PLINTHITE – QUANTIFICATION AND INTERPRETIVE IMPORTANCE IN SOILS OF THE SOUTHEAST U.S.

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ABSTRACT

Plinthite is common in kaolinitic, weathered soils in the southeastern U.S. Redoximorphic processes segregate iron. Iron-rich pedogenic concentrations can develop into a continuous, cemented subsoil layer as plinthite, which restricts the penetration of roots and movement of water. Identification and quantification of plinthite can be subjective due to its weak cementation and leads to inconsistent classification and correlation of soils. Eleven pedons representing five soil series (Kandiudults and Kanhapludults) from South Carolina were examined in this study with objectives to (1) quantify the amount of plinthite, (2) evaluate the impact of this plinthite on soil properties, and (3) discuss the importance of properly recognizing this material for soil interpretation. This study has shown that pedon descriptions of similar soils often vary widely in both the quantity of plinthite materials (identified via volume estimates from standardized charts) and in the identification of the "degree of cementation." These differences have resulted in inconsistent correlation and pedon classification from one region to another. An established procedure was modified to consistently estimate the volume of plinthite. Weakly cemented plinthite was identified (beginning between 61 to 96 cm) and amounts varied from 0 to 30 percent. Horizons rich in plinthite (Btv and Btvx) had bulk densities ranging from 1.58 to 1.78 g cm^{-3}, with citrate-dithionite extractable Fe up to 4.2 percent. There was no general relationship of percent plinthite with clay, citrate dithionate extractable Fe (Fed), or bulk density.

INTRODUCTION

Hard, dense subsoils are common in soils found on Upper Coastal Plain (UCP) landscapes in South Carolina (Smith and Callahan, 1987) and the southeastern United States (Smith and Daniels, 1989). The hard, dense subsoil character is attributed to plinthite in some soils and fragic properties in others. The properties affect many non-urban and urban land uses by impeding water movement (Prasad and Perkins, 1978; Shaw, et. al., 1997) and downward root growth, reducing available water, and by increasing excavation difficulty. Recognizing these dense subsoils is usually not difficult during soil survey activities although field estimation for the quantity of the dense materials can be subjective. Greater volumes of the dense materials can make the soils more limiting for use.

Plinthite is an iron-rich, humus-poor mixture of clay with quartz and other minerals. Plinthite forms by iron segregation through repeated wetting and drying (Soil Survey Staff, 1999). As a result, horizons with plinthite have a reticulate pattern of iron concentrations and iron depletions. The degree of cementation for plinthite is at least very weakly cemented; rupture resistance is moderately hard when dry. Daniels, et al. (1978) proposed a field method for estimating the volume of plinthite. The method required air-drying a bulk sample and slaking it on a No. 10 (2-mm) sieve. This method has been modified by NRCS soil scientists to assess the degree of cementation for various earthy materials. While it is generally agreed that the hydraulic regime of the non-plinthic soils has not been conducive to the formation of large volumes of plinthite, we tested the modified method on non-plinthic and plinthic soils alike to find out what effect the cementing agent has on aggregating the soil material. The purpose of this work was to determine, using a modified slake procedure, the volume of cemented soil material in several soils commonly occurring on Upper Coastal Plain landscapes in South Carolina. The objectives were (1) to compare the volume of unslaked material in plinthic and non-plinthic soils, and (2) compare the volume of plinthite to several soil properties.

MATERIALS and METHODS

Study Area

This study focused on soils developed on Upper Coastal Plain landscapes of Lee and Sumter counties, South Carolina (Fig. 1A and 1D). The Upper Coastal Plain lies inland from the Orangeburg scarp, a post-late Miocene or Pliocene (2 to 3 my-old) wave-cut scarp separating the UCP from the Middle Coastal Plain (MCP).

