THE REJUVENATION OF SOILS IN THE UPPER COASTAL PLAIN OF GEORGIA

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ABSTRACT

During the 19th century, the Coastal Plain and Piedmont of Georgia were intensely farmed, with cotton being the economically dominant crop. With the decline of cotton production in the early 20th century, many fields were abandoned and returned to forest land. The Georgia Geologic Survey and the National Resource Conservation Service entered into a joint agreement to carry out a study to determine if soil rejuvenation has occurred in these reforested areas.

A study area was selected in southeastern Sumter County, approximately 60 miles south-southwest of Macon, Georgia, and approximately 1 mile west of Lake Blackshear. The study site contains sub-areas of mature forest, cultivated land, and reforested land. Other variables in the study area, such as soil type, geology, climate, and physiography, are generally constant.

Samples were collected from fifteen pits and three hand-auger holes. Each pit was sampled for grain size analysis, specific gravity, and thin-sections. Auger samples were used for major element analysis, minor element analysis, and measurements of pH, carbon dioxide, and total organic carbon. Detailed soil descriptions were made from one pit in each sub-area.

The cultivated sub-area differs from the mature forest sub-area in soil structure, reduced porosity, decreased Loss on Ignition, decreased CaO, decreased Ba, decreased CO_2, decreased total organic carbon, and increased specific gravity. The soil from the reforested sub-area is intermediate between the cultivated sub-area and the mature forest sub-area in all of these variables. We therefore conclude that rejuvenation of the soils in the reforested area is under way but not complete after 45 years of reforestation.

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1.0 INTRODUCTION

During the 19th century, the Coastal Plain and Piedmont of Georgia were intensely farmed, with cotton being the economically dominant crop. With the decline of cotton production in the early 20th century (Hodler and Schretter, 1986), many fields were abandoned and returned to forest land. Some of these fields have remained uncultivated for almost one hundred years (Hodler and Schretter, 1986) and may be undergoing soil rejuvenation. Such rejuvenated soils exhibit improved porosity, moisture retention, infiltration rates, and thickening of the soil profile.

Ground water is the primary source of water for drinking, industry and agriculture in the Georgia Coastal Plain. The recharge areas for the aquifers that supply this water coincide with the areas of intense agricultural use during the 19th Century. Rejuvenation of these soils would enhance the recharge of the aquifers and would provide additional justification for expanded protection of the ground-water recharge areas.

During August of 1997, the Georgia Geologic Survey and the National Resource Conservation Service (Agreement No: 65-4310-7) entered into a joint contract with Dr. Juri Chendev to carry out a study of soil rejuvenation in an area of previous intense cultivation.

2.0 OBJECTIVE AND SCOPE

The objective of the current investigation was to determine if soils in abandoned crop lands in Georgia are undergoing rejuvenation. This was done by comparing the soil characteristics of abandoned crop land that has been reforested, with soil from land that has remained under intensive cultivation, and with soil from land that has never been cultivated. Variables such as soil type, geology, climate, and physiography, were held constant by confining the investigation to a single, 129 acre site.

An initial assumption of this investigation is that cultivation will alter some soil variables. We assume that pre-cultivation values for these variables are approximated in the soil from areas currently covered with a mature forest. For the purposes of this investigation, rejuvenation is defined as the return of variables, altered by cultivation, toward pre-cultivation values.

3.0 DESCRIPTION OF THE STUDY AREA

3.1 Location

Criteria for the selection of the study area were that it falls within the Fall Line recharge area for Coastal Plain aquifers and within the area of previous intense cultivation. In addition, the study area would have to lie within a single soil series and contain mature forest land, reforested abandoned agricultural land, and land currently under cultivation. As many other variables (such as physiography and geology) as possible should also be constant within the selected area.

The area selected for the investigation is a rectangular plot located in southeastern Sumter County, approximately 60 miles south-southwest of Macon, Georgia, and approximately 70 miles southeast of Columbus, Georgia (Figure 1). It is situated approximately 0.6 miles north of the Sumter-Lee County line and approximately 1 mile west of Lake Blackshear. It is located between Lime Creek and Choree Creek in the Flint River watershed and is approximately 2,000 feet wide, in an east-west direction, by 2,800 feet long, in a north-south direction (as measured from aerial photography). The southern portion of the study area (south of Fish Road) is on a property (the Wheatley Tract) owned by the University of Georgia, and the northern portion of the study area (north of Fish Road) is on the farm of Mr. Troy Dinkins (Figure 2).

3.2 Physiography

The study area lies within the Fall Line Hills District of the Coastal Plain physiographic province. The Fall Line Hills District is characterized by Clark and Zisa (1976) as: "...highly dissected with little level land except the marshy floodplains and their better drained, narrow stream terraces. Stream valleys lie 50 to 250 feet below the adjacent ridge tops." Within the study area elevations range from slightly less than 290 to slightly more than 300 feet above sea level. A very slight rise traverses the area from northeast to southwest producing slopes of approximately 2 degrees to the northwest and the southeast.

No streams occur within the study area itself. An unnamed, intermittent tributary of the Flint River lies immediately southeast. The headwaters of Collins Branch, an intermittent tributary of the Flint River, lies immediately to the southwest of the study area.

3.3 Climate

The summers in Sumter County are long, warm and humid with an average daily maximum temperature of 91°F in August. The temperature reaches 100°F or more for five or six days during the summer. Winters are mild with an average daily minimum temperature of 39°F in January. Freezing temperatures occur on 30 to 40 days during the winter. Annual rainfall is approximately 50 inches per year. (Pilkinton, 1974)

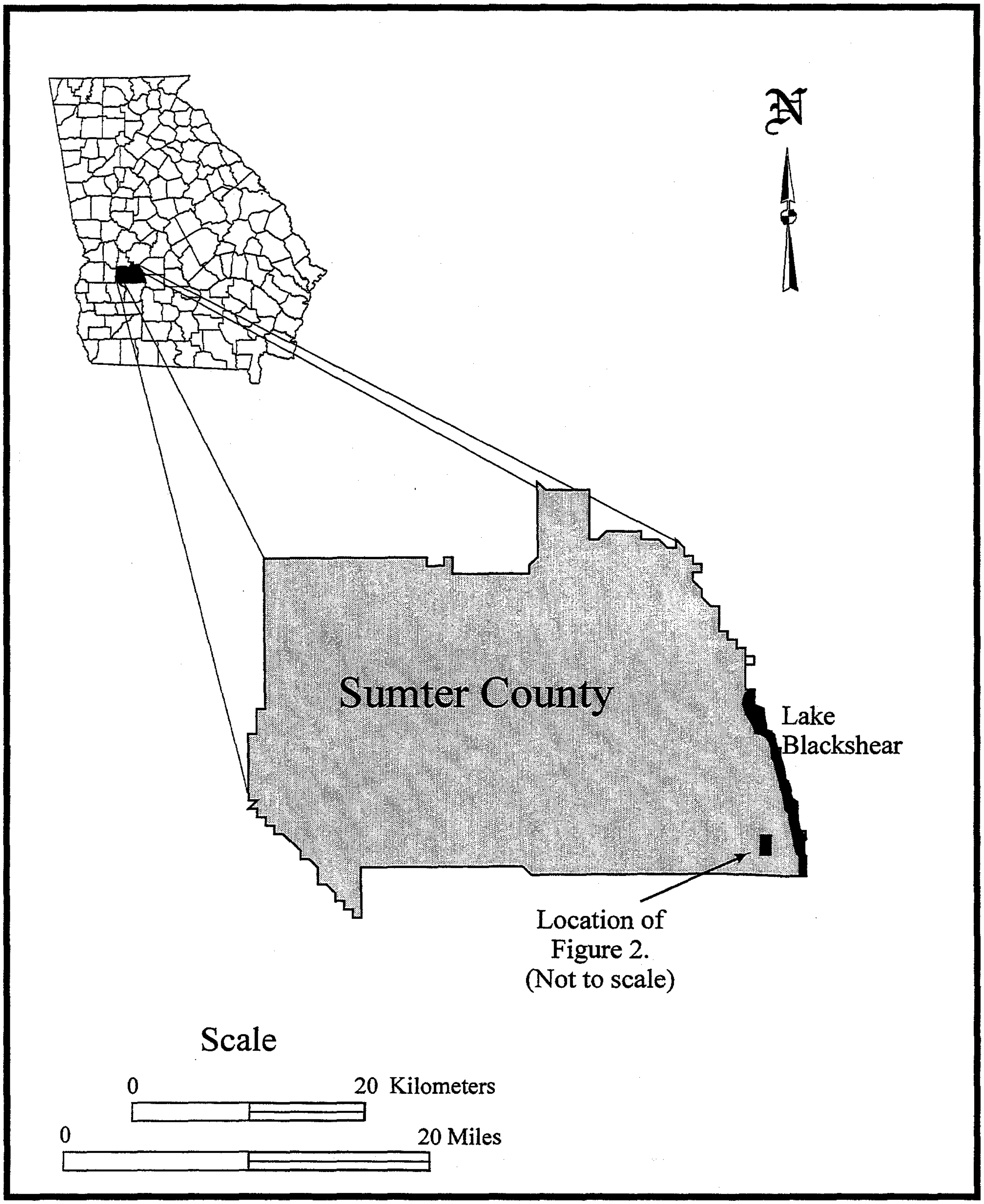

Figure 1. Location of study area.

