SOIL INDICATORS OF POST COLONIZATION LAND USE CHANGE AT

WORMSLOE STATE HISTORIC SITE, GEORGIA, USA

by

JULIA HOLLY CAMPBELL

(Under the Direction of Lawrence A. Morris)

ABSTRACT

Soil is a fundamental part of the ecosystem and one that humans depend on for a variety of services. Our interaction with the soil yields artifacts, or legacies. Soil legacies are studied by archaeologists to infer human history and soil scientists to interpret natural processes; consequently, legacies reveal our history and how that history impacts the broader ecosystem. This project investigated: the influence of historic agriculture on soil properties and vegetation and geophysical methods, electromagnetic induction and resistivity, for identification of soil legacies at Wormsloe State Historic Site. Results indicated that soil pH and extractable P remained significantly elevated over 80 years since abandonment of agriculture and that vegetation patterns were not significantly related to soil legacies. Geophysical methods guided soil sampling, identifying artifacts and distinguishing between sites of land use intensity. Results can be used to update land use history maps and provide non-invasive field techniques for future studies.

INDEX WORDS: Land Use History, Agricultural Legacy, Wormsloe, Phosphorous, Shell Middens, Geophysical Methods, EMI, Resistivity

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JULIA HOLLY CAMPBELL

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JULIA HOLLY CAMPBELL

Major Professor: Lawrence Morris

Committee: Thomas Jordan
Julia Gaskin

Electronic Version Approved:

Julie Coffield
Interim Dean of the Graduate School
University of Georgia
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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Introduction

Human land use activities like agriculture, forestry, and residential use can lead to long-term alteration of soil nutrients, soil structure, soil biology, and hydrology (Bidwell and Hole, 1965; Callaham et al., 2006; Kirkman et al., 1996). These alterations, or soil legacies, can persist from decades to millennia (Dupouey et al., 2002; Foster et al., 2003; Goodale and Aber, 2001). Archaeologists have often utilized soil legacies, like soil phosphorus concentration (McLauchlan, 2006) and changes in soil physical properties, to infer human history. Soil scientists and ecologists have incorporated soil legacies into ecosystem dynamic studies for interpretation of vegetation patterns and nutrient cycling (Compton et al., 1998; Hurtt et al., 2006; Motzkin et al., 1996). Additionally, soil legacies are increasingly important in natural resource management and ecological restoration planning (Foster et al., 2003; Grossmann and Mladenoff, 2008).

Agricultural land use leaves more enduring soil legacies than most other land use activities (McLauchlan, 2006). Soil disturbance created by cultivation, or tillage, can lead to soil compaction (Maloney et al., 2008), rapid oxidization of soil carbon (C) and nitrogen (N), and loss of extractable nutrients through crop utilization, leaching, or volatilization (Hurtt et al., 2006; Matson et al., 1997). Agricultural nutrient amendment with manure or mineral fertilizers can lead to long term, elevated soil phosphorus (P) and other nutrients (MacDonald et al., 2012; McLauchlan, 2006).

Residential activities also lead to long-term soil legacies. Construction activities invert, compact, and move soil, as well import materials, such as lime, stone, and brick that influence the surrounding soil chemical and physical properties. Daily household and garden activities result in the addition or burial of ash or charcoal, shells and bones, debris, and human or animal wastes (Eidt, 1984). Elevated soil C, N, P, and calcium (Ca) are commonly located on sites of human habitation (Entwistle et al., 2000; Hejcman et al., 2013; Holliday and Gartner, 2007).

Investigating spatial and temporal trends in soil legacies across a site requires land use history records and maps over multiple time periods, areas that contained specific land use activities, reference areas that did not encounter the land use activity (Hooker and Compton, 2003; MacDonald et al., 2012; Maloney et al., 2008), and diverse field methods for investigating legacies.

Wormsloe State Historic Site, located outside of Savannah, Georgia, has a long history of human use, including evidence of pre-Colonial Native American activity and stewardship by nine generations of one family since 1736 as a residence and site of long-term agriculture, horticulture, forestry, and residential activity (Swanson, 2012). The 333 hectare (ha) site encountered dramatic land use change since the Colonial period. This change mirrored land development common across the Lower Coastal Plain at this time; including large scale deforestation for agriculture and forest products, followed by long periods of cultivation, and subsequent reforestation (Napton et al., 2010). Wormsloe contains close to three centuries of land use records and maps, areas of the property used for agriculture, and areas never farmed or under long-term forest cover (Jordan and Madden, 2013; Swanson, 2012).

The purpose of this study was to investigate the influence of historic land use on soil chemical and physical properties at Wormsloe Historic Site. To address this research goal, two studies were conducted. To evaluate how historic agriculture influenced soil nutrients, profile characteristics, and vegetation at Wormsloe, a comparative study was established that investigated differences between historic agriculture and non-agriculture areas, soil series, and time since agricultural abandonment. To evaluate geophysical methods for locating soil legacies at Wormsloe, we used two geophysical instruments, Electromagnetic Induction and Resistivity, combined with traditional soil sampling.

Literature Review

Activities associated with essential human needs such as food production, construction of shelter, garment production and cooking result in long-term landscape changes (Olofsson and Hickler, 2008). These land use activities leave a legacy in the landscape that are expressed as buried artifacts, altered vegetation patterns (Compton et al., 1998), hydrology (Kirkman et al., 1996), biology (Callaham et al., 2006; Mitchell et al., 2002), or soil properties (Bidwell and Hole, 1965; Liiri et al., 2012; Trimble, 1974) when compared to adjacent areas where the land use activity did not occur. The duration and intensity of the legacy is dependent on a variety of factors, including activity type, climate, and soil. Legacies are important for providing interpretation of human history and current ecosystem dynamics (MacDonald et al., 2012; Motzkin et al., 1996), for measuring the influence of human activity on the landscape (Hurtt et al., 2006), and for helping guide future resource management decisions (Foster et al., 2003; Grossmann and Mladenoff, 2008; Hurtt et al., 2006; Ramankutty et al., 2008).

Legacy of Agriculture

Agricultural land use leaves an enduring legacy. It results in alteration of soil properties (Compton et al., 1998; Kacalek et al., 2011; Richter et al., 2000; Wall and Hytönen, 2005) and other ecosystem factors (Tilman et al., 2001) that can endure for decades to millennia (Foster et al., 2003; Goodale and Aber, 2001) after cessation of agriculture (McLauchlan, 2006). The duration and type of agricultural soil legacy depends on the length and intensity of agriculture, recolonized or planted vegetation following agriculture, time since agricultural abandonment, climate, and soil type (Compton et al., 1998; Guo and Gifford, 2002; MacDonald et al., 2012; Morris et al., 2013).

Major differences in soil properties occur between abandoned agricultural areas that have reforested to those never farmed (Compton et al., 1998; Dupouey et al., 2002; Foster et al., 2003; Richter et al., 2000). Because soil is the primary physical support and reservoir of nutrients and moisture essential to terrestrial life, investigating soil legacy effects helps understand other ecosystem processes and systems, like differences in vegetation structure and function (Dobson et al., 1997; Matson et al., 1997). Agricultural activities that improve crop production in the short term can lead to either increases (Wall and Hytönen, 2005) or decreases (Liiri et al., 2012) in soil fertility and soil structure (Falkengren-Grerup et al., 2006) in the long term.

Cultivation (tillage) and addition of nutrient amendments have more pronounced effects on chemical and physical soil properties than other agricultural activities (McLauchlan, 2006; von Oheimb et al., 2008). Cultivation mechanically turns and homogenizes the top 0-20 cm of soil, or O and A horizons, accelerating the decomposition of organic matter (OM) and mineralization of nutrients (Hurtt et al., 2006; Matson et al., 1997). Mineralized nutrients can be absorbed by crops and removed during harvest or lost from the soil through leaching or volatilization to the atmosphere. Thus, cultivation has the potential to reduce the OM content and fertility of the soil in the long term (McLauchlan, 2006).

The homogenized surface layer created by cultivation (Ap horizon or plow layer) is visible in a soil profile. This Ap horizon is often depleted in soil carbon (C) and nitrogen (N) (Foster et al., 2003) unless nutrient amendments, like manure or mineral fertilizer, were added (Compton et al., 1998; Richter et al., 2000). An Ap horizon can persist for centuries (Foster et al., 2003). Soil C is very sensitive to tillage (Compton et al., 1998). Soil C can be reduced by 30-70% and lost as carbon dioxide (CO_2) to the atmosphere after only 25 years of tillage (Matson et al., 1997; McLauchlan, 2006). Since soil C is an important component of soil structure, nutrient storage, and erosion protection (Leeper and Uren, 1993) accelerated loss due to tillage can lead to significant, long-term changes in biogeochemical dynamics (Dobson et al., 1997; Goodale and Aber, 2001; Hurtt et al., 2006; Liiri et al., 2012; Tilman et al., 2001) and reduced biodiversity (Green et al., 2005; Matson et al., 1997) following the cessation of agriculture. Alternatively, abandonment of agricultural areas and subsequent reforestation result in soil C accretions and increased biodiversity over time (Tilman et al., 2001).

Fertilization of fields has been practiced for centuries. Prior to the advent of commercial inorganic fertilizers, manure application was common. Manure application can lead to century long elevation of soil C, N, and phosphorus (P), when compared to non-agriculture areas (Blake et al., 2000; Compton and Boone, 2000; McLauchlan, 2006). For example, the highly fertile, sandy-textured plaggen soils of Germany, Belgium, and the Netherlands, amended over a thousand years with manure and crop residue, have 20% more soil C, and other soil nutrients, than reference sites on similar soils, despite cessation of agriculture (Clymans et al., 2013).

The extent of agricultural legacy is both nutrient and site specific. The legacy effect for soil N varies. A study of a Rhode Island secondary forest found that over a century after agricultural abandonment, there was no difference in soil N when compared to areas never farmed (Hooker and Compton, 2003). In contrast, a southeastern South Carolina Piedmont forest had lower concentrations of soil N on abandoned agricultural lands fertilized with N when compared to forest land never farmed (Richter et al., 2000). Generally, legacy effects are greater and more consistent for soil P than for N. The P legacy is influenced by the type (Hansen et al., 2002) and amount of P fertilizer applied (Motavalli and Miles, 2002; Negassa and Leinweber, 2009; Newman, 1997; Rasmussen and Parton, 1994), soil type, and concentration of other soil elements that bind P (Blake et al., 2000). A century following agricultural abandonment, a Massachusetts forest that had received manure application still had greater P concentrations than areas never farmed (Compton and Boone, 2000). Soil pH is often elevated on reforested, former agriculture lands when compared to areas never farmed (Compton et al., 1998; Falkengren-Grerup et al., 2006); however, pH begins to decrease relatively rapidly following reforestation, particularly under vegetation with acidic litter (Grieve, 2001). Forest vegetation with more basic litter, like hickory, may help sustain higher soil pH in areas that were limed (Motzkin et al., 1996). Elevated calcium (Ca) and lower soil C:N ratios may be an indication of fertilization (Kacalek et al., 2011).

The time frame required for abandoned agricultural soils to return to native, or reference, soil levels, is not consistent or well understood (Latty et al., 2004) in part, because we often lack a reference for the initial fertility of a site's soils. Known pre-existing soil and site conditions prior to agricultural activity is essential for drawing conclusions on disturbed and reference sites (Compton and Boone, 2000; Dupouey et al., 2002; Matlack, 2009), but this information is often not available. Variability in legacy times of different sites makes comparisons between sites unreliable (Blake et al., 2000). Variability in legacy recovery time may be explained by investigating different soil types and diverse agriculture histories (Matlack, 2009). Research examining reference soil recovery times report that a few decades (Brown and Lugo, 1990; Grossmann and Mladenoff, 2008; Maloney et al., 2008; Switzer et al., 1979) to one or more centuries (Compton and Boone, 2000; Knops and Tilman, 2000; Matlack, 2009) are required for soil to return to reference levels. Soil C and N recovered in 40-50 years and 15-20 years, respectively, in a Puerto Rican subtropical forest following abandonment of agriculture (Brown and Lugo, 1990). In the cooler climate of Minnesota, and soil C and N were predicted to reach near reference levels in 230 and 180 years, respectively, on a sand plain (Knops and Tilman, 2000). Some studies report that soil legacy effects following abandonment of agriculture may persist up to a millennia or more (Dupouey et al., 2002; Sandor et al., 1986) and result in irreversible changes of vegetation composition (Dupouey et al., 2002; Koerner et al., 1997). For example, soil P concentration of a 900 year old New Mexico agriculture site is still lower than an adjacent reference site (Sandor et al., 1986). Available chronosequence studies indicate a gradual return of soil properties to reference levels (Falkengren-Grerup et al., 2006; Hooker and Compton, 2003; Knops and Tilman, 2000). One study demonstrated that C:N ratio increased and soil pH decreased with each additional year since reforestation of abandoned agriculture land (Compton et al., 1998) and another study observed a linear increase of soil C by 2.10 Mg C ha^{-1} yr^{-1} at a New England site (Hooker and Compton, 2003).

Soil type influences soil P availability and retention following agriculture abandonment (Lawrence and Schlesinger, 2001; MacDonald et al., 2012; Negassa and Leinweber, 2009), as does soil OM content due to increased sorption sites and the complexes that increased clay content have with OM (Blake et al., 2000). Morris et al. (2013) found that soil series responded differently to agriculture abandonment a century after cultivation. In examining differences in regional P legacy, MacDonald et al. (2012) found that labile P elevation following agriculture abandonment decreased as clay content increased due to the strong sorbing capacity of clay soils. Soil orders, Entisol, Ultisol, and Andisol, containing a mean clay content of 15% or less, exhibited significantly higher extractable P than Oxisols and Alfisols with mean clay contents greater than 26%, and lower or no change in extractable P following agricultural abandonment (MacDonald et al., 2012). Lightly weathered and low clay content Spodosols exhibited increased total and labile P following abandonment.

In addition to inherent differences in some soils to retain or lose nutrients, the interaction between soil type and human use will appear in the soil legacy. Some soils were preferentially selected for farming due to higher nutrient content or available moisture. Higher sand percentage may make soils less suitable for farming due to rapid drainage and lower nutrient retention (Abrams and Hayes, 2008), and clay-textured soils are harder to till. Roman farmers at an abandoned agricultural village in present day

France appeared to select agriculture fields with lower clay content and higher silt content (Dupouey et al., 2002). At the Cumberland Island National Seashore, Georgia, a preference for one soil series over another for agriculture was apparent (Bratton and Miller, 1994).

Geophysical Methods

Both agricultural and residential activities result in soil compaction, soil movement, and the intentional or unintentional burial of debris like ash, shells, household items, and human and animal waste (Eidt, 1984). Over time, soil additions or disruptions from cultural activities become obscured and are no longer visible at the soil surface. These hidden features provide valuable information on the human history of a site, as well as the influence of human activity on the soil landscape (Brown, 2008). Locating soil legacies within a landscape can, in part, be directed by historical maps and records combined with archaeological excavations; however, random soil investigations and extensive excavations are expensive, time consuming, and destructive to a site (Gaffney, 2008; Wynn and Sherwood, 1984). As well, these techniques may overlook human land use features not apparent from the soil surface or within the area of excavation (Collins and Molyneaux, 2003).

The use of shallow geophysics is a preferred, non-invasive reconnaissance survey for quick, spatial investigation of historic sites prior to soil excavation (Alaia et al., 2008; Batayneh, 2011; Drahor, 2006; Grangeia et al., 2011; Keenan and Ellwood, 2014; Piro and Campana, 2009). Geophysical surveys are useful for directing soil sampling, in addition to evaluating areas where excavation is not always appropriate, for example, in burial sites (Hargrave et al., 2002).

Geophysical instruments are utilized in a variety of disciplines, including archaeology, geology, pedology, agronomy, and engineering (Pellerin, 2002; Soupios et al., 2007). They have been used to detect objects or environmental patterns as diverse as buried artifacts, geologic faults, salt water intrusion, boundaries of a landfill, soil mapping, and irrigation for crops (Bernard and Leite, 2004). Since the 1940s, they have been used with increasing frequency for archaeological investigations (Batayneh, 2011). Generally, these instruments measure contrasts or differences in soil physical properties that can be used to detect buried artifacts or other evidence of human activity (Batayneh, 2011; Gaffney and Gater, 2003) individually, or at the landscape scale (Collins and Molyneaux, 2003; Drewett, 1999). These contrasts are easier to detect when the surrounding soil or sediment is homogenous because the contrasts are more prominent (Sambuelli et al., 1999). With careful data interpretation, approximate location and dimension of contrasts can be identified. Since buried evidence of human activity encompasses a small, often minute, area of the soil landscape, instruments must measure physical soil properties at a fine resolution on a vertical and horizontal scale, usually not exceeding a 5 m depth (Batayneh, 2011). A primary limitation of geophysical instruments is when the object depth is greater than its size (Bevan, 2006). One exception to this limitation is the detection of deeply buried metallic objects by electromagnetic induction (Bevan, 2006).

Each geophysical instrument has strengths and weaknesses depending on the intended application, so careful consideration should be made for instrument selection based on site and potential buried features of interest (Zheng et al., 2013). Human activity, like agricultural tillage, or heterogeneous soil and sediment composition make detection of buried features difficult to assess (Sambuelli et al., 1999). Combining multiple geophysical instruments enhances detection of buried features and increases accuracy of the survey (Bevan, 2006; Drahor, 2011; Garrison, 2003; Sambuelli et al., 1999; Zheng et al., 2013). This combination with soil sampling or excavation helps verify the detection abilities of the instruments (Bevan, 2006; Hargrave et al., 2002).

Electrical methods are common geophysical techniques used in archaeology (Batayneh et al., 2007) to rapidly investigate large areas prior to excavation (Batayneh, 2011). The two main types of electrical methods used either have indirect contact with the soil by inducing a current into the soil, or have direct contact with the soil through the insertion of probes in the soil. Electromagnetic induction (EMI) is an example of an indirect method and electric resistance, or resistivity, is a direct method. Both instruments have a long history of use across diverse fields and are commonly used to detect a variety of buried cultural and environmental features. These two methods are also uniquely suited for detecting soil disturbance when no obvious cultural objects are found, including subtle changes in organic matter (OM) or porosity that differ from the surrounding soil (Bevan, 2006).

EMI measures the conductivity (σ) of an electric current through the subsurface terrain, measured in millisiemens per meter ($mS\ m^{-1}$), and detects the geometry and depth of shallow electrical conductors (Collins and Molyneaux, 2003; Dualem, 2009). Originally used for locating areas of conductive sulfide mineralization, EMI is increasingly used for shallow subsurface mapping across a variety of fields, including archaeology (Dualem, 2009; Milson, 2003) and pedology. EMI measures subsurface properties by inducing an electromagnetic (EM) field in the ground from a transmitter coil located at one end of the instrument (Drewett, 1999). A secondary magnetic field is created within the soil that is correlated with the conductivity of the soil volume where the magnetic field is generated. This secondary EM field is measured by one or more receiver coils at a specified distance from the transmitter coil. The strength of the secondary EM field increases with the electrical conductivity of the soil (Bevan, 2006; Piro and Campana, 2009). Transmitter and receiver coil spacing and direction (horizontal versus perpendicular coil direction) are directly related to the depth of exploration (DOE) (Dualem, 2009). One primary advantage of EMI versus other geophysical methods is that the induction of a current into the subsurface does not require that the instrument be in contact with the ground, thus, it is faster and relatively easier to use (Bevan, 2006) over large areas and challenging terrain than other geophysical instruments (Drewett, 1999).   EMI can locate shallow metallic objects (Bevan, 2006; Drewett, 1999) like cans and buried pipe, and foundations. In addition, soil moisture is detectable by EMI because ions in the soil solution and surficial charges on clay induce an electric current that can be measured by the instrument (McNeill, 1980; Palacky, 1991; Pellerin, 2002; Pellerin and Wannamaker, 2005). For this reason, EMI also detects soil salinity, organic matter, clay, restrictive soil layers preventing downward water movement, and objects that hold moisture or impede water movement (Pellerin and Wannamaker, 2005).

Electrical resistance, or resistivity, was the first geophysical method used in archaeology (Garrison, 2003) and remains the most widely used technique in this field, in part, due to refinement of methodologies across several disciplines investigating shallow subsurface properties (Alaia et al., 2008; Soupios et al., 2007). A resistivity instrument measures the resistance to an electric current across the subsurface matrix, including both soil and cultural features (Collins and Molyneaux, 2003). Most often, resistivity data is reported as apparent resistivity (ρ_α), which is the product of measured resistance (R) and a geomagnetic factor (K_g) reported in ohm-meters. Subsurface resistance is measured by passing a current through two current electrodes then measuring the current density reduction and increasing potential gradient by two additional electrodes, called potential electrodes (Collins and Molyneaux, 2003). Apparent resistivity is measured between the applied current and the potential resistivity based on the arrangement and spacing of electrodes (EPA, 2011; Milson, 2003). The ratio between the measured voltage and applied current increases with increased resistance in the soil (Bevan, 2006). Elevated ρ_α values indicate that the location of measurement has higher resistance than the surrounding soil and is a potential location of interest (Keenan and Ellwood, 2014).

Results of a resistivity survey are dependent on the probe array geometry of the instrument. The two most popular arrays used in archaeology are the Wenner and Dipole-Dipole arrays (Garrison, 2003). The Wennner array is considered the "standard array" to which other arrays are compared (Milson, 2003). This array consists of two potential electrodes, equally spaced, between two current electrodes (Collins and Molyneaux, 2003). The Dipole-Dipole array separates both potential and current electrodes by a specified distance, where distance between probe pairs is the same and specified by parameter, *n* (Garrison, 2003). The current electrodes are paired and separated from the paired potential electrodes. The Wenner array has a higher sensitivity than the Dipole-Dipole array at greater depths. Dipole-Dipole has an advantage over

Wenner by displaying a single peak measure of high ρ_α over resistant subsurface features whereas the Wenner array produces a double peak measurement, which can reduce ρ_α and distort the appearance and location of resistant features (Drewett, 1999). These and other types of arrays can be configured within a grid or along a transect. Probe spacing is roughly equivalent to the depth of investigation, where a one meter probe spacing equates to a one meter depth survey. Closer spacing allows for higher resolution within the volume of soil evaluated (Cardarelli and Di Filippo, 2009). Probes arranged in a grid provide a 3-dimensional survey of an area, whereas transects provide a 2-dimensional survey.

Resistivity instruments are more affordable than other geophysical instruments and often easier to use (Bevan, 2006). As well, they are not limited by soil type and geology, nor as susceptible to electrical interference as other instruments (Bevan, 2006). This electrical method is useful for detecting buried artifacts when the cultural object is in stark contrast with the surrounding soil matrix (Drahor, 2006), for example, resistivity will detect organic trash piles in coarse textured, sandy soils and stone debris in fine textured clay and silt soils (Bevan, 2006). Resistivity is also useful for detecting foundations, old roads, hearths, and rubble (Collins and Molyneaux, 2003; Gaffney and Gater, 2003; Garrison, 2003). Resistivity surveys will not detect metallic objects. Other disadvantages include the time and physical labor involved in carrying out a resistivity survey, though newer capacitance devices have significantly improved running time of the instrument (Garrison, 2003).

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CHAPTER II

A SOIL LEGACY OF LAND USE IN THE LOWER COASTAL PLAIN: A CASE STUDY OF WORMSLOE STATE HISTORIC SITE, GEORGIA

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Abstract

Agriculture alters soil chemical and physical properties, often decades to millennia, following agricultural cessation when compared to areas not farmed. Tillage and fertilization leave the strongest soil legacies, with a residence time influenced by soil type, climate, and land use activity. Wormsloe State Historic Site, near Savannah, Georgia, has nearly a 300 yr. documented history of agricultural land use since 1736. To investigate agricultural soil legacies at Wormsloe, 120 random sample points were established across two land use areas: Agriculture (some agricultural activity from 1736 to present) and Reference (forest soils from 1736 to present); within two soil series (Chipley and Olustee); and three blocks (North, Central, South). Differences in soil nutrients (total C and N, pH, extractable P, Ca, Mg), profile characteristics, dominant vegetation, and site features were compared across land use and soil series. Agricultural Periods (Civil War, Depression, Modern, No Agriculture) were established to investigate time since agricultural abandonment. Field investigations revealed that over 80 yrs since abandonment, pH ($p=0.036$) and P ($p=0.049$) differed significantly across soil series and land use, respectively. Total C and N, Ca, and Mg, though not significant, were elevated after 80 yrs when compared to reference sites. Soil Ca was also elevated in areas where the dominant overstory species were characterized by *Carya glabra, Quercus spp.*, *Liquidambar styraciflua*, and *Sabal minor*.

INDEX WORDS: Land Use Legacy, Agricultural Abandonment, Phosphorus, Total C and N, Calcium, Shell Middens, Wormsloe

Introduction

Many studies have found that agriculture leads to the long-term alteration of soil chemical and physical properties (Compton et al., 1998; Kacalek et al., 2011; Richter et al., 2000; Wall and Hytönen, 2005) for decades to millennia after cessation of the agricultural activity (Dupouey et al., 2002; Foster et al., 2003; Goodale and Aber, 2001; McLauchlan, 2006). These alterations are apparent when comparing abandoned agricultural areas that have reforested to forested areas that were never farmed (Compton et al., 1998; Dupouey et al., 2002; Foster et al., 2003; Richter et al., 2000).

Agricultural Legacy: Tillage

Tillage and fertilization are the two agricultural activities that most alter soil properties (McLauchlan, 2006; von Oheimb et al., 2008). Cultivation mechanically turns and homogenizes the top 0-20 cm of soil, accelerating the decomposition of organic matter (OM) and mineralization of nutrients (Hurtt et al., 2006; Matson et al., 1997). Mineralized nutrients are then removed by cropping or lost from the soil through leaching to the groundwater or volatilization to the atmosphere. Thus, cultivation has the potential to reduce the OM content and fertility of the soil in the long term (McLauchlan, 2006).

Soil carbon (C) seems to be more affected by tillage than soil nitrogen (N) (Compton et al., 1998). Soil C can be reduced by 30-70% and lost as carbon dioxide (CO_2) to the atmosphere after only 25 years of tillage (Matson et al., 1997; McLauchlan, 2006). Since soil C and OM are important components of soil structure, nutrient storage, and erosion protection (Leeper and Uren, 1993), their accelerated loss due to tillage can lead to significant, long term changes in biogeochemical dynamics (Dobson et al., 1997; Goodale and Aber, 2001; Hurtt et al., 2006; Liiri et al., 2012; Tilman et al., 2001). Alternatively, abandonment of agricultural lands and subsequent reforestation result in soil C accretions (Tilman et al., 2001).

Agricultural Legacy: Fertilization

Fertilization and liming of agriculture fields has been practiced for centuries. Prior to the advent of commercial inorganic fertilizers, manure application was common. Manure application can lead to century long elevation of soil C, N, and phosphorus (P), (Blake et al., 2000; Compton and Boone, 2000; McLauchlan, 2006). The highly fertile, sandy-textured plaggen soils of northwestern Europe, amended over a thousand years with manure and crop residue, have 20% more soil C than reference sites on similar soils (Clymans et al., 2013). Soil N fertilizer legacies have a variable response following agriculture abandonment, demonstrating no difference (Hooker and Compton, 2003), elevation (Compton and Boone, 2000), or depletion (Richter et al., 2000) in concentration when compared to reference areas. Soil P legacy is influenced by the type (Hansen et al., 2002) and amount of P fertilizer applied (Motavalli and Miles, 2002; Negassa and Leinweber, 2009; Newman, 1997; Rasmussen and Parton, 1994), in addition to soil type which influences soil P binding (Blake et al., 2000). A century following abandonment of agriculture, soil P concentration beneath forested areas was elevated compared to forested areas never farmed (Compton and Boone, 2000).