Eleven pedons representing five soil series were studied (Table 1). Elevations range from 64 to 107 m. Plinthic and Arenic Plinthic Kandiudults representing Dothan and Fuquay Series (Fig. 1B) occur on nearly level to gently sloping summits of the pre-Brandywine surface. Typic and Arenic Kanhapludults representing Cowarts and Ailey Series (Fig. 1C) occur on dissected landforms. These soils formed in unconsolidated sediments of probable Upper Cretaceous age (Ku) underlying the pre-Brandywine surface (Mb), exposed by stream dissection and geomorphic erosion. Barnwell Series generally occurs on gently sloping shoulder and backslope landforms. A discontinuity in this soil separates overlying Mb soil material from Ku soil material.

Slaking Procedure and Background

The procedure described by Daniels, et al. (1978) was used initially in field and correlation activities for the Soil Survey of Lee County, South Carolina (Ogg, 2007) to distinguish between UCP plinthic soils and MCP soils of similar appearance but lacking a significant volume of plinthite. Co-author John Kelley modified the procedure to accommodate a larger volume of whole-soil to obtain more accurate estimates of plinthite volume. Subsequently, National Soil Survey Laboratory (NSSL) scientists have further modified the procedure as a test for degree of cementation in various earthy materials encountered in a number of soil environments. A brief outline of the procedure is shown in Figure 2.

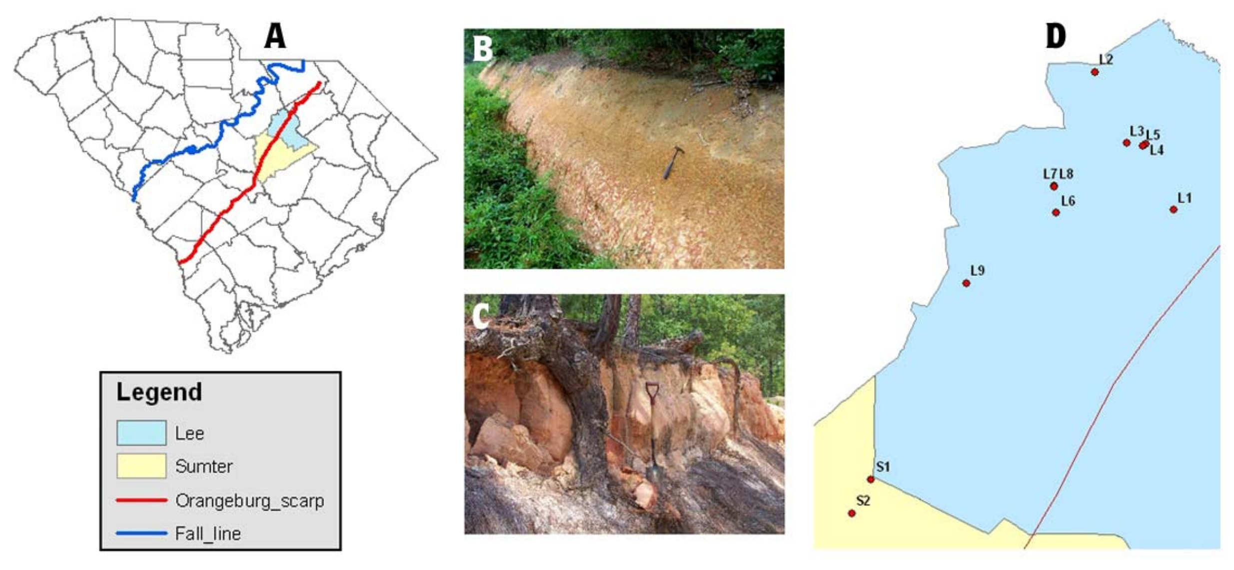

Figure 1. A - Location of Lee and Sumter counties, SC. The UCP is between the Fall Line and the Orangeburg scarp. B - Roadcut of a plinthic soil (Mb soil materials). C - Roadcut of non-plinthic soil (Ku soil materials). D - Close-up map showing the location of the study sites.

Figure 2. Outline of the modified slake procedure.

