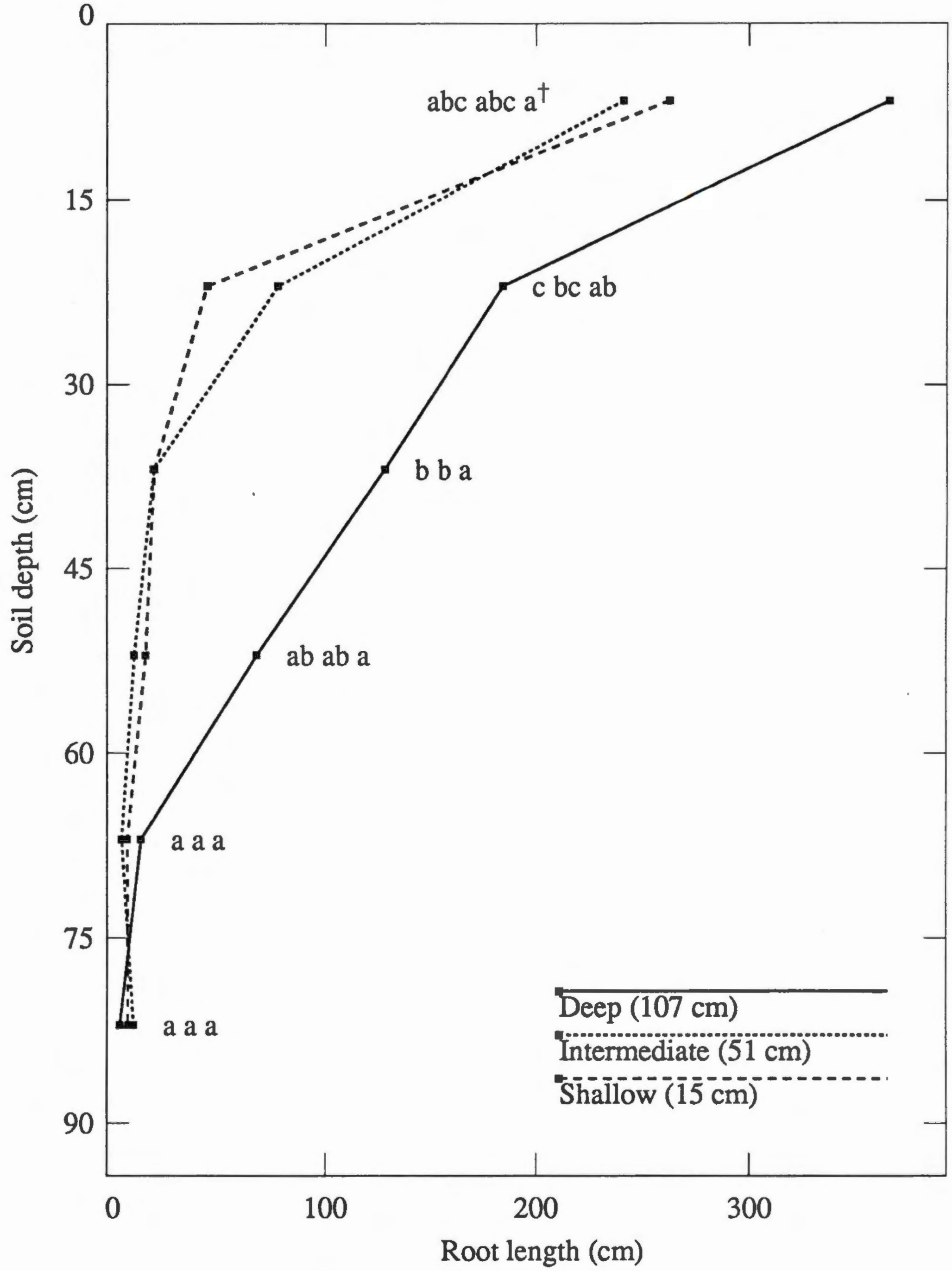

Figure 5. Corn root length for sites with deep, intermediate, and shallow depths to the fragipan on 6 June 1985.