Soil pH is also often elevated on reforested, former agricultural fields (Compton et al., 1998; Falkengren-Grerup et al., 2006) due to liming amendments; however, pH begins to rapidly decrease following reforestation, particularly under vegetation with acidic litter (Grieve, 2001). Forest vegetation with more basic litter, like hickory (*Carya spp.*), may help sustain higher soil pH on areas that were limed (Motzkin et al., 1996).

Agricultural Legacy: Agricultural Abandonment

Soil recovery times following agricultural abandonment vary from a few decades (Brown and Lugo, 1990; Grossmann and Mladenoff, 2008; Maloney et al., 2008; Switzer et al., 1979) to one or more centuries (Compton and Boone, 2000; Knops and Tilman, 2000; Matlack, 2009). Soil C and N recovered in 40-50 years and 15-20 years, respectively, in a Puerto Rican subtropical forest following agricultural abandonment (Brown and Lugo, 1990). In the cool climate of Minnesota, soil C and N were predicted to reach near reference levels in 230 and 180 years, respectively, on a sand plain (Knops and Tilman, 2000). Some studies report that soil legacy effects following agricultural abandonment may persist up to a millennia or more (Dupouey et al., 2002; Sandor et al., 1986). For example, soil P concentration of a 900 year old New Mexico agricultural field is still lower than reference soil concentrations (Sandor et al., 1986) and differences in soil properties on a nearly 2,000 year old Roman agriculture field in France led to long term changes in vegetation species richness (Dupouey et al., 2002) compared to reference soils.

Chronosequence studies suggest a gradual return of soil properties to reference levels (Falkengren-Grerup et al., 2006; Hooker and Compton, 2003; Knops and Tilman, 2000). One study demonstrated that C:N ratio increased and soil pH decreased with each additional year since reforestation of abandoned agricultural land (Compton et al., 1998) and another study observed a linear increase of soil C by 2.10 Mg C ha^{-1} yr^{-1} (Hooker and Compton, 2003) and another study observed a linear increase of soil C by 2.10 Mg C ha^{-1} yr^{-1} at a New England site (Hooker and Compton, 2003).

Agricultural Legacy: Soil Type

Several studies have shown soil type to influence legacy recovery time. Soil texture influences soil P availability and retention following agricultural abandonment (Lawrence and Schlesinger, 2001; MacDonald et al., 2012; Negassa and Leinweber, 2009), as does soil OM content due to increased sorption sites and the complexes increased clay content have with OM (Blake et al., 2000). Morris et al. (2013) found that soil series responded differently to agricultural abandonment a century after cultivation. In examining differences in regional P legacy, MacDonald et al. (2012) found that labile P elevation following agricultural abandonment decreased as clay content increased due to the strong sorbing capacity of clay soils. Soil orders, Entisol, Ultisol, and Andisol, containing a mean clay content of 15% or less, exhibited significantly higher extractable P than Oxisols and Alfisols with mean clay contents greater than 26%, and lower or no change in extractable P following agriculture abandonment (MacDonald et al., 2012). Lightly weathered and low clay content Spodosols exhibited increased total and labile P following abandonment.

In addition to inherent differences of some soils to retain or lose nutrients, the interaction between soil type and human use will appear in the soil legacy. Some soils were preferentially selected for farming due to higher nutrient content or available moisture (Bratton and Miller, 1994). Higher sand percentage may make soils less suitable for farming due to rapid drainage and lower nutrient retention (Abrams and Hayes, 2008) and clay-textured soils are more difficult to till. Roman farmers at an abandoned agriculture village in present day France appeared to select agriculture fields with lower clay content and higher silt content (Dupouey et al., 2002). At the Cumberland Island National Seashore, Georgia, a preference for one soil series over another for agriculture was apparent (Bratton and Miller, 1994).

US Southeastern Lower Coastal Plains Legacy

Many European and American studies have investigated soil legacy effects from historic agricultural activities, yet only a few studies (Bratton and Miller, 1994; Smith and McGrath, 2011) document the influence of post-colonial agriculture on southeastern, US Lower Coastal Plains soils. Coastal Georgia was first settled by Spanish missionaries in the 1560s and later by British colonists in the mid-1730s (Swanson, 2012). Though local Native Americans tribes were reported to have farmed in parts of the region (Bullard, 2003), the degree of land cover change for agricultural development following British arrival was significant (Swanson, 2012). Agricultural productivity in Lower Coastal Plain soils would have necessitated nutrient amendments to sustain crop yields due to the sandy texture and generally low pH, cation exchange capacity, and C content (Novak et al., 2009) of the soil. Soil OM in this region rapidly oxidizes and nutrients, like soil nitrogen, readily leach from the soil (Tiessen et al., 1994; Zotarelli et al., 2007). As well, soil P is often low in Lower Coastal Plain soils (Boruvka and Rechcigl, 2003).

Project Objectives

Knowledge of a sites soil is essential to accurately interpret past, present, and future land use and understand ecological conditions. The goal of this study was to determine and quantify how agricultural land use alters soil properties of coarse-textured soils in the southeastern US Lower Coastal Plains, where post-European colonization history is the longest in North America. Our specific objectives were to: (1) determine what differences in soil profile characteristics and soil chemistry exist between historically cultivated and non-cultivated areas that remained in forest cover; (2) compare the effects of agriculture on two contrasting soil series, a Spodosol and a non-Spodosol; and (3) establish relationships among vegetation and soil characteristics of the site. Due to the degrading effects of tillage on soil OM, the inherent low, soil OM content in Coastal Plain soils, and the long term crop removal of soil nutrients, we predicted that total C and N would be reduced and a lower C:N ratio would occur in surface soils on previous agricultural fields in comparison to areas never farmed. Next, we predicted that extractable P would be elevated in surface soils in comparison to areas never farmed, due to the immobile nature of soil P and the low, native soil P concentration that would have necessitated P nutrient amendments to maximize crop yields. We also predicted that pH and extractable Ca and Mg would be elevated in agricultural areas due to the necessity of liming from low, native pH and the influence of shell middens on the property. We predicted that soil series across different soil orders would behave differently from agricultural land use, even though soil characteristics for each series were similar. And finally, we predicted that differences in dominant over and understory vegetation across historic agricultural areas would not be apparent due to the varied land use activities on the property since agricultural abandonment.

Materials and Methods

Site Description

Wormsloe State Historic Site is located on the southern end of the Isle of Hope, approximately ten miles outside of downtown Savannah, Georgia (Fig. 2.1). The Isle of Hope, not an actual island, is a peninsula connected to the mainland by a small strip of land (Swanson, 2012). The 333 ha site houses Wormsloe Historic Park, the UGA Center for Research and Education at Wormsloe (UGA-CREW), and the private residence of the descendants of the first colonial settlers who established Wormsloe. Wormsloe is bordered by salt flats and marsh on all sides except on its northern boundary (Swanson, 2012). The property, and adjacent islands, like Skidaway Island to the east, are part of a labyrinth of marsh, hammocks, and waterways between Savannah and the Atlantic Ocean (Swanson, 2012). Wormsloe receives an average of 121.4 cm (47.8 in) of precipitation a year and experiences average annual temperatures of 18.4 C (65.2 F) (NOAA, 2014). Elevation ranges from zero to 4.3 m (14 ft) above sea level (NOAA, 2012).

Like many peninsulas and barrier islands on the Southeast Atlantic Coast, the Isle of Hope is a composite landform. Its core is comprised of ancient dune and beach deposits formed during the Late Pleistocene Epoch, some 40,000 to 50,000 years ago

(NGE, 2014). In the last 15,000 years, Holocene Epoch sediments have been deposited over the older sediments forming the structure of the current coastal landforms. These deposits are shaped by wind and water erosion through tidal action, precipitation, wind, alluvial deposits, and storms. Pleistocene sediments were identified approximately sixteen feet below the soil surface on St. Catherines Island, Georgia (Booth et al., 1999), but estimates of the intersection depth between Pleistocene and Holocene sediments at Wormsloe are not known.

Wormsloe soils, mapped by the Natural Resource Conservation Service (NRCS) in 1968, are typical of the Lower Coastal Plain. Series mapped include Chipley (thermic, coated Aquic Quartzipsamments), Olustee (sandy, siliceous, thermic Ultic Alaquods), Ellabelle (loamy, siliceous, semiactive, thermic arenic Umbric Paleaquults), Albany (sandy, siliceous, subactive, thermic aquic Arenic Paleudults), Leon (sandy, siliceous, thermic Aeric Alaquods), and Lakeland (thermic, coated Typic Quartzipsamments). These soils are characterized by a sandy surface over a sandy or loamy subsurface, underlain by marine sediments. These soils are formed on flat to gently sloping landscapes, drained by shallow depressions (Soil Survey Staff, 1974). Soil variability and genesis reflected in mapped soils is influenced by elevation, geologic age, slope, water table, and drainage. The site's water table ranges from 122 to 244 cm (4 to 8 ft) depending on elevation and season. Drainage and depth to water table influence soils at Wormsloe, which contain moderately well drained to poorly drained soils, with most soils being somewhat poorly drained.

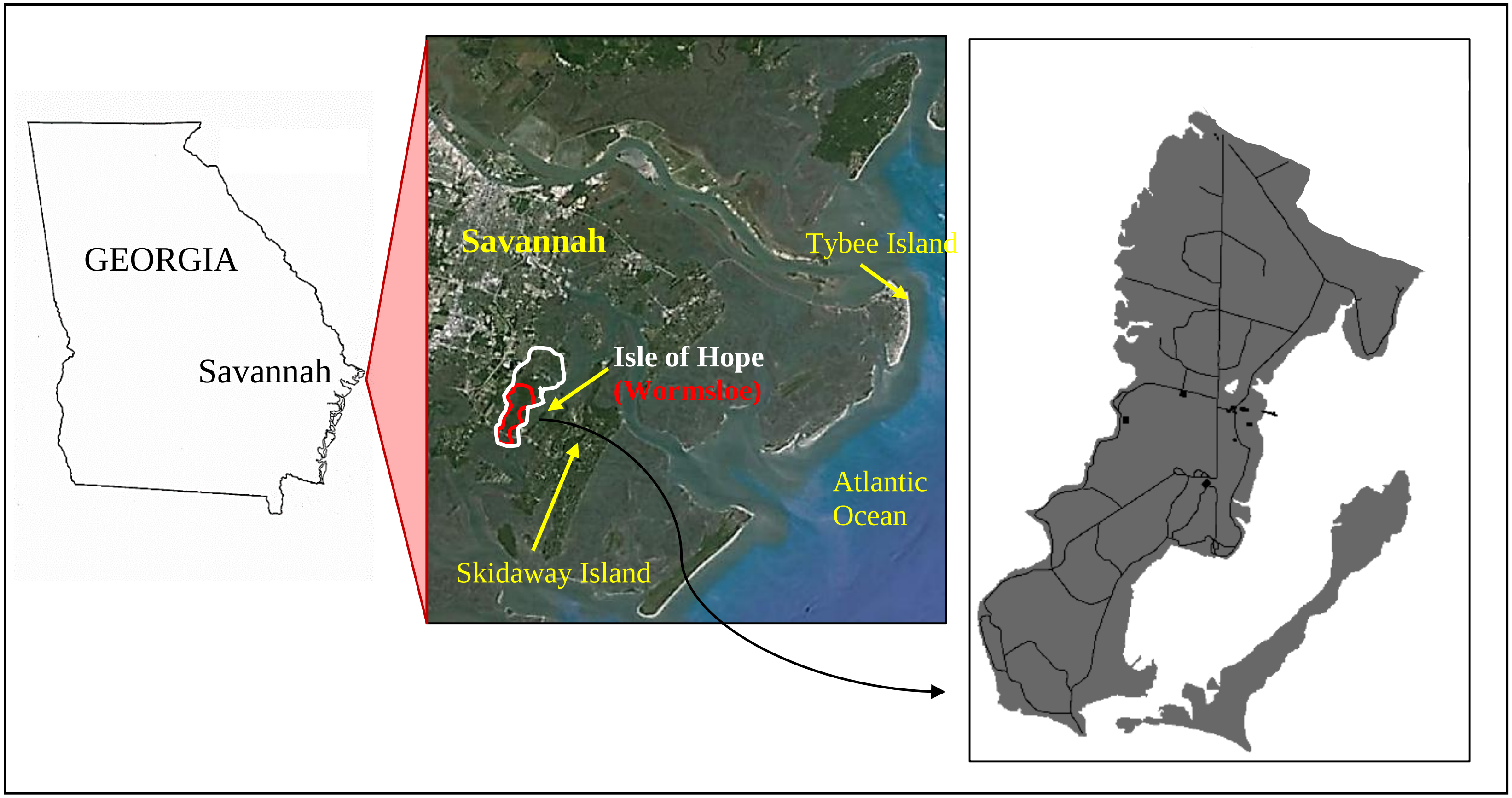

Figure 2.1: Map of Wormsloe State Historic Site, located on the Isle of Hope, southeast of Savannah, Georgia.

Vegetation at Wormsloe consists of Lower Coastal Plain maritime forest plants in various stages of succession. Common overstory species on better drained sites include live oak (*Quercus viginiana*), water oak (*Quercus nigra*), laurel oak (*Quercus hemisphaerica*), loblolly pine (*Pinus taeda*), sweetgum (*Liquidambar styraciflua*), southern magnolia (*Magnolia grandiflora*), pignut hickory (*Carya* spp.), red bay (*Persea borbonia*), and cabbage palm (*Sabal major*) (Hodler and Schretter, 1986; NPS, 2005). On poorly drained sites near marsh or depression areas, slash pine (*Pinus elliottii*), eastern red cedar (*Juniperus virginiana*), baldcypress (*Taxodium distichum*), and red maple (*Acer rubrum*) are common. Common understory species at Wormsloe include American holly (*Ilex opaca*), galberry (*Ilex glabra*), yaupon (*Ilex vomitoria*), wax myrtle (*Morella cerifera*), saw palmetto (*Serenoa repens*), sabal palm (*Sabal minor*), switch cane (*Arundinaria gigantea*), lyonia (*Lyonia lucida*) and various grass and fern species (NGE, 2013). At colonist arrival in the 1730s, forest cover at Wormsloe consisted of *Quercus viginiana* hammocks on poorly drained sites and open canopy forests of *Pinus taeda and palustris* on better drained sites (Swanson, 2012).

The leaf and woody litter of maritime forest species contains elevated carbon to nitrogen ratios (C:N) and high concentrations of tannin compounds. This litter decomposes slowly, resulting in soils with low fertility and high acidity. Soluble organic compounds produced during the decomposition of this litter leach through the profile, removing essential plant nutrients, or base cations, from surface horizons (Phillips and FitzPatrick, 1999).

Wormsloe Land Use History

Land use history at Wormsloe varies across both spatial and temporal scales. In 1736, British colonist Noble Jones acquired the first 202 ha (500 ac) tract of the present day Wormsloe property and immediately began building a home and clearing land for agriculture (Swanson, 2012). Agricultural activity at Wormsloe peaked during the Civil War, when it encompassed between 40-50% of the property. After the war, agriculture decreased until the mid-1930s, after which cultivated fields and pastures were abandoned and naturally regenerated to the forest cover present today (Swanson, 2012) (Fig. 2.2). By the 1960's, no portion of the landscape was cultivated for agriculture.

Even though significant acreage was used for agriculture, large areas of the property have remained uncultivated and under some forest cover since 1736. In 1945, Wormsloe was reported to have approximately 324 ha of timberland (Barrow, 1945), with 162 ha reported to never have been logged by the 1960s (Audubon, 1963). Over time, these forests areas were utilized for lumber and fuel wood, hunting, and open-range grazing (Swanson, 2012). It was not uncommon for forest areas to be burned, thinned, or, less commonly, clearcut (personal communication with property residents). In 1974, after 304 ha of the Wormsloe property were donated to the Nature Conservancy and subsequently sold to the state of Georgia to be run as a historic park by the Georgia Department of Natural Resources, the entire tract's pines were logged due to a Southern Pine Beetle outbreak (Swanson, 2012). Despite varying and infrequent forest activity, as compared to the effects of agriculture tillage, forest soils at Wormsloe are relatively undisturbed. These forest areas serve as a reference that represent native soil conditions (Fig. 2.2).

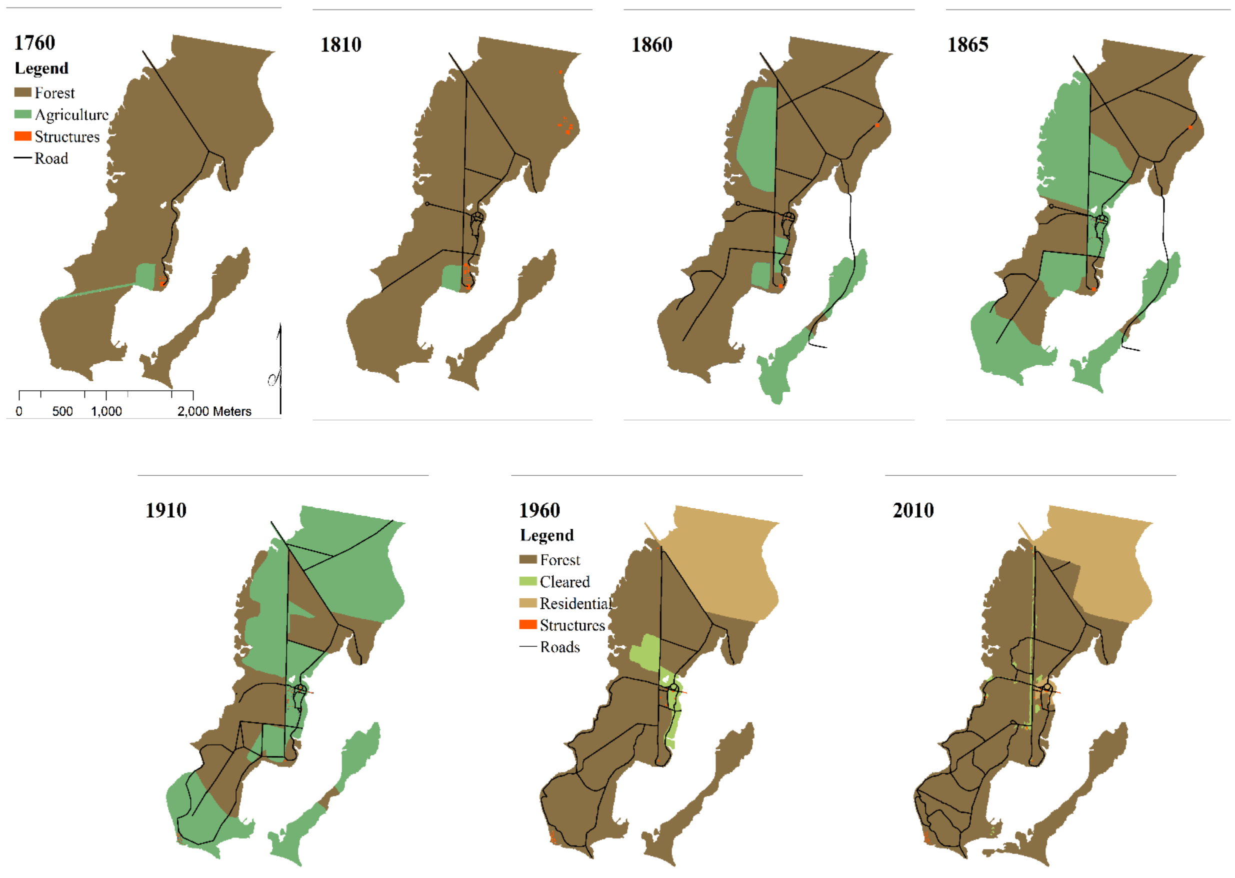

Figure 2.2: Land use history maps of Wormsloe from 1760 to 2010 (UGA CGR) demonstrate areas used for agriculture and areas that have remained forested.

Sampling Design

In traditional soil surveys, soil scientists use landscape features and vegetation to select soil survey locations (USDA, 1996). To avoid the potential bias that a traditional soil survey might generate, random soil sample plots were generated for this study using ArcGIS 10.1 (ESRI, 2012) to investigate if and how soil properties at Wormsloe differ among historical land use types.

Prior to randomization of survey locations, candidate areas of Wormsloe were identified and mapped based on three criteria: Wormsloe land use history records and maps from years 1730-2010 (Jordan and Madden, 2013; Swanson, 2012); the predominant soil series (Soil Survey Staff, 1974) and the geographic location on the property (North, Central, South) (Fig. 2.3). Land use history was classified into two main categories: (1) areas used for historic agriculture some time from year 1730 to present (Agriculture) and (2) areas never farmed and under continuous forest cover from year 1730 to present (Reference). Agriculture and Reference are used to represent high and low soil disturbance, respectively. Additionally, land use history maps were investigated to establish Agricultural Periods, or time since agricultural abandonment: Post Civil War (abandoned over 100 years ago), Depression (abandoned over 80 years ago), Modern (continues to receive nutrient amendments like ash or garden fertilizer), and No Agriculture History, or Reference, (280 years of some forest cover and no agriculture).

From the six soil series mapped at Wormsloe, Chipley and Olustee were selected for investigation. Significant acreage in Agriculture and Reference areas across the length of the property contain both series. Chipley and Olustee soil series and Agriculture and Reference areas were spatially combined in ArcGIS 10.1™ to create four distinct land use-soil series combinations: Chipley-Agriculture, Chipley-Reference, Olustee-Agriculture, and Olustee-Reference (Fig. 2.3). Each of these four land use-soil series combinations were separated into North, Central, or South locations on the property (blocks), thus generating twelve sample areas. A ten meter buffer was established around each of these areas, and ten sampling plots were randomly generated within each of the areas using ArcGIS 10.1™ spatial tool, Create Random Points. Randomization was constrained by establishing minimum distances between plots of 15 m in the Olustee soil, which was limited in area, and 30 m in Chipley soils, which was more extensive in area. Thus, a total of 120 sampling plots were established for detailed description and sampling (Fig. 2.3).

Soil Profile Description and Sampling

At all random sample plots, the soil profile was described using methods of the USDA Soil Survey Laboratory Methods Manual for field surveys (USDA, 1996). In the field, plot coordinates assigned by ArcGIS were located with a handheld Flint S Series™ (F4 Devices, Tallahassee, Florida) GPS unit (1-3 m accuracy) and compass. An open bucket soil auger (10 cm diameter) was used to auger one 160 cm hole at all plots. A subset (n=10) of plots were also observed using a 2 m long open bucket auger.

At each plot, the soil profile was described, dominant vegetation and landscape features were recorded, photos were taken, and a surface composite soil sample was obtained. Profile description included horizon depth, color, texture, structure, consistence, description of redoxymorphic features, drainage class, and notes of any

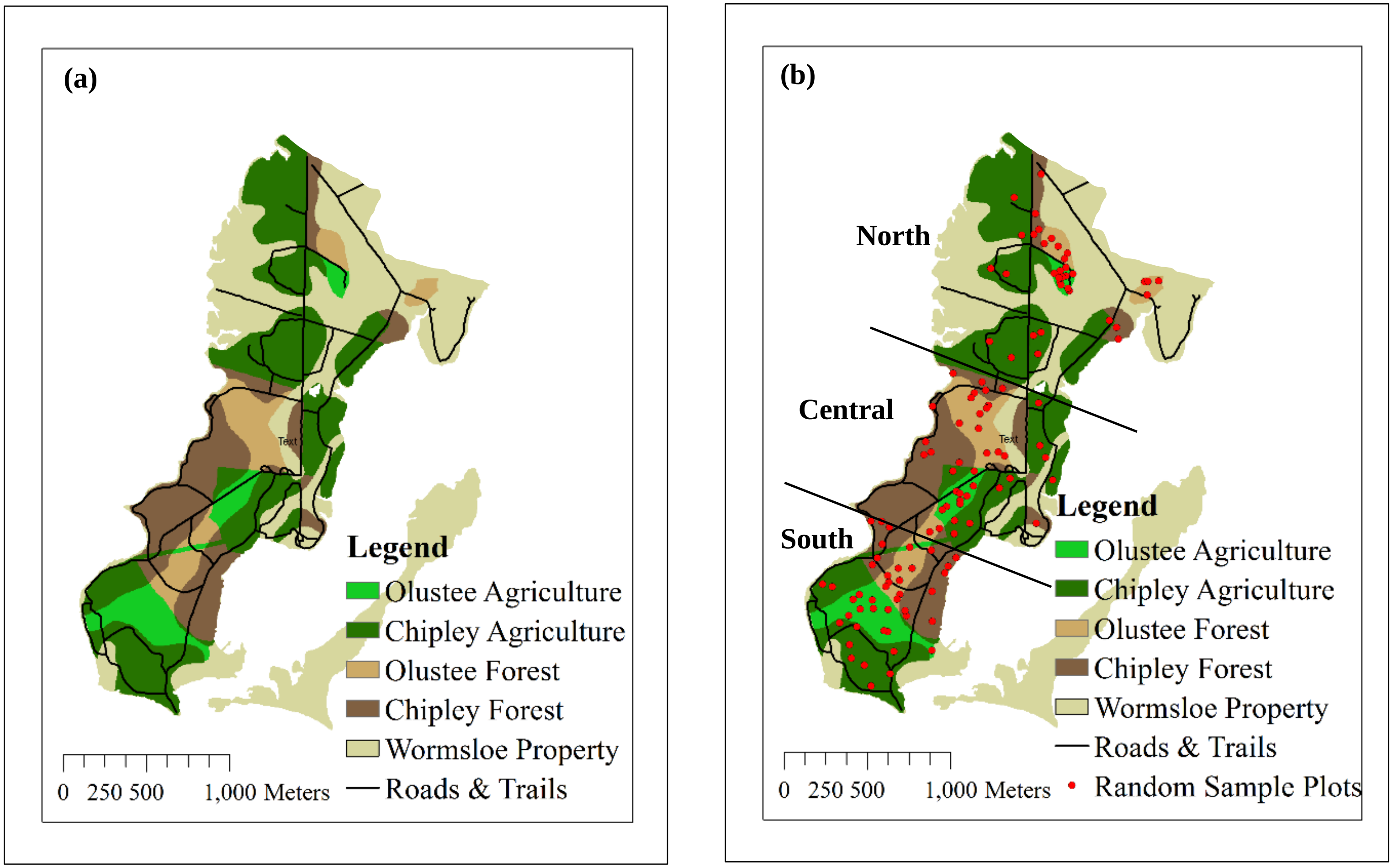

Figure 2.3: (a) Map of land use-soil series combinations at Wormsloe. (b) Random sample plots distributed across land use-soil series combinations. Maps made by author in ArcGIS using base data from the UGA CGR Wormsloe geodatabase.

artifacts or other unusual features found. Vegetation descriptions included dominant over and understory species. Landscape features noted were slope and landscape position. Plot elevation was obtained from a aerial LiDAR map (NOAA, 2012).

An Oakfield probe was used to collect a composite of six soil samples at a 0-15 cm depth within a 3 m radius around the point. This composite was thoroughly mixed and subsampled for return to the laboratory. Additional soil samples were collected at all 120 plots at depths: 0-15 cm, 70-90 cm, and 140-160 cm, generally representing the surface, top of the B horizon, and C horizon, respectively. A subset of these multi-depth, soil samples were used for particle size analysis (n=72), and sand grain size analysis (n=14). Lastly, the location of all 120 plots were marked with a labeled polyvinyl chloride (PVC) stake.