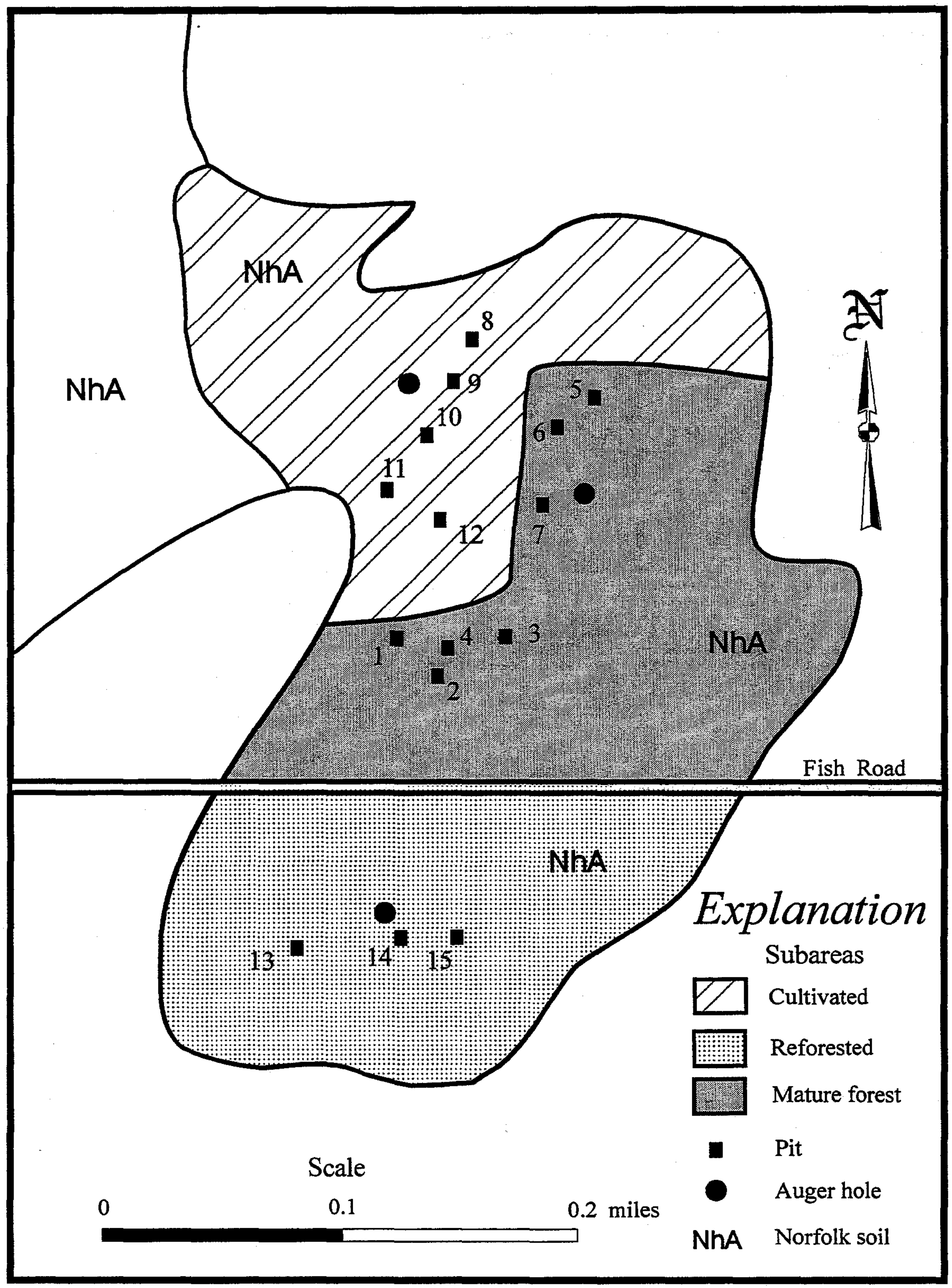

Figure 2. Map of study area showing location of pits and auger holes. Pits and auger holes are not shown to scale. Area marked "NhA" is underlain by the Norfolk loamy sand, 2 to 5 percent slopes.

3.4 Geology

Sumter County is underlain by Paleocene- and Eocene-age sediments of the Coastal Plain Geologic Province. Paleocene-age Clayton, Nanafalia, Tuscahoma Formations, and the Eocene-age Claiborne Formation crop out in the stream valleys. Interfluve areas are capped by residuum of Eocene-age Ocala Limestone and stratigraphically undetermined Oligocene-age limestones (Georgia Geologic Survey, 1976).

The study area lies within the outcrop area of the Eocene-Oligocene residuum. This residuum consists of a brick-red to light yellow, sandy clay to clayey sand. Sand fraction is fine- to coarse-grained and contains fragments of silicified Eocene and possibly Oligocene limestone that range in size from pebbles to boulders. This residuum can be up to 40 feet thick. For the details of the geology of Sumter County see Owen (1963).

3.5 Soils

Five soil types occur in the study area. These include the Norfolk, Orangeburg, Goldsboro, Grady, and Rains soil series (Pilkinton, 1974). Sampling was confined to the area underlain by the Norfolk soil series (Figure 2). The Norfolk soil series consists of well-drained, nearly level to very gently sloping soils on uplands (Pilkinton, 1974). The specific soil phase occurring within the study area is the "Norfolk loamy sand, 2 to 5 percent slopes."

3.6 Vegetation

The study area contains three sub-areas based on vegetation. These include a sub-area covered by mature forest, a reforested sub-area, and a sub-area currently under cultivation.

The mature forest sub-area is characterized by an association of scarlet oak (*Quercus coccinea*), southern red oak (*Quercus falcata*), water oak (*Quercus nigra*), goldenrod (*Solidago sp.*), wax myrtle (*Myrica ceriferus*), grass (*Agrostis sp.*), and long leaf pine (*Pinus palustri*). Current flora of the reforested sub-area includes heather (*Calluna vulgaris*), aster (Asteraceae sp.), wax myrtle (*Myrica ceriferus*), goldenrod (*Solidago sp.*), reed (*Phragmites sp.*), pig weed (*Chenopodium album*), and ticklegrass (*Agrostis hyemalis*). Prior to harvesting in 1994, the reforested sub-area was planted in long leaf pine (Timothy Harrington, 1998, personal communication). The cultivated sub-area is planted in millet and peanuts.

3.7 Land Use

Sumter County is 485.3 square miles in area with 52% of the area in forestland and the remainder in urban and cropland use. The forestland consists of hardwoods, mixed hardwood and pine, and pine forests. Major crops in the county are peanuts, corn, wheat, soybeans, and cotton (Boatright and Bachtel, 1998)

Within the study area, the reforested sub-area was under cultivation until the early 1950's. In 1953, the sub-area was planted with pine trees. These trees were harvested in 1994. Shrubs and grasses currently cover the sub-area.

The cultivated section of the study area has been under cultivation since at least 1937 (based on aerial photography) and was planted in millet at the time of the study. The mature forest sub-area has been in forest since at least 1937 (based on aerial photography).