†Data shown are for three of the six sites. Refer to Table A.5 for the 38, 56, and 76 cm sites. For each depth in Figure 5 values followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range test.

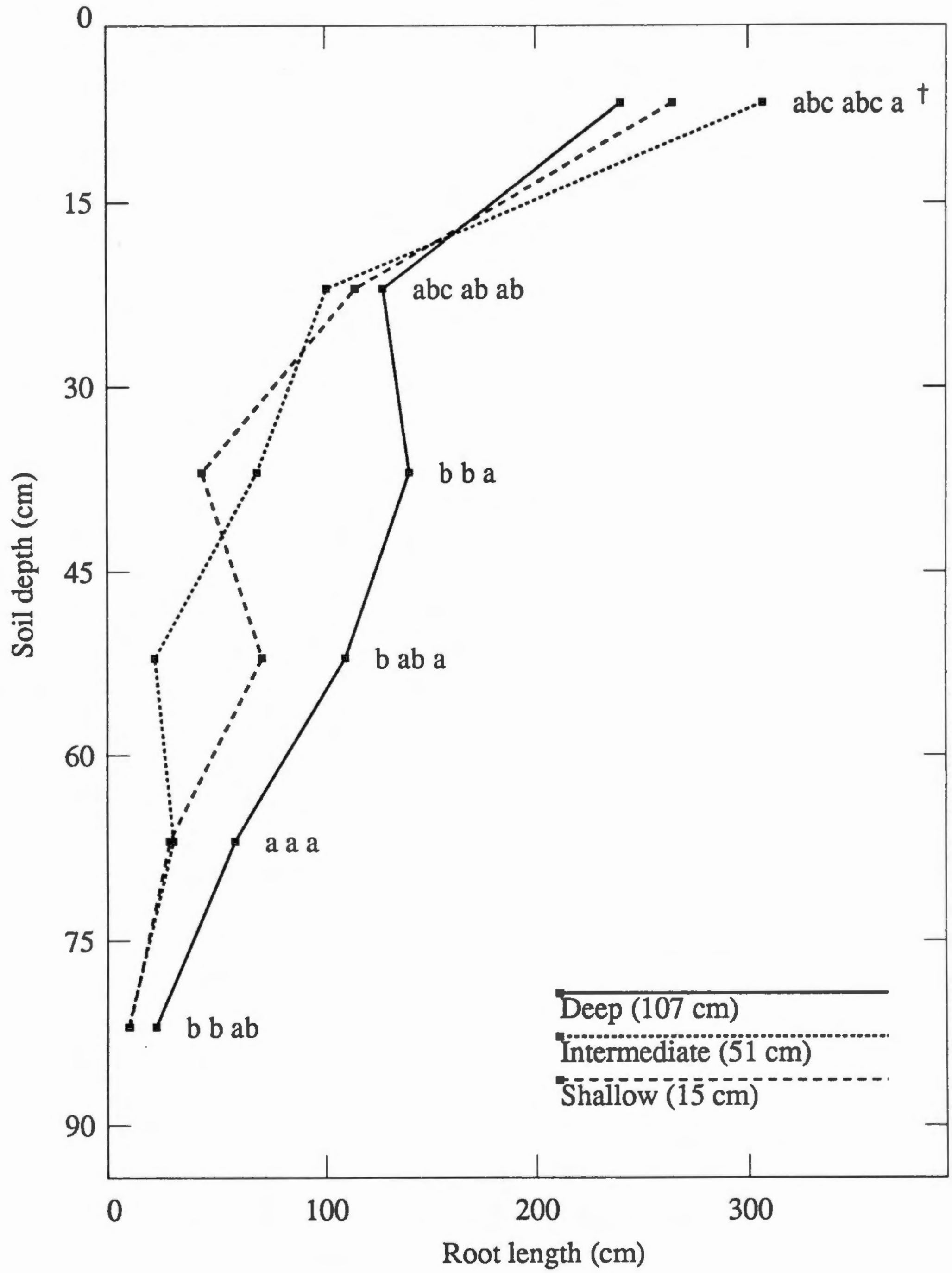

Figure 6. Corn root length for sites with deep, intermediate, and shallow depths to the fragipan on 27 June 1985.