Laboratory Chemical Analysis

Sieved samples were analyzed for C, N, P, calcium (Ca), magnesium (Mg), and pH. Following field collection, soil samples were dried in a 65C° forced-air oven and sieved through a 2mm screen. Samples analyzed for total N and C were ball mill ground in a SPEX CertiPrep 8000 D Mixer Mill™ (Thermo Fisher Scientific, Waltham, Massachusetts) and analyzed for total N and C using a dry combustion CN Soil Analyzer (Flash 2000-Organic Elemental Analyzer™, Thermo Fisher Scientific, Waltham, Massachusetts). Phosphorus, Ca, and Mg were extracted with a Mehlich-1 (M1) extraction solution (0.05 N HCl and 0.025 N H_2SO_4) (Mehlich, 1953). Phosphorus was analyzed on a Genesys 2 Spectrophotometer™ (Spectronics, Westbury, New York) using methods outlined by Murphy and Riley (1962). Calcium, Mg, and K were analyzed on an AAnalyst 200 Atomic Absorption Spectrometer (Perkin Elmer, Waltham, Massachusetts) using Methods of Soil Analysis SSSA (1996) for atomic absorption spectrophotometry. Soil pH was determined on an Orion 710A (Sigma Aldrich, St. Louis, Missouri) using an electrode in both water and calcium chloride solutions using methods from (Soil Survey Staff, 2010; Thomas, 1996).

Laboratory Physical Analysis

A subset of samples were used to measure soil texture. Particle size analysis was determined at three depths for 24 sample points (n=72) using the hydrometer method (Day, 1965). Sand grain size analysis (ASTM D 422 - Standard Test Method for Particle-Size Analysis of Soils) was determined at two depths on 7 sample points (n=14).

Statistical Analysis

Following a test of normalization by using mean residuals for all 12 treatment areas, relationships among soil series, land use, and the interaction between land use and soil series, with blocks as a fixed effect, were investigated using a generalized linear model (SAS Institute, Inc., Cary, North Carolina). Duncans Multiple Range Test determined significance among categorical variables. To further evaluate patterns within the data set, we used Discriminant Function Analysis and Principle Components Analysis (SAS Institute, Inc., Cary, North Carolina).

Results

Agricultural Legacy: Soil Profile Characteristics

Field investigations revealed much more diverse soil series than were mapped at Wormsloe by the NRCS in 1968. Soils mapped as poorly drained Olustee were more often identified as somewhat poorly drained Ridgeland and Mandarin, moderately well drained Echaw or poorly drained Boulogne and Lynn Haven. The first three of these series are defined as sandy, siliceous, thermic Oxyaquic Alorthods and the latter two as sandy, siliceous, thermic Typic Alaquods. Excluding Echaw and Lynn Haven, all series contained a near-surface spodic (Bh) horizon, with or without a preceding E horizon, from 5 to 40 cm in depth and were typically followed by a second Bh from 75 to 150 cm in depth. Echaw and Lynn Haven contained only one Bh horizon that began from depths greater than 76 cm and 40 cm, respectively. Though Olustee also contained a near-surface spodic horizon, it differed from these other series by containing an argillic horizon below the Bh horizon. Chipley was identified at several sample plots where it was mapped, but many Chipley-mapped plots were also identified as Alorthods and Alaquods found in Olustee areas. Chipley differed from these soils in that it has no Bh horizon.

Chipley soil profiles contained a very dark gray (Munsell color 10YR 3/1), very friable, granular fine sand A or Ap horizon up to a 20 cm depth (Fig. 2.4). This surface horizon was underlain by a C horizon (fine sand texture, single grain structure) to a 160 cm depth, or depth of sampling. Olustee soils had a black (10YR 2/1) very friable, granular loamy sand A/ Ap horizon to a 15 cm depth (Fig. 2.4). This horizon was underlain by a very dark brown (7.5YR 2.5/2), very friable, massive fine sand Bh horizon from a 20 to 80 cm or more depth. Below the Bh horizon was a light brownish gray (10YR 6/2) friable, subangular blocky sandy clay loam Btg horizon to a 130 cm depth. The Olustee Btg horizon was followed by a dark yellowish brown (10YR 4/4) very friable, single grain sand C horizon to a 160 cm depth.

Evidence of a plow layer, or Ap horizon, was apparent in many but not all agricultural areas (Fig. 2.5). A surface Bh horizon was a similar depth to the Ap horizon at many sample plots and may, in fact, have been incorporated into the Ap horizon (Fig. 2.5). Sample points taken in or near depression areas or containing charcoal (staining) contained a deep, black surface horizon that masked the Ap. Reference areas displayed A horizons typical of forest soils (Fig. 2.5).

Oyster shell and charcoal fragments were located in several surface, and sometimes deeper, soil horizons across the property. Shell fragments were found in sample plots adjacent to the marsh or near residential areas, with none located at interior sample plots. Charcoal fragments were identified at several sample plots across the property, sometimes to depths of 50 cm or more. One sample plot in a Reference area contained a charcoal-stained E horizon that yielded charcoal C^{14} dated at 810 years before present (UGA Center for Applied Isotopes Studies, 2013).

Particle size analysis indicated that surface soils mapped as Chipley contained a mean sand:silt:clay percentage of 85:5:10 and Olustee surface soils contained a mean sand:silt:clay percentage of 89:5:6. Sand grain size analysis identified that Wormsloe soils were, on average, 83% fine sand. These lab findings verified our field texturing, indicating that most soil textures across Wormsloe, from a 0-160 cm depth were sand or loamy sand, with occasional sandy loam, sandy clay loam, and sandy clay.

Figure 2.4: Chipley and Olustee sample profiles at Wormsloe State Historic Site. Horizons are noted in yellow.

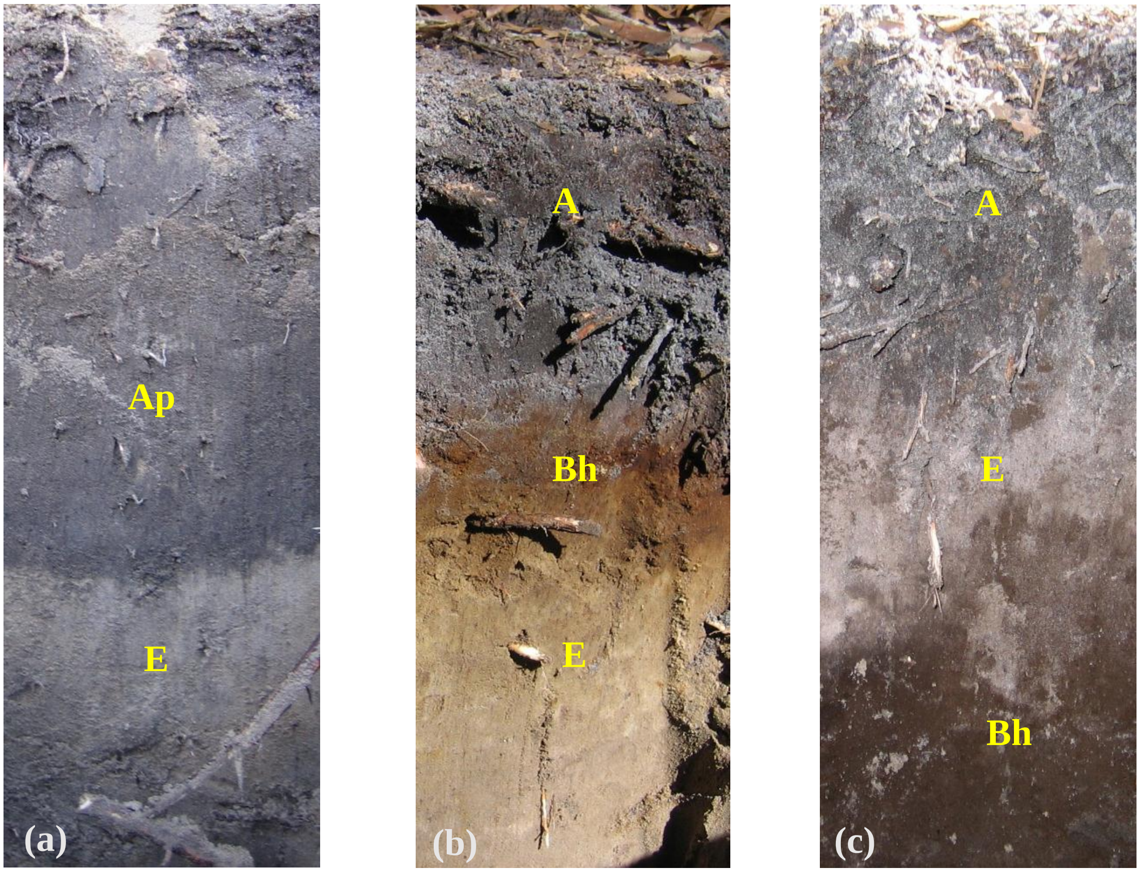

Figure 2.5: (a) Evidence of a plow layer in the abrupt boundary between the Ap and E horizon. (b) Surface Bh horizon in Agriculture area. (c) Forest soil “pit and mound”, wavy boundary between horizons, indicating a lack of soil disturbance from cultivation. Horizons are identified in yellow.

Average soil drainage class at Wormsloe was somewhat poorly drained, with occasional poorly drained sites. Average sample plot elevation was 3.38 m. Poorly drained sites were often at lower elevations (1.16-2.74 m), but not always; several small depression areas were also scattered across the property at higher elevations (3.35-3.66 m) compared to the mean elevation.

Agricultural Legacy: Soil Nutrients

Differences in land use, soil series, or the interaction of land use and soil series did not significantly affect total C and N, extractable Ca and Mg, and C:N ratio; however, using a generalized linear model, we found strong differences across land use ($p=0.049$) for extractable P and soil series ($p=0.036$) for pH (Tables 2.1 and 2.2). Agriculture extractable P mean (85.31 mg kg^{-1}) was significantly greater than Reference P mean (25.26 mg kg^{-1}) and Chipley pH mean (pH=4.10) was significantly greater from Olustee pH mean (3.77).

Great variability existed in all nutrients within land use-soil series combinations, though this variability was not always statistically significant (Fig. 2.6 and 2.7). Outliers, or values outside of most of the other values in a dataset, were useful for discriminating potential agricultural legacy effects from landscape effects like elevation and landscape position. Total C and N in Agriculture-Chipley, Agriculture-Olustee, and Reference-Olustee areas contained several outlier sample plots that were located in depression or low elevation landscape positions. The overall mean for total C and N was 3.2 and 0.12

Table 2.1: Arithmetical mean and standard error of soil chemical properties in land use soil series combination areas, averaged across blocks.

	Chipley				Olustee			
Soil Property	Agriculture		Reference		Agriculture		Reference	
pH†	4.3	± 0.1	3.9	± 0.1	3.8	± 0.1	3.7	± 0.05
C (% by mass)	3.7	± 0.6	2.9	± 0.2	2.9	± 0.3	3.2	± 0.2
N (% by mass)	0.16	± 0.03	0.1	± 0.01	0.11	± 0.01	0.11	± 0.01
P (mg/kg) ††	113	± 27	30	± 11	58	± 12	20	± 3
Ca (mg/kg) ††	1337	± 495	601	± 245	77	± 13	84	± 13
Mg (mg/kg) ††	108	± 58	40	± 10	20	± 3	32	± 3
C:N	29	± 5	33	± 2	27	± 0.8	31	± 0.7

Table 2.2: Arithmetical mean and standard error of soil chemical properties in soil series and land use areas, averaged across blocks.

	Overall				Overall			
Soil Property	Agriculture		Reference		Chipley		Olustee	
pH†	4.0	± 0.1	3.8	± 0.1	4.1	± 0.1§	3.8	± 0.04
C (% by mass)	3.3	± 0.35	3.02	± 0.14	3.3	± 0.3	3.1	± 0.2
N (% by mass)	0.13	± 0.02	0.1	± 0.01	0.13	± 0.02	0.1	± 0.01
P (mg/kg) ††	85	± 15§	25	± 6	72	± 15	39	± 7
Ca (mg/kg) ††	707	± 259	342	± 126	969	± 278	81	± 9
Mg (mg/kg) ††	64	± 5	36	± 5	74	± 30	26	± 2
C:N	28	± 2.5	32	± 1.1	31	± 2.6	29	± 0.6

†-1:1 water:soil extraction
††-Mehlich I extractable
§-significant at .05 level

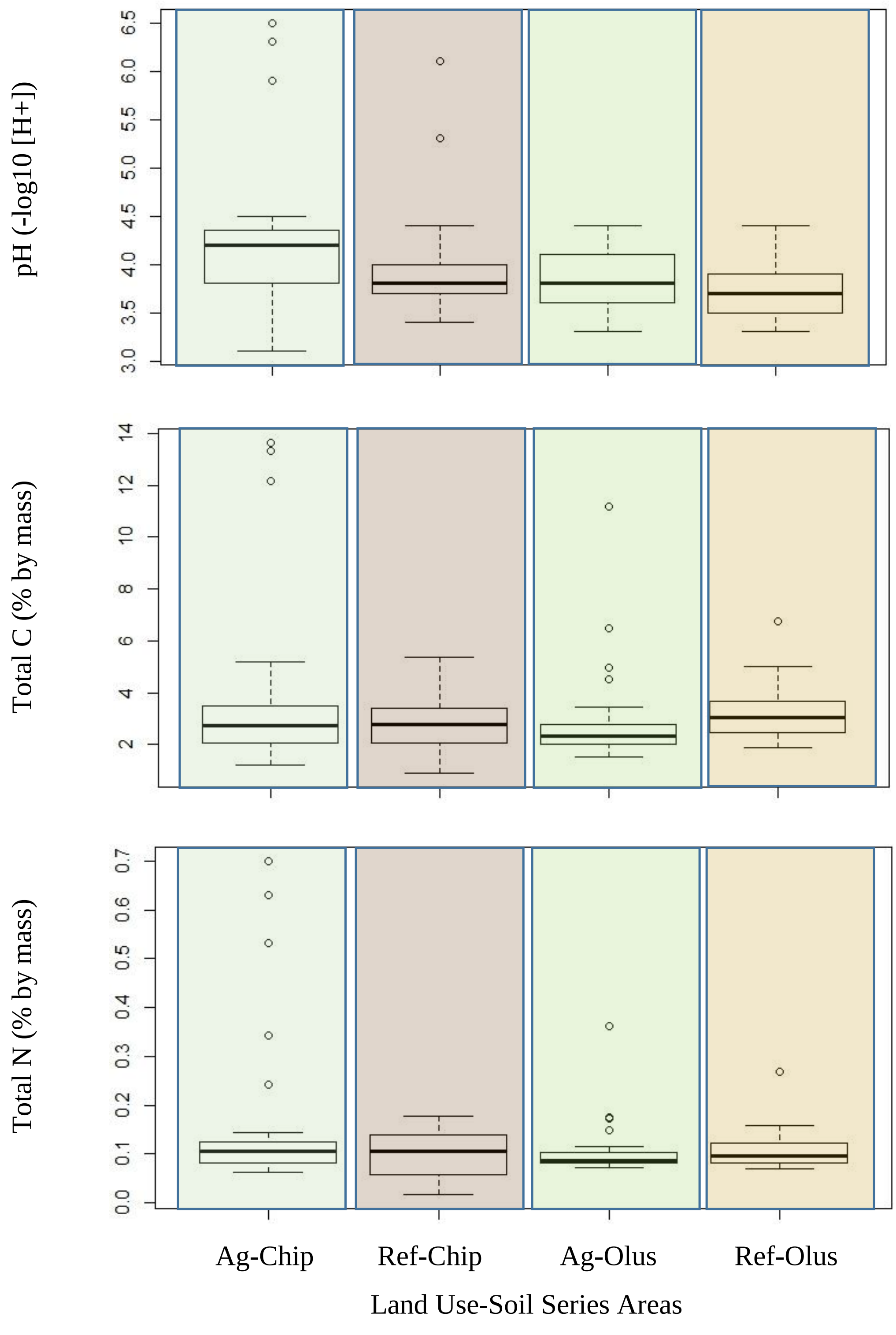

Figure 2.6: Boxplots of land use soil series combination areas for pH, C, and N. Outliers (indicated by small circles) were either related to land use legacies or site features.

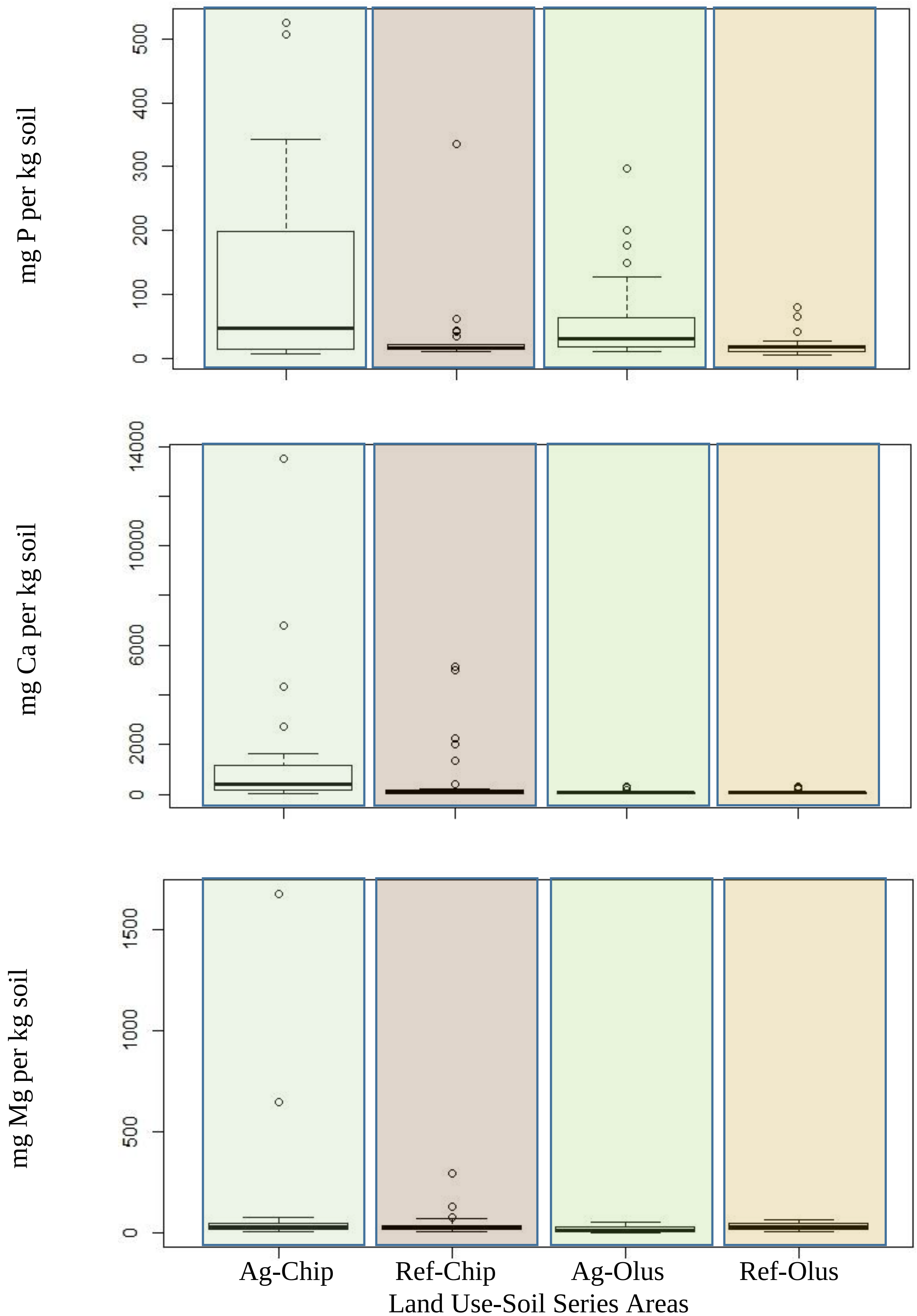

Figure 2.7: Boxplots of land use soil series combination areas for P, Ca, and Mg. Outliers (indicated by small circles) were either related to land use legacies or site features.

percent by mass, respectively, and the mean elevation was 3.38 m. These outliers ranged from 4.9 to 13.6% total C and 0.16 to 0.70% for total N with a mean elevation of 2.7 m.

Overall, mean pH at Wormsloe was 3.9 ± 0.05, with a mean Agriculture-Chipley pH of 4.3 ± 0.1 and Reference-Chipley pH of 3.9 ± 0.1 (Table 2.1). Soil pH outliers shown in Fig. 2.6 for Agriculture-Chipley areas were at a long-term burn pile (pH=5.9), garden (6.5), and depression area (6.3). In the Reference-Chipley areas they occurred at a shell midden (6.1) and hickory forest (5.3). All of these sites occurred in the North and Central blocks, with the Agriculture-Chipley areas in or adjacent to a grassy field and the Reference-Chipley areas under forest cover. Though not considered outliers, several areas at Wormsloe contained very low pH (< 4.0). Figure 2.8 demonstrated that lowest soil pH predominantly occurred in Reference areas. Higher pH occurred beneath forest on old agricultural fields.

Mean labile P values overall at Wormsloe were 55 ± 8 mg kg^{-1}, with a mean Agriculture-Chipley of 113 ± 27 mg kg^{-1}, Reference-Chipley of 30 ± 11 mg kg^{-1}, Agriculture-Olustee of 58 ± 12 mg kg^{-1}, and Reference-Olustee of 20 ± 3 mg kg^{-1} (Table 2.1). Extractable P outlier values (Fig. 2.7) occurred across all land use-soil series combination areas. The highest values, over 200 mg kg^{-1}, occurred within previous agriculture fields and a hickory forest (Fig. 2.9); with most occurring in Agriculture-Chipley, Agriculture-Olustee, and Reference-Chipley areas. The highest extractable P value at Wormsloe was located on a historical agricultural field later used as a refuse pile and currently utilized for burning debris (526 mg kg^{-1}).

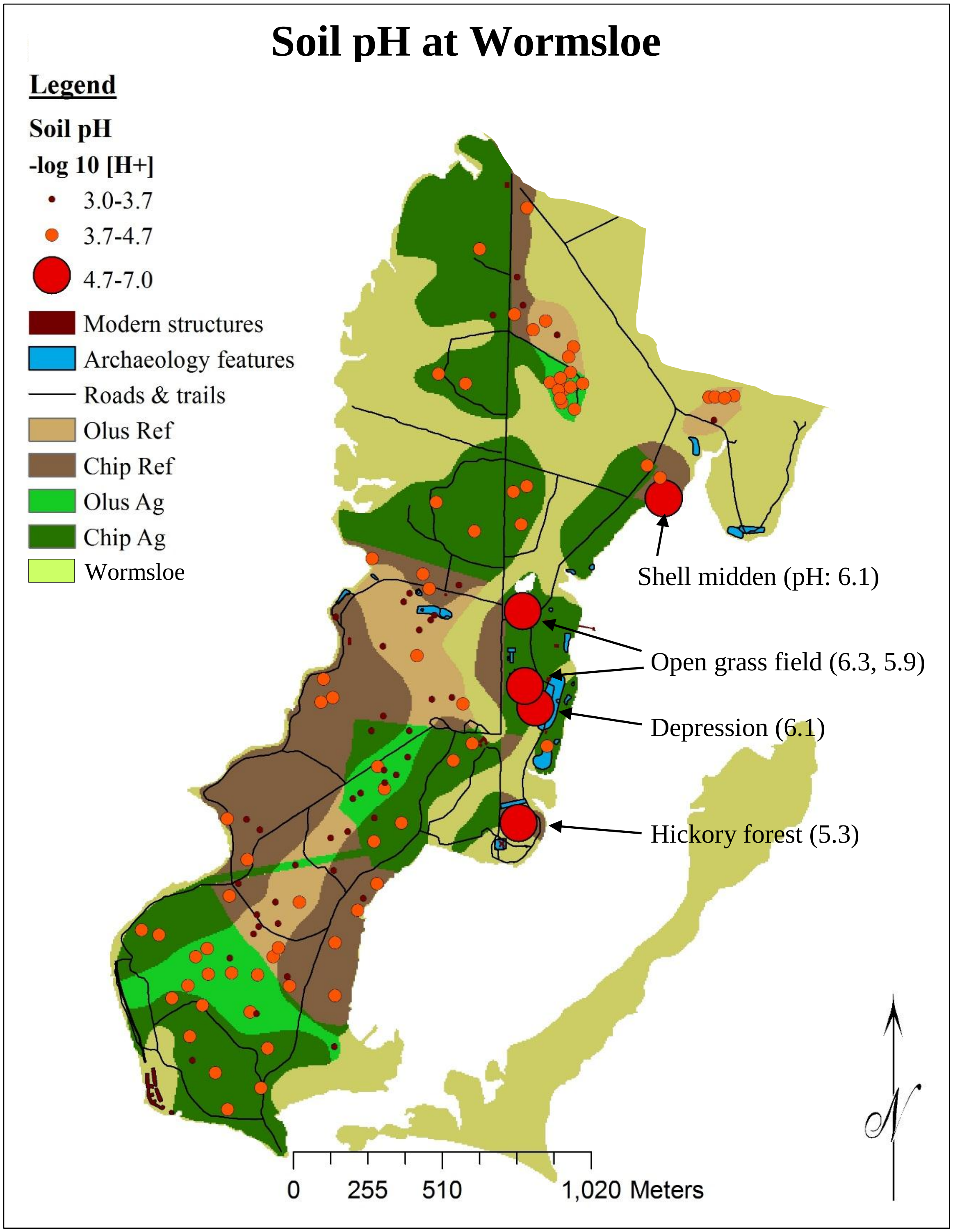

Figure 2.8: Spatial variation of soil pH across Wormsloe State Historic Site. Soil pH less than 3.7 occurred more often on Reference versus Agriculture sites. Highest pH values are located in current residential and garden areas that still receive fertilizer or liming, in areas with abundant charcoal and shells, or historic residential areas. Map made by author in ArcGIS using base data from the UGA CGR.

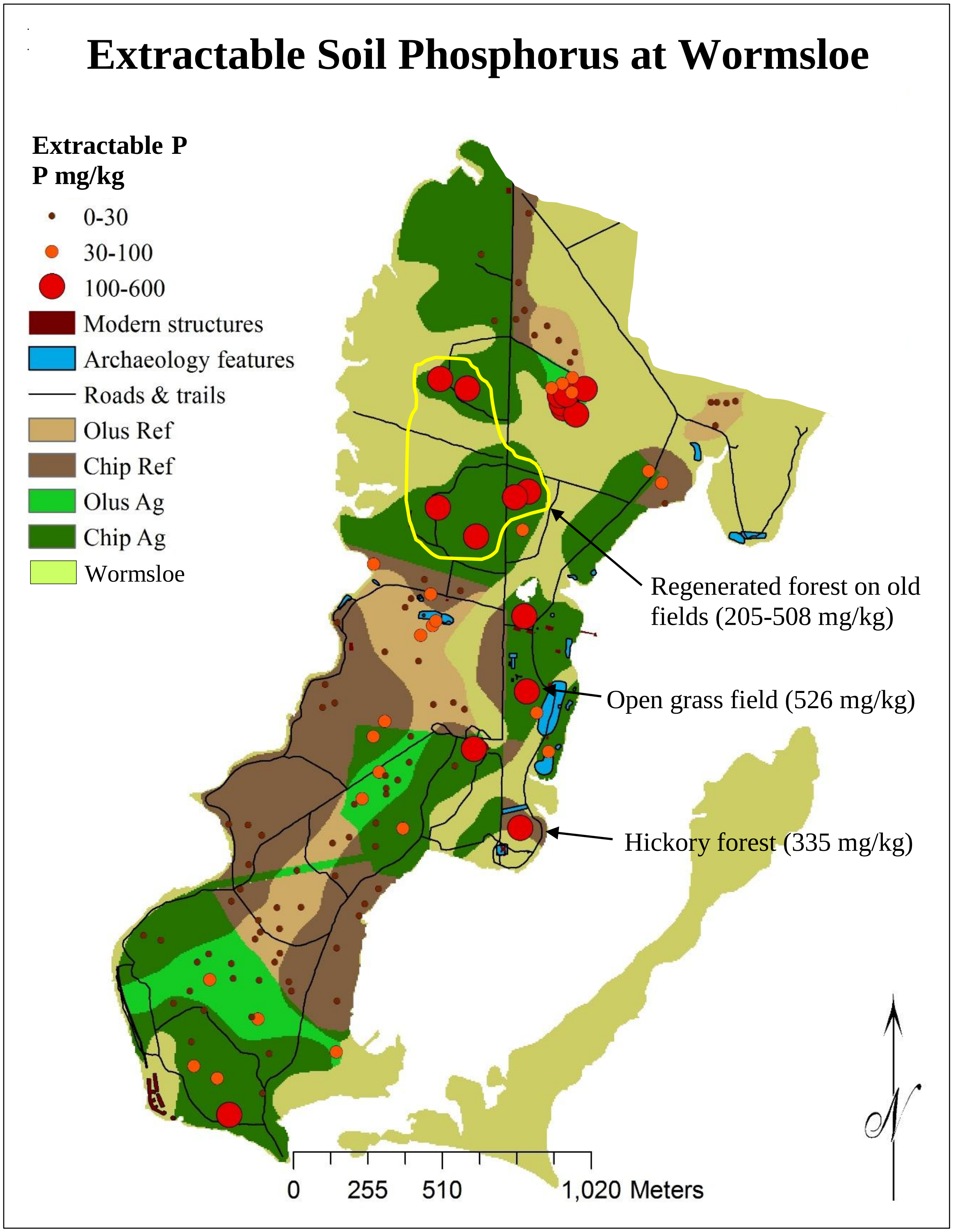

Figure 2.9: Spatial variation of exchangeable P across Wormsloe State Historic Site. Highest P values occurred in Agriculture areas. Reference areas with elevated P occur in old trash piles and near shell middens. Map made by author in ArcGIS using base data from the UGA CGR.

