MANAGEMENT EFFECTS ON CLAY DISPERSIBILITY OF A RHODIC PALEUDULT IN THE TENNESSEE VALLEY REGION, ALABAMA

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ABSTRACT
Conventional tillage coupled with monoculture cotton (Gossypium hirsutum L.) production has resulted in declining soil quality in the Tennessee Valley Region. However, conservation tillage systems that have been shown to increase soil quality are increasingly more common. Surface horizons in the region have appreciable silt and clay, which are mostly composed of quartz, kaolinite, hydroxy-interlayered vermiculite, and Fe oxides. Similar clay mineralogical suites have been shown to be dispersive under certain conditions, which can degrade soil physical properties. We evaluated the clay dispersibility of these soils cropped to cotton in: 1) a no-till system without a cover crop (NT), 2) a no-till system with a rye (Secale cereale L.) cover crop (NTC), 3) a no-till system with a rye cover crop and fall paratilling (NTCP), and 4) a conventional tillage system (CT). Soils consisted of fine, kaolinitic, thermic Rhodic Paleudults. Water dispensible clay (WDC), extractable Fe forms, and soil organic carbon (SOC) were evaluated for surface samples. Particle size distribution (PSD) and mineralogy of in situ soil, runoff sediment, and WDC were also evaluated. Increased clay amounts were recovered when samples had dithionite extractable Fe removed (FeD) compared to soil organic matter removal. The WDC quantities were positively correlated with SOC (%), which was higher under reduced versus conventional management and negatively correlated with FeD (%) and water stable aggregates (%). The aggregate of data suggests Fe oxides play a more vital role in clay aggregation than SOC in these soil systems. Particle size and mineralogy of runoff sediment collected under simulated rainfall was similar to in situ soil, suggesting models depicting erosion and nutrient runoff can be developed using in situ soil as a surrogate for sediment characterization.

KEYWORDS
Water dispensible clay, Ultisols, conservation tillage

INTRODUCTION
In recent years, reduced tillage systems have become common in the Tennessee Valley region of Alabama. These soils are mostly Ultisols with surface horizons possessing appreciable silt and clay particles. Quartz dominates the sand and course silt fractions, and kaolinite and hydroxy-interlayered vermiculite are found in the fine silt and clay fractions. Relatively high quantities of Fe oxides are found in both surface and subsurface horizons.

Similar soil mineralogical systems have been shown to possess appreciable quantities of water dispensible clay (WDC) under certain conditions (Miller and Bahanuddin, 1986; Miller and Radcliffe, 1992; Chiang et al., 1994). Water dispensible clay has been correlated with erodibility (Bajracharya et al., 1992) and relatively high quantities of WDC results in soil crusting (Chiang et al., 1994), which decreases infiltration (Zhang and Miller, 1996). Studies have established WDC quantities are correlated with total clay content, soil organic matter content (SOM), dithionite extractable Fe and Al content, exchangeable cations, pH, and ionic strength (Goldberg et al., 1990; Miller et al., 1990; Brubaker et al., 1992; Heil and Sposito, 1993).

Due to the importance of water dispensible particles to soil properties, this study was undertaken to: 1) develop an understanding of the interactions of management systems on the dispersion characteristics of surface soils in the Tennessee Valley Region, and 2) characterize sediment and dispersed particles from these soils.

MATERIALS AND METHODS
Our research site was located at the Belle Mina Experiment Station in the Tennessee Valley Region of Alabama. Soils possessed fine-textured surface horizons, and were classified as fine, kaolinitic, thermic Rhodic Paleudults (Table 1). Soils are moderately to severely eroded due to historical conventional tillage management during inten-
sive cotton (*Gossypium hirsutum* L.) monocropping. However, since 1996, conservation tillage management systems using cover crops are now predominant in the region. The study site was part of a long-term experiment (1995 to present) evaluating conservation versus conventional tillage management systems cropped to cotton in a RCB design with four replications (Schwab et al., 2002). We selected four treatments (plots are 8 m wide x 15 m long) consisting of no-till without a cover crop (NT), no-till with a rye (*Secale cereale* L.) cover crop (NRC), no-till with a rye cover crop and fall paratilling (NTCP), and a conventional tillage system (CT) that consisted of diskling and chisel plowing in the fall, followed by diskling and leveling in the spring.