1. Air-dry a minimum dried sample weight of 1000-g (2.2-lb).
2. Sieve the air-dried sample with No. 10 sieve and discard <2-mm portion.
3. Wrap sample tightly in self-adhesive plastic wrap.
4. Add water to 19-L bucket (or smaller, straight-sided bucket that accommodates the sample) and mark the point of the water surface on the bucket (see photo).
5. Add the wrapped sample and quickly mark the water level.
6. Remove sample and quantify volumetric increase in water. This step may be accomplished by measurement of the difference of water levels with and without sample and diameter of vessel:

   $V = \pi r^2(h_2-h_1)$
   where:
   V = Volume displacement (cm^3)
   π = 3.14
   r = radius of vessel (cm)
   h_1 = height of initial water level in vessel (cm)
   h_2 = height of resultant water level (with soil added) in vessel (cm)

8. Submerge dry soil material; most will immediately begin to slake (see photo).
9. Allow to soak for 5-10 minutes, swirl gently by hand for 5 seconds, and pour the soil-water mixture through a No. 10 sieve. Rinse the material remaining on the sieve (see photo).
10. Refill the bucket with fresh water (about ½ full) and add the soil material from the sieve. Wash the material from the inverted sieve into the bucket and allow it to disaggregate overnight. Most slaking will be complete in 1-2 hours, but by convention the sample is allowed to soak "over night" (e.g., slaking is initiated in afternoon and completed the subsequent morning).
11. After the elapsed time, swirl the sample gently by hand 20 times in 1-second rotations and pour through a No. 10 sieve. Rinse the sample under a spray of water.
12. The volume of the recovered (cemented) material can be measured by adding water to a 19-L bucket or other appropriate, straight-sided vessel. Add materials that are retained on the sieve and measure increase in the amount of water displaced as previously described (see photo).
13. Place the retained material on a tray. Discard the water and material passing the sieve. Avoid pouring soil down the sink. Add $CaCl_2 \cdot 2H_2O$ to help flocculate the soil material.
14. Let set for a minimum of 8 hours or overnight, then decant the supernatant and discard soil in an appropriate place.

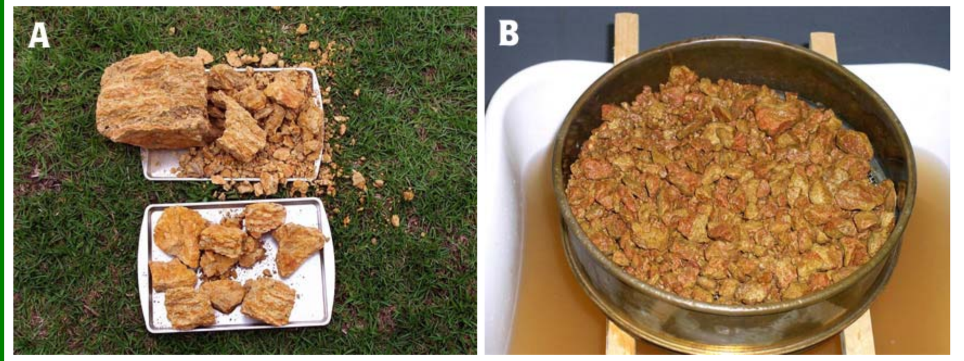

Figure 3. A - Bulk sample of plinthic soil material prior to slaking. B - Plinthite material remaining after slaking.