†Data shown are for three of the six sites. Refer to Table A.6 for the 38, 56, and 76 cm sites. For each depth in Figure 6 values followed by the same letter are not significantly different at P≤0.05 according to Duncan's Multiple Range test.

were observed at the shallow site only at the 30–45 cm increment as compared to the deep site. While intermediate site measurements were significantly lower at the 30–45 and 45–60 cm depths.

The final sampling for corn was 13 August, which corresponded to the end of the grain-fill period. Total root lengths are shown in Figure 7. Compared to the deep site, shallow site measurements were significantly lower at the 0–15 and 45–60 cm depths. Whereas, measurements at the intermediate site were significant at the 0–15, 45–60, and 60–75 cm increments.

Total root lengths and corn yields for the six experimental sites relative to fragipan depth are shown in Figure 8. The relationship between yield and total root length was not as distinct as that observed with soybeans, but the general patterns of yield reductions associated with shallower fragipan depths were evident. Yields of 10.0 Mg ha^{-1} were observed on the 107 cm site and decreased to 6.7 Mg ha^{-1} on the 15 cm site. A further yield reduction of 5.5 Mg ha^{-1} was recorded at the exposed fragipan site (Table 4).

Crops growing on shallow soils are more susceptible to water stress, particularly during growing seasons without adequate rainfall. Sufficient rainfall with even distribution was observed in 1985 (Table 5) as compared to lower rainfall with uneven distribution in 1984 (Table 6). The relative differences in yields recorded for corn and soybeans, two-fold and six-fold, respectively, correspond to the rainfall patterns.

Three distinct yield ranges could be distinguished for corn in 1985. Essentially identical yields were observed at the deepest sites. Another division of reduced, but similar, yields was noted at the 56 and 51 cm intermediate sites, followed by a third closely corresponding set at the 38, 15, and 0 cm sites. Whereas, 1984 soybean yields were divided into only two ranges, there being a significant yield reduction between the 56 and 51 cm sites. Thus, it may be concluded that the loss of available soil