For deep pedon characterization, soils were sampled by horizon according to National Cooperative Soil Survey Standards. Particle size determination, cation exchange capacity, exchangeable cations, extractable Al, base saturation, and pH were analyzed according to standard techniques (Soil Survey Investigations Staff, 1996).

Soils were composite (= -20) sampled at the 0-1 cm depth in the four replications of the selected treatments. Soil organic carbon (SOC) was measured using dry combustion (Yeomans and Bremmer, 1991). Organically bound Fe was extracted with sodium pyrophosphate (Fe$_{py}$), non-crystalline (poorly crystalline and organically bound) Fe was extracted with acid ammonium oxalate (Fe$_{aao}$), and total Fe oxides and organically-bound Fe were extracted with dithionite-citratebicarbonate (Fe$_{dcb}$) (Jackson et al., 1986). Particle size was determined with: 1) SOM removed (using H$_2$O$_2$), 2) Fe$_{py}$ removed, and 3) both SOM and Fe$_{aao}$ removed (Kilmer and Alexander, 1949). The WDC was measured using the method of Miller and Miller (1987). The WDC was measured using both distilled H$_2$O (H$_2$O$_{dist}$) and well water used during rainfall simulation experiments (H$_2$O$_{w}$) [pH=7.41, EC=0.17 dS m$^{-1}$, total electrolyte concentration (TEC)=2 mol m$^{-3}$, Ca=33.2 ppm, Na=1.7 ppm].

Water stable aggregates (WSA) (0-3 cm) were determined for composited (5) samples for the first and third replication using the method of Kemper and Rosnau (1986). The first and third replications were chosen to coincide with rainfall simulation experiments (first replication in the fall, third replication used in spring, see Truman et al., in review).

Rainfall simulation experiments were conducted during November, 1999 on duplicate 1-m$^2$ plots placed within the first replication (Truman et al., in review). Briefly, rainfall was applied to duplicate plots within each treatment at a target intensity of 50 mm h$^{-1}$ using an oscillating nozzle rainfall simulator. Rain was applied for 1 h, paused for 1 h, and then resumed for 1 additional h. Runoff sediment was collected at an outlet placed on the corner of each plot.

Runoff sediment, WDC (from first replication), and *in situ* soil samples (from first replication) were fractionated into fine (0-0.2μm) and coarse clay (0.2-2 μm) after organic matter removal using standard techniques (Jackson, 1975). Oriented clay fractions were examined by XRD using these treatments: Mg-saturation / ethylene glycol solvation @ 25C, Mg-saturation @ 25 C, K-saturation @ 25C, 300C, and 550C. Magnesium-saturated clay fractions were analyzed using thermogravimetric analyses (TGA). Hydroxy-interlayered vermiculite (HIV) and quartz (Qtz) quantities were estimated using the techniques of Karathanasis and Hajek (1982).

### RESULTS AND DISCUSSION

The 0-1 cm depth in these soils possessed appreciable clay (Table 2). Overall, for particle-size measurements with SOM removed (standard procedure), the CT plots possessed slightly higher clay than all of the NT treatments.

### Table 1. Soil characterization data for the Tennessee Valley site (fine, kaolinitic, thermic Rhodic Paleudult). Values for Ca, Mg, K, and Na are NH$_4$OAc extractable bases, values for Al are the KCl extractable quantity, ECEC is the effective cation exchange capacity, CEC is the cation exchange capacity, pH is the pH in 1:2 soil:water, and BS is the base saturation.