4.0 METHODS

4.1 Field Methods

Samples were collected from fifteen pits and three hand-auger holes (Figure 2). Three pits were dug in the reforested sub-area, five pits in the cultivated sub-area, and seven pits in the mature forest sub-area. All field measurements were recorded in the metric system. Each pit was approximately 2 meters long by 1 meter wide, and was dug to the water table (approximately 40 centimeters). The hand-auger holes (located immediately adjacent to the central pit in each sub-area) were advanced at 10 centimeter intervals to a depth of 1.7 meters using a 3-1/4" AMS clay bucket.

Each pit was sampled for grain size analysis, specific gravity, and thin-sections. Channel samples, of approximately 200 grams, were collected at 10 centimeter intervals from the top to the bottom of each pit for grain size analysis. Grab samples for specific gravity were obtained by driving a steel tin (8 centimeters in diameter) into the side of the pit at 8 centimeter intervals from the surface to approximate water table depth. Intact samples for thin-section analysis were collected from the side of each pit at depths of 0-8 centimeters, 10-18 centimeters, and 22-30 centimeters. Each sample measured approximately 8 centimeters long, 6.5 centimeters wide and 3 centimeters deep.

The auger samples were used for geochemical analysis. Channel samples of approximately 200 grams were taken at 10 centimeter intervals.

Detailed soil descriptions were made from one pit in each sub-area. A Munsell Soil Color Chart was used to describe soil colors.

4.2 Laboratory Methods

Most laboratory procedures followed specifications established by the American Society for Testing and Materials (ASTM). Specific procedures are specified by number (for example ASTM D 422-63). Details of individual procedures are available in ASTM publications.

Sieve and hydrometer analysis of the soils was carried out following ASTM D 422-63. Analyses were performed by Atlanta Testing and Engineering, Duluth, Georgia. Samples were analyzed from three pits from each sub-area (pits 5, 6, 7, 8, 9, 10, 13, 14, and 15).

Specific gravity analyses of the samples were carried out in accordance with ASTM D 854-83. Analyses were performed by the Georgia Department of Transportation Materials and Testing Laboratories, Forest Park, Georgia. Samples were analyzed from three pits from each sub-area (pits

5, 6, 7, 8, 9, 10, 13, 14, and 15).

For thin-sections, samples were first vacuum impregnated with epoxy. Thin-sections were prepared by Spectrum Petrographics, Inc., Winston, Oregon. Samples were analyzed from one pit from each sub-area (pits 5, 9, and 13).

Major element and trace element analysis of the samples was carried out using research quality Fusion-ICP. Analyses were performed by Activation Laboratories Ltd., Ancaster, Ontario, Canada. Samples were analyzed from one pit from each sub-area (pits 7, 9, and 14). Detection limits for all major elements were 0.01%. Detection limits for trace elements were: 2 ppm for Ba, Sr, Y, Zr, Sc; 1 ppm for Be; and 5 ppm for V.

Carbon dioxide (CO_2) analysis was performed by assay by Activation Laboratories Ltd., Ancaster, Ontario, Canada. Detection limit for CO_2 was 0.05%. Total organic carbon was determined following ASTM D 2974-71. Analyses were performed by Atlanta Testing and Engineering, Duluth, Georgia. The detection limit for total organic carbon was 0.01%. Samples for CO_2 and total organic carbon were analyzed from one pit from each sub-area (pits 7, 9, and 14).

Ten (10) gram splits of each sediment sample were used for pH measurements. Each sediment split was mixed with 25 milliliters of deionized water in a 100-milliliter beaker. The material was allowed to settle to the bottom of the beaker, and the pH of the liquid was taken using a Hydac U-10 digital multimeter. The procedure was repeated for a second 10-gram split, and the two values were averaged. Samples were analyzed from one pit from each sub-area (pits 7, 9, and 14).

5.0 RESULTS

5.1 Detailed Soil Descriptions

Detailed descriptions of the soils in the three sub-areas are presented in Table 1 (mature forest sub-area), Table 2 (cultivated sub-area), and Table 3 (reforested sub-area). In general, these soil descriptions are consistent with the Norfolk Series soils described by Pilkinton (1974) in Schley and Sumter Counties. The major difference is that Pilkinton (1974) noted "yellowish brown" to "strong brown" mottles at depths of 76 to 102 centimeters (30 to 40 inches) and gray mottles at depths of 102 to 127 centimeters (40 to 50 inches). These mottles were not observed during the current investigation.

The major descriptive differences between the soils observed in the three sub-areas are the lack of an organic layer (O) in the cultivated sub-area, the substitution of a plowed horizon (Ap) in the cultivated sub-area for the A1 horizon in the mature forest sub-area, and the presence of a thin plowed horizon (Ap) below A1 horizons in the reforested sub-area.

5.2 Geochemistry

The results of the major element geochemical analyses are shown in Table 4. Results of trace element geochemical analyses are shown in Table 5. Results of pH measurements are given in Table

6. CO_2 measurements are given in Table 7. Total organic carbon measurements are given in Table 8. Variations with depth for major elements are shown in Figure 3, for trace elements in Figure 4, for pH in Figure 5, for CO_2 in Figure 6, and for total organic carbon in Figure 7.

Major element and trace element geochemistry show that, in general, SiO_2 (Figure 3h), CaO (Figure 3b), and MnO (not illustrated because all samples deeper than 50 centimeters are below the detection level) decrease with increasing depth. Al_2O_3 (Figure 3a), Fe_2O_3 (Figure 3c), TiO_2 (Figure 3i), V (Figure 4d), and Sc (Figure 4b) increase with increasing depth. K_2O (Figure 3d), MgO (Figure 3f), P_2O_5 (Figure 3g), Ba (Figure 4a), and Y (Figure 4e) peak at intermediate depths. Loss on ignition (LOI) peaks at the surface, decreases, and then increases with increasing depth (Figure 3e). Although pH exhibits considerable variability, it generally decreases with increasing depth in all three sub-areas (Figure 5). Carbon dioxide (CO_2) decreases with increasing depth (Figure 6). All three sub-areas exhibit a trough in the concentration of total organic carbon at 20-50 centimeters (Figure 7).

Mature forest, cultivated, and reforested sub-areas differ in Loss on Ignition, CaO, Ba, CO_2, and total organic carbon (Figures 3e, 3b, 4a, 6, and 7). The differences occur only within the upper 5 to 10 centimeters. For all five variables, the mature forest sub-area exhibits relatively high concentrations, the cultivated sub-area shows low concentrations, and the reforested sub-area shows intermediate concentrations.

5.3 Grain Size Distribution

Results of the grain size analyses are shown in Table 9. The three sub-areas show no significant differences in grain size distribution.

5.4 Specific Gravity

The results of the specific gravity analyses are shown in Table 10 and Figure 8. The upper 8 centimeters of soil from the cultivated sub-area has a much higher specific gravity than soils from either the mature forest or reforested sub-areas. Within the upper 8 centimeters, there is no significant difference in specific gravity between the mature forest and the reforested sub-areas. Below 8 centimeters there are no significant differences between any of the three sub-areas.

5.5 Thin Sections

Tracings from thin-sections in the upper 3 to 8 centimeters of each sub-area are shown in Figure 9. Major differences between the sub-areas are apparent in the distribution of porosity of the soils (Figure 9).

Soil from the mature forest sub-area has a large amount of pore space (approximately 25%). Pores have a uniform distribution and have a preferential horizontal orientation. Average width of pores is 3 to 4 millimeters.