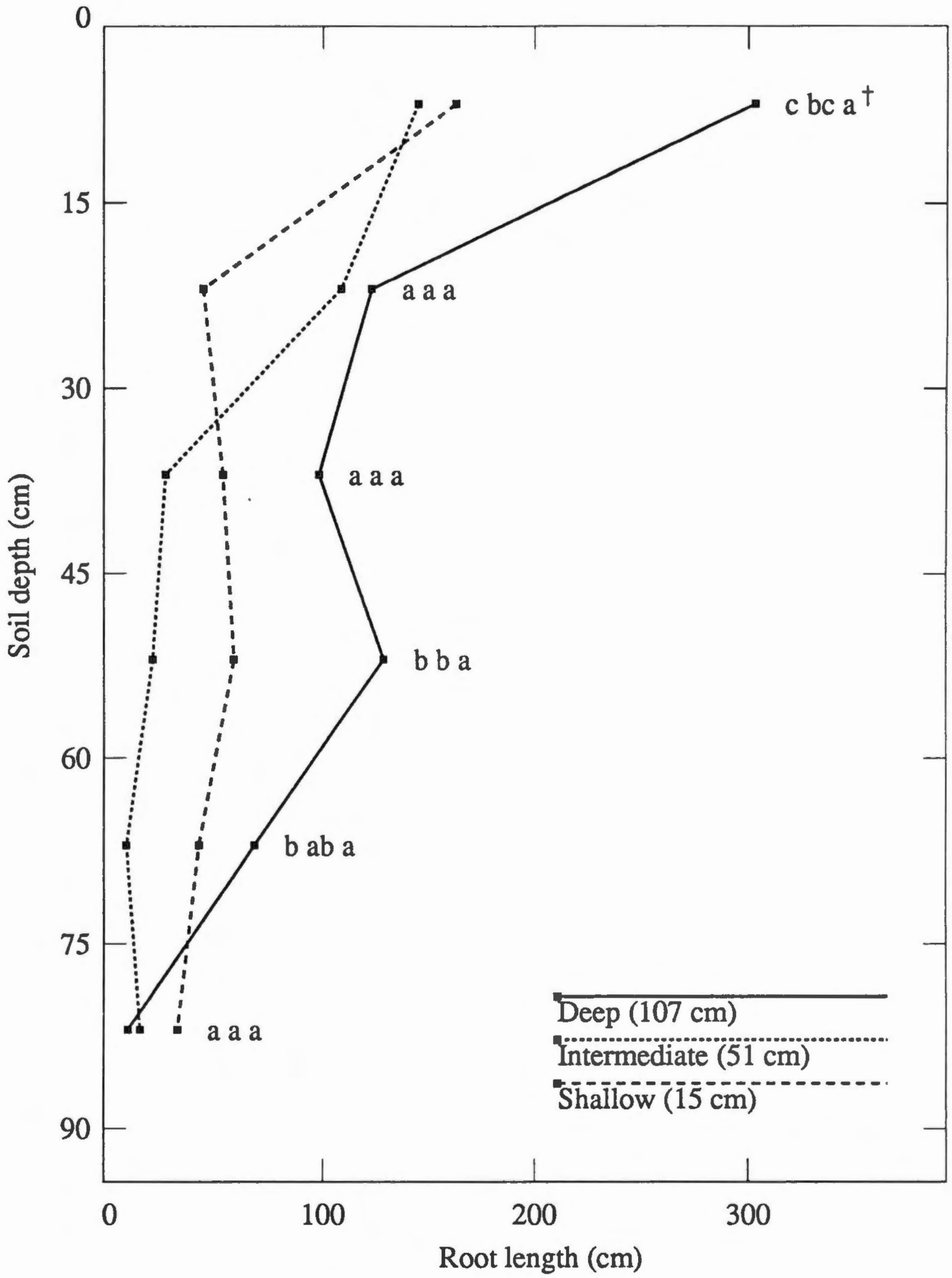

Figure 7. Corn root length for sites with deep, intermediate, and shallow depths to the fragipan on 13 August 1985.

†Data shown are for three of the six sites. Refer to Table A.7 for the 38, 56, and 76 cm sites. For each depth in Figure 7 values followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range test.