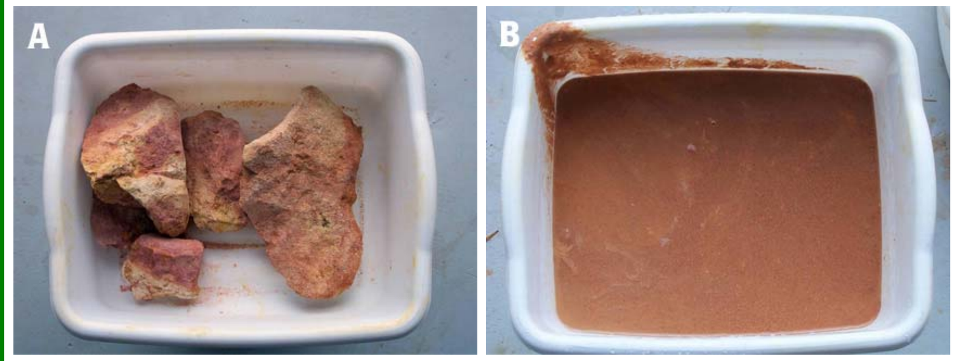

Figure 4. A - Bulk sample of non-plinthic soil material prior to slaking. B - Non-plinthic material remaining after slaking.

Table 1. Site and soil identification and classification for the pedons studied.

Site ID	Soil Series: Sampled as	Soil Series: Revised to	Classification
L1	Fuquay	N/A	fine-loamy, kaolinitic, thermic Plinthic Kanhapludults
L2	Dothan	Tifton	fine-loamy, kaolinitic, thermic Plinthic Kandiudults
L3	Ailey	N/A	loamy, kaolinitic, thermic, Arenic Kandiudults
L4	Cowarts	Neeses	fine, kaolinitic, thermic Typic Fragiudults
L5	Cowarts	Irvington	fine-loamy, parasesquic, subactive, Plinthic Fragidudults
L6	Barnwell	N/A	fine-loamy, kaolinitic, thermic Plinthic Kanhapludults
L7	Barnwell	N/A	fine-loamy, kaolinitic, thermic Plinthic Kanhapludults
L8	Dothan	N/A	coarse-loamy, kaolinitic, thermic Plinthic Kanhapludults
L9	Barnwell	Neeses	fine, kaolinitic, thermic, Typic Kanhapludults
S1	Dothan	Varina	fine, kaolinitic, thermic, Plinthic Kandiudults
S2	Ailey	Ailey	loamy, kaolinitic, thermic, Arenic Kanhapludults

Table 2. Horizonation, bulk densities, plinthite, clay and elemental composition for pedons.

Site ID	Soil Series	Horizon	Soil horizon-depth upper (cm)	lower (cm)	Pararock (Plinthite) Volume %	clay %	BD Soil Mg m^{-3}	Citrate-dithionite Fe (% of 2 mm)	Citrate-dithionite Al	Oxalate Fe	Oxalate Al	Oxalate Si
L1	Fuquay	Btv	75	90	14	29.9	1.63	2.5	0.5	0.05	0.08	0.01
		Btvx1	90	113	19	36.5	1.61	2.6	0.5	0.05	0.11	0.02
		Btvx2	113	129	21	34.7	1.70	2.8	0.5	0.05	0.09	0.02
		Btvx3	129	133	30	45.1	1.58	3.8	0.6	0.05	0.11	0.02
		B't1	133	160	7	34.5	1.76	1.7	0.3	0.02	0.06	0.01
		B't2	160	200	5	35.1	1.68	1.7	0.3	0.01	0.02	0.01
L2	Dothan	Bt2	61	98	12	34.2	1.60	2.5	0.5	0.05	0.09	0.01
		Btvx1	98	142	32	34.3	1.67	2.7	0.5	0.03	0.06	0.01
		Btvx2	142	165	24	35.4	1.74	2.7	0.4	0.02	0.05	0.01
		2BC	165	210	21	40.0	1.63	1.6	0.2	0.01	0.05	0.01
L3	Ailey	Btx	123	150	0	20.3	1.72	0.5	0.1	0.01	0.02	0.00
L4	Cowarts	Btx	58	70	0	32.7	1.53	2.7	0.4	0.05	0.09	0.01
L5	Cowarts	Btv	27	36	35	38.3	1.73	2.3	0.4	0.02	0.09	0.01
		3B't1	72	153	5	68.3	1.41	2.7	0.3	0.02	0.08	0.02
L6	Barnwell	Btvx	86	117	21	52.4	1.56	3.2	0.6	0.05	0.09	0.01
L7	Barnwell	Bt3	113	126	9	46.6	1.44	2.9	0.6	0.07	0.10	0.01
		2Btx	126	174	14	30.5	1.75	1.8	0.2	0.03	0.04	0.01
L8	Dothan	Btv	96	107	15	36.1	1.66	3.6	0.6	0.06	0.10	0.02
		Btvx1	107	120	26	40.1	1.63	4.2	0.7	0.05	0.10	0.02
		2Btvx2	120	140	30	34.4	1.63	3.3	0.6	0.03	0.06	0.01
		2Btvx3	140	157	20	29.7	1.78	2.5	0.5	0.02	0.05	0.01
L9	Barnwell	Bt2	62	87	4	34.7	1.55	2.3	0.3	0.04	0.07	0.01
S1	Dothan	Bt2	76	100	5	41.1	1.51	3.3	0.6	0.05	0.07	0.02
		Btvx1	100	118	15	40.5	1.59	3.7	0.7	0.06	0.08	0.02
		2Btvx2	118	132	19	40.1	1.60	4.0	0.6	0.05	0.08	0.02
		2Btvx3	132	152	32	38.9	1.64	3.4	0.5	0.04	0.08	0.02
S2	Ailey	Btx2	80	102	1	25.1	1.75	1.4	0.2	0.03	0.05	0.01