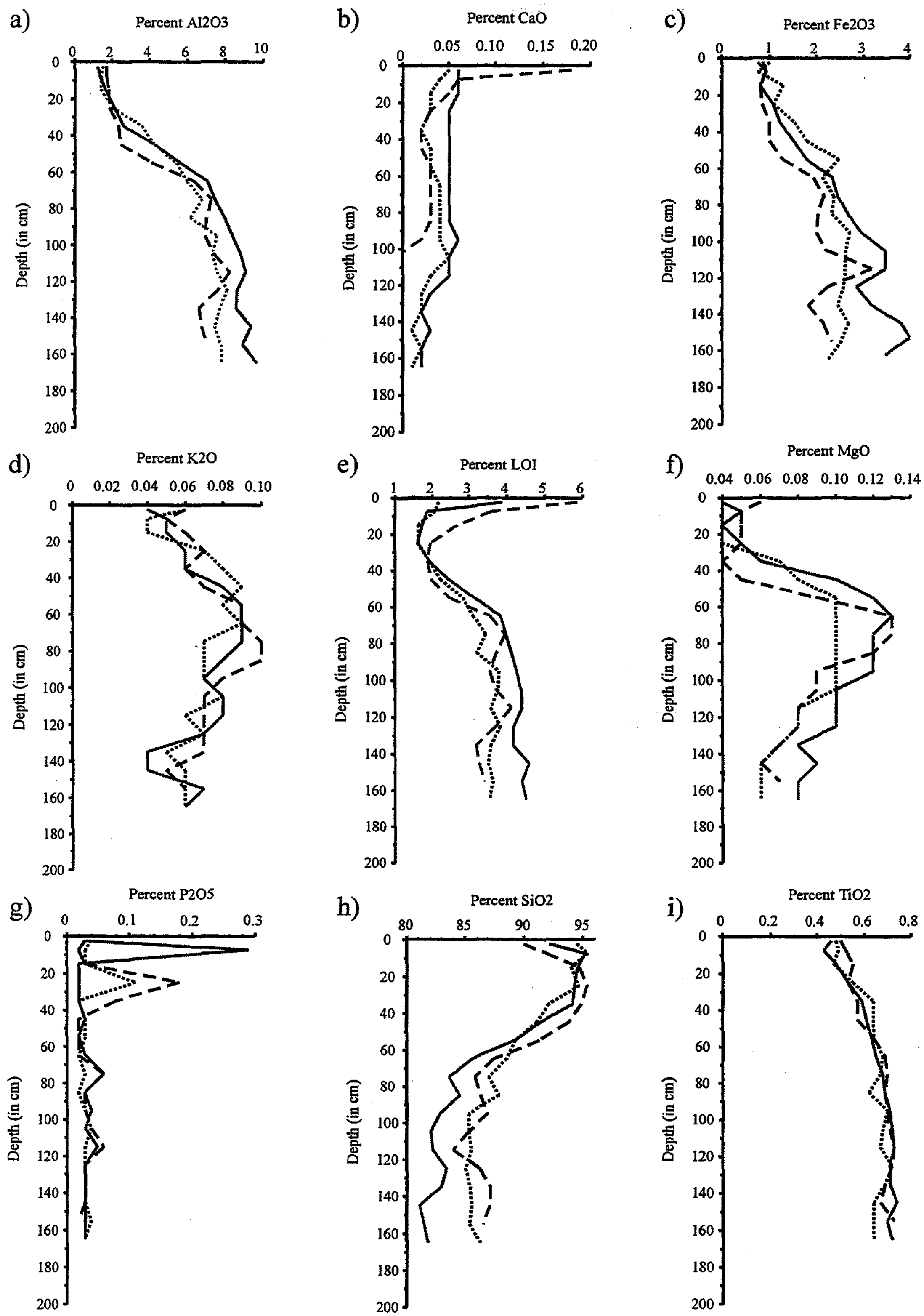

Figure 3. Variation of major element geochemistry with depth. Arranged in alphabetic order. Dotted line is the cultivated sub-area. Dashed line is the mature forest sub-area. Solid line is the reforested sub-area. MnO and Na_2O not shown because most values are below detection level.

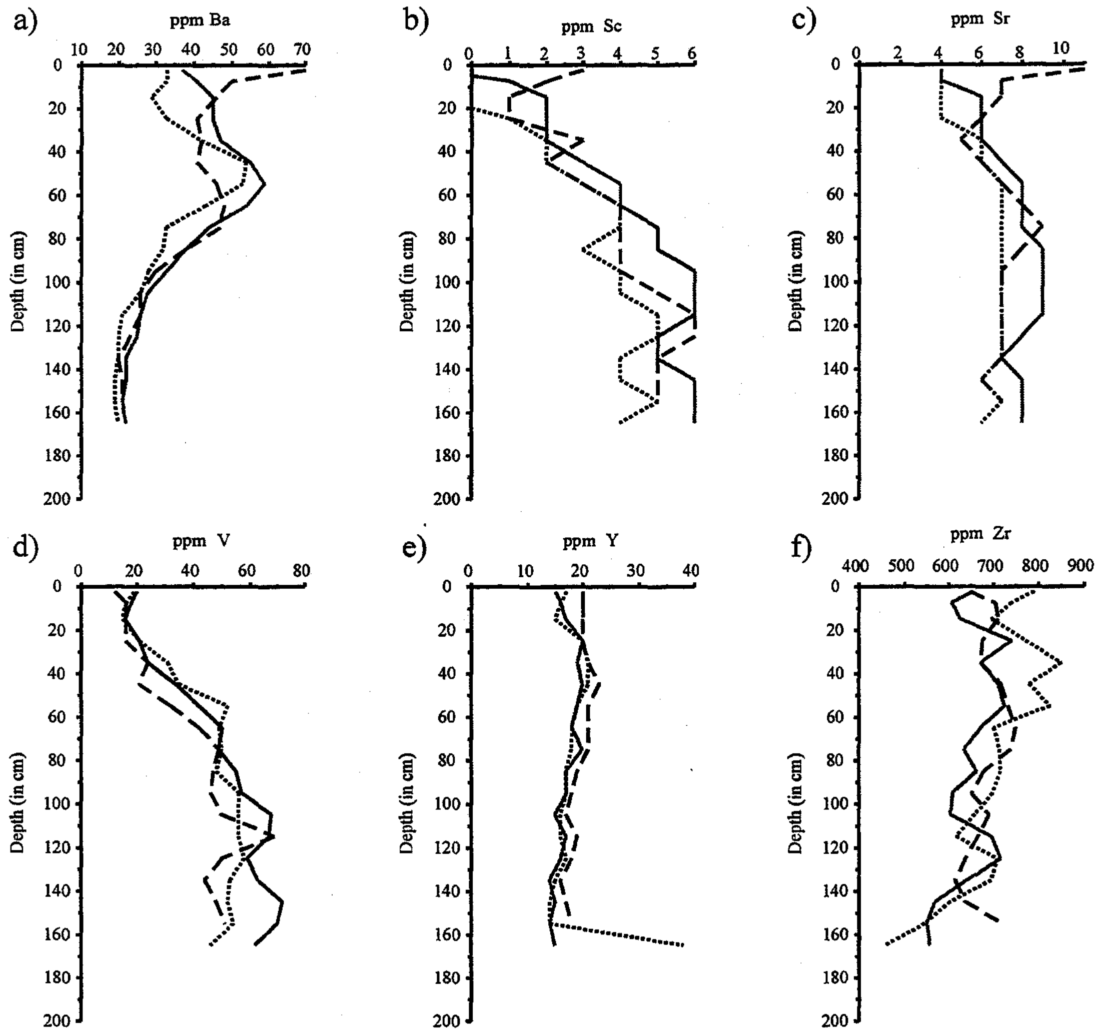

Figure 4. Variation of trace element geochemistry with depth. Elements arranged in alphabetic order. Dotted line is the cultivated sub-area. Dashed line is the mature forest sub-area. Solid line is the reforested sub-area.

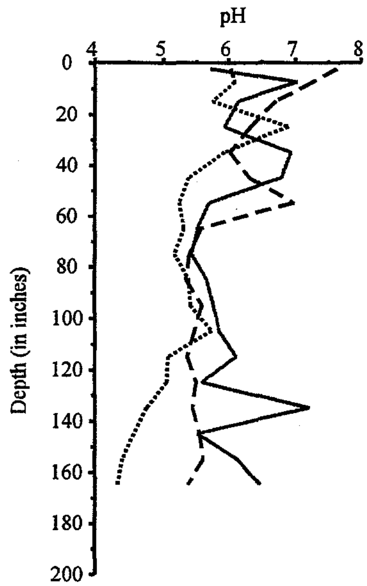

Figure 5. Variation of pH with depth. Dotted line is cultivated sub-area. Dashed line is mature forest sub-area. Solid line is reforested sub-area.

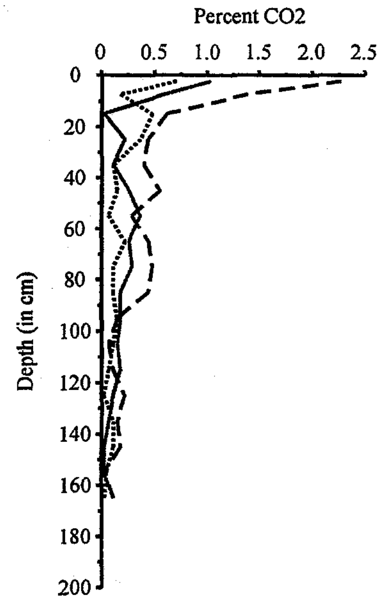

Figure 6. Variation of CO_2 with depth. Dotted line is cultivated sub-area. Dashed line is mature forest sub-area. Solid line is reforested sub-area.