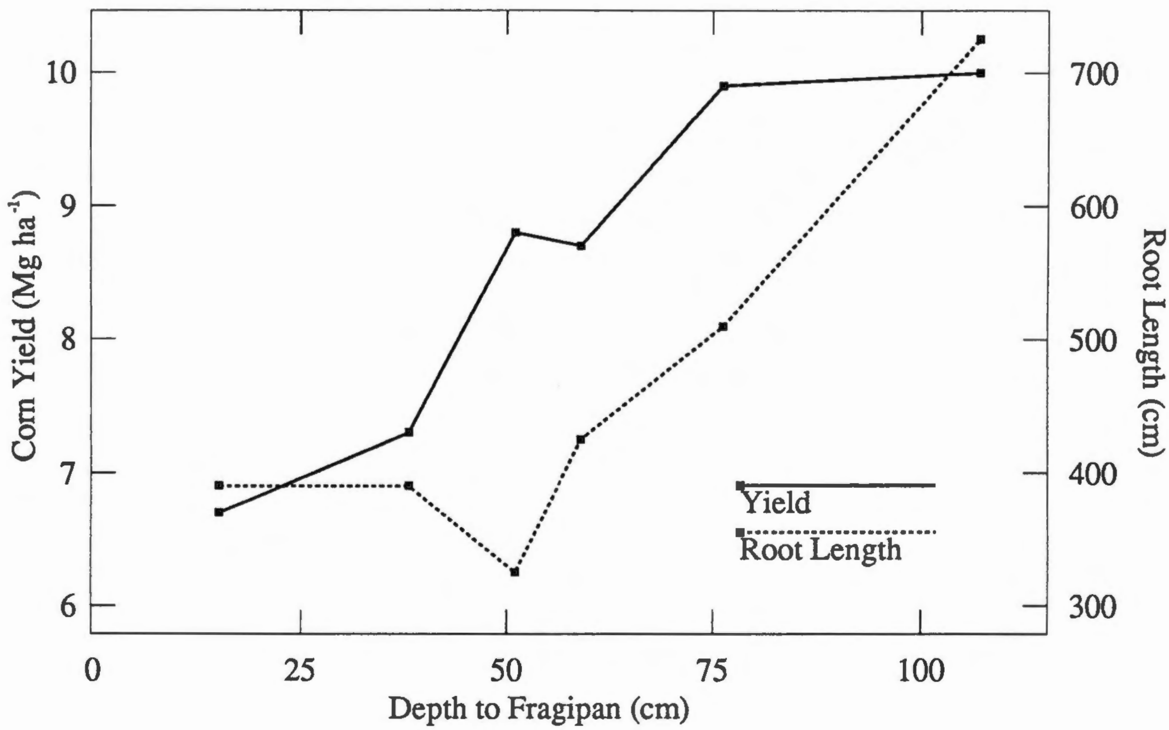

Figure 8. Corn yield and total root length (13 August sampling) for the six sites relative to the depth of the fragipan.

Table 4. Corn yield and total root length (13 August sampling) for the seven sites relative to the depth of the fragipan.

Average Depth to Fragipan	Root Length	Yield
——cm——		$Mg\ ha^{-1}$
107	729.1	10.0±0.6†
76	509.0	9.9±0.9
56	430.8	8.7±0.8
51	320.7	8.9±0.9
38	376.1	7.4±0.4
15	390.6	6.7±0.9
0‡	—	5.5±0.7

†95% confidence interval
‡No root length measurement

Table 5. Rainfall recorded from 1 April to 30 September 1985 in Mason, Tennessee.

Date	April	May	June	July	August	September
	mm					
1–7	8	48	0	33	28	0
8–14	10	5	15	5	10	0
15–21	3	61	30	13	38	0
22–28	94	25	33	30	33	30
29–30/31	0	3	8	0	0	51
Total	115	142	86	81	109	81

Table 6. Rainfall recorded from 1 April to 30 September 1984 in Mason, Tennessee.

Date	April	May[†]	June	July	August	September
	mm					
1–7	33	—	8	0	8	28
8–14	15	—	5	5	3	15
15–21	61	—	0	43	0	3
22–28	36	—	13	20	25	13
29–30/31	23	—	0	0	3	0
Total	168	165	26	68	39	59

[†]No daily measurements were taken.

water-holding capacity and water-supplying capacity, resulting from decreased depth to the fragipan, are the primary yield limiting factors when rainfall is inadequate during the growing season.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Selected physical and chemical properties of the 107 and 15 cm experimental sites as compared to a virgin area in Crockett County, Tennessee indicated that profile modification at the cultivated sites had occurred as a result of erosion. Thus, depth to the fragipan can be used to estimate the degree of past erosion that has occurred on the Grenada series.

Total root lengths and crop yields for both soybeans and corn were reduced significantly as depth to the fragipan decreased. However, the effects of reduced soil depth on plant productivity were more pronounced when rainfall was inadequate throughout the growing season. The loss of available soil water-holding and water-supplying capacities were concluded to be the primary factors limiting crop productivity in these soils.

Continued erosion will eventually make crop production uneconomical as damage to soil water-holding capacity is difficult and expensive to mitigate. This research observed significant yield reductions when there was less than 50 cm of soil above the fragipan. As no practical reclamation program is currently available on these soils, the development of management strategies that maintain the soil above the critical depth should be emphasized.

BIBLIOGRAPHY

BIBLIOGRAPHY

Barber, S.A. 1984. Soil nutrient bioavailability. p. 136–159. John Wiley & Sons, Inc. New York, NY.

Batchelder, A.R., and J.N. Jones, Jr. 1972. Soil management factors and growth of *Zea mays* L. on topsoil and exposed subsoil. Agron. J. 64:648–652.

Bennett, A.C. 1974. Toxic effects of aqueous ammonia, copper, zinc, lead, boron, and manganese on root systems. p. 669–683. *In* E.W. Carson (ed.) The plant root and its environment. University of Virginia Press, Charlottesville, VA.

Blake, G.R., and K.H. Hartge. 1986. Bulk density. *In* A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agronomy 9:363–375.