Mean extractable Ca values overall at Wormsloe are 524 ± 144 mg kg^{-1}, with a mean Agriculture-Chipley of 1337 ± 495 mg kg^{-1}, Reference-Chipley of 601 ± 245 mg kg^{-1}, Agriculture-Olustee of 77 ± 13 mg kg^{-1}, and Reference-Olustee of 84 ± 13 mg kg^{-1} (Table 2.1). Like P, extractable Ca contained outliers (Fig. 2.7) in all land use-soil series combination areas; however, highest Ca concentrations (> 1,000 mg kg^{-1}) occurred in Agriculture-Chipley and Reference-Chipley areas with values ranging from 1,052 to 13,524 mg kg^{-1}. Over half of these higher concentration sites contained shell fragments or charcoal within the soil profile; occurring near shell middens, residential areas, or within a hickory forest.

Mean extractable Mg values overall at Wormsloe are 51 ± 15 mg kg^{-1}, with a mean Agriculture-Chipley of 108 ± 58 mg kg^{-1}, Reference-Chipley of 40 ± 10 mg kg^{-1}, Agriculture-Olustee of 20 ± 3 mg kg^{-1}, and Reference-Olustee of 32 ± 3 mg kg^{-1} (Table 2.1). Extractable Mg contained few outliers (Fig. 2.7), with all occurring within Agriculture-Chipley and Reference-Chipley areas. Two outliers occurred in or near a grassy field, while others were located under forest cover. Their values ranged from 131 to 1678 mg Mg per kg soil.

Results from the Principle Components Analysis of soil and site variables are presented in Table 2.3. Over 30% of the variation in the 11 quantitative variables included in the analysis was explained on Principle Component 1, which was best described as being driven by soil alkalinity. Soil pH, Ca, Mg, and, to a lesser extent, P concentrations were all positively loaded on the component. The positive loading of

Table 2.3: Principle component analysis results investigating correlations between soil nutrient and profile characteristics. Component 1 explains that 30.4% of the variability in data is influenced by Ca, Mg, and pH and 19.9% of the variability in data is influenced by total C.

Loading Matrix	**Prin Comp 1**	**Prin Comp 2**	**Prin Comp 3**	**Prin Comp 4**
Forest Cover Yrs	-0.385	0.201	0.474	0.424
Elevation (m)	-0.559	-0.387	-0.261	0.252
A depth (cm)	0.523	0.422	0.029	0.475
Depth to surface Bh (cm)	0.379	0.394	0.295	0.005
pH†	0.739	-0.433	0.284	0.104
Total C (%)	0.272	0.801	-0.300	-0.220
Total N (%)	0.548	0.495	-0.551	0.122
C:N	-0.236	0.481	0.481	-0.569
P (mg kg^{-1}) ††	0.504	-0.510	-0.285	-0.303
Ca (mg kg^{-1}) ††	0.814	-0.312	0.143	-0.075
Mg (mg kg^{-1}) ††	0.760	-0.071	0.295	0.273
Percent variability explained by component	30.4	19.9	--	--

†-1:1 water:soil extraction

††-Mehlich I extractable

extractable soil P would be expected in acid soils as pH is increased toward more neutral pH due to decreased fixation in non-labile forms by aluminum (Al) and iron (Fe). A horizon depth and N were also positively correlated with this component. Elevation was negatively loaded on this component, perhaps reflecting a tendency for the highest and driest soils to have lower inherent fertility and to have been less intensively managed for agriculture. Principle Component 2 explained an additional 19.9% of the variability and is largely a component describing organic matter accumulation in the soil surface. Carbon, N, and C:N ratio were all positively loaded on this component, as was A horizon depth. We expect these variables to be associated with increasing forest development and organic matter inputs. Both pH and extractable P were negatively associated with this component, again a likely result of lower pH and increased P fixation in soils beneath mature forests. The remaining components, including components 3 and 4 shown in Table 2.3 and others not shown, only included a few significant variables and are not easily explained.

Agricultural Legacy: Vegetation

From vegetation observations at each sample plot, seven dominant overstory forest cover types and six dominant understory cover types were detected. Dominant overstory forest types included: Wateroak (*Quercus nigra*); Oakpinesweet (*Q. nigra*, *Pinus taeda*, *Liquidambar styraciflua*); Oakmix-(*Q. nigra*, *virginiana*, *hemisphaerica*, and *falcata*); Oakpinetupelo- (*Q. nigra*, *Q. virginiana*, *P. taeda*, *Nyssa biflora*); Pinemix- (*P. taeda*, *P. elliottii*); Oakhickory- (*Q. nigra*, *Q. virginiana*, *Magnolia grandiflora*, *Carya glabra*); and Open-field (no forest cover). Dominant understory forest types included: Mix (*Persia spp., Symplocus tinctoria, Morella cerifera, Vaccinium aboreum. Serenoa repens*); Sawpalm- (*S. repens, Morella cerifera*); Galberry- (*Ilex glabra, S. repens*); Lyonia- (*Lyonia lucida*); Sabalpalm- (*Sabal minor, Morella cerifera*); Open- (grass). Discriminant Function Analysis was used to investigate correlations between soil nutrient and profile characteristics and dominant over and understory forest cover (Table 2.4 and 2.5). Extractable Ca and pH were elevated on Oakmix (n=19) and Oakpinesweet (n=45) forest types in comparison to the Wateroak (n=20) forest type. Extractable P had the highest concentration on Oakmix forest types. Higher total C occurred at lower elevations on most forest types. Other than Open areas, Oakhickory forests (n=7) contained the highest extractable P, Ca, and Mg.

Agricultural Legacy: Time Since Agricultural Abandonment

A Discriminant Function Analysis was utilized to analyze differences in soil nutrients and profile characteristics across Agricultural Periods (Fig. 2.10). Soil variables in Agriculture areas abandoned in the decades following the Civil War were difficult to discriminate from No Agriculture History, or Reference areas. Depression era agricultural abandonment differed from the Civil War Period and clearly differentiated from the Modern Period, areas that continue to receive nutrient amendments (ash, fertilizer). Investigation of group means (Table 2.6) within Agricultural Periods provides further evidence of Period differences. Reference and Civil War Periods contain similar mean pH, total C and N, exchangeable Ca and Mg, and A horizon depth. Civil War and Depression Periods have similar mean C:N ratios and extractable P. Total N means are

Table 2.4: Discriminant function analysis group means investigating correlations between soil variables and dominant overstory (DOV) forest cover groups. The discriminate method is linear.

DOV	**Count**	**Elevation (m)**	**A depth (cm)**	**Depth to surface Bh**	**pH**[†]	**Total C**[§]	**Total N**[§]	**C:N**	**P**[††‡]	**Ca**[††‡]	**Mg**[††‡]
Wateroak	20	3.75	11.40	20.15	3.88	2.77	0.10	28.43	46.65	67.89	19.389
Oakpinesweet	45	3.19	12.98	58.64	3.95	3.42	0.12	32.17	47.32	537.95	67.441
Oakmix	19	3.24	11.68	51.58	4.07	2.79	0.10	28.34	72.73	648.96	33.696
Oakpinetupelo	24	3.64	13.21	17.83	3.65	2.92	0.09	31.16	16.90	75.77	30.193
Pinemix	4	3.17	20.75	49.50	3.76	5.03	0.18	25.04	144.12	726.82	40.978
Oakhickory	7	3.20	9.14	94.14	4.38	3.09	0.20	22.06	88.79	973.12	66.635
Open	1	3.05	13.0	13.0	5.90	5.21	0.34	15.14	526.39	13524.0	649.60
All	120	3.38	12.59	44.33	3.93	3.16	0.12	29.77	55.29	524.64	50.562

Table 2.5: Discriminant function analysis group means investigating correlations between soil variables and dominant understory (DUV) forest cover groups. The discriminate method is linear.

DUV	**Count**	**Elevation (m)**	**A depth (cm)**	**Depth to surface Bh**	**pH**[†]	**Total C**[§]	**Total N**[§]	**C:N**	**P**[††‡]	**Ca**[††‡]	**Mg**[††‡]
Mix	63	3.54	11.57	31.86	3.85	2.99	0.12	28.61	37.42	243.36	27.30
Sawpalm	15	3.40	9.73	53.20	3.85	2.23	0.07	34.57	29.89	70.87	20.96
Galberry	10	3.71	16.70	20.50	3.56	3.40	0.10	32.48	17.03	95.87	37.36
Lyonia	3	3.35	11.0	16.67	3.57	4.0	0.12	33.27	7.47	49.37	33.20
Sabalpalm	22	2.70	12.86	71.91	4.32	2.72	0.14	23.84	125.95	1201.90	121.50
Open	7	2.72	21.59	96.86	4.34	7.41	0.26	43.18	123.55	2716.44	126.79
All	120	3.38	12.59	44.33	3.93	3.16	0.11	29.77	55.29	524.64	50.56

†-1:1 water: soil extraction
††-Mehlich I extractable
§-Percent by mass
‡-mg kg^{-1}

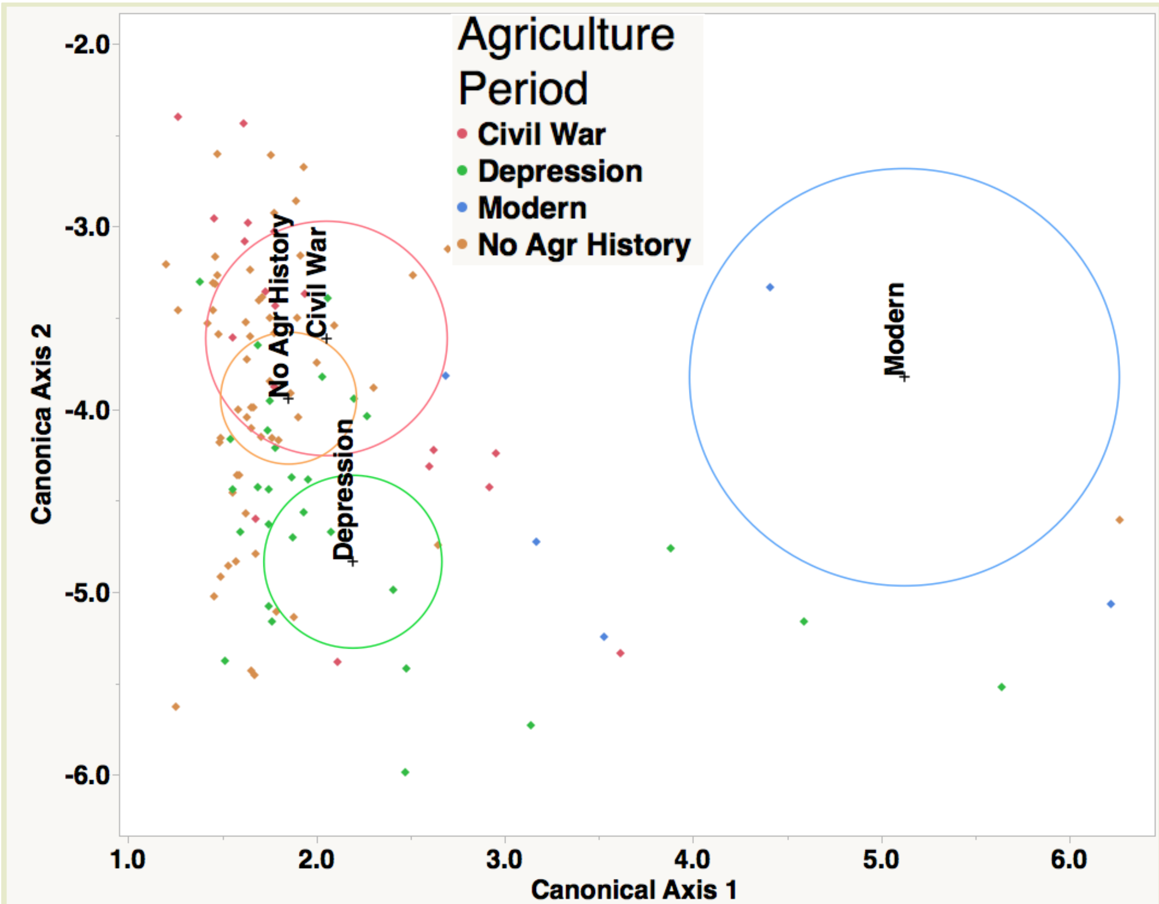

Figure 2.10: Discriminant function analysis of soil nutrients and profile characteristics across four agricultural periods that equate to time since agricultural abandonment. The Civil War Period (over 100 years since abandonment), the Depression Period (80+ years), the Modern Period (not abandoned), and No Agriculture/ Reference Period (never farmed). Overlap and separation of periods (circles) represent the similarity or difference of variables between Periods. The size of the circle corresponds to the 95% confidence limit for the mean.

Table 2.6: Discriminant function analysis group means of soil chemical and physical properties between Agricultural Periods. The discriminate method is linear.

Agricultural Period	**Count**	**Elevation (m)**	**A depth (cm)**	**Depth to surface Bh**	**pH††**	**Total C§**	**Total N§**	**C:N**	**P‡**	**Ca‡**	**Mg‡**
No Ag History/ Reference	60	3.40	12.12	43.88	3.84	3.02	0.10	31.71	25.26	342.16	35.93
Civil War	19	3.79	12.74	29.84	3.72	3.17	0.11	28.40	68.58	118.24	23.92
Depression	35	3.15	13.17	49.97	4.07	3.49	0.15	29.05	67.83	501.06	71.66
Modern	6	3.20	13.50	61.83	4.77	2.62	0.15	18.79	240.26	3774.0	158.20
All	120	3.38	12.59	44.33	3.93	3.16	0.11	29.77	55.29	524.64	50.56

††-1:1 water: soil extraction
§-Percent by mass
‡-mg kg^{-1}

similar for Civil War and Reference Periods. Depression Period areas had lower mean elevation (3.18 m) than earlier abandoned Civil War areas (3.79 m) and depth to surface Bh horizon means were deeper for Depression Period areas (49.97 cm) than Civil War Period areas (29.84 cm). Elevated extractable P (240.26 mg kg^{-1}), Ca (3774 mg/kg), Mg (158.20 mg kg^{-1}), and soil pH (4.77); reduced C:N ratio (18.79) and % total C (2.621); and deepest A horizons (13.50 cm) and depth to surface Bh (61.83 cm) are consistently found in Modern Periods in comparison to other Periods. Step-wise Discriminant Function Analysis found that 70% of the classification was based on significance of the following variables, from greatest to least: extractable P, elevation, extractable Ca, pH, and total C and N.

Discussion

Agricultural Legacy: Soil Profile Characteristics and Physical Properties

The greater diversity in soil series found at Wormlsoe than were mapped on the property in 1968 by the NRCS were not unexpected considering the map scale. A NRCS Level I soil survey requires, on average, one soil observation every forty acres (USDA, 1996). We averaged one sample every ten acres, resulting in detection of local variation not possible in large scale surveys. In addition, several Lower Coastal Plain series, like Olustee, that were commonly mapped in the 1960s on Georgia barrier islands and coastal peninsulas, are almost exclusively mapped on the mainland today (Soil Survey Staff, 2014). This change in classification suggests that Olustee may have been mis-classified at Wormsloe and provides possible explanation why locating it in sample plots within its mapped boundaries was difficult. Chipley was also not located in all sample plots within its mapped area. Clearly, some of the variability in soil characteristics that we observed in some of the data is due to natural soil variation within the mapped series.

Over half of the sample plots investigated at Wormsloe contained a soil within the Spodosol soil order. Most series contained a near surface Spodic horizon, or Bh horizon, beneath the A horizon, with or without an E horizon between the A and Bh. Mean top of the surface spodic horizon depth was similar between Reference and Agriculture sites (15 and 13 cm, respectively). Surface Bh horizons are destroyed during agriculture tillage due to rapid oxidation of C rich organic compounds in the Bh horizon (Soil Survey Staff, 2014). Surface Bh horizons are reported to form in 300 years or less, whereas deeper spodic horizons in the profile develop over several millennia (Lundstrom et al., 2000; Mokma et al., 2004). Identification of surface spodic horizons in Agriculture areas suggest that within 80 years since agriculture abandonment, surface Bh horizons have reformed.

Foster et al. (2003) suggested that an Ap horizon could persist for centuries. At Wormsloe, Ap horizons were not always apparent in Agriculture areas. Differences in landscape features, like elevation and drainage class, and legacies of human activity within the soil profile, like charcoal and shells, often masked the characteristic abrupt boundary in this horizon. Ap horizons were most apparent in Modern Period sample sites with partial visibility in Depression Period sites. This suggests that using Ap horizons at Wormsloe as an indicator of agricultural activity may not be a reliable method for the two soil series investigated.

Agricultural Legacy: Soil Nutrients

Studies suggest that soil carbon (C) and nitrogen (N) are reduced from tillage (Foster et al., 2003) unless organic amendments, like manure or crop residues, are applied to cropping fields (Compton et al., 1998; Kirchmann et al., 2004). At Wormsloe, there were no significant differences in total C and N across land use-soil series combinations; however, investigating total C and N concentrations since agricultural abandonment revealed a legacy effect in both nutrients. Depression Period sample plots (80+ yrs since agriculture abandonment) contained the highest group mean (3.49) for total C, followed by the Civil War (100+ yrs) group mean (3.17), and Reference (never farmed) group mean (3.02). These results suggested that over 80 years since abandonment of agriculture, total C remained elevated in previous agriculture fields compared to Reference areas. These findings are consistent with a study by Switzer et al. (1979) who found that soil C stocks could be elevated up to a century following abandonment of agriculture in southeastern Coastal Plain soils, but in contrast to studies that found soil C matched reference levels after 50 years since abandonment of agriculture (Compton et al., 1998; Maloney et al., 2008). Agricultural fields abandoned during the Depression received manure application (Swanson, 2012) that may account for the elevated total C between Depression and Reference Periods; however, historical records do not indicate quantities or location of this application. Elevated total N over 80 years since agricultural abandonment compared to Reference areas was unexpected since soil N readily leaches from sandy, low OM soils (Zotarelli et al., 2007). This difference, as with total C, may be a legacy effect from manure application during that period. Total N legacy effects from sea bird guano applied to fields in the late 1850s do not seem as obvious in Civil

War Period sample plots. As expected, in accordance with other studies examining C:N ratios on reforested sites following agriculture abandonment, as time since abandonment increases, C:N ratio slowly increases.

At Wormsloe, soil pH means in Chipley (4.10) and Olustee (3.77) sample plots, though significantly different ($p=0.036$), were very low values that necessitate liming to sustain agriculture crops. Soil pH in Entisols and Spodosols of the Lower Coastal Plains range from 3.5 to 5.0 (Bratton and Miller, 1994; Long et al., 1969); with a pH greater than 4.5 usually influenced by agriculture liming. To ameliorate low acidity on Wormsloe fields, crushed oyster shells were reported to have been applied to agricultural fields prior to the Civil War (Swanson, 2012); however, location or quantity used is not indicated in historical records. Since native pH range is similar for Chipley and Olustee, differences in pH means between the series may indicate preference for one series over another in agriculture. This is consistent with a land use legacy study on Cumberland Island Georgia that observed a preference for Chipley over Olustee soils in historic agriculture fields (Bratton and Miller, 1994). Chipley fields may have preferentially received more liming amendments than Olustee fields. Differences in soil pH between Agriculture and Reference areas may also be attributed to forest litter. Acidic litter from native forest species, like oak and pine, that reforested abandoned fields, contributes to continued acidification of the soil. Conversely, native hickories contain more basic litter that increase soil calcium (Ca) levels, in turn elevating soil pH (Smalley, 1990).

Phosphorus (P) is the most common soil nutrient legacy from agriculture due to its relative immobility in the soil and frequent over-application to agricultural fields (McLauchlan, 2006). Across Agricultural Periods at Wormsloe, Depression and Civil

War Period elevated group means (67.83 and 68.58 mg kg^{-1}), in relationship to the Reference group mean (25.26 mg kg^{-1}), suggested that extractable P has remained elevated over a century since agricultural abandonment. Phosphorus-rich guano was applied to Wormsloe agricultural fields in the late 1850s, with over 10 tons applied to fields in 1858 alone, and P-rich manure was used to fertilize fields in the early twentieth century (Swanson, 2012). Soil P is most exchangeable, or plant available, between a pH of 6 and 7, where is does not bind with acidic cations (iron (Fe), aluminum (Al) at a pH below 5.5 or basic cations (Ca, magnesium (Mg), manganese (Mn) at a pH above 7 (Blake et al., 2000). Clay soils bind soil P more strongly than sandy soils leading to an increase in extractable P on sandy soils when fertilization application exceeds crop needs (McLauchlan, 2006). At Wormsloe, the significant difference ($p=0.049$) in exchangeable P in Agriculture versus Reference areas, especially at an average pH less than 6, suggested application of P in excess of crop needs was applied at Wormsloe. These results are consistent with a North Carolina study that found elevated extractable P in a loamy sand versus clay loam soil when P fertilizer was applied in excess of crop needs (Schmidt et al., 1996).

Extractable Ca concentration at Wormsloe was influenced by both human activity and natural site factors. The influence of shell middens on extractable Ca and pH was apparent in several sample plots. Middens slowly release concentrated calcium carbonate into the soil solution over time, leading to long term alteration of the surrounding soil chemistry (Smith and McGrath, 2011). Two midden sample plots at Wormsloe contained Native American pottery sherds, which suggested some shell middens preceded European settlement and have impacted soil chemistry close to three centuries or more. These finding were consistent with a study on St. Catherine's Island, Georgia, that investigated the influence of shell middens, some dated to 4,000 years before present, on soil chemistry (Smith and McGrath, 2011). Crushed shells from middens were scattered across agriculture fields as a liming amendment. Over time, these shells decomposed, calcium was leached from the soil profile, and soil pH approximated native forest soil levels (3.0-4.5). As a result, no statistically significant differences were seen in extractable Ca across land use or soil series at Wormsloe but differences across soil series were notable; with a Chipley group mean of 968.76 mg kg^{-1} and an Olustee group mean of 80.53 mg kg^{-1}. The highest extractable Ca values seen at Wormsloe ranged from 500 mg kg^{-1} to 13,500 mg kg^{-1} and were all located within Chipley areas. Values between 500 and 5000 mg kg^{-1} occurred on historic agriculture fields and old trash piles. Values exceeding 5000 mg kg^{-1} all contained significant quantities of shells, excluding a forested site that contained a high percentage of pignut hickory (*C. glabra*). Hickory leaf litter contains elevated Ca concentrations (Smalley, 1990) that likely correlated to the elevated Ca (5008 mg kg^{-1}) and pH (5.3) found at this sample plot, as no shells were identified at the plot. These findings are consistent with Ca and pH values under pignut hickory forest at St. Catherine's Island, Georgia (Smith and McGrath, 2011). Extractable Ca across Agricultural Periods demonstrated a temporal decrease in soil Ca from Modern to Reference Periods, excluding Civil War Period plots. Sample plots abandoned following the Civil War demonstrated a lower extractable Ca group mean (118.24 mg kg^{-1}) than the Reference group mean (342.16 mg kg^{-1}). The Reference group mean is influenced by several outliers that resulted from Native American and post-Colonial human activity. Removing these outliers from the data set resulted in an overall extractable Ca Reference mean of 86 ± 10.49 mg kg^{-1}. Comparing this to agricultural areas abandoned after the Civil War suggests a Ca legacy may still exist over a century later.

Extractable Mg was not significant across land use or soil series, yet was influenced by human land use activities that also influenced Ca. Mg was significantly correlated with Ca and pH as a principle component that explained over 30% of the variation in the data.

Agricultural Legacy: Vegetation

The influence of agricultural legacy on soil properties and subsequent effect on vegetation at Wormsloe is unclear from our soil investigations. Though soil nutrients, like extractable P and Ca, were elevated on dominant overstory forest cover types with a significant oak and sweetgum component, presumably related to land use legacy, there were no other distinct patterns in measured soil properties across the seven defined dominant overstory groups. Most notably, within the six dominant understory groups, sabal palm (*Sabal minor*) occurred on soils with the highest pH, lowest C:N ratio, and highest extractable P, Ca, and Mg. This is consistent with other studies documenting *S. minor* growing in higher calcium soils (Smith and McGrath, 2011). From our investigations, forest cover at Wormsloe seemed more impacted by variable land use since agricultural abandonment, most notably a clearcut across most of the property in the mid-1970s, than the influence of historic agriculture.

Conclusion

Clear evidence of an agricultural legacy was evident in the coarse-textured sand and loamy sand soils of the Wormsloe Historic Park. Surface soils of former agricultural areas had higher extractable soil phosphorus (P) than continuously forested Reference areas. This P legacy persisted for at least 80 years. A trend of elevated concentrations of C, N, Ca and Mg also occurred in agricultural areas, but these differences were not statistically significant. Further discriminant analysis by agricultural period indicated that little difference in soil chemistry between fields abandoned at the time of the Civil War and continuously forested reference stands, but a clear separation of stands abandoned in the Depression or Modern periods. Several locations with surface soil concentrations of calcium (Ca) or P several orders of magnitude greater than the overall average were identified. In most cases, these outliers could be explained and were due to proximity to shell middens, burn piles or historic structures.

Profiles described at sampling points often differed from NRCS mapped soil series, and this contributed to difficulty in observing differences in profile characteristics. Generally, an Ap horizon was described in former agricultural areas and an A horizon was described in reference forests. Bh horizons were often observed immediately beneath the Ap horizon of former agricultural areas, suggesting that these horizons, likely disturbed by cultivation, were reforming. Soils mapped as the non-Spodosol Chipley series had a significantly higher soil pH than soils mapped as Olustee series, and this seemed to reflect both inherent differences in the soil and a preferential use of Chipley soils for agriculture.

Only a few distinct associations between overstory and understory vegetation type and soil characteristics occurred. Overstory hickory was associated with increased soil pH as was an understory that contained sabal palm.