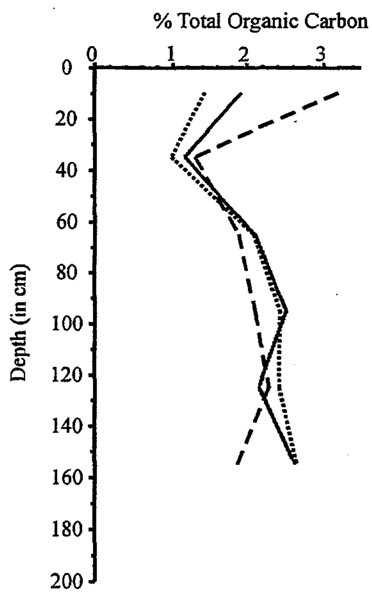

Figure 7. Variation of total organic carbon with depth. Dotted line is cultivated sub-area. Dashed line is mature forest sub-area. Solid line is reforested sub-area.

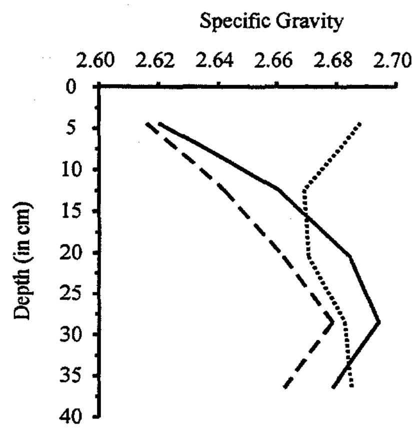

Figure 8. Variation of specific gravity with depth. Dotted line is cultivated sub-area. Dashed line is mature forest sub-area. Solid line is reforested sub-area.

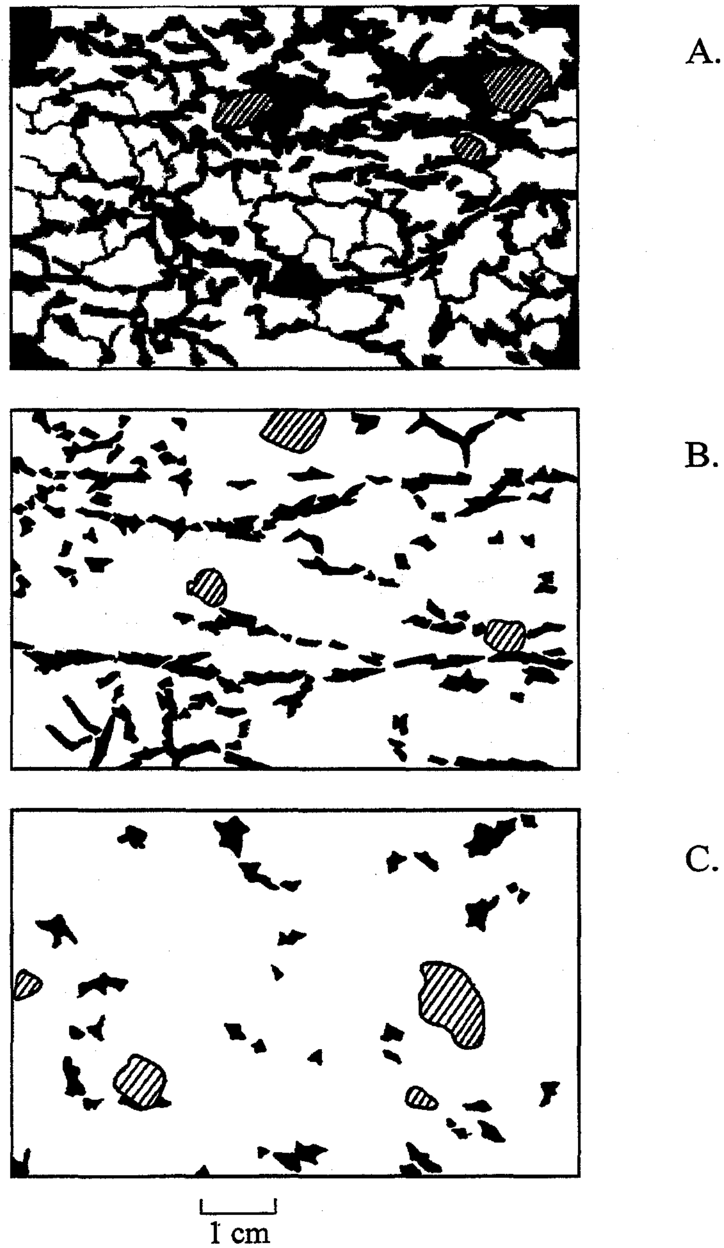

Figure 9. Tracings of thin-sections of soils from depths of 3 to 8 centimeters in the three sub-areas. The upper 3 centimeters from each sample were not used. "A" is from the A1 soil horizon, in pit 7, in the mature forest sub-area. "B" is from the A1 and A1Eg soil horizons, in pit 14, in the reforested sub-area. "C" is from the Ap1 soil horizon, in pit 9, in the cultivated sub-area. Areas shown in black are pores; areas shown in white are soil; and hachured areas are iron concretions.

Soil from the cultivated sub-area has a relatively small amount of pore space (approximately 5%). The pores have a uniform distribution with no apparent orientation. Average width of the pores is 2 to 3 millimeters.

Soil from the reforested sub-area has a porosity that is intermediate between that of the mature forest sub-area and the cultivated sub-area. Pore space in the reforested sub-area is approximately 15%. Pores have an irregular distribution with a preferential horizontal orientation. Pores have about the same width as in the cultivated sub-area.

6.0 CONCLUSIONS

The cultivated sub-area differs from the mature forest sub-area in the loss of the organic horizon (O) and replacement of the A1 soil horizon with a structureless Ap horizon; by a reduction in porosity of the upper part of the A horizon; by a reduction in Loss on Ignition, CaO, Ba, CO_2, and total organic carbon in the upper 10 to 20 centimeters; and by an increase in specific gravity in the upper 8 centimeters. Soil from the reforested sub-area shows the redevelopment of O and A1 soil horizons and is intermediate in all of the variables by which the soil from the cultivated sub-area differs from the soil from the mature forest sub-area.

Generalizations from these results must be treated with caution. The investigation considered only a single site. Sampling within individual land-use areas was generally limited to a single sample per horizon. With these caveats in mind, however, we conclude that rejuvenation of the soils in the reforested area appears to be under way but not complete after 45 years of reforestation.

7.0 REFERENCES

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Table 1. Description of soil horizons from the mature forest sub-area. Described from pit 7 and supplemented by auger data. Soil horizon designations follow Soil Survey Division Staff (1993).

Horizon	**Depth (in cm)**	**Description**
Oi	0-1	Yellowish-brown litter of small oak twigs and leaves.
Oe	1-2	Dark grey (10 YR 2/1); loamy sand to sandy loam; weak-moderate, fine granular structure; friable; rare small (0.5-1.5 centimeters) iron concretions; many fine grass roots and a few medium-sized tree roots; clear, wavy lower boundary.
A1	2-14	Dark-grey (10 YR 2/1); loamy sand to sandy loam; weak-moderate, fine, granular structure; friable; rare, small (0.5-1.5 centimeters), iron concretions; many fine grass roots and a few medium-sized tree roots; clear, wavy lower boundary.
A1Eg	12-28	Yellowish-grey with dove-colored hue (10 YR 4/2); loamy sand; weak, fine, granular structure; friable; rare, small (0.5-1.5 centimeters), iron concretions; rare, old mole-borrows, filled in by material from the A1 horizon (diameter 3.0 to 6.0 centimeters) with indistinct boundaries; common fine grass roots and medium-sized tree roots; clear, wavy lower boundary.
Bt1Eg	28-49	Olive-light-yellow with dove-colored hue (2.5 YR 5/2); sandy loam; weak, fine, subangular blocky structure; friable; a few, small, iron concretions (0.75-2.5 centimeters); a few fine- and medium-sized roots; gradual, wavy lower boundary.
Bt1g	49-67	Light-olive-yellow with dove-colored hue (2.5 YR 5/5); sandy, clayey loam; weak, fine, subangular blocky structure; friable; a few, small, iron concretions (1.3-2.5 centimeters); a few, fine roots; gradual, wavy lower boundary.
Bt2	67-105	Reddish-yellow (2.5 YR 6/6); sandy clay loam; friable; a few, small- and medium-sized iron concretions (1.3-3.8 centimeters); gradual lower boundary.
Bt3g	105-138	Reddish-yellow with weak olive hue (2.5 YR 6/8); sandy clay loam to sandy, loamy clay; firm; a few, small- and medium-sized iron concretions; gradual lower boundary.
BtCg	138-152	Brownish-yellow with dove-colored hue (10 YR 6/7) variegated; sandy, loamy clay; firm; common small- and medium-sized iron concretions; clear lower boundary.
Cg	152-170	Inhomogeneous and variegated, dove-colored-orange (10 YR 6/6); sandy, loamy clay; firm; few, small- and medium-sized iron concretions.