Buol, S.W. 1973. Soils of the southern states and Puerto Rico. Southern Cooperative Series Bull. No. 174. North Carolina State Univ., Raleigh, NC.

Brown, D.A., and H. Don Scott. 1984. Dependence of crop growth and yield on root development and activity. p. 101–136. *In* S.A. Barber and D.R. Bouldin (ed.) Roots, nutrient and water influx, and plant growth. Proc. Symp., Anaheim, CA. 28 Nov.–3 Dec. 1982. SSSA, CSSA, ASA. Madison, WI.

Claassen, M.M., and R.H. Shaw. 1970. Water deficit effects on corn. II. Grain components. Agron. J. 62:652–655.

Crosson, P.R. 1983. Productivity effects of cropland erosion in the United States. p. 23–28. Resources for the future. Washington, DC.

Doss, B.D., R.W. Pearson, and H.T. Rogers. 1974. Effect of soil water stress at various growth stages on soybean yields. Agron. J. 66:297–299.

Flowers, R.L., J.A. Phillips, W.C. Mangrum, R.K. Moore, and L.A. Dungan. 1964. Soil survey of Fayette County, Tennessee. USDA Soil Cons. Serv., Washington, DC.

Foy, C.D. 1974. Effects of aluminum on plant growth. p. 601–642. *In* E.W. Carson (ed.) The plant root and its environment. University of Virginia Press, Charlottesville, VA.

Frye, W.W., S.A. Ebelhar, L.W. Murdock, and R.L. Blevins. 1982. Soil erosion effects on properties and productivity of two Kentucky soil. Soil Sci. Soc. Am. J. 46:1051–1055.

Frye, W.W., L.W. Murdock, and R.L. Blevins. 1983. Corn yield-fragipan depth relations on a Zanesville soil. Soil Sci. Soc. Am. J. 47:1043–1044.

Gambrell, G.W., and W.H. Patrick, Jr. 1982. Manganese. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agronomy 9:313–322.

Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. *In* A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agronomy 9:383–409.

Hairston, J.E., J.O. Sanford, F.E. Rhoton, and J.G. Miller. 1988. Effect of soil depth and erosion on yield in the Mississippi Blacklands. Soil Sci. Soc. Am. J. 52:1458–1463.

Langdale, G.W., J.E. Box, Jr., R.A. Leonard, A.P. Barnett, and W.G. Fleming. 1979. Corn yield reduction on eroded Southern Piedmont soils. J. Soil Water Conserv. 34:226–228.

McLean, E.O. 1982. Soil pH and lime requirement. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agronomy 9:199-223.

Meyer, L.D., F.E. Rhoton, and K.G. Renard. 1985. Soil erosion-soil productivity: a look to the future. p. 266–277. *In* D.K. McCool (ed.) Erosion and soil productivity. Proc. Natl. Symp. on Erosion and Soil Productivity, New Orleans, LA. 10–11 Dec. 1984. ASAE, St. Joseph, MI.

Moore, D.P. 1974. Physiological effect of pH on roots. p. 135–151. *In* E.W. Carson (ed.) The plant root and its environment. University of Virginia Press, Charlottesville, VA.

Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agronomy 9:539–577.

Olson, K.R., and E. Nizeyimana. 1988. Effects of soil erosion on corn yields of seven Illinois soils. J. Prod. Agric. 1:13–19.

Pearson, R.W. 1974. Significance of rooting pattern to crop production and some problems of root research. p. 247–270. *In* E.W. Carson (ed.) The plant root and its environment. University of Virginia Press, Charlottesville, VA.

Rhoton, F.E., and D.D. Tyler. 1990. Erosion-induced changes in the properties of a fragipan soil. Soil Sci. Soc. Am. J. 54:223–228.

SAS Institute. 1985. SAS/STAT Guide for personal computers. Version 6 ed. SAS Institute, Inc., Cary, NC.

Spring, M.E., and J.A. Elder. 1980. Soils of Tennessee. Univ. of Tennessee Agric. Exp. Stn. Bull. 596.