For Wormsloe State Historic Site, soil P and pH data can be used to refine boundaries of historical agricultural fields on land use history maps. Soil P and pH data also provides information on early fertilization and liming practices at Wormsloe. Vegetation data can be used to support more extensive vegetation inventory studies. Soil profile observations can be used to partially update the existing soil map for Wormsloe. Finally, this study contributes to a growing body of world-wide research investigating the influence of agricultural practices on soil and vegetation, research that is represented by few US Southeastern Coastal Plain studies.

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CHAPTER III

USE OF ELECTROMAGNETIC INDUCTION AND RESISTIVITY FOR IDENTIFYING SOIL DISTURBANCE AT WORMSLOE STATE HISTORIC SITE, SAVANNAH, GA, USA

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Abstract

Geophysical surveys provide a non-invasive reconnaissance survey for quick, spatial investigation of soil disturbance resulting from human land use activities. Geophysical instruments measure contrasts in soil properties for detection of buried artifacts and other evidence of human activity. Surveys are useful for directing soil sampling and evaluating areas where excavation may not be necessary, saving time, expense, and extensive site disruption. Wormsloe State Historic Site contains nearly three centuries of recorded land use activities, from 1736 to present, providing a unique site to investigate the long term influence of historic land use activities on sandy soils of the Coastal Plain. We used a Dualem 2S EMI™ and an AgiSting™ resistivity meter in combination with traditional soil sampling to investigate soils. Three sites (Cabin, Dairy, and Forest Charcoal) were chosen to survey using both instruments. EMI surveys were made at each site on a 12 X 14 m grid and resistivity surveys were made on a 6 X 7 m grid nested within the larger grid. EMI measured to depths of 0.1 and 2.1 m and resistivity measured to a depth of 1 m. Geophysical data was converted to a visual format using ordinary krigging in ArcGIS™ for EMI data and inversion software EarthImager 3D™ for resistivity data. These visual maps were used to direct traditional soil sampling. EMI was useful for detecting broad soil patterns originating from natural soil variation on both high and low activity sites and resistivity more accurately identified objects of human origin, as verified by soil sampling.

INDEX WORDS: Electromagnetic Induction, Resistivity, Geophysical Survey, Land Use Legacy, Electrical Soil Conductivity, Apparent Resistivity

Introduction

Human land use activities result in long-term alterations of the soil, including soil compaction, soil movement or inversion, and the intentional or unintentional burial of debris. Agricultural and residential activities, as would have occurred on historic home sites, included the scattering or burial of house and garden debris, such as ash, shells, household items, and human and animal waste (Eidt, 1984). Over time, soil additions or disruptions from cultural activities become obscured and are no longer visible at the soil surface. These hidden features provide valuable information on the human history of a site, as well as the influence of human activity on the soil landscape (Brown, 2008). Locating soil legacies within a landscape can, in part, be directed by historical maps and land use records combined with archaeological excavations; however, random soil investigations and extensive excavations are expensive, time consuming, and destructive to a site (Gaffney, 2008; Wynn and Sherwood, 1984). In addition, these techniques may overlook human land use features not apparent from the soil surface or within the area of excavation (Collins and Molyneaux, 2003).

Geophysical surveys provide a non-invasive method for quick, spatial investigation of historic sites prior to soil excavation (Alaia et al., 2008; Batayneh, 2011; Drahor, 2006; Grangeia et al., 2011; Keenan and Ellwood, 2014; Piro and Campana, 2009). Geophysical surveys are useful for directing soil sampling and evaluating areas where excavation is not always appropriate, for example, in burial sites (Hargrave et al., 2002). Geophysical surveys are complementary to archaeological techniques and can be included in the methods to assess a site (Hargrave et al., 2002).

Geophysical instruments measure contrasts in soil physical properties for detection of buried artifacts and other evidence of human activity (Batayneh, 2011; Gaffney and Gater, 2003). Contrasts are easier to detect in homogenous soils or sediments because they stand out within the homogenous soil matrix (Sambuelli et al., 1999). Human activity, like agricultural tillage, or heterogeneous soil composition make detection of buried features difficult to assess (Sambuelli et al., 1999). By combining multiple geophysical instruments with soil sampling, detection of buried features and accuracy of the survey increases (Bevan, 2006; Drahor, 2011; Garrison, 2003; Zheng et al., 2013).

Electromagnetic Induction

Electromagnetic Induction (EMI) instruments are increasingly used for shallow subsurface mapping across a variety of fields, including archaeology (Dualem, 2009; Milson, 2003) and pedology. EMI locates shallow metallic objects (Bevan, 2006; Drewett, 1999) like cans and buried pipe and large buried objects like walls and foundations. The instrument readily detects soil moisture because ions in the soil solution and surficial charges on clay induce an electric current that is measured by the instrument (McNeill, 1980; Palacky, 1991; Pellerin, 2002; Pellerin and Wannamaker, 2005). For this reason, EMI also detects soil salinity, organic matter, clay, restrictive soil layers preventing downward water movement, and objects that hold moisture (Pellerin and Wannamaker, 2005).

EMI instruments measure the conductivity (σ), millisiemens per meter (mS m^{-1}), of the soil by inducing an electromagnetic (EM) field in the ground (Drewett, 1999). The instrument detects the geometry and depth of shallow electrical conductors (Collins and Molyneaux, 2003; Dualem, 2009) when a secondary magnetic field is created within the soil that is measured by the EMI. The strength of the secondary EM field increases with the electrical conductivity of the soil (Bevan, 2006; Piro and Campana, 2009). One primary advantage of EMI compared to other geophysical instruments is that it can be transported across the ground and, thus, is faster and relatively easier to use (Bevan, 2006) over large areas and challenging terrain (Drewett, 1999).

Resistivity

Electrical resistance, or resitivity, is a geophysical method that has been in use since the 1940s and remains popular, in part, due to its continuous refinement in methodologies across several disciplines investigating subsurface properties (Alaia et al., 2008; Soupios et al., 2007). Resistivity methods measure diverse soil types and geology, and are not as susceptible to electrical interference as other instruments; however, dry or rocky soils can be challenging for inserting the probes into the ground to make sufficient electrical contact with the soil (Bevan, 2006). Resistivity is useful for detecting buried artifacts when the object is in stark contrast with the surrounding soil matrix (Drahor, 2006), such as organic trash piles in coarse textured, sandy soils and stone debris in fine textured clay and silt soils (Bevan, 2006). Resistivity is also used for detection of foundations, old roads, hearths, and rubble (Collins and Molyneaux, 2003; Gaffney and Gater, 2003; Garrison, 2003).

A resistivity instrument measures the resistance to an electric current across the subsurface matrix. Most often, resistivity data is reported as apparent resistivity (ρ_{α}), measured in ohm-meters. Apparent resistivity is the product of measured resistance (R) and a geomagnetic factor (K_g). Subsurface resistance is measured by passing a current through two current electrodes and measuring the current reduction and increasing potential gradient by two additional electrodes, called potential electrodes (Collins and Molyneaux, 2003). The ratio between the measured voltage and applied current increases with increased resistance in the soil (Bevan, 2006). Elevated ρ_{α} values indicate that the location of measurement has higher resistance than the surrounding soil and is a potential soil feature of interest (Keenan and Ellwood, 2014).

Resistivity survey results are dependent on the probe array of the instrument. Two commonly used arrays are the Wenner and Dipole-Dipole arrays (Fig. 3.1). The Wennner array consists of two potential electrodes, equally spaced, between two current electrodes (Collins and Molyneaux, 2003). The Dipole-Dipole array separates both potential and current electrodes by a specified distance, where distance between probe pairs is the same and specified by parameter, n (Garrison, 2003). The Wenner array is more sensitive at deeper depths than the Dipole-Dipole array, whereas Dipole-Dipole produces a cleaner image and more accurately locates features than the Wenner array (Drewett, 1999). These and other types of arrays can be configured within a grid or along a transect. Grids provide a 3-dimensional survey of an area and transects provide a 2-dimensional survey. Probe spacing is roughly equivalent to the depth of

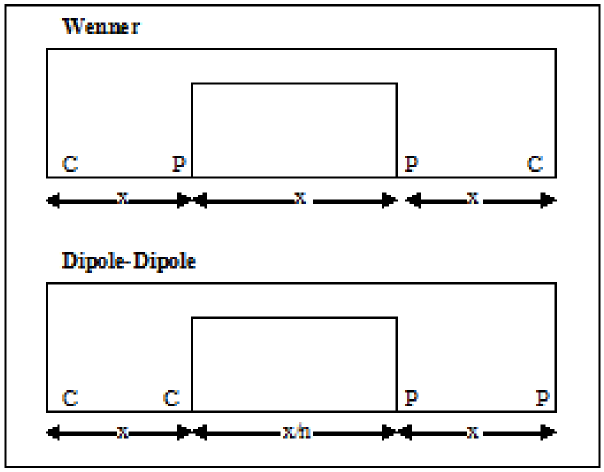

Figure 3.1: Resistance arrays showing current (C) and potential (P) electrode arrangements. Distance between electrodes (x) is equidistant or a specific distance (n) as in the Dipole-Dipole array.

investigation, where a one meter probe spacing equates to a one meter depth of survey. Closer spacing allows for higher resolution within the volume of soil evaluated (Cardarelli and Di Filippo, 2009).

Project Objectives

The objectives of this project were to evaluate EMI and resistivity for investigation of human land use disturbance on coarse-textured Coastal Plains soils and for directing soil sampling based upon disturbance features identified by the instruments. Specifically, we sought to determine if anomalies observed using EMI and resistivity were associated with changes in soil profile characteristics, disturbance features, or artifacts. We also sought to establish protocols for using EMI and resistivity instruments to provide reliable spatial data.

Materials and Methods

Site Description

Wormsloe, a 333 ha historic site located outside of Savannah, Georgia, USA, has a long and diverse history of land use (Fig. 3.2). The property currently includes Wormsloe State Historic Site, the University of Georgia Center for Research and Education at Wormsloe, and the private residence of descendants of the family that originally settled Wormsloe. Beginning in 1736, Noble Jones, one of the first British colonists to settle Savannah, leased a 202 ha (500 ac) parcel of the present day Wormsloe site (Swanson, 2012). Since that time, descendents of the Jones family have stewarded the property for almost 280 years. Evidence of Native American presence pre-dating colonial settlement is apparent in the numerous shell piles, or middens, dotting the marsh edge.

As a colonial fort, residence, and small farm, Wormsloe experienced a variety of land uses. Nearly half of the property was cleared by the 1860s for a variety of agricultural ventures, such as Sea Island cotton production (Swanson, 2012). Several areas of the property were used for housing and residential activities and expansive forest areas were utilized for lumber and grazing (Swanson, 2012). Though the extensive forest cover now masks its diverse past, impressions of these land uses remain in the soil. Extensive land use history records and maps, as well as personal communication with property residents, provides significant information on general locations of historic land uses.

Average annual precipitation at Wormsloe is 121.4 cm (47.8 in) and average annual temperature is 18.4°C (65.2°F) (NOAA, 2014). Elevation ranges from zero to 4.3 m (14 ft) above sea level (NOAA, 2012). The site's water table ranges from 122 to 244 cm (4 to 8 ft) depending on elevation and season (Soil Survey Staff, 2010). Geographic location and geologic history have shaped the ecosystems present on the property today. Wormsloe soils are typical of the US southeastern Lower Coastal Plain. Predominant soil series mapped by the Natural Resource Conservation Service in the 1970s include Chipley (thermic, coated Aquic Quartzipsamments), Ellabelle (loamy, siliceous, semiactive, thermic arenic Umbric Paleaquults), Olustee (sandy, siliceous, thermic Ultic Alaquods), and Albany (sandy, siliceous, subactive, thermic aquic Arenic

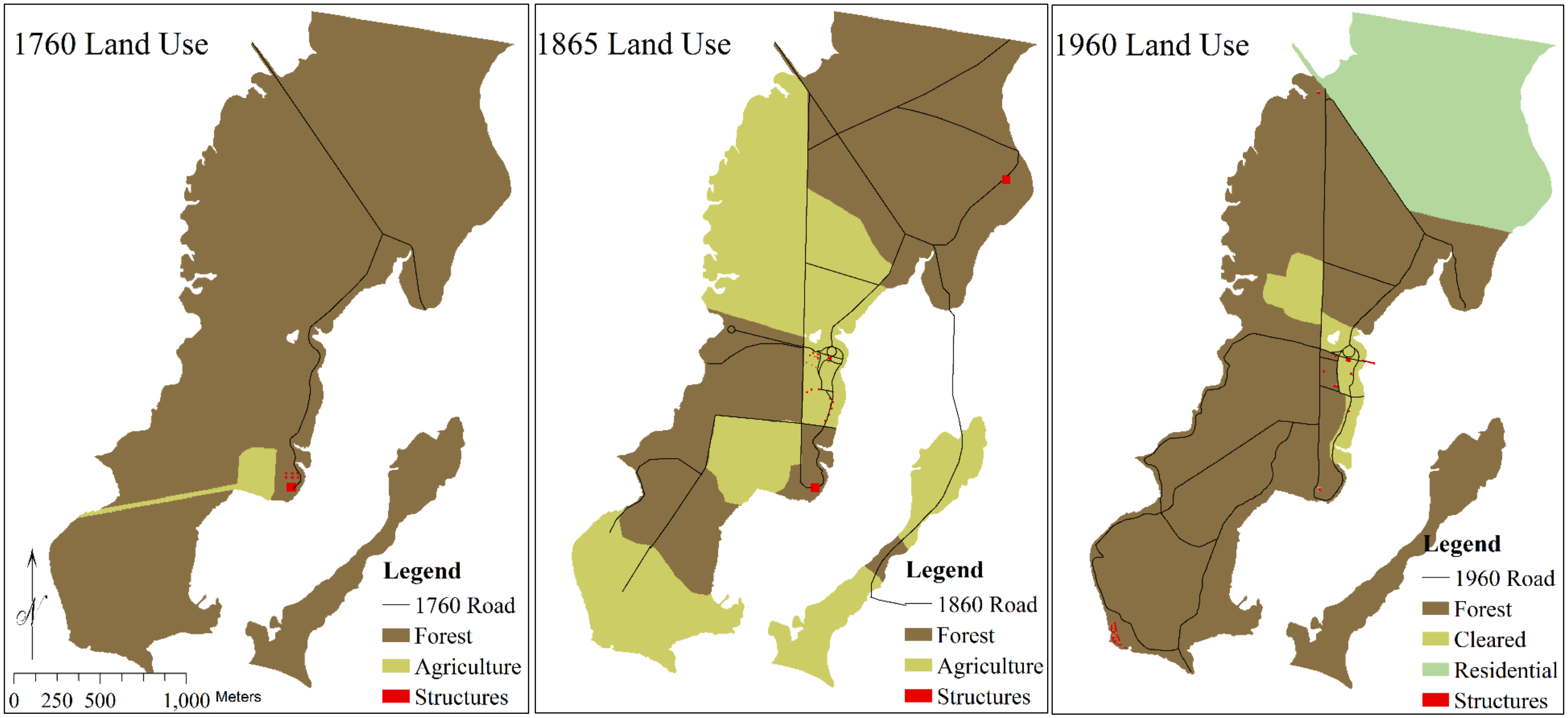

Figure 3.2: Wormsloe timeline maps demonstrating the change in land use over a 200 year period, from 1760 to 1960. The 1865 map indicates that close to half of the land area at Wormsloe was utilized for agriculture. Maps created by author in ArcGIS using base data from the UGA CGR.

Paleudults) with smaller areas of Leon (sandy, siliceous, thermic Aeric Alaquods) and Lakeland (thermic, coated Typic Quartzipsamments) (Soil Survey Staff, 1974). These soils range from very poorly to excessively drained and occur within depressions or on nearly level landscape positions (Soil Survey Staff, 2010).

The sandy composition of the soil and the depth to bedrock (>9 m) (Weems and Edwards, 2001) creates a homogenous matrix within which soil disturbance and artifacts should produce distinct signals during geophysical investigation (Bevan, 2006; Sambuelli et al., 1999).

Survey Site Selection

Based on historic land use maps (Jordan and Madden, 2013; Swanson, 2012), soils data, previous EMI surveys, and personal communication with property residents, three survey sites were selected for geophysical investigation (Fig. 3.3). The Cabin Site is located directly north of a remodeled nineteenth century slave cabin. This site was a long-term residential area for servants and slaves, and currently houses guests and students. The existing cabin was one of eight original slave cabins located at the site. The others were razed in the twentieth century. This site was chosen for its obvious historical significance and to correspond with a recent archaeological excavation of the slave cabin (Archaeological Research Collective, Charleston, South Carolina).

The Dairy Site was recommended by property residents as a site with multiple historic land use activities (rice mill, dairy, pasture, buried refuse, burn piles, buried

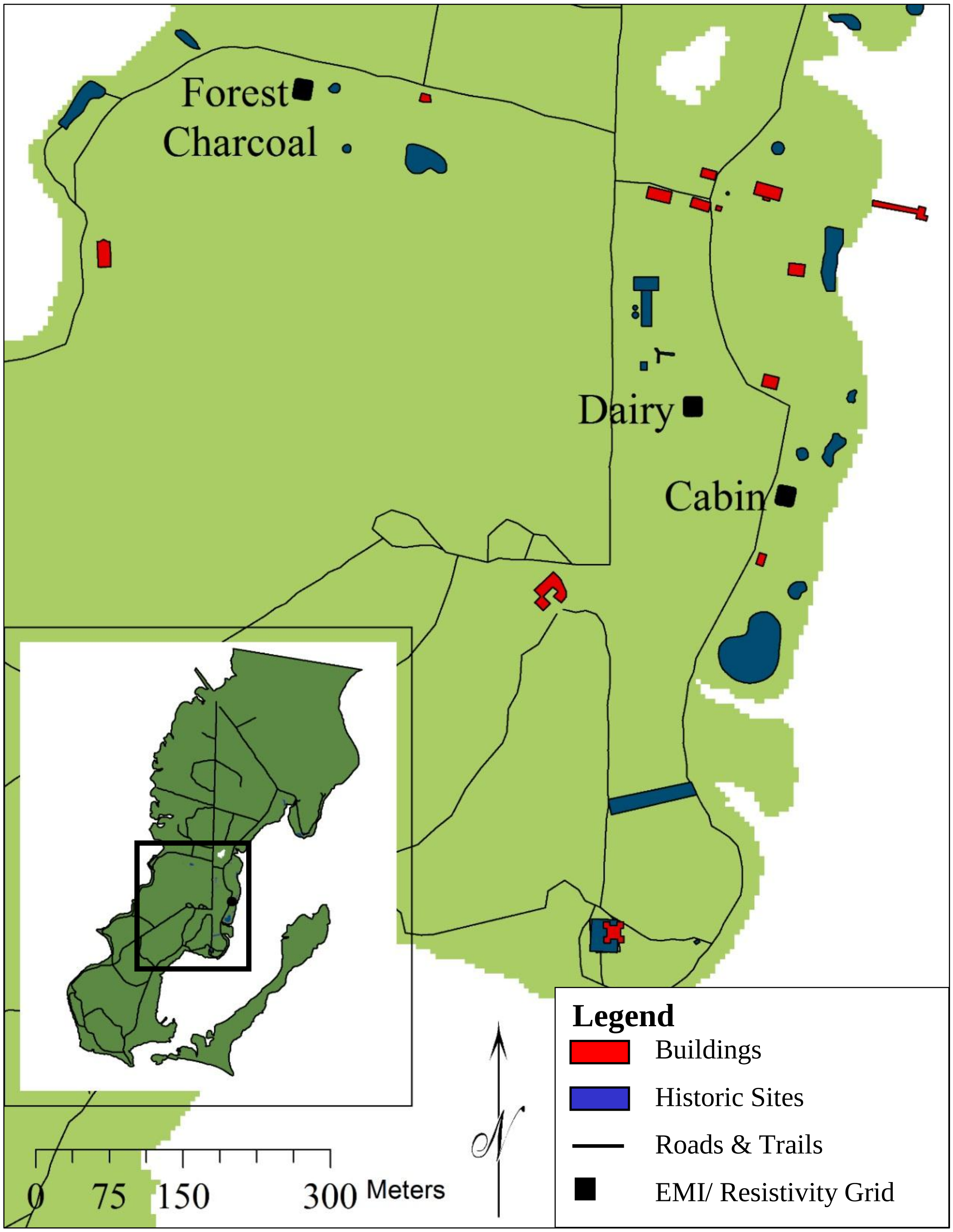

Figure 3.3: Wormsloe site map displaying three geophysical survey site locations (Cabin, Dairy, and Forest Charcoal). Map inset shows location of sites (black box) in relationship to the property. Map made in ArcGIS by author, using base data from the UGA CGR.

building foundation). An initial EMI survey at the Dairy site in March 2013 identified an anomaly feature that warranted further investigation (Fig. 3.4).

The third site, Forest Charcoal, was selected to determine potential archaeological significance and to provide a site with minimal post-colonial human activity under continuous forest cover since before the year 1736. At this site, random soil sampling with a soil auger revealed a distinct charcoal layer (Fig. 3.5). Radiocarbon dating this charcoal resulted in an age of 810 year C^{14} before present (UGA, Center for Applied Isotopes Studies, 2013).

Grid Establishment: EMI survey

One 14 X 12 meter grid with the 14 meter sides on a roughly due north orientation were established at each of the three sites. Coordinates of grid corners for all three survey sites were geopositioned with a Flint S Series (BAP Precision Ltd., Taiwan) handheld Geographic Positioning System (GPS) device (1-5 m accuracy) and grid corners were marked with polyvinyl chloride (PVC) stakes. Meter tapes and fluorescent ribbon were used to establish 1 meter spacing throughout the grid (Fig. 3.6). The EMI instrument was walked along each tape line once on a north-south orientation moving from the west to east side of the grid (Fig. 3.7). Three σ data points were taken for every meter walked, by walking a 3 second per meter pace across the grid.

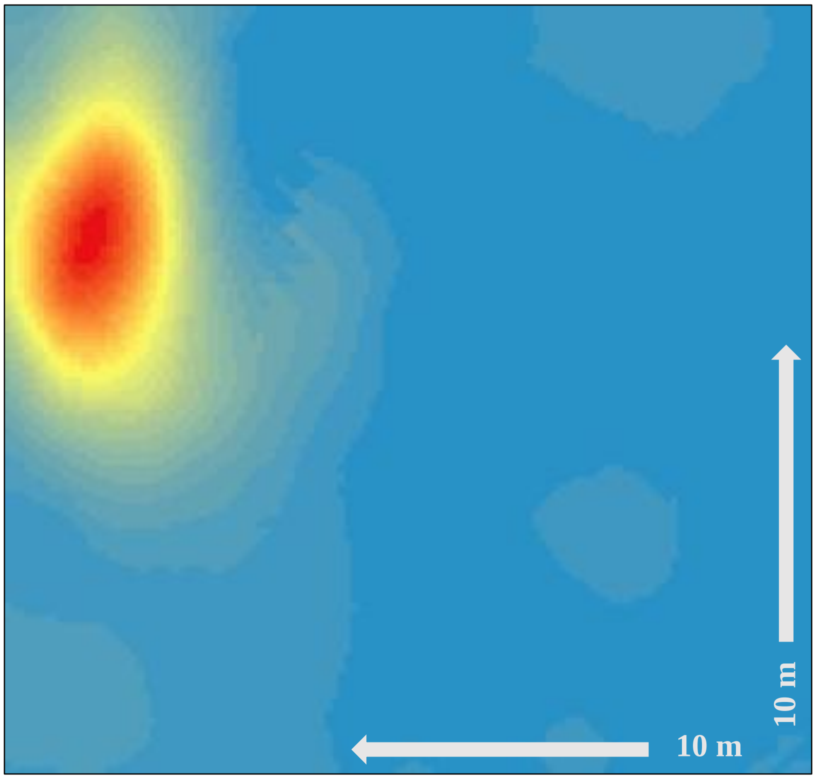

Figure 3.4: Preliminary 10 X 10 m EMI survey at the Dairy Site. This survey was taken in a grassy field with no obvious disturbance from the soil surface. The area in red (very high σ) was located under a slight depression in the soil surface. This anomaly feature was selected for further investigation with EMI, Resistivity, and soil sampling. Image created in ArcGIS by author using ordinary krigging.

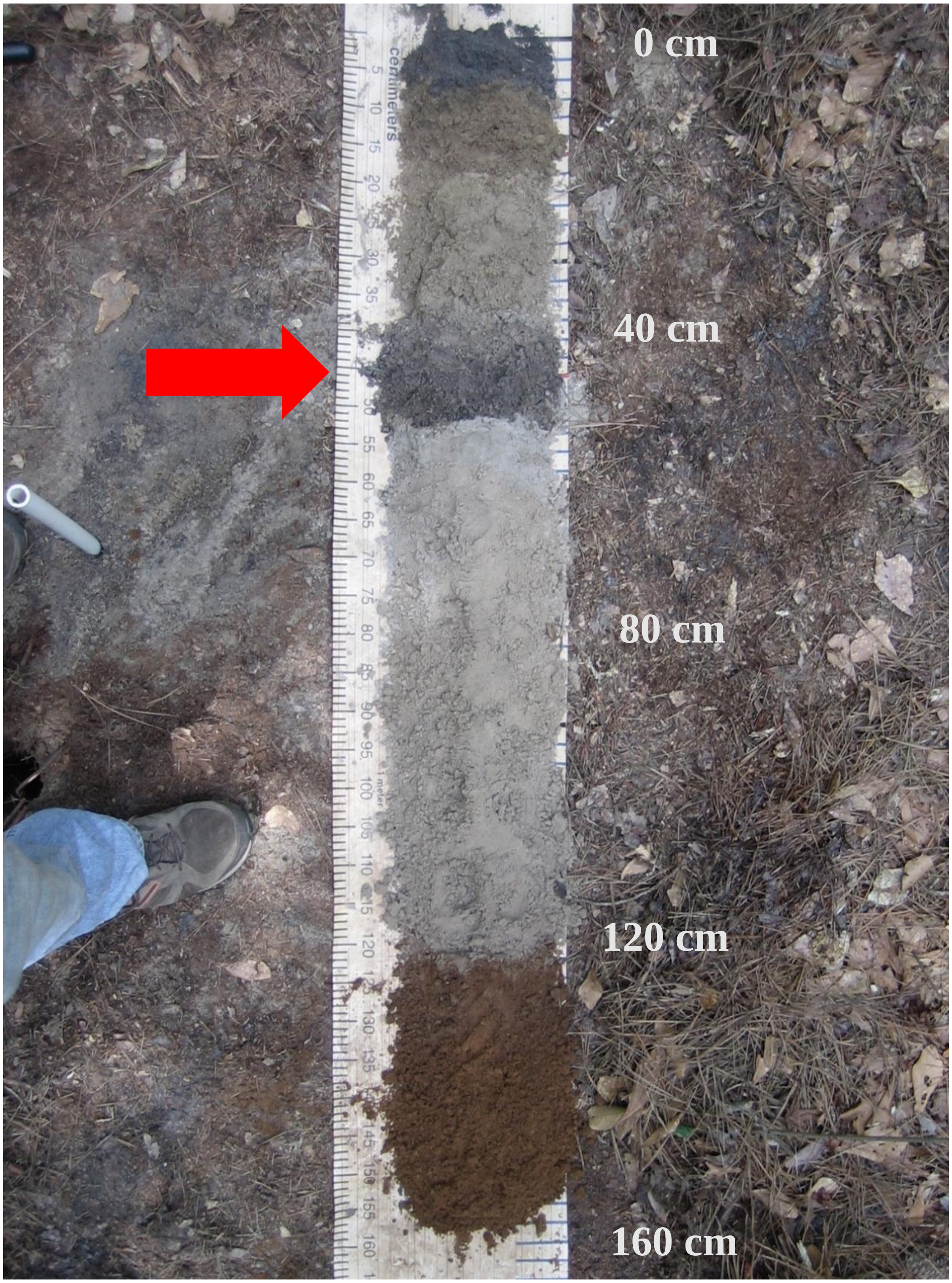

Figure 3.5: Red arrow indicates charcoal layer within soil profile at the Forest Charcoal Site.