Table 2. Description of soil horizons from the cultivated sub-area. Described from pit 9 and supplemented by auger data. Soil horizon designations follow Soil Survey Division Staff (1993).

Horizon	**Depth (in cm)**	**Description**
Ap1	0-16	Grey (2.5 Y 4/3); loamy sand to sand; weak, fine, subangular granular structure; very friable; rare, small yellowish-brown, iron concretions (0.5-2.0 centimeters); few, very small, charcoal particles; common, fine roots; clear, smooth lower boundary.
Ap2	16-29	Grey (2.5 Y 4/2); loamy sand; weak, fine, granular, sub-angular structure; very friable; common, iron concretions (0.5-2.0 centimeters); few, very small, charcoal particles; rare, fine roots; abrupt, smooth lower boundary.
BtlAlg	29-40	Greyish-yellow with dove-colored hue (10 YR 6/4); loamy sand; weak, fine, subangular structure; friable; many iron concretions (0.5 to 2.5 centimeters); inclusions of thin, charcoal fragments and one Indian artifact (flint arrowhead); rare mole-burrows, filled by dark-grey, loamy sand (5.0-6.6 centimeters in diameter), with abrupt boundaries; clear, wavy lower boundary.
Bt1	40-85	Yellowish-light-brown (10 YR 6/7); sandy loam; weak, fine, subangular blocky structure; friable; common iron concretions (less common than in BtA1g horizon); clear lower boundary.
Bt2	85-112	Brownish-yellow (7.5 YR 6/7); sandy clay loam to sandy, loamy clay; firm; few iron concretions; gradual lower boundary.
Bt3g	112-148	Reddish-yellow (7.5 YR 6/8); sandy, loamy clay; firm; many small- (0.5-1.5 centimeters) and medium-sized (1.8-2.5 centimeters) iron concretions; gradual lower boundary.
BtCg	148-160	Yellowish-light-red with dove-colored-olive zones, fully inhomogeneous (10 YR 6/8); sandy, loamy clay; firm; many iron concretions; gradual lower boundary.
Cg	160-170	Variegated, consists of orange (5 YR 5 /6), yellow (10 YR 6/8) and olive-dove-colored (5 Y 7/4) zones; sandy, loamy clay to sandy clay loam; firm; common iron concretions.

Table 3. Description of soil horizons from the reforested sub-area. Described from pit 14 and supplemented by auger data. Soil horizon designations follow Soil Survey Division Staff (1993).

Horizon	Depth (in cm)	Description
O	0-2	Brownish-gray; forest litter consisting of small twigs, and pine needles.
A1	2-6	Dark-grey (2.5 Y 3/1); loamy sand; weak, fine, subangular structure; friable; rare, small, iron concretions; many fine roots; clear, smooth lower boundary.
A1Eg	6-12	Yellowish-grey with olive hue (2.5 Y 4/2); loamy sand; weak, fine, granular subangular structure with elements of platy structure; friable; rare, small, iron concretions; worm burrows (0.75 to 1.5 centimeters), filled with dark grey, loamy sand; few, fine roots; clear, wavy lower boundary.
Apg	12-21	Olive-grey (2.5 Y 4/3); loamy sand; weak, fine, subangular, granular structure; friable; rare, small, iron concretions; rare, fine, grass roots; abrupt, smooth lower boundary; (lower part of an old plowed layer).
BtA1g	21-38	Greyish-yellow with dove-colored hue (2.5 YR 5/4); sandy loam; weak, fine, subangular blocky structure; friable; common, iron concretions; rare inclusions of grass and tree roots; clear, wavy lower boundary.
Bt1g	38-68	Greyish-yellow with dove-colored hue (dove-colored channels between structural aggregates, 1.0-1.5 centimeters wide) (10 YR 5/5); sandy, loamy clay; weak, fine, subangular, blocky structure; firm; very abundant, iron concretions (0.5-2.8 centimeters); clear, wavy lower boundary.
Bt2g	68-92	Yellowish-light-red with olive hue (7.5 YR 5/8); sandy, loamy clay to sandy clay; firm; few iron concretions; clear lower boundary.
Bt3	92-135	Brownish-yellow (7.5 YR 6/8); sandy clay; firm; few small iron concretions; gradual lower boundary.
BtCG	135-160	Brownish-yellow with dove-colored hue (10 YR 6/7); inhomogeneous; sandy, loamy clay; firm; many, small, iron concretions; gradual lower boundary.
Cg	160-170	Inhomogeneous dove-colored-yellow with yellowish-red zones (10 YR 6/6); sandy, loamy clay; firm; common, small, iron concretions.

Table 4. Major element geochemistry of soils representing the three sub-areas. Values are in weight percent. Negative numbers indicate values below the detection limit.