Table 3. Median bulk densities comparing Mb and Ku soil horizons.

		Horizon	Soil horizon-depth upper (cm)	lower (cm)	BD Soil Mg m^{-3}	Median BD Soil Mg m^{-3}
Mb BD - vx horizons†						
L1	Fuquay	Btvx1	90	113	1.61	
		Btvx2	113	129	1.7	
		Btvx3	129	133	1.58	
L2	Dothan	Btvx1	98	142	1.67	
		Btvx2	142	165	1.74	
L6	Barnwell	Btvx	86	117	1.56	
L8	Dothan	Btvx1	107	120	1.63	
S1	Dothan	Btvx1	100	118	1.59	1.62
Ku BD - x and vx horizons‡						
L3	Ailey	Btx	123	150	1.72	
L4	Cowarts	Btx	58	70	1.53	
L5	Cowarts	3B't1	72	153	1.41	
L7	Barnwell	2Btx	126	174	1.75	
L8	Dothan	2Btvx2	120	140	1.63	
		2Btvx3	140	157	1.78	
S1	Dothan	2Btvx2	118	132	1.6	
		2Btvx3	132	152	1.64	
S2	Ailey	Btx2	80	102	1.75	1.64
Ku BD - x horizons (lack plinthite)‡						
L3	Ailey	Btx	123	150	1.72	
L4	Cowarts	Btx	58	70	1.53	
L5	Cowarts	3B't1	72	153	1.41	
L7	Barnwell	2Btx	126	174	1.75	
S2	Ailey	Btx2	80	102	1.75	1.72

†Mb = pre-Brandywine surface materials ‡Ku = Upper Cretaceous age

Table 4. Correlation of plinthte and bulk density to elemental extracts.

Property	Correlation, r
Correlation to Plinthite	
clay	0.13
BD	0.22
DCB Fe	0.48
DCB Al	0.46
Ox Fe	0.03
Ox Al	0.31
Ox Si	0.27
Correlation to Bulk Density	
clay	-0.72
DCB Fe	-0.43
DCB Al	-0.35
Ox Fe	-0.51
Ox Al	-0.51
Ox Si	-0.35

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RESULTS and DISCUSSION

Plinthite ranges widely in these soils from 0 to 35 percent (Table 2). Plinthite content for Btv and Btvx horizons ranges from 14 to 35 percent. Three Bt horizons above Btv horizons (pedons L2, L7, S1) have more than 5 percent plinthite, the minimum requirement for subgroup placement (Soil Survey Staff, 1999). This suggest when the actual volume is between 10 and 15 percent, a higher degree of certainty is obtained for recognizing substantial volumes of plinthite and thus interpretive differences. Daniels, et al. (1978) estimated about 10 percent platy plinthite would perch water.