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>Na</th>
<th>Al</th>
<th>ECEC</th>
<th>CEC</th>
<th>pH</th>
<th>BS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ap1</td>
<td>0-19</td>
<td>15.3</td>
<td>54.2</td>
<td>30.5</td>
<td>3.36</td>
<td>0.42</td>
<td>0.63</td>
<td>0.01</td>
<td>0.07</td>
<td>4.49</td>
<td>8.91</td>
<td>5.10</td>
<td>49.6</td>
</tr>
<tr>
<td>Ap2</td>
<td>19-30</td>
<td>12.7</td>
<td>51.8</td>
<td>35.5</td>
<td>4.14</td>
<td>0.49</td>
<td>0.59</td>
<td>0.01</td>
<td>0.06</td>
<td>5.29</td>
<td>10.01</td>
<td>5.52</td>
<td>52.2</td>
</tr>
<tr>
<td>Bt1</td>
<td>30-46</td>
<td>10.0</td>
<td>39.4</td>
<td>50.6</td>
<td>3.36</td>
<td>0.44</td>
<td>0.41</td>
<td>0.02</td>
<td>0.85</td>
<td>5.08</td>
<td>11.87</td>
<td>4.62</td>
<td>35.6</td>
</tr>
<tr>
<td>Bt2</td>
<td>46-110</td>
<td>10.0</td>
<td>36.3</td>
<td>53.7</td>
<td>2.20</td>
<td>0.45</td>
<td>0.25</td>
<td>0.01</td>
<td>1.15</td>
<td>4.06</td>
<td>10.49</td>
<td>4.44</td>
<td>27.7</td>
</tr>
<tr>
<td>Bt3</td>
<td>110-150</td>
<td>9.1</td>
<td>27.9</td>
<td>63.0</td>
<td>1.38</td>
<td>0.52</td>
<td>0.26</td>
<td>0.01</td>
<td>2.21</td>
<td>4.39</td>
<td>10.90</td>
<td>4.10</td>
<td>19.9</td>
</tr>
</tbody>
</table>
reflecting the more thorough mixing of surface and subsurface soils and possibly a slightly higher degree of erosion for CT treatments. In the southeastern region, eroded soils typically have finer-textured surface horizons due to the exposure of argillic horizons and the mixing of these clay-rich subsurface horizons with surface horizons through tillage (Olson et al., 1994).

Many studies have shown the role SOM plays in clay aggregation, which is partly attributed to clay-organic interactions facilitated through cation bridging (Oades, 1989). However, for these soils, the amount of clay recovered increased when Fe_d was removed compared to SOM removal (Table 2). In fact, recovered clay quantities were similar with Fe_d removed compared to having both Fe_d and SOM removed (Table 2). These data suggest Fe_d plays a more substantial role in aggregating clay minerals in these soils than SOM. The Fe_d is composed of “free” Fe oxides, which consist of crystalline (hematite, goethite), poorly crystalline (ferrhydrite and other forms), and organic Fe forms. The high proportion of Fe_d compared to Fe_o (poorly crystalline) and Fe_p (organic forms) suggests much of the free Fe is in crystalline oxide form (Table 2). At the resident pH of these soil systems (5 to 6), Fe oxides possess an appreciable (+) charge (ZPC from 6.5-7.5), thus promoting the bridging of (+) charged phyllosilicate surfaces (e.g., kaolinite has a ZPC from 3.5-5). Although in many surface soils SOM plays a large role in clay aggregation, our data suggests in these soil systems (>2.5% Fe_d on a whole-soil basis) Fe oxide minerals play a more substantial role.

Overall, an average of 14% (H_2O_{wv}) to 18% (H_2O_d) of the clay fraction was water-dispersible (Table 2). Brubaker et al. (1992) analyzed soils from eight orders and found an average of 34% of the clay fraction was water-dispersible. Our soils have relatively less WDC overall, likely due to the high quantities of Fe oxides in these soil systems. The slightly greater amount of WDC using H_2O_d is likely due to a combination of lower total electrolyte concentration (TEC) for this treatment, and the relatively higher Ca in the H_2O_{tv} treatment causing a slight decrease in the double layer and slightly reduced dispersion. It has been suggested in highly weathered systems with low TEC, such as mimicked with the H_2O_d treatment, repulsive forces between clays result in increased dispersion (Kaplan et al., 1996).