Taylor, H.M. 1974. Root behavior as affected by soil structure and strength. p. 271–291. *In* E.W. Carson (ed.) The plant root and its environment. University of Virginia Press, Charlottesville, VA.

Thomas, G.W. 1982. Exchangeable cations. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agronomy 9:159–164.

Tennant, D. 1975. A test of a modified line intersect method of estimating root length. J. of Ecol. 63:995–1001.

White, A.W., Jr., R.R. Bruce, A.W. Thomas, G.W. Langdale, H.F. Perkins, and R.L. Wilson. 1983. Effect of soil erosion on soybean production in the Southern Piedmont of Georgia. Agron. Abst. 75:205.

APPENDIX

Table A.1. Supplemental chemical and physical data from the virgin, deep, and shallow sites.

Horizon	Depth	Sand	Silt	Clay	pH H_20	pH $CaCl_2$	Exchangeable Ca	Exchangeable Mg	Exchangeable K	Exchangeable Acidity	Exchangeable Al	Exchangeable H	CEC	Extractable Fe	Extractable Mn
	-cm-	%	%	%			cmol$_c$ kg^{-1}							mg kg^{-1}	
Virgin															
A1	0-10	0.5	82.1	17.4	6.5	5.8	8.4	3.1	0.5	0.1	0.1	0.0	12.1	2.8	287.0
A2	10-20	0.4	82.7	16.9	5.3	4.5	1.3	1.6	0.3	1.4	1.2	0.2	4.6	37.0	259.0
BA	20-36	2.6	79.3	18.1	5.1	4.4	1.4	2.4	0.3	1.6	1.4	0.2	5.7	58.4	191.0
BW	36-48	3.1	78.0	18.9	5.0	4.4	1.6	3.3	0.3	2.6	2.3	0.3	7.8	60.9	146.0
Bt1	48-64	3.6	75.8	20.6	4.7	4.1	1.2	3.1	0.2	4.7	4.3	0.4	9.2	66.4	51.9
E/Btx	64-74	3.5	74.8	21.7	4.6	4.1	1.2	3.7	0.2	6.2	5.6	0.6	11.4	63.5	34.8
Btx1	74-127	2.7	71.1	26.2	4.4	4.1	1.9	5.6	0.2	7.4	6.7	0.7	15.3	92.0	47.2
Btx2	127+	1.2	77.9	20.9	4.7	4.2	3.2	7.5	0.2	2.3	1.6	0.7	13.8	60.2	34.6
Deep (107 cm)															
Ap1	0-11	1.1	87.6	11.3	6.1	5.8	5.8	1.2	0.3	0.1	0.0	0.0	7.4	45.5	239.0
Ap2	11-18	0.8	75.9	23.3	5.6	5.4	6.3	2.5	0.2	0.2	0.2	0.0	9.3	51.3	133.0
BA	18-30	1.3	71.0	27.7	5.1	4.7	5.2	3.9	0.1	1.4	1.2	0.2	10.8	63.0	78.4
BW	30-47	2.7	74.6	22.7	5.0	4.5	3.5	3.6	0.1	2.5	2.2	0.3	9.9	79.5	102.0
Bt1	47-59	5.0	77.5	17.5	5.0	4.3	2.4	3.1	0.1	2.7	2.2	0.5	8.5	79.2	132.0
E/Btx	59-70	4.9	80.3	14.8	5.0	4.3	2.0	3.0	0.1	2.5	2.0	0.5	7.8	72.0	130.0
Btx1	70-101	2.4	78.8	18.8	4.8	4.2	2.3	4.1	0.1	2.7	2.1	0.6	9.6	72.8	89.1
Btx2	101+	1.6	82.2	16.2	5.2	4.4	2.7	4.2	0.1	1.8	1.3	0.5	9.2	73.1	85.6
Shallow (15 cm)															
Ap	0-12	9.0	77.7	13.3	5.7	5.4	5.5	1.7	0.3	0.1	0.1	0.0	7.7	34.0	103.0
E/Btx	12-50	7.0	77.5	15.5	4.8	4.4	2.4	3.4	0.2	2.0	1.6	0.4	8.1	60.8	118.0
Btx1	50-130	2.5	80.5	17.0	4.9	4.3	2.7	4.1	0.2	2.0	1.6	0.4	9.3	67.6	81.2
Btx2	130+	1.8	82.5	15.7	5.2	4.6	3.4	3.8	0.1	1.2	0.9	0.3	9.0	69.2	81.2

Table A.2. Soybean root length at three sites with varying depths to the fragipan on 17 July 1984.