Sub-Area	Pit no.	Depth (cm)	SiO2 %	Al2O3 %	Fe2O3 %	MnO %	MgO %	CaO %	Na2O %	K2O %	TiO2 %	P2O5 %	LOI %	TOTAL %
Reforested	14	0-5	92.24	1.26	0.76	0.03	0.04	0.06	0.01	0.04	0.46	0.03	3.88	98.80
Reforested	14	5-10	95.25	1.35	0.91	0.03	0.05	0.06	0.01	0.05	0.43	0.29	1.88	100.31
Reforested	14	10-20	94.55	1.65	0.80	0.03	0.04	0.06	0.01	0.05	0.48	0.02	1.74	99.42
Reforested	14	20-30	94.29	2.16	1.07	0.03	0.05	0.05	0.01	0.06	0.53	0.02	1.61	99.89
Reforested	14	30-40	94.16	2.64	1.22	0.02	0.06	0.05	0.01	0.06	0.59	0.02	1.93	100.76
Reforested	14	40-50	91.40	4.23	1.51	0.01	0.10	0.05	0.01	0.08	0.61	0.03	2.46	100.49
Reforested	14	50-60	89.22	5.61	1.80	-0.01	0.12	0.05	0.01	0.09	0.63	0.02	3.15	100.71
Reforested	14	60-70	85.62	7.06	2.34	-0.01	0.13	0.05	0.01	0.09	0.65	0.03	3.84	99.81
Reforested	14	70-80	83.66	7.47	2.45	-0.01	0.12	0.05	0.01	0.09	0.68	0.06	3.97	98.56
Reforested	14	80-90	84.59	7.96	2.66	-0.01	0.12	0.05	-0.01	0.08	0.69	0.03	4.12	100.32
Reforested	14	90-100	82.86	8.39	2.95	-0.01	0.12	0.06	0.01	0.07	0.71	0.04	4.26	99.47
Reforested	14	100-110	82.07	8.81	3.47	-0.01	0.10	0.05	-0.01	0.08	0.72	0.03	4.37	99.70
Reforested	14	110-120	82.26	9.09	3.48	-0.01	0.10	0.05	-0.01	0.08	0.73	0.05	4.40	100.25
Reforested	14	120-130	83.42	8.62	2.84	-0.01	0.10	0.03	-0.01	0.07	0.71	0.03	4.18	100.01
Reforested	14	130-140	82.99	8.57	3.17	-0.01	0.08	0.02	-0.01	0.04	0.71	0.03	4.16	99.79
Reforested	14	140-150	81.11	9.36	3.81	-0.01	0.09	0.03	0.01	0.04	0.74	0.03	4.58	99.79
Reforested	14	150-160	81.51	8.91	4.05	-0.01	0.08	0.02	-0.01	0.07	0.70	0.03	4.40	99.77
Reforested	14	160-170	81.84	9.64	3.48	-0.01	0.08	0.02	0.01	0.06	0.72	0.03	4.51	100.39
Cultivated	9	0-5	94.52	1.53	1.00	0.02	0.04	0.05	-0.01	0.06	0.48	0.04	2.18	99.91
Cultivated	9	5-10	95.47	1.43	0.75	0.02	0.04	0.04	-0.01	0.04	0.49	0.03	2.08	100.40
Cultivated	9	10-20	93.99	1.42	1.28	0.02	0.04	0.03	0.01	0.04	0.47	0.03	1.63	98.98
Cultivated	9	20-30	94.68	2.07	1.08	0.02	0.04	0.03	-0.01	0.07	0.55	0.11	1.64	100.30
Cultivated	9	30-40	92.14	3.60	1.54	0.02	0.07	0.02	-0.01	0.08	0.64	0.02	1.93	100.06
Cultivated	9	40-50	91.11	4.23	1.80	0.01	0.08	0.03	-0.01	0.09	0.64	0.03	2.23	100.26
Cultivated	9	50-60	89.24	5.40	2.47	-0.01	0.10	0.03	-0.01	0.08	0.64	0.03	2.84	100.84
Cultivated	9	60-70	88.56	5.98	2.14	-0.01	0.10	0.04	-0.01	0.09	0.68	0.02	3.12	100.73
Cultivated	9	70-80	87.08	6.80	2.37	-0.01	0.10	0.04	-0.01	0.07	0.67	0.03	3.44	100.61
Cultivated	9	80-90	87.91	6.13	2.33	-0.01	0.10	0.04	-0.01	0.07	0.62	0.02	3.21	100.44
Cultivated	9	90-100	85.34	7.56	2.70	-0.01	0.10	0.04	-0.01	0.07	0.70	0.03	3.80	100.36
Cultivated	9	100-110	85.38	7.34	2.62	-0.01	0.10	0.05	0.01	0.08	0.68	0.04	3.76	100.07
Cultivated	9	110-120	85.59	7.58	2.61	-0.01	0.08	0.03	-0.01	0.06	0.67	0.03	3.58	100.24
Cultivated	9	120-130	85.11	8.10	2.57	-0.01	0.08	0.02	0.01	0.07	0.72	0.03	3.83	100.55
Cultivated	9	130-140	85.46	7.71	2.45	-0.01	0.07	0.02	-0.01	0.05	0.69	0.03	3.59	100.07
Cultivated	9	140-150	85.63	7.45	2.67	-0.01	0.06	0.01	-0.01	0.06	0.64	0.03	3.51	100.06
Cultivated	9	150-160	85.43	7.78	2.52	-0.01	0.06	0.02	-0.01	0.06	0.64	0.04	3.64	100.18
Cultivated	9	160-170	86.35	7.79	2.25	-0.01	0.06	0.01	-0.01	0.06	0.64	0.03	3.54	100.73
Mature Forest	7	0-5	90.07	1.71	0.86	0.04	0.06	0.18	0.01	0.06	0.50	0.03	5.86	99.39
Mature Forest	7	5-10	91.91	1.72	0.92	0.03	0.05	0.06	-0.01	0.05	0.52	0.02	3.62	98.90
Mature Forest	7	10-20	94.72	1.83	0.80	0.03	0.05	0.05	0.01	0.06	0.55	0.03	2.69	100.82
Mature Forest	7	20-30	95.37	1.88	0.84	0.02	0.05	0.03	0.01	0.07	0.53	0.18	1.97	100.96
Mature Forest	7	30-40	94.89	2.38	1.00	0.02	0.04	0.02	-0.01	0.06	0.57	0.08	1.88	100.95
Mature Forest	7	40-50	93.81	2.48	0.99	0.02	0.05	0.02	-0.01	0.07	0.57	0.02	1.98	100.03
Mature Forest	7	50-60	91.32	4.10	1.27	-0.01	0.09	0.03	-0.01	0.09	0.64	0.02	2.48	100.05
Mature Forest	7	60-70	87.50	6.37	1.95	-0.01	0.13	0.03	-0.01	0.09	0.69	0.02	3.55	100.36
Mature Forest	7	70-80	85.92	7.28	2.17	-0.01	0.13	0.03	0.01	0.10	0.70	0.06	3.96	100.38
Mature Forest	7	80-90	86.39	7.02	2.04	-0.01	0.12	0.03	0.01	0.10	0.69	0.03	3.73	100.15
Mature Forest	7	90-100	86.95	6.93	2.01	-0.01	0.09	0.02	-0.01	0.08	0.70	0.03	3.56	100.37
Mature Forest	7	100-110	85.36	7.41	2.21	-0.01	0.09	-0.01	-0.01	0.07	0.71	0.04	3.71	99.62
Mature Forest	7	110-120	84.02	8.25	3.18	-0.01	0.08	-0.01	-0.01	0.07	0.73	0.06	4.11	100.51
Mature Forest	7	120-130	86.30	7.59	2.25	-0.01	0.08	-0.01	-0.01	0.07	0.72	0.03	3.70	100.76
Mature Forest	7	130-140	87.20	6.60	1.83	-0.01	0.07	-0.01	-0.01	0.07	0.69	0.03	3.21	99.70
Mature Forest	7	140-150	87.16	6.75	2.15	-0.01	0.06	-0.01	-0.01	0.05	0.67	0.03	3.27	100.14
Mature Forest	7	150-160	86.60	7.06	2.32	-0.01	0.07	-0.01	-0.01	0.06	0.73	0.02	3.40	100.27
Mature Forest	7	160-170	85.77	7.00	2.65	-0.01	0.06	-0.01	-0.01	0.06	0.73	0.03	3.47	99.79

Table 5. Trace element geochemistry of soils representing the three sub-areas. Negative numbers indicate values below the detection limit.

Sub-Area	Pit no.	Depth (cm)	Ba ppm	Sr ppm	Y ppm	Sc ppm	Zr ppm	Be ppm	V ppm
Reforested	14	0-5	37	4	15	-1	654	-1	12
Reforested	14	5-10	41	4	16	1	605	-1	16
Reforested	14	10-20	45	6	17	2	626	-1	16
Reforested	14	20-30	45	6	20	2	741	1	21
Reforested	14	30-40	47	6	19	2	671	-1	24
Reforested	14	40-50	55	7	20	3	712	-1	34
Reforested	14	50-60	59	8	19	4	725	-1	42
Reforested	14	60-70	54	8	18	4	671	-1	50
Reforested	14	70-80	44	8	20	5	634	-1	49
Reforested	14	80-90	38	9	17	5	662	-1	55
Reforested	14	90-100	33	9	17	6	608	-1	57
Reforested	14	100-110	28	9	15	6	604	-1	68
Reforested	14	110-120	26	9	17	6	697	-1	67
Reforested	14	120-130	25	8	16	5	716	-1	59
Reforested	14	130-140	22	7	14	5	642	-1	63
Reforested	14	140-150	22	8	15	6	569	-1	72
Reforested	14	150-160	21	8	14	6	550	-1	70
Reforested	14	160-170	22	8	15	6	558	-1	62
Cultivated	9	0-5	33	4	17	-1	790	-1	19
Cultivated	9	5-10	33	4	16	-1	740	-1	16
Cultivated	9	10-20	29	4	15	-1	697	-1	15
Cultivated	9	20-30	33	4	20	1	772	-1	21
Cultivated	9	30-40	42	6	21	2	849	-1	31
Cultivated	9	40-50	54	6	21	2	780	-1	35
Cultivated	9	50-60	53	7	19	3	825	-1	52
Cultivated	9	60-70	43	7	18	4	701	-1	49
Cultivated	9	70-80	33	7	18	4	714	-1	50
Cultivated	9	80-90	32	7	17	3	716	-1	48
Cultivated	9	90-100	28	7	17	4	698	-1	56
Cultivated	9	100-110	26	7	16	4	659	-1	56
Cultivated	9	110-120	21	7	16	5	617	-1	56
Cultivated	9	120-130	20	7	17	5	708	-1	58
Cultivated	9	130-140	20	7	15	4	696	-1	53
Cultivated	9	140-150	19	6	14	4	603	-1	52
Cultivated	9	150-160	19	7	14	5	545	-1	54
Cultivated	9	160-170	20	6	38	4	458	-1	46
Mature Forest	7	0-5	70	11	20	3	648	-1	20
Mature Forest	7	5-10	50	7	20	2	704	-1	18
Mature Forest	7	10-20	46	7	20	1	711	-1	16
Mature Forest	7	20-30	41	6	20	1	675	-1	16
Mature Forest	7	30-40	42	5	21	3	671	-1	24
Mature Forest	7	40-50	41	6	23	2	718	-1	21
Mature Forest	7	50-60	46	7	21	3	733	-1	32
Mature Forest	7	60-70	48	8	21	4	749	-1	42
Mature Forest	7	70-80	47	9	21	4	739	-1	49
Mature Forest	7	80-90	38	8	19	4	679	-1	47
Mature Forest	7	90-100	30	7	18	4	651	-1	46
Mature Forest	7	100-110	26	7	17	5	691	-1	50
Mature Forest	7	110-120	26	7	19	6	666	-1	69
Mature Forest	7	120-130	23	7	18	6	637	-1	50
Mature Forest	7	130-140	20	7	16	5	615	-1	44
Mature Forest	7	140-150	21	6	17	5	637	-1	48
Mature Forest	7	150-160	21	7	18	5	719	-1	51
Mature Forest	7	160-170	20	7	20	6	626	-1	57