Figure 3.6: Cabin site 14 X 12 m grid with 1 X 1 m spacing, outlined by orange tape.


Figure 3.7: Author surveying a forest site with the Dualem 2S™ EMI. As shown, EMI was carried at hip height.

Grid Establishment: Resistivity Survey

One 7 X 6 m grid (resistivity grid dimensions required for a 56 probe, 1-meter grid spacing) with the 7 m sides on a roughly due north orientation was established at each of the three sites, nested within the larger EMI grid. Coordinates of grid corners for all three survey sites were taken with a Flint S Series™ (F4 Devices) handheld GPS device. Grid corners were marked with PVC stakes. Meter tapes and fluorescent ribbon were used to establish 1 meter spacing throughout the grid (Fig. 3.8).

Geophysical Instruments

A Dualem 2S™ EMI instrument (Dualem, Milton, Canada) was used to investigate each 14 X 12 m grid. The instrument was carried over the operator's shoulder by attaching a strap to both ends of the EMI unit (Fig. 3.7) and then walked at a slow, steady pace (approximately 0.33 m sec^{-1}) along parallel transects at 1m spacing within each 14 X 12 m grid as seen in Fig. 3.6. The EMI instrument was attached to a Juniper Archer field computer (Juniper Systems, Logan, Utah) with Global Sat GPS™, ArcGIS™, and Sensor Trac™. Conductivity data was logged by the Juniper Archer every second. The Dualem 2S™ EMI contains one transmitter coil with two receiver coils spaced at 2.0 and 2.1 m from the transmitter on the boom. The transmitter has horizontal windings (coils) and the 2.0 m receiver has horizontal windings (coils) that form the horizontal coplanar (HCP), or vertical dipole, and the 2.1m receiver has vertical windings that form the perpendicular coplanar, or PRP (horizontal dipole). The Dualem 2S™ depth of exploration (DOE) measures conductivity at a 1 m depth for PRP and a 3.0 meter depth

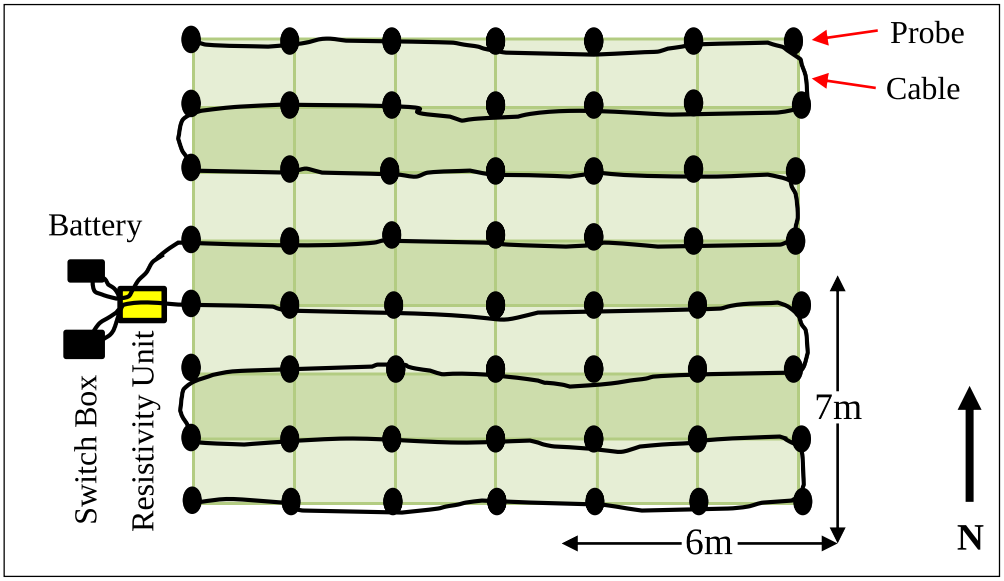

Figure 3.8: Diagram of 7 X 6 m resistivity grid. Resistivity instrument probes (56) are located at the intersection of each grid line and are attached with cables to the instrument switch box.

for HCP. Precise calibration for the instrument is permanently established in factory with a patented Dualem technique. Carrying this instrument at hip height decreases each DOE by approximately 0.9 m, so actual PRP DOE will be approximately 10 cm (0.1 m) and the DOE of HCP will be approximately 2.1 m (Dualem, 2009).

An AgiSuperStingR8 IP™ Resistivity meter (AGI Advanced GeoSciences, Inc., Austin, TX) was used to investigate each 7 X 6 m grid. A 56 probe grid (Fig. 3.8) was established with 1 meter spacing. Electrode probes were driven into the ground with a mallet at all 56 grid corners and cables were connected each probe. Within EarthImager 3D™ (AGI Advanced GeoSciences, Inc) a command file was created for a: dipole-dipole array (x probe:7, y-probe:8, z-probe:0, scaling factor:1m, 2 cycles, 3.6 seconds/ cycle/ probe). At the Cabin and Forest Charcoal sites, the first probe corresponds with the southwest corner, or bottom left, of the grid. Due to conditions at the Dairy site, the first probe corresponds to the northeast corner that grid. One meter probe spacing measured ρ_α to an approximate 1m depth.

Geophysical Data Analysis

EMI data was exported to a Microsoft Excel™ (Microsoft Corporation, Redmond, Washington) chart as a text file from the Juniper Archer unit. Four measurements were taken at each site: Aux 1-horizontal coplanar conductivity (mS/m), Aux 2-horizontal coplanar in phase (parts per thousand (ppt)), Aux 3-perpendicular conductivity (mS/m), and Aux 4-perpendicular in phase (ppt). Due to the inaccuracy of the Archer GPS unit (5-10 m accuracy) at the 14 X 12 m scale, coordinates were assigned to conductivity data based on the four corner grid coordinates obtained by the Flint GPS unit (1-3 m accuracy). Because data was taken every second and each pass along the grid with the EMI was methodically paced along the grid and timed in seconds, precise coordinates could be tagged to conductivity measurements at each second mark. The conductivity data with corresponding assigned GPS coordinates were downloaded into ArcGIS (ESRI, 2012) from the Excel™ chart to be interpolated by ordinary krigging. Color ramps were selected such that high conductivity measurements were displayed in red and low conductivity measurements in blue. Different conductivity scales were used on each survey site due to differences in site conditions. Placing all sites on the same color scale would cause unique features of some sites to be lost.

Resistivity data was downloaded from the AgiSuperSting R8 IP™ unit in the field onto a laptop computer. The files (.out, .stg, and .dat files) were read into EarthImager 3D™ software (Advanced Geosciences, Austin, Texas) and processed using an inversion algorithm. A three dimensional image of the grid site was then generated. Various two dimensional (2D) slices were obtained from the data (surface, 0.5 m, and 1 m). The color ramp displayed high apparent resistivity measurements in red. These are considered to be anomaly features. The same apparent resistivity scale was used for all survey sites.

Soil Sampling: 14 X 12 m EMI Grid

Within the Dairy and Forest Charcoal EMI grids, twelve and nine features were investigated, respectively. No further soil investigation was made at the Cabin Site due to archaeological sensitivity. Soil profiles were described within and outside of anomaly features using an open bucket soil auger to a depth of 160 cm or until a feature of anthropogenic origin prevented further augering. The augered sample was evaluated for color, texture, structure, thickness of horizons, redoximorphic features, and presence of archaeological features.

Soil Sampling: 7 X 6 m Resistivity Grid

Within the 7 X 6 m resistivity grids, two to three anomaly features were chosen to investigate by augering. The Dairy and Cabin Sites each contained three anomaly features that were investigated. The Forest Charcoal Site had no anomaly features, but two areas were investigated based on the carbon-dated charcoal found at the site and an area of moderately high apparent resistivity displayed on the Forest Charcoal map. To investigate the accuracy of the geophysical data, one or more soil sample points were selected within 1 to 3 m adjacent to each anomaly or feature of interest. This resulted in a total of eight soil samples taken at the Cabin Site, six at the Dairy Site, and four at the Forest Charcoal Site.

At each soil sample point, the soil was augered to a depth of 160 cm or until a feature of anthropogenic origin prevented further augering. The augered sample was evaluated for color, texture, structure, thickness of horizons, redoximorphic features, and presence of archaeological features.

Results

Cabin: Soils

The Cabin Site soils were classified as a variant of the Blanton series (loamy, siliceous, semiactive, thermic Grossarenic Paleudults). The surface Ap horizon was black (10YR 2/1) to very dark greyish brown (10YR 3/2), very friable, and granular loamy sand to about a 20 cm depth underlain by an elluvial E horizon to about a 150 cm depth. The E horizon texture was fine sand and the color ranged from yellowish brown (10YR 5/6) to light grey (10YR 7/2). A brown (10YR 4/3) sandy clay loam textured Bt horizon occurred below the E horizon and extended to the depth of observation. This horizon had a subangular blocky structure and common grayish brown (10YR 5/2) depletions and yellowish brown (10YR 5/8) oxidations.

Cabin: Electromagnetic Induction

At the Cabin Site, the electromagnetic induction (EMI) survey data indicated no defined anomaly features at either the 10 cm or 210 cm depths, as displayed on the survey "maps" (Fig. 3.9 and 3.10). Rather, these maps displayed a gradient of conductivity (σ) values, increasing in σ from west to east, likely indicating natural soil variation. The 10 cm depth of exploration (DOE) values ranged from 20.1 to 47.6 mS m^{-1} (Fig. 3.9) and the 210 cm DOE values from 52.0 to 104.4 mS m^{-1} (Fig. 3.9). This represents a considerable variation in values as compared to the Forest Charcoal Site, but not the Dairy Site.

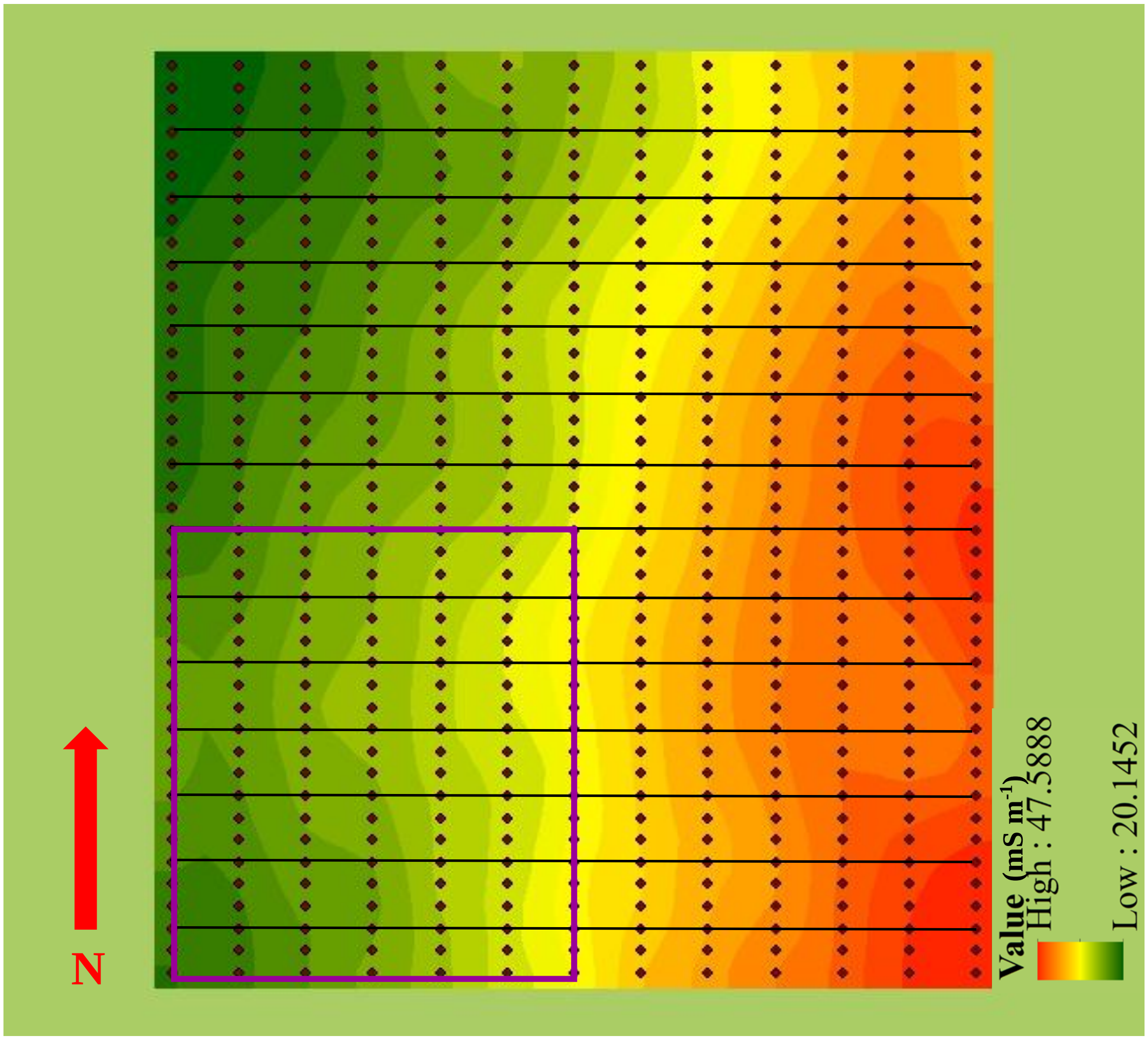

Figure 3.9: EMI "map" of the 14 X 12 m Cabin Site at approximate 10cm depth. Each diamond shape equals one conductivity measurement along the transect. Horizontal black lines break the north-south transects into 1 m spacing. Areas in red are high σ with low σ in green. Values ranged from 20.1 to 47.6 mS m^{-1}. Purple box is the location of the 7 X 6 m resistivity grid. Image made in ArcGIS by author.

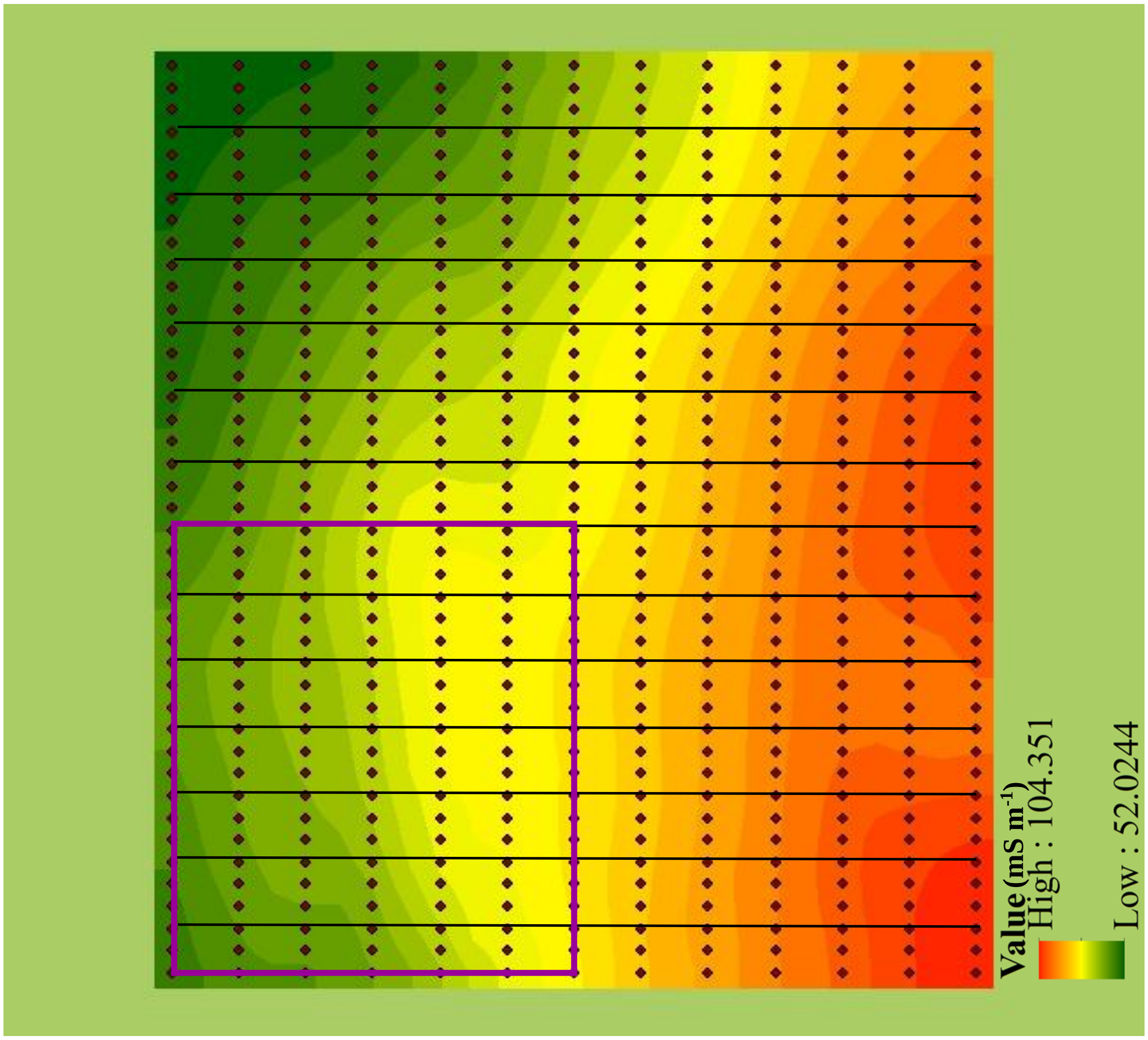

Figure 3.10: EMI "map" of the 14 X 12 m Cabin Site at approximate 210 cm depth. EMI data was interpolated in ArcGIS using ordinary krigging. Each diamond shape represents a conductivity measurement along the transect. Horizontal black lines break the north-south transects into 1 m spacing. Areas in red are high σ and low σ in green. Values ranged from 52.0 to 104.4 mS m^{-1}.

Though no soil profile descriptions were taken at the Cabin Site following the EMI survey in March 2014, profiles described during the resistivity survey in August 2013, as well as artifacts and soil disturbance revealed during a Spring-Summer 2014 archaeological excavation (Archaeological Research Collective, Charleston, SC), revealed a clay (Bt) horizon beginning at a 150 cm depth and located numerous artifacts. The Bt horizon depth also corresponds to the seasonal high water table at this elevation on the property. Higher σ values generally indicate higher moisture content. The Cabin Site is a relatively flat landscape, though a slight elevation change and changes in the Bt horizon depth may influence this gradient in west-east σ values. The only features apparent at the soil surface are occasional oyster shells. There is little to no litter layer, or organic matter (O) horizon, on the soil surface and widespread patches of bare soil.

Cabin: Resistivity

Resistivity maps generated of the Cabin Site indicated a number of anomaly features present (Fig. 3.11). Due to the archaeological sensitivity of the sight, limited soil profile observations were made. Soil samples 1a, 2a, and 3a were identified as the most distinctive features at a 1 m depth and were investigated using a 160 cm soil auger. Accompanying these three samples were paired samples (1b, 1c, 2b, 3b, 3c) located approximately one meter outside of soil samples 1a, 2a, and 3a.

The first anomaly feature investigated was Soil Sample 1a, indicated to contain ρ_α values from 8,000 to 10,000 ohm-m on the Cabin resistivity map (Fig. 3.12). Paired soil

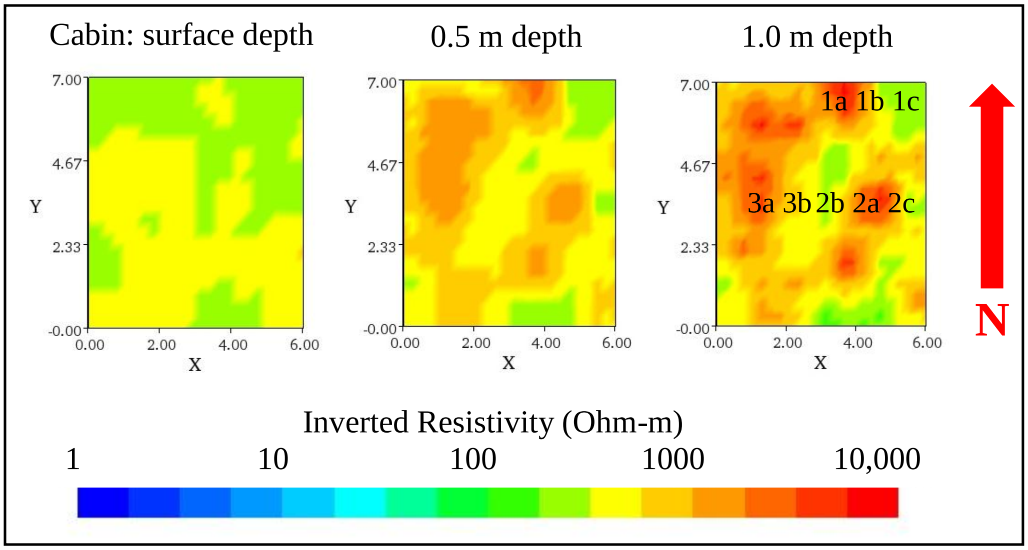

Figure 3.11: Resistivity images from the Cabin Site represent three depths (surface, 0.5 m, and 1 m) over a 7 X 6 m grid. Apparent resistivity values at the Cabin Site varied from 100-500 ohm-m at the surface to 100 to 10,000 ohm-m at a 1 m depth. The one meter depth image was used to select anomaly features for soil investigation. Soil Samples 1a, 2a, and 3a were paired with one or more soil samples (1b, 1c, 2b, 2c, 3b) one meter outside of the anomaly feature. Images were created by the author using EarthImager™ software.

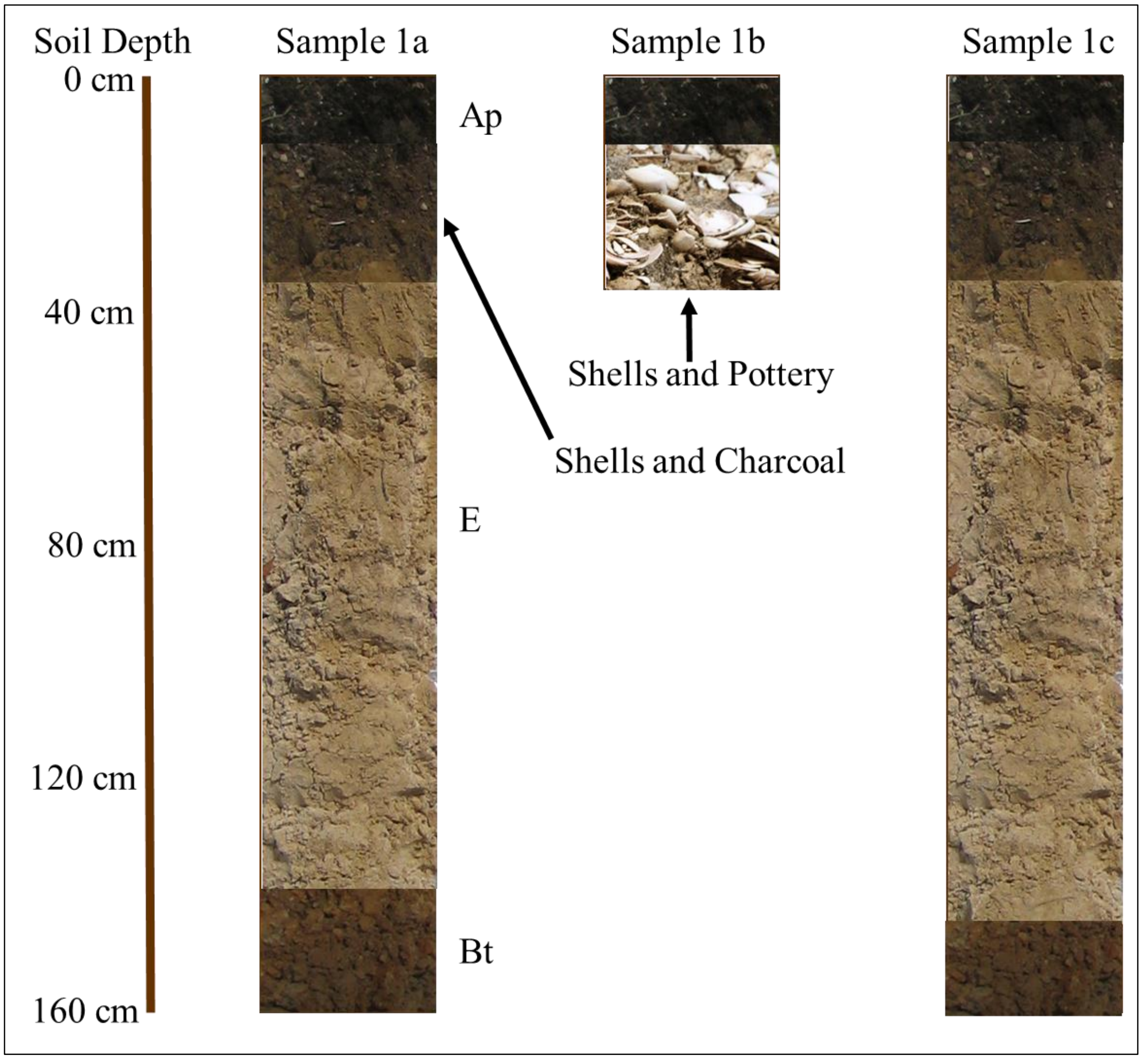

Figure 3.12: Samples 1a, 1b, and 1c approximate soil profiles at the Cabin Site. Depth, horizon nomenclature (Ap, E, Bt), and artifact features (shell, charcoal, pottery) are approximated on the profiles. Sample 1b contained a shell and household debris pile, or midden, beginning at depth 15 cm.

samples 1b and 1c, with ρ_α values ranging from 100 to 300 ohm-m, were used to compare differences seen in sample 1a. From soil investigations, all three samples contained a disturbed Ap horizon. Soil Sample 1a and 1c each contained occasional shell and charcoal fragments to approximately 60 cm depth, but were otherwise followed by a normal soil profile (Fig. 3.12). Soil Sample 1b contained a dense shell and household debris pile starting at a 15 cm depth (Fig. 3.12). Sample 1b could not be excavated beyond a 30 cm depth without considerable effort due to the density of the shells it contained. Artifacts from Sample 1b are included in Fig. 3.13.

Soil Sample 2a was the second anomaly feature investigated at the Cabin Site. Resistivity maps indicated 2a contained ρ_α values from 8,000 to 10,000 ohm-m and paired samples, 2b and 2c, contained ρ_α values from 100 to 300 ohm-m (Fig. 3.11). All three samples had a disturbed Ap horizon and contained shell fragments to approximately 20 cm depth. Soil samples 2a and 2c were characterized by a normal profile, whereas a density of shells and household debris prevented soil investigation of 2b beyond a 20 cm depth (Fig. 3.15). Figure 3.14 displays artifacts found in Soil Sample 2b.

Soil Sample 3a was the final anomaly feature investigated at the Cabin Site. Sample 3a contained ρ_α values from 8,000 to 10,000 ohm-m and the paired Sample Point 3b contained ρ_α values from 500 to 800 ohm-m (Fig 3.11). Samples 3a and 3b both contained disturbed Ap horizons. An abundance of gravel beginning at a 35 cm depth in Sample 3a prevented further augering. Charcoal fragments were found from a 35 to 135 cm depth in sample 3b, but the sample otherwise exhibited a profile similar to samples 1a and 2a.

Figure 3.13: Artifacts found at soil sample 1b include nineteenth century pottery, animal bones, and oyster shells.

Figure 3.14: Artifacts located at sample point 2b included nineteenth century pottery and the stem of a tobacco pipe.