Soil depth	Average depth to fragipan (cm)		
	76	56	38
	cm		
0-15	54.3bc†	94.4ab	55.5bc
15-30	66.0a	54.1ab	32.6ab
30-45	62.3a	7.5c	28.2bc
45-60	19.1a	12.2a	15.1a
60-75	7.2ab	15.6ab	5.6ab
75-90	7.7a	11.8a	1.7a

†Values are the means of four sub-samples; means in the same row followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range test.

Table A.3. Soybean root length at three sites with varying depths to the fragipan on 8 August 1984.

Soil depth	Average depth to fragipan (cm)		
	76	56	38
	cm		
0-15	233.1a†	208.1a	137.1b
15-30	99.6a	76.3a	32.1bc
30-45	65.7ab	43.5b	34.1b
45-60	69.6ab	67.2ab	66.4ab
60-75	65.1a	48.4ab	36.0ab
75-90	46.8a	30.0ab	12.3b

†Values are the means of four sub-samples; means in the same row followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range test.

Table A.4. Soybean root length at three sites with varying depths to the fragipan on 6 September 1984.

Soil depth	Average depth to fragipan (cm)		
	76	56	38
	cm		
0-15	320.3ab[†]	295.0ab	172.0dc
15-30	84.5ab	75.0ab	26.5b
30-45	51.8a	32.7a	34.6a
45-60	62.8a	68.3a	44.8a
60-75	73.0a	92.3a	83.0a
75-90	66.5a	29.3a	42.8a

[†]Values are the means of four sub-samples; means in the same row followed by the same letter are not significantly different at P≤0.05 according to Duncan's Multiple Range test.

Table A.5. Corn root length at four sites with varying depths to the fragipan on 6 June 1985.

Soil depth	Average depth to fragipan (cm)			
	76	56	38	0
	cm			
0-15	192.6bc†	383.6a	340.9ab	166.0c
15-30	165.2ab	167.9ab	215.4a	88.4bc
30-45	48.5b	37.1b	54.5b	42.0b
45-60	13.2ab	6.2b	42.1ab	1.3b
60-75	8.2a	4.8a	30.2a	2.1a
75-90	7.8a	3.4a	18.2a	0.5a

†Values are the means of four sub-samples; means in the same row followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range test.

Table A.6. Corn root length at three sites with varying depths to the fragipan on 27 June 1985.

Soil depth	Average depth to fragipan (cm)		
	76	56	38
	cm		
0-15	297.6ab†	220.2bc	196.0c
15-30	144.6a	44.9c	65.9bc
30-45	83.0ab	49.3b	58.7b
45-60	28.1b	64.0ab	58.9ab
60-75	47.3a	22.9a	25.2a
75-90	38.7a	14.8ab	1.5b

†Values are the means of four sub-samples; means in the same row followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range test.

Table A.7. Corn root length at three sites with varying depths to the fragipan on 13 August 1985.

Soil depth	Average depth to fragipan (cm)		
	76	56	38
	cm		
0–15	208.2abc[†]	279.4ab	169.8bc
15–30	116.1a	59.0a	53.9a
30–45	77.8a	37.8a	27.2a
45–60	44.2b	22.2b	28.3b
60–75	29.4ab	22.3ab	64.7a
75–90	33.3a	10.1a	32.2a

[†]Values are the means of four sub-samples; means in the same row followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range test.

VITA

Jan Recia Jones was born ♡ a small cracker February 12, 1960 in McMinnville, Tennessee. She graduated from Warren County Senior High in June 1978.

In September 1978 she entered the University of Tennessee in Knoxville where she received a Bachelor of Arts degree in Anthropology in August 1982.

She began study toward a Master's degree in Plant and Soil Science in September 1984. This degree was awarded in December 1990.