Table 6. pH of soils representing the three sub-areas.

Depth	Reforested pit 14	Cultivated pit 9	Mature Forest pit 7
0-5	5.71	6.03	7.61
5-10	7.02	6.09	7.26
10-20	6.15	5.75	6.71
20-30	5.94	6.90	6.34
30-40	6.93	5.93	6.02
40-50	6.80	5.38	6.32
50-60	5.70	5.24	6.98
60-70	5.52	5.31	5.87
70-80	5.42	5.16	5.39
80-90	5.66	5.38	5.34
90-100	5.77	5.41	5.59
100-110	5.85	5.73	5.47
110-120	6.12	5.07	5.36
120-130	5.59	5.05	5.50
130-140	7.21	4.75	5.44
140-150	5.52	4.57	5.55
150-160	6.14	4.41	5.61
160-170	6.48	4.33	5.37

Table 7. CO2 of soils representing the three sub-areas. "bdl" equals "below detection limit."

Depth	Reforested pit 14	Cultivated pit 9	Mature Forest pit 7
0-5	1.03	0.70	2.27
5-10	0.59	0.18	1.39
10-20	bdl	0.48	0.62
20-30	0.22	0.37	0.44
30-40	0.11	0.11	0.40
40-50	0.26	0.15	0.55
50-60	0.37	0.07	0.29
60-70	0.26	0.22	0.44
70-80	0.29	0.11	0.48
80-90	0.18	0.11	0.44
90-100	0.18	0.15	0.15
100-110	0.15	0.11	0.07
110-120	0.18	0.07	0.11
120-130	0.11	bdl	0.22
130-140	0.07	0.11	0.15
140-150	bdl	0.11	0.18
150-160	bdl	0.05	bdl
160-170	0.11	bdl	0.11

Table 8. Total organic carbon of soils representing the three sub-areas.

Depth	Reforested pit 14	Cultivated pit 9	Mature Forest pit 7
0-20	1.93	1.43	3.19
20-50	1.16	0.98	1.30
50-80	2.11	2.09	1.89
80-110	2.51	2.43	2.11
110-140	2.16	2.42	2.29
140-170	2.63	2.65	1.88

Table 9. Grain size analyses of soils representing the three sub-areas. Values are percentage of total weight. Diameters are in mm.

Sub-Area	Pit no.	Depth (cm)	TOTAL				SILT		SAND				
			clay <0.002	silt 0.02-0.05	sand 0.05-2.0	gravel 2.0-75.0	fine 0.002-0.02	coarse 0.02-0.05	very fine 0.05-0.1	fine 0.1-0.25	medium 0.25-0.50	coarse 0.5-1.0	very coarse 1.0-2.0
Mature Forest	5	0-10	1.7	16.6	81.5	0.2	14.5	2.1	12.1	25.7	26.9	13.6	3.2
		10-20	3.8	15.1	80.9	0.2	11.5	3.6	13.9	30.5	20.9	11.2	4.4
		20-30	4.0	14.8	80.3	0.9	11.6	3.2	14.9	25.8	24.6	11.6	3.4
	6	0-10	1.9	14.0	83.0	1.1	10.3	3.7	14.5	27.7	24.8	11.7	4.3
		10-20	2.2	19.4	76.9	1.5	11.8	7.6	9.7	26.1	25.3	13.2	2.6
		20-30	3.0	16.5	77.2	3.3	10.1	6.4	13.9	24.2	24.4	12.8	1.9
	7	0-10	1.5	14.1	82.8	1.6	8.5	5.6	12.5	24.8	26.7	13.6	5.2
		10-20	1.9	15.1	80.6	2.5	10.9	4.1	15.3	25.5	25.1	12.3	2.4
		20-30	2.8	14.8	80.2	2.2	9.3	5.5	16.1	24.9	26.1	11.4	1.7
Reforested	13	0-10	2.2	13.3	81.4	3.1	4.6	8.7	15.5	46.9	18.2	0.4	0.4
		10-20	2.7	13.5	80.6	3.2	9.4	4.1	16.3	28.5	21.7	11.9	2.2
		20-30	6.9	17.0	72.9	3.2	9.9	7.1	13.3	26.6	21.2	10.3	1.5
	14	0-10	2.6	10.5	83.9	3.0	7.7	2.8	14.8	27.1	25.1	13.4	3.5
		10-20	2.1	9.5	85.2	3.2	5.7	3.8	17.7	25.5	25.8	13.5	2.7
		20-30	5.0	12.7	80.2	2.1	6.7	6.0	14.9	25.7	24.1	13.5	2.0
	15	0-10	3.4	9.4	84.4	2.8	4.6	4.8	13.7	28.1	24.3	14.2	4.1
		10-20	3.6	13.3	82.0	1.1	7.6	5.7	14.4	24.6	24.1	13.8	5.1
		20-30	4.5	10.6	83.9	1.0	7.7	2.9	13.9	27.4	23.2	9.1	10.3
Cultivated	8	0-10	2.4	16.2	79.3	2.1	8.9	7.3	15.2	27.2	21.9	12.1	2.9
		10-20	1.8	16.2	80.2	1.8	9.4	6.8	15.6	28.5	23.1	10.6	2.4
		20-30	1.8	15.1	81.5	1.6	9.2	5.9	18.3	28.8	21.8	11.3	1.3
	9	0-10	2.0	12.9	77.5	7.6	9.2	3.7	15.8	27.3	21.6	10.4	2.4
		10-20	2.7	9.4	83.7	4.2	5.5	3.9	19.3	26.2	22.1	11.3	4.8
		20-30	3.0	9.2	83.9	3.9	7.7	1.5	19.1	28.1	21.5	12.3	2.9
	10	0-10	2.3	20.8	74.4	2.5	9.4	11.4	11.2	27.7	21.2	10.8	3.5
		10-20	3.2	17.9	75.8	3.1	10.1	7.8	7.9	32.3	19.5	12.6	3.5
		20-30	8.1	17.1	72.6	2.2	10.2	6.9	12.4	26.1	20.3	10.9	2.9

Table 10. Specific gravity of soils representing the three sub-areas.

Depth	Reforested			Cultivated			Mature Forest		
	pit 13	pit 14	pit 15	pit 8	pit 9	pit 10	pit 5	pit 6	pit 7
0-8	2.618	2.642	2.601	2.704	2.693	2.667	2.593	2.625	2.631
8-16	2.658	2.656	2.668	2.667	2.661	2.680	2.647	2.623	2.656
16-24	2.675	2.670	2.708	2.660	2.682	2.670	2.654	2.645	2.688
24-32	2.689	2.685	2.708	2.690	2.676	2.682	2.673	2.697	2.666
32-40	2.685	2.684	2.667	2.695	2.672	2.688	2.640	2.686	2.662