Fragic soil properties were described in all pedons (Table 2). Median bulk density (BD) (Table 3) is not different between all fragic (x) horizons in the Mb soils (1.62 Mg m^{-3}) versus Ku soils (1.64 Mg m^{-3}). Exclusion of plinthic (v) horizons from the analysis of horizons with fragic properties of the Ku soils reveals a somewhat higher BD (1.72 Mg m^{-3}). This value more closely compares to the median BD of 1.69 Mg m^{-3} for similar Ku horizons investigated by Smith and Callahan (1978).

Early classification of Ku soils recognized fragipans with high BD and a hard-when-dry character. A unique characteristic of the Ku soil horizons noted in South Carolina and Georgia is that, when moist, at least some portion of the material is friable (Guthrie, 1978; 1981). Because of this characteristic, soil scientists from South Carolina (Guthrie, 1978) recommended changing the classification of Ailey, Cowarts, and Vaucluse Series so they would not classify into Fragi great groups or Fragic subgroups. We observed this characteristic, but our field tests also confirm brittleness in these soil materials.

Plinthite is firm when moist and hard to very hard when dry. Iron oxides and oxyhydroxides are thought to be the cementing agent for plinthite (Soil Survey Staff, 1999) and for the Ku soil horizons. Table 2 shows values for the citrate-dithionite (CD) Fe and the oxalate extractions for Fe, Al, and Si. Correlations for plinthite to clay, bulk density, and the elemental extracts are given in Table 4. No strong correlations point to a specific cementing agent for the soil materials.

Slaking is defined as a process that results in breakdown of soil aggregates (aggregate disintegration) to a finer aggregate size > 2μm. Slake tests found the horizons in the Mb soil materials contain predominantly 14 to 35 percent very weakly to strongly-cemented plinthite and have a brittle manner of failure (Fig. 3A and 3B). Slake test results from this (Table 2) and previous investigations on Ku soils materials show 0 to 5 percent of the soil material withstands slaking for 5 to 10 min (Fig. 4A and 4B). The cementation class (Schoenberger, et al., 2002), then, for most of these materials is non-cemented. Only minor amounts of the material are extremely weakly cemented.

SUMMARY and CONCLUSIONS

The modified slake procedure is effective for quantifying plinthite and defining classes for rupture resistance and degree of cementation for soils on Upper Coastal Plain landscapes in South Carolina. Plinthic soil horizons from Mb soils have a fairly high median bulk density (1.62 to 1.64 Mg m^{-3}); non-plinthic horizons formed in Ku soils have higher median bulk density (1.72 Mg m^{-3}). Although Fe is the suspected cementing agent for these soils, correlations between plinthite content and elemental extracts are not definitive.

Slake tests results found up to 35 percent of the Mb soil material and up to 5 percent of Ku soil material did not slake. Consequently, although more than 50 percent slaked, the horizons are not fragipans because less than 60 percent of the volume has a firm or firmer moist rupture resistance class and brittle manner (Soil Survey Staff, 1999). These soil horizons do, however, exhibit fragic soil properties, and the x suffix designation is appropriate.

Even though the dry rupture resistance class for Ku soil materials is hard to extremely hard, these materials place in non-cemented or extremely weakly cemented classes because 95 to 100 percent of the soil material will slake. Soil moisture content seems to control the rupture resistance of these soil materials, a conclusion drawn by previous investigations of similar soils (Guthrie, 1978). The Ku soil horizons become hard and excavation difficulty increases when soils become increasingly dry. The dry rupture resistance classes for the plinthic horizons are also hard to extremely hard, but in contrast to the Ku soils horizons, these horizons place in very weakly to strong cementation classes.

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