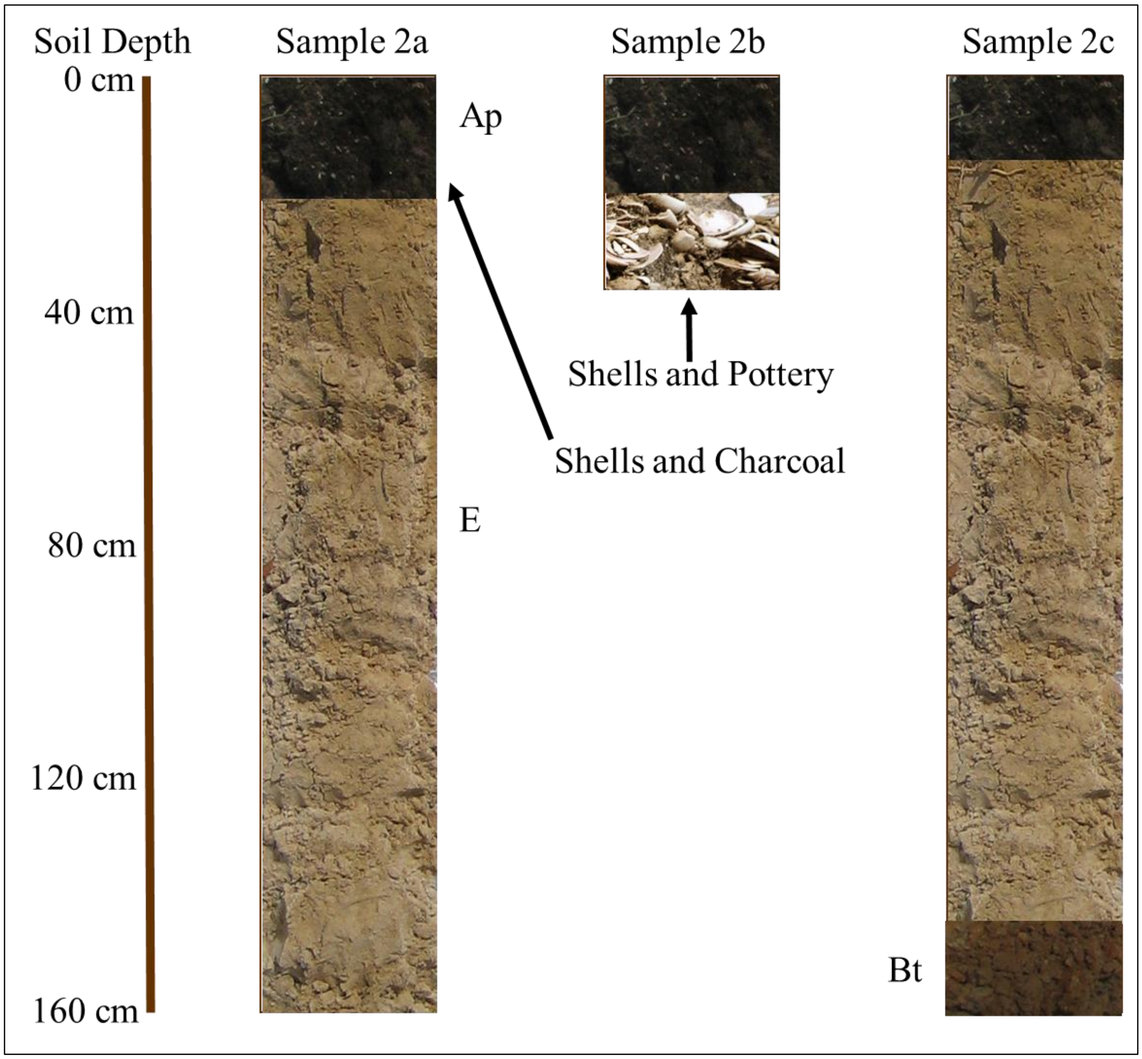

Figure 3.15: Samples 2a, 2b, and 2c approximate soil profiles at the Cabin Site. Depth, horizon nomenclature (Ap, E, Bt), and artifact features (shell, charcoal, pottery) are approximated on the profiles. Sample 2b contained shells and pottery at a 20 cm depth.

Dairy: Soils

Soils of the Dairy Site were classified as variants of the Echaw (sandy, siliceous, thermic Oxyaquic Alorthods) and Pelham (Loamy, siliceous, subactive, thermic Arenic Paleaquults) series. Surface soils had a disturbed, very dark brown (10YR 2/1) very friable, granular sand or loamy sand Ap horizon that extended to a 10 to 30 cm depth. The Ap horizon was underlain by an E horizon that ranged to an approximate 100 cm depth in the Echaw series and a 70 to 100 cm depth in the Pelham series. The Eg horizon texture in the Echaw series was fine sand with a color that ranged from brown (10YR 4/3) to light gray (10YR 7/1). Within the Pelham series, the Eg horizon texture was loamy sand and the color ranged from dark grayish brown (10YR 4/2) to gray (10YR 6/2). In the Echaw series, a dark reddish brown (5YR 3/4) to dark brown (7.5YR 3/2) Bh horizon occurred below the Eg horizon, extending to the depth of observation. The Bh horizon had a massive structure and, in places contained ortstein characteristics, or cemented iron and aluminum spodic materials. In the Pelham series, the Eg horizon was underlain by a gray (10YR 6/1) sandy clay loam textured Btg horizon that extended to an approximate 140 to 160 cm depth. This horizon contained subangular blocky structure and common redoxymorphic features throughout the horizon.

Dairy: Electromagnetic Induction

Unlike the Cabin maps, the Dairy maps revealed very different patterns between the 10 and 210 cm depths. At the Dairy Site, two large anomaly features were observed at the 10 cm DOE whereas natural variation appeared to dominate the 210 cm DOE (Fig. 3.16 and 3.17).

From the 10 cm DOE map, the first anomaly chosen to investigate was the large bulls-eye feature located at the center of the image (Fig. 3.16). The area had very high σ values, about 80 mS m^{-1} (red), when compared to other areas on the 10 cm DOE map. This area was located in a slight depression on the landscape and there was a small amount of debris (glass, metal, gravel, brick, charcoal, and wood chips) on the surface. Soil Sample 4a was taken within this high σ area and samples 4b and 4c were taken immediately northeast of it. The amount of buried debris immediately below the surface made sampling with an auger difficult, so a shovel was used to excavate a small area. Even with a shovel, the amount of debris inhibited excavation below a 30 cm depth at samples 4a and 4b without considerable effort. Though Soil Sample 4c contained small amounts of debris found in samples 4a and 4b to a 30 cm depth, 4c contained a normal Echaw series profile beyond the Ap horizon. Profiles observed from samples 4a, 4b, and 4c are illustrated in Fig. 3.18.

The second anomaly investigated from the 10 cm DOE map was a linear feature located along the southwestern portion of the grid (Fig. 3.16), including Soil samples 5a, 5b, and 5c. This feature contained three isolated moderately higher σ values than the surrounding soil. Within all three samples, the surface, or 0-30 cm depth contained charcoal, brick, and gravel, high OM, and soil mixing. Other than a disturbed Ap horizon, samples 5a, 5b, and 5c contained profiles similar to Sample 4c, of the Echaw series.

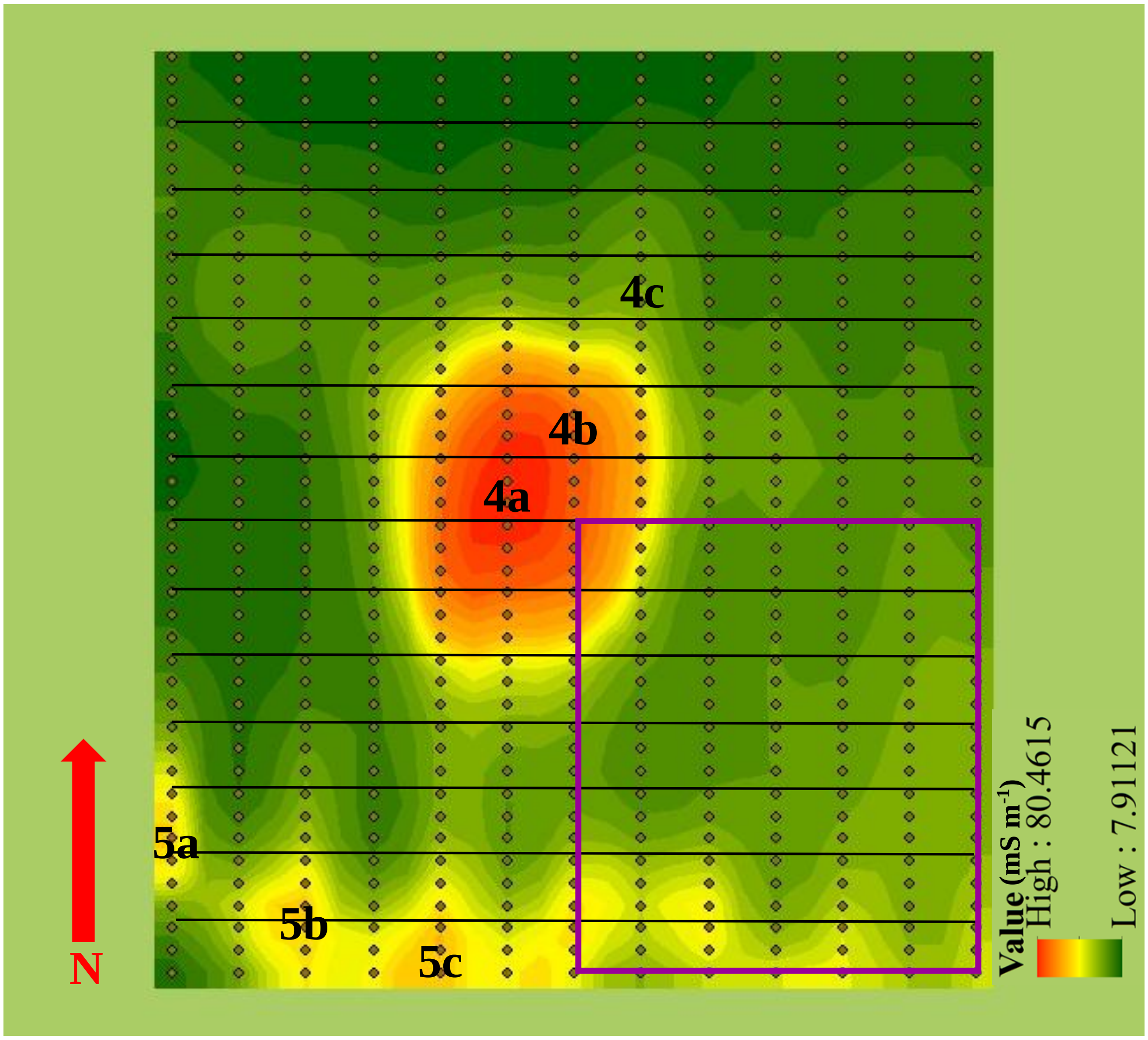

Figure 3.16: EMI "map" of the Dairy 14 X 12 m Site at an approximate 10cm depth. Areas in red are high σ with low σ in green. Values ranged from 7.9 to 80.5 mS m^{-1}. Soil sample sites are 4a to 5c. Purple box is the location of the 7 X 6 m grid.

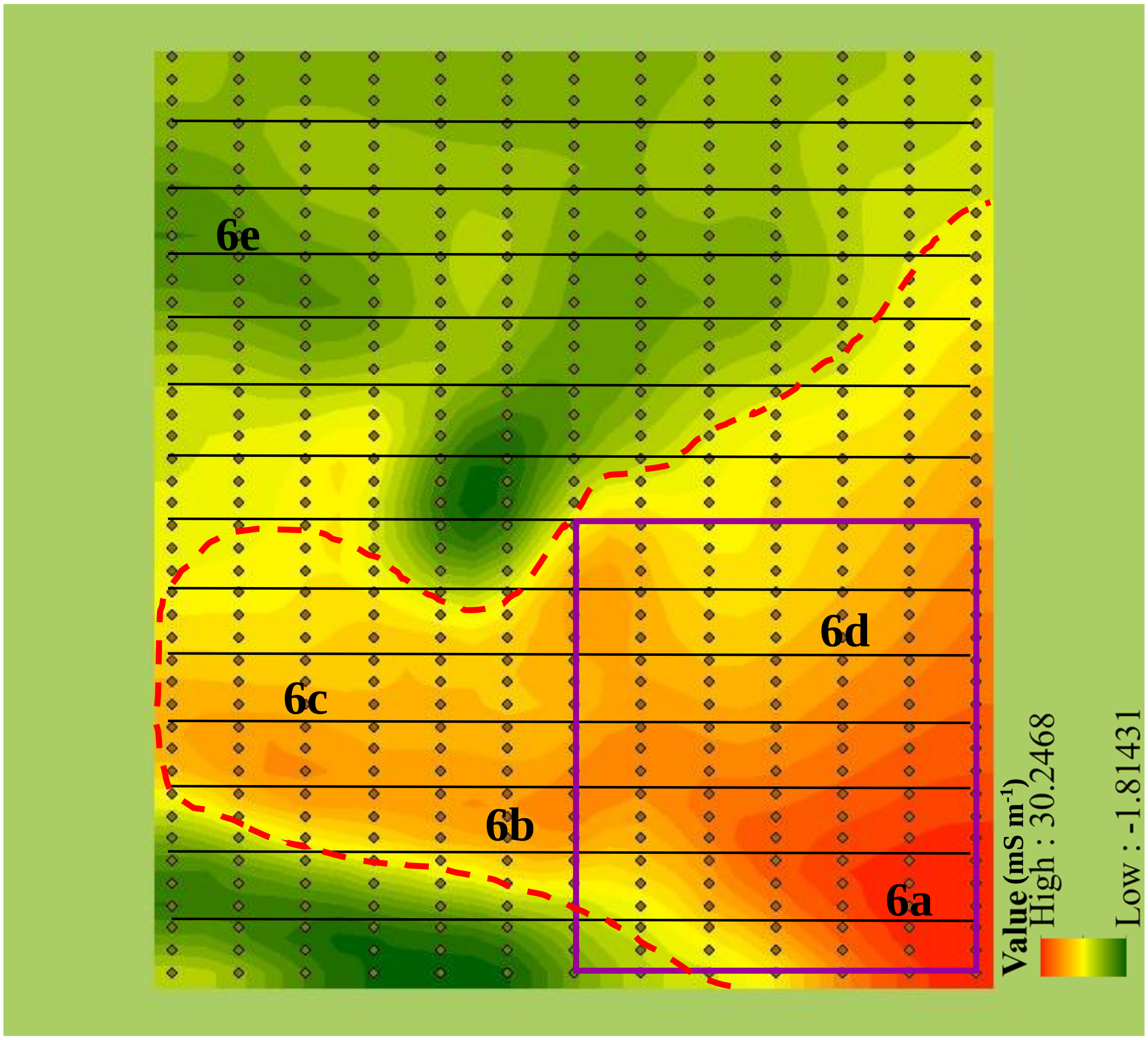

Figure 3.17: EMI “map” of the Dairy 14 X 12 m Site at an approximate 210 cm depth. Areas in red are high σ with low σ in green. Values ranged from 1.8 to 30.2 mS m^{-1}. Soil sample sites are 6a-6e. Purple box is the location of the 7 X 6 m grid. The red dotted line represents the boundary between two soil orders.

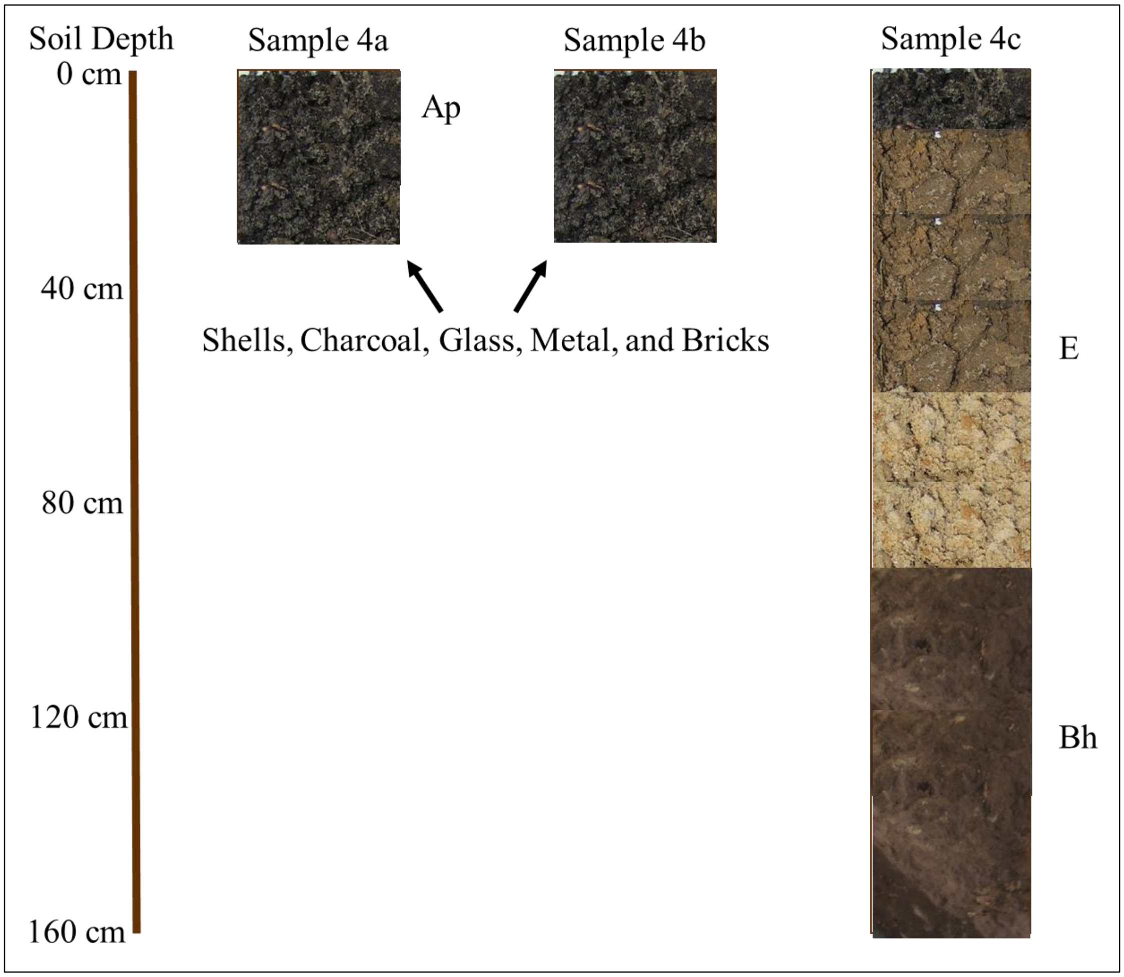

Figure 3.18: Soil samples 4a, 4b, and 4c at the Dairy Site. Both 4a and 4b contained significant debris to a 30 cm depth and were difficult to excavate beyond this depth. Sample 4c contained a moderate amount of debris within 0-30 cm, but contained no further debris beyond this depth, as seen in the profile of 4c.

The 210 cm DOE map displayed a gradation of σ values across the entire site, from -1 to 30 mS m^{-1} (Fig. 3.17). Previous soil investigation at the Dairy Site (August 2013) located a clay layer at a 70 cm depth near Soil Sample 6d. The soil was identified as the Pelham series, of the Ultisol soil order. Since soil samples taken in the western and central part of the Dairy 210 cm grid were a different soil order (Spodosol) than soils investigated in the southeastern part of the grid (Ultisol), two transects with five soil samples (6a through 6e) were established to investigate a potential boundary between soil orders. Following soil investigations, samples 6a through 6e contained similar disturbed Ap horizons ranging from 10 to 30 cm in depth. Samples 6a, 6b, and 6d contained profiles of the Pelham series and samples 6c and 6e contained profiles of the Echaw series. Fig. 3.19 demonstrates the approximate transition from Pelham to Echaw across samples 6a, 6b, and 6c.

Dairy: Resistivity

Dairy Site resistivity images (Fig. 3.20) indicated several, distinct anomaly features at a 1 m depth. Three features (Soil samples 7a, 8a, 9a) and three paired points (samples 7b, 8b, 9b) were selected for investigation. All samples contained buried debris (charcoal, shells, mulch, gravel, brick, glass, metal) at some depth within the profile. Not all anomaly features chosen to investigate at this site were expressed as high ρ_{α}. Soil

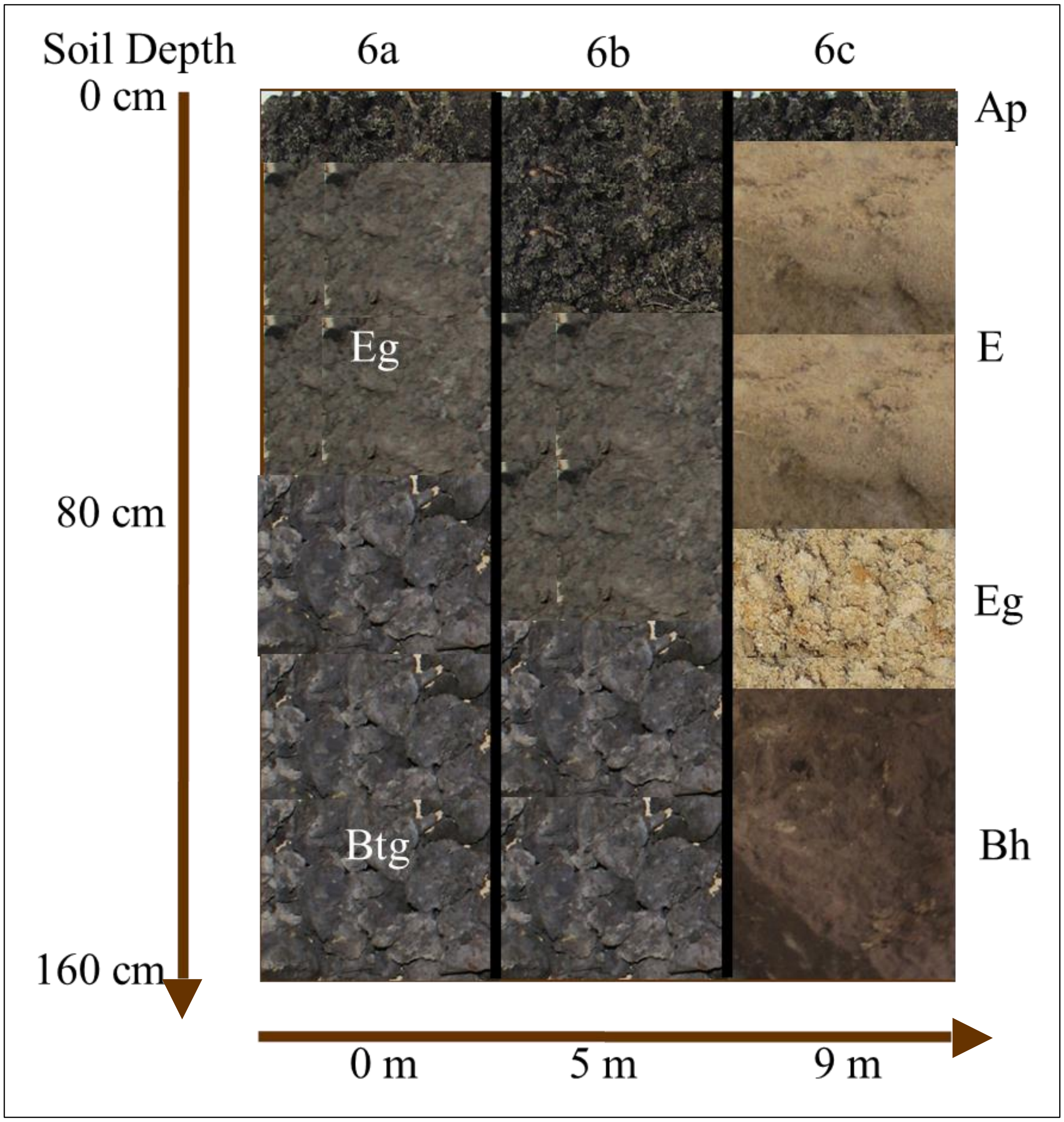

Figure 3.19: Soil samples 6a, 6b, and 6c at the Dairy Site demonstrated the change in soil series along a 9 m long transect with 4 to 5 m spacing between soil samples. The transect begins at Soil Sample 6a. Samples 6a and 6b are the Pelham series and 6c is the Echaw series. Letters on or beside profiles are horizon designations.

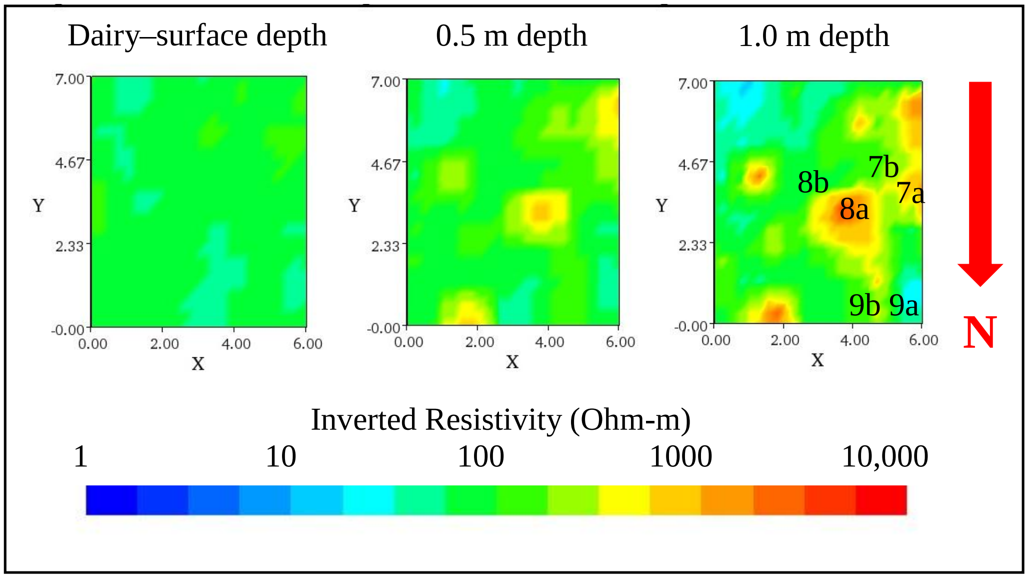

Figure 3.20: Resistivity images from the Dairy Site represent three depths (surface, 0.5 m, and 1.0 m) over a 7 X 6 m grid. Apparent resistivity values at the Dairy Site varied from 40-100 ohm-m at the surface to 10 to 10,000 ohm-m at a 1 m depth. The 1.0 m depth image was used to select anomaly features for soil investigation. Each feature of interest for soil investigation (7a, 8a, 9a) was paired with one sample taken outside the feature (7b, 8b, 9b). Images were created by the author using EarthImager™ software.

Samples 7a and 8a both contained high ρ_α and Sample 9a contained very low ρ_α. The range in ρ_α values at the Dairy Site at a 1 m depth were 10 to 10,000 ohm-m. Samples 7a and 8a both contained substantial debris to a 90 cm (sample 7a) and 60 cm (sample 8a) depth, respectively. Soil investigation beyond these depths was not possible without using a bucket auger. Conversely, samples 7b and 8b, though containing small amounts of debris in the Ap horizon, were otherwise undisturbed soil profiles with similar soil characteristics to samples 6b and 6d; all variants of the Pelham series. The ρ_α values of 7a and 8a approximated 10,000 ohm-m and samples 7b and 8b measured approximately 100 ohm-m.