No relationship existed with regard to H_2O_d dispersible clay quantities and SOC or Fe_d (Fig. 1a and b). However, the H_2O_{tv} dispersible clay quantities increased with increasing SOC (r^2=0.65) and decreased with increasing Fe_d (r^2=0.35) (Fig. 1c and d). Studies have indicated in some systems, SOC may enhance dispersion by decreasing Ca activities while increasing negative charges on clay colloids (Oades, 1984). For these soils, increasing Fe oxide quantities resulted in a general decrease in WDC. We also found WDC was exponentially related to percent water stable aggregates (WSA), suggesting WDC should be included in soil quality data sets (Figure 2).

The runoff sediment was similar in texture to in situ soil (Table 3). Similarities in texture between sediment and soil is consistent with results obtained by Meyer et al. (1992) and Shaw et al. (in review) for other Southeastern soils.
Analyses of the clay mineralogy of the in situ soil, runoff sediment, and WDC suggest little enrichment of specific clay minerals in transported versus in situ soil. Similar quantities of kaolinite, hydroxy-interlayered vermiculite (HIV), quartz, and Fe$_2$O$_3$ were observed between the soil, sediment, and WDC (Table 4). These data suggest models depicting off-site nutrient movement do not need to incorporate enrichment ratios for specific particle size separates and minerals, i.e., characterization of in situ texture and mineralogy adequately reflect sediment size characteristics and mineralogical composition.

CONCLUSIONS

Increasing amounts of dispersible clay has been shown to decrease infiltration as well as generally degrade soil physical properties. It is widely accepted that in many soil systems, increases in SOM resulting from conservation tillage systems generally result in increased infiltration rates. Results from a companion study (Truman et al., in review) suggested minimal differences in infiltration between the CT, NT, and NTC treatments of this experiment, which may be due to the clay dispersion phenomena shown in this study. Infiltration rates were greatly increased in the no surface tillage systems with non-inversion deep tillage
Table 3. Particle-size of soil and sediment collected during a rainfall simulation experiment on first replication. Numbers in parentheses are standard deviations of means.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Soil</th>
<th>Sediment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sand</td>
<td>Silt</td>
</tr>
<tr>
<td>NT</td>
<td>6.8</td>
<td>74.3</td>
</tr>
<tr>
<td>NTC</td>
<td>8.0</td>
<td>72.4</td>
</tr>
<tr>
<td>NTCP</td>
<td>11.6</td>
<td>58.8</td>
</tr>
<tr>
<td>CT</td>
<td>10.5</td>
<td>56.2</td>
</tr>
</tbody>
</table>

NT = no tillage, NTC = no tillage with cover crop, NTCP = no tillage with cover crop and fall paratilling, CT = conventional tillage.

Table 4. Comparison of mineralogical composition of clay (<2 µm) fraction between in situ soil, runoff sediment, and WDC. Mineral quantities averaged over all treatments for first replication. Recovered mineral quantities normalized to 100%. Numbers in parentheses are standard deviations of mean.

<table>
<thead>
<tr>
<th></th>
<th>0 - 0.2 µm</th>
<th>0.2 - 2 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kao</td>
<td>HIV</td>
</tr>
<tr>
<td>Soil</td>
<td>49.1(3.5)</td>
<td>42.2(3.1)</td>
</tr>
<tr>
<td>Sediment</td>
<td>44.5(1.9)</td>
<td>45.0(2.0)</td>
</tr>
<tr>
<td>WDC</td>
<td>44.9(1.8)</td>
<td>46.1(2.5)</td>
</tr>
</tbody>
</table>

Kao=kaolinite, HIV= hydroxy-interlayered vermiculite, Qtz=quartz, Fe_d = dithionite extractable Fe.

(NTCP), which suggests the mechanical disruption induced by deep tillage overwhelms surface soil WDC effects on infiltration. Corollary relationships observed in a study of Southeastern Coastal Plain soils (Shaw et al., in review) between SOM, water stable aggregates, and infiltration were not evident in these soils. Future work should evaluate the effects of liming and other amendment applications for stabilizing organic matter and refining reduced tillage systems in this region.

![Graph](https://example.com/graph.png)

**Fig. 2.** The relationship between water stable aggregates and water dispersible clay for the first and third replications.
LITERATURE CITED


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