Soil Sample 9a was selected as an anomaly with very low ρ_α values (10 ohm-m), as indicated on the Dairy Site resistivity map (Fig. 3.19). Both 9a and 9b contained highly disturbed profiles and could not be augered beyond 50 and 25 cm depths, respectively (Fig. 3.21). Both samples contained abundant debris and high soil OM. The soil was not moist, as low resistivity values would indicate.

Forest Charcoal: Soils

Little to no variation in soil profile characteristics existed at the Forest Charcoal Site. Table 3.1 provides the horizon nomenclature and soil characteristics for all soil samples at the Forest Charcoal Site. The soil series is Ridgeland (sandy, siliceous, thermic Oxyaquic Alorthods).

Figure 3.21: Image displays soil profiles of samples 9a and 9b. Debris (concrete, brick, gravel, shells, charcoal) prevented further soil excavation beyond a 25 cm (9b) and 50 cm (9a) depth.

Table 3.1: Average profile description of nine soil samples at the Forest Charcoal Site. The soil series is a variant of Ridgeland.

Horizon	Depth (cm)	Color	Structure	Texture	Consistence
A	0-20	10YR 2/1	granular	fine sand	very friable
Bh1	20-30	7.5YR 2.5/3	massive	fine sand	very friable
Bh2	30-40	7.5YR 3/4	massive	fine sand	very friable
E	40-90	10YR 5/3	single grain	fine sand	very friable
Bh'1	90-115	7.5YR 4/2	massive	fine sand	very friable
Bh'2	115-140	5YR 2.5/2	massive	fine sand	very friable
Bh'3	140-150	5YR 3/3	massive	fine sand	very friable
BC or C	150-190	5YR 3/3 & 10YR 7/4	single grain	fine sand	very friable

Forest Charcoal: Electromagnetic Induction

The Forest Charcoal Site contained a narrow range of conductivity values, from 5.5 to 6.2 (10 cm depth) (Fig. 3.21) and 3.3 to 5.3 mS m^{-1} (210 cm depth) (Fig. 3.22), when compared to the Cabin and Dairy sites.

The Forest Charcoal Site EMI maps contained no significant anomaly features of interest compared to the Dairy site, but the circular patterns on each map prompted further investigation. We noted that the circular patterns on maps at both depths were directly beneath the drip line, or the outer circumference of tree or shrub branches, of over and under-story vegetation. To investigate if undetected features were present, nine soil profiles were observed (soil samples 10-18). All soil profiles were similar and, despite charcoal located within the soil profile of Soil Sample 12 having similarities to Soil Sample X, no features were located at this site indicating historic human activity.

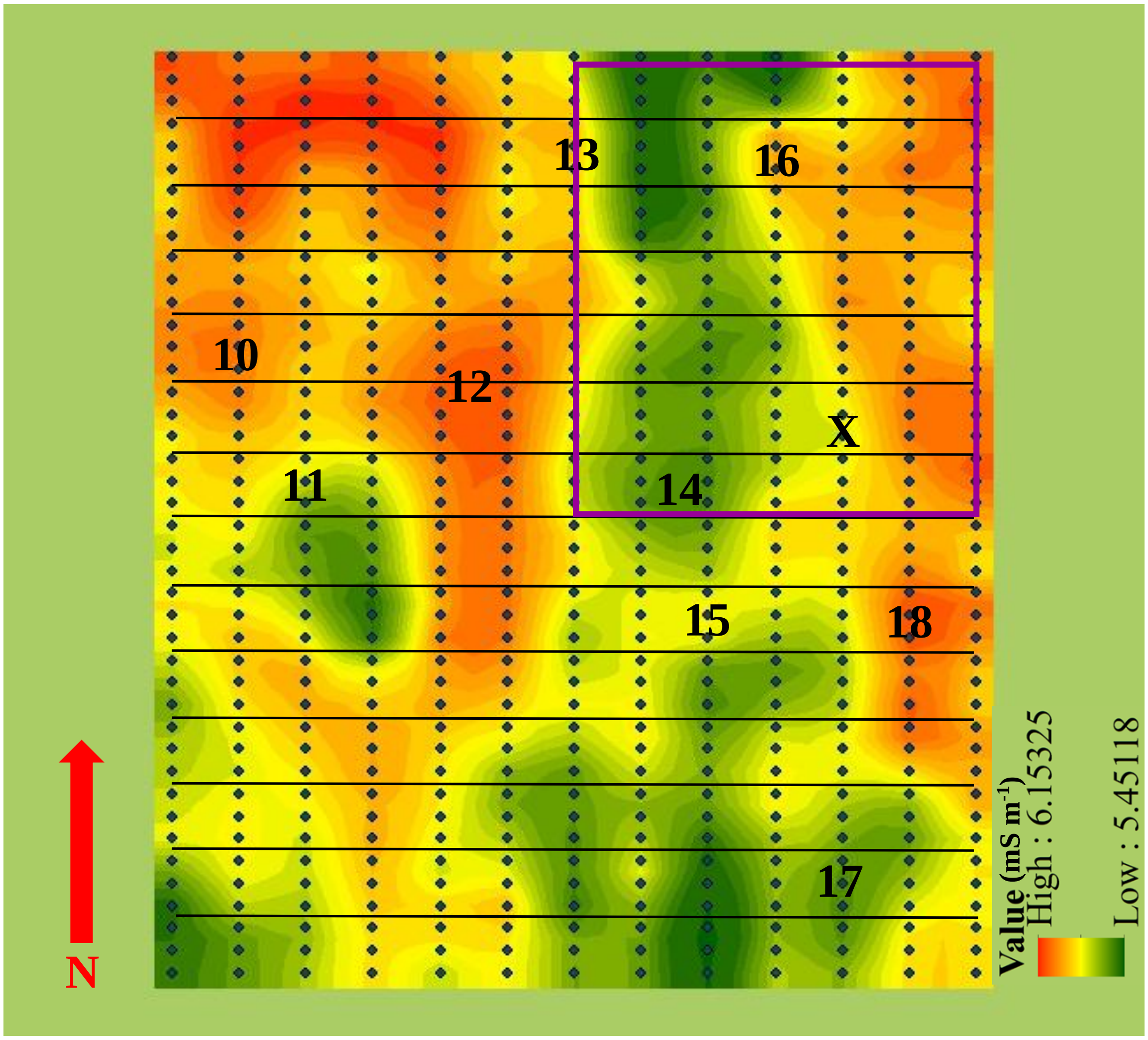

Figure 3.22: EMI “map” of the Forest Charcoal 14 X 12 m Site at an approximate 10 cm depth, the PCP measurement. Areas in red are high σ with low σ in green. Values ranged from 6.2 to 5.5 mS $m^{-}1$. Soil sample sites are 10-18. Charcoal found originally on the site was located at X. Purple box is the location of the 7 X 6 m grid.

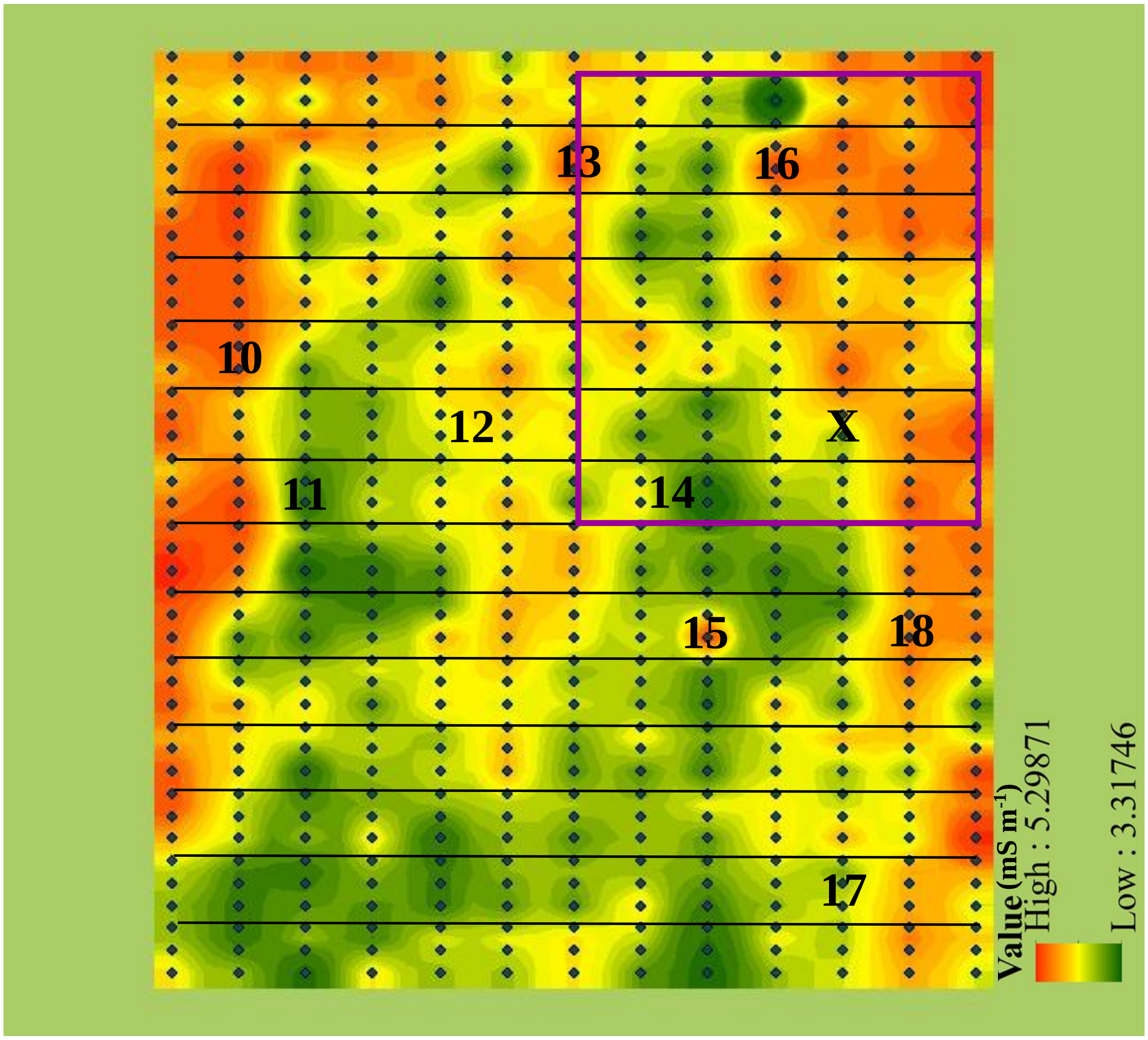

Figure 3.23: EMI “map” of the Forest Charcoal 14 X 12 m Site at an approximate 210 cm depth, the HCP measurement. Areas in red are high σ with low σ in green. Values ranged from 3.3 to 5.3 mS m^{-1}. Soil sample sites are 10-18. Charcoal found originally on the site was located at X. Purple box is the location of the 7 X 6 m grid.

Forest Charcoal: Resistivity

The Forest Charcoal resistivity map did not reveal significant anomaly features compared to the Cabin and Dairy Sites, but two areas were investigated. Samples 18b and 18c were selected to investigate the extent of buried charcoal outside of the original sample X at this site (Fig. 3.24). Samples 18b and 18c did not contain the obvious charcoal layer present in Soil Sample X (Fig. 3.5). Additionally, Sample 19a was investigated as an area that contained the highest ρ_α value compared to the rest of the site. As with the Cabin and Dairy Sites, one paired sample, 19b, was chosen approximately 1 m outside of Sample 19a. Sample 19a and 19b contained normal profiles with no evidence of human activity. Soil profiles were consistent across the Forest Charcoal Site (Table 3.1) and were classified as variants of the Ridgeland series.

Discussion

Electromagnetic Induction

We found that the GPS unit used to operate our Dualem 2S™ Electromagnetic Induction (EMI) instrument was not accurate enough to survey soil disturbance under a forest canopy. Plots of measurement points collected during our initial surveys varied as much as 10 m from the actual location and the lack of location accuracy masked the ability to develop useful maps. We overcame this limitation by establishing a grid over the area of interest and walking the gridlines at a specified rate. Measurements were then post-processed using time to establish location within the grid. Using this approach, we identified important features within the EMI grid. A moisture gradient at the Cabin Site,

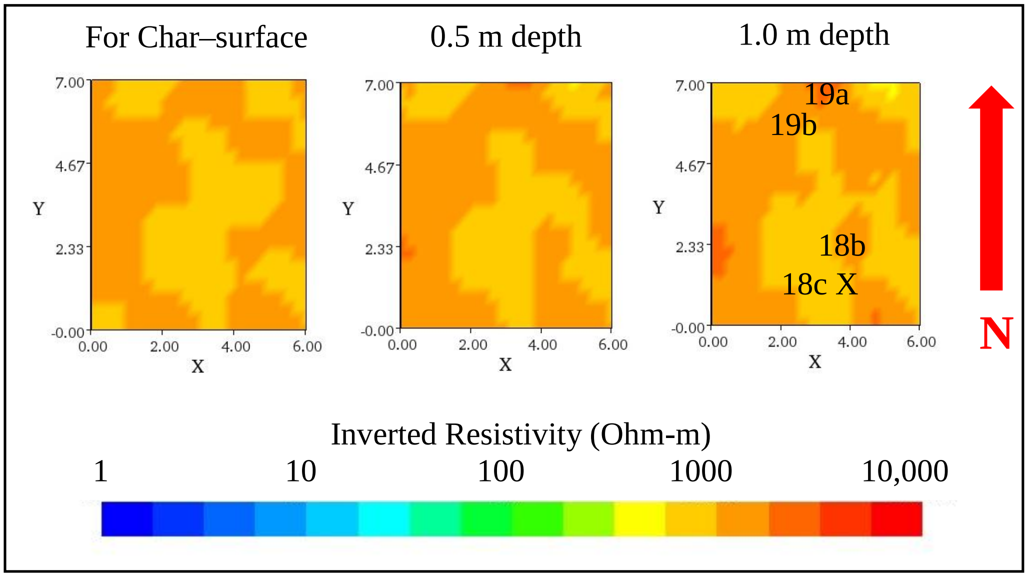

Figure 3.24: Resistivity images from the Forest Charcoal Site represent three depths (surface, half meter, and one meter) over a 7 X 6 m grid. Apparent resistivity values at the Forest Charcoal Site varied from 900-1000 ohm-m at the surface to 900 to 1,200 ohm-m at a 1 m depth. The one meter depth image was used to select anomaly features for soil investigation. Each soil sample (18a and 19a) was paired with one or more soil samples outside of the feature of interest (18b and 19b). Images were created by the author using EarthImager™ software.

a boundary between two soil orders and an old foundation at the Dairy Site, and the possible effects of transpiration on soil moisture at the Forest Charcoal Site were all evident in EMI surveys made using this post-processing approach.

Several possible explanations for the moisture gradient indicated in EMI maps at the Cabin Site exist. Soil samples taken at this site on the western side of the grid returned abundant shell, charcoal, and household debris indicative of human activity. Historical records suggest that a now deconstructed 19th century cabin existed at the western side of the grid and the observed gradient may be associated with a human activity gradient associated with proximity to the cabin. Alternatively, a septic drain line runs through the western portion of the grid and gradient may represent pooling or flow of water from the pipe. The EMI maps of the Dairy Site showing a large anomaly feature in the center of the grid was unquestionably associated with an old foundation and associated debris that restricted water movement. Higher conductivity values in the 10 cm map suggest increased water content due to restriction of vertical flow and ponding and correspond to correspond to low conductivity value beneath the structure. Also, the boundary evident in Fig. 3.17 was verified as being the boundary between two soil orders, a Spodosol and an Ultisol. Thus, the Dairy Site provided an example of the potential of post-processed EMI measurements for identification of both natural soil features and larger (1-5 m) features created by human activity. Finally, EMI maps of the Forest Charcoal Site had lower variability than maps of either the Cabin or Dairy Sites and, when placed on the same scale, indicated an undisturbed area. Our soil sampling confirmed this. When measurements were mapped at a scale of greater resolution at the

Forest Charcoal Site, it was possible to relate observed features to clusters of vegetation. This suggests that EMI may have some utility for mapping root distribution and water use.

Resistivity

It was presumed that all effects of human activity would appear within 1 m of the surface, with most activity in the top 20 cm. As well, the effects of human activity may be clustered in an area that a single transect may miss. As a result, resistivity surveys at Wormsloe were designed to capture a 3 dimensional space within a meter horizontal and vertical distance of accuracy. Most soils at Wormsloe were well sorted and contained 90% or more fine sand or loamy sand. The homogenous nature of Wormsloe soils enabled contrasts in soil conditions to be more apparent and using resistivity at a 1 m depth (with 1 m spaced probes) improved the resolution of detecting contrasts.

We found that the close probe spacing of 1 m and the dipole-dipole probe array allowed us to locate many small-scale features; however, anomalies suggested by resistivity maps were not always associated with an obvious soil feature like buried debris. Both the Cabin and Dairy Site contained a high degree of surface soil disturbance compared to the Forest Charcoal site. Resistivity maps may reflect changes in soil chemistry and OM rather than buried debris. Additional soil samples would be needed to verify this and would be useful for future studies evaluating resistivity's efficacy in detecting changes in soil chemistry.

Similar to EMI data, apparent resistivity data was more variable on sites of higher human activity (Dairy and Cabin Sites) than at the Forest Charcoal site, which, according to historic Wormsloe maps, is a site presumed to represent soils undisturbed by human activity.

Resistivity maps were two-dimensional slices of a three-dimensional grid at three depths (surface, 0.5 m, 1.0 meter). We assumed these depths would capture evidence of human activity. At the Cabin site, resistivity maps at the 0.5 m and 1.0 m depths clearly defined several high apparent resistivity features. Soil investigation of these features produced mixed results. Not all mapped features were associated with obvious soil profile characteristics or artifacts. Also, observed features were not always at the depth indicated on the map.

At the Dairy site, resistivity maps indicated a few isolated areas of high apparent resistivity that, upon soil investigation, yielded an abundance of high resistance debris, including brick, gravel, glass, mulch, and charcoal. The Dairy maps also accurately indicated a shallow Bt horizon beginning within 70-100 cm depth. Considering the great abundance of debris and trash in all the soil samples we examined, we were surprised that additional anomaly features were not indicated by the map.

Resistivity maps at the Forest Charcoal sites indicated no anomaly features and provided little information on the extent or location of the buried charcoal at the site. Soil investigations revealed similar undisturbed profiles across the site. Due to the narrow range in apparent resistivity values and lack of soil disturbance or artifacts, this site was not expected to contain evidence of human activity and was assumed to more accurately approximate soil undisturbed by human activity at Wormsloe.

Conclusion

The varied historic land use history at Wormsloe, coupled with its well-sorted, coarse textured soils and areas of the property with minimal human activity, provided an ideal site to evaluate how contrasts in soil properties can be used for identification of soil legacies. The combined use of two geophysical instruments, EMI and resistivity, with targeted soil investigations, optimized strengths of each method and provided characteristic soil patterns that provide indicators of human land use activity at Wormsloe. The instruments located features of varying sizes, from nineteenth century household artifacts, building debris, and shellfish middens to a buried foundation. Post EMI data processing, which included manually tagging coordinates to conductivity data within a grid, was necessary to achieve sufficient accuracy for this technique to be useful. Resistivity identified features at a finer resolution than EMI and, for this reason, is recommended for investigating areas with a known history of human land activity.

For Wormsloe State Historic Site, this study located artifacts that provide information of the property's human and environmental history. Research results revealed a buried shell midden near a former slave cabin, providing information on the diet of former slaves at Wormsloe. The boundary between two soil series located in a field near the old dairy provides clues of the island's ecological history. This study provided examples of markers (noted by variability and patterns in the data), or symbols, that can be used to locate evidence of historic human activity on geophysical maps. Geophysical investigations used elsewhere on the property could rely on these symbols as an indicator of human activity, helping direct soil sampling on sites where extensive excavation is not preferred.

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CHAPTER IV

CONCLUSIONS

This study investigated the influence of past land use on soil properties at Wormsloe State Historic Site, in the Lower Coastal Plain of Georgia. We developed a field study to investigate agricultural soil legacies in forested areas of the site by sampling 120 random points across two historical land use types: Agriculture (areas with an agricultural history that have been reforested) and Reference (areas that were never used for agriculture), and two mapped soil series: Chipley (thermic, coated aquic Quartzisamments) and Olustee (sandy siliceous, thermic Ultic Alaquod). Soil profiles were described at each sample point and surface and subsurface soil samples collected for chemical analyses. Soil pH, total carbon (C) and nitrogen (N) and extractable soil phosphorus (P), calcium (Ca), and magnesium (Mg) were analyzed from the collected soil samples. We also evaluated two geophysical methods, electromagnetic induction (EMI) and resistivity, as non-invasive methods for identifying soil disturbance resulting from historic human activity. For this evaluation, EMI and Resistivity instruments were used to map three sites, two sites with a long-term history of human use and one site with no known history of human land use but that had a charcoal layer dating to 810 years before present.

Results from agricultural land use investigations concluded that significant differences in extractable P existed between former agricultural areas and reference forest areas and in soil pH between areas mapped as Chipley or Olustee soils. Differences in soil P between agricultural and reference were shown to persist in the soil for at least 80 years after abandonment of agriculture. Phosphorus elevation likely related to heavy application of P-rich organic fertilizers like guano and manure in agricultural fields and soil pH elevation in Chipley may have related to preferential selection of Chipley for farming and liming amendments in the form of crushed shells. Though not significant at p=0.05, total C and N, and extractable Ca and Mg were also elevated in former agricultural areas in comparison to reference forest areas. Most soil nutrients demonstrated a steady decline (or increase, in the case of C:N ratio) in nutrient concentration as the period since agricultural abandonment increased along the sequence Modern<Depression<Civil War <Reference (no agricultural history) indicating a slow return to Reference levels. Shell middens had a strong influence on the surrounding soil chemistry, leading to elevated pH and Ca. Variation in forest types was not associated with differences in land use or soil type, but soils with elevated Ca either contained pignut hickory (*Carya glabra*) or sabal palm (*Sabal minor*).

The varied land use history at Wormsloe, coupled with its well-sorted, coarse textured soils and areas of the property with minimal human activity, provided an ideal site to evaluate how contrasts in soil properties can be used for identification of soil legacies. The combined use of two geophysical instruments, EMI and Resistivity, with targeted soil investigations, optimized strengths of each method and provided characteristic soil patterns that provide indicators of human land use activity at Wormsloe. The instruments located features of varying sizes, from nineteenth century household artifacts, building debris, and shellfish middens to a buried foundation. Post EMI data processing, which included manually tagging coordinates to conductivity data within a grid, was necessary to achieve sufficient accuracy for this technique to be useful. Resistivity identified features at a finer resolution than EMI and, for this reason, is recommended for investigating areas with a known history of human land activity.

CHAPTER V

APPENDICES

Soil Nutrient Data-Sample Plots

Table 5.1: Soil nutrient data of Chipley Agriculture plots. North, Central, and South indicate blocks.

Plot No.	**Total C**†	**Total N**†	**C:N**	**pH**††	**P**‡	**Ca**‡	**Mg**‡
1North	1.21	0.07	16.89	4.42	242.48	1360.00	42.40
2	1.47	0.08	19.06	3.79	55.48	60.44	11.42
3	2.03	0.09	21.77	4.32	342.42	479.33	20.00
4	1.44	0.09	16.25	4.39	507.64	1052.00	40.00
5	2.81	0.11	26.24	3.75	13.99	188.94	29.42
6	2.61	0.12	21.67	3.97	236.54	328.33	28.00
7	2.43	0.10	23.79	4.33	51.36	395.33	17.20
8	12.17	0.53	22.83	3.73	26.87	408.31	36.40
9	1.62	0.08	20.18	4.10	304.09	1640.00	52.00
10	2.35	0.13	17.66	4.21	205.02	1148.00	45.60
1Central	2.54	0.12	20.51	4.20	44.12	1148.00	58.40
2	2.62	0.12	22.25	4.10	197.88	860.00	75.20
3	3.22	0.12	27.34	3.52	47.69	412.62	18.00
4	5.21	0.34	15.14	5.94	526.39	13524.0	649.60
5	1.99	0.06	31.88	3.86	12.67	59.58	12.22
6	2.62	0.09	28.17	3.79	13.82	232.09	14.40
7	3.38	0.24	14.02	6.49	48.01	6804.00	1678.40
8	3.66	0.14	25.55	4.31	30.98	2740.00	47.60
9	3.01	0.07	43.96	3.15	9.54	60.15	32.04
10	1.39	0.08	16.99	6.34	164.06	4324.00	68.40
1South	3.51	0.12	30.36	4.10	14.92	173.96	35.29
2	2.67	0.08	33.67	4.17	11.83	46.13	17.38
3	3.53	0.10	34.13	3.97	14.39	407.11	26.00
4	3.05	0.07	42.07	4.19	12.09	59.11	13.51
5	2.05	0.07	28.99	4.36	109.91	251.38	14.80
6	3.47	0.12	28.39	4.17	15.53	145.07	20.53
7	13.66	0.08	163.55	3.81	6.36	85.12	57.82
8	2.77	0.12	22.83	4.00	11.31	303.20	8.00
9	2.98	0.63	4.73	4.54	33.86	480.89	40.40
10	13.32	0.70	19.00	3.56	80.30	932.00	30.40

†Total % carbon and nitrogen by mass
††1:1 water: soil pH extraction
‡Extractable P, Ca, and Mg (mg kg^{-1})

Table 5.2: Soil nutrient data of Chipley Reference plots. North, Central, and South indicate blocks.

Plot No.	**Total C**†	**Total N**†	**C:N**	**pH**††	**P**‡	**Ca**‡	**Mg**‡
1North	3.96	0.10	38.28	3.70	21.17	139.12	32.22
2	0.89	0.02	46.07	6.09	19.68	5156.00	54.00
3	3.71	0.15	24.45	4.11	42.62	2032.80	68.80
4	5.36	0.18	30.24	3.76	13.99	77.16	78.00
5	3.18	0.13	24.31	4.43	61.57	419.31	25.20
6	3.04	0.11	26.53	4.11	34.04	43.38	20.62
7	2.06	0.08	25.00	3.91	17.39	31.72	18.76
8	2.70	0.11	24.55	3.66	21.27	151.32	40.93
9	3.72	0.16	23.70	3.60	16.81	46.85	22.53
10	3.33	0.14	24.06	4.11	18.38	2260.00	131.60
1Central	2.62	0.18	14.73	5.26	334.71	5008.00	295.20
2	2.54	0.09	28.93	3.87	13.90	36.22	13.60
3	3.42	0.12	29.60	3.36	19.21	95.27	26.31
4	1.27	0.05	25.33	3.85	15.52	38.27	17.51
5	2.81	0.08	33.47	3.54	41.46	66.72	23.78
6	1.49	0.05	28.63	3.59	13.45	33.86	7.91
7	3.00	0.11	27.89	3.68	15.07	138.04	30.80
8	3.30	0.12	28.48	3.91	21.85	40.46	24.04
9	3.06	0.11	26.94	3.76	17.64	55.38	30.80
10	4.27	0.17	24.89	3.84	22.05	234.36	30.80
1South	4.69	0.16	28.74	4.12	15.98	1332.00	58.40
2	2.68	0.06	45.68	4.04	10.88	37.08	10.53
3	2.44	0.07	37.32	3.49	13.77	166.84	20.40
4	1.10	0.02	67.48	3.99	14.65	44.05	17.87
5	4.84	0.18	27.50	3.78	15.18	83.00	38.36
6	2.59	0.07	35.96	4.02	11.04	70.25	16.93
7	1.95	0.04	55.38	3.59	9.89	36.66	8.71
8	2.36	0.07	36.16	3.69	14.74	38.36	11.78
9	1.61	0.04	37.18	3.73	10.15	43.86	14.49
10	1.50	0.03	55.88	3.87	12.62	59.89	17.29

†Total % carbon and nitrogen by mass

††1:1 water: soil pH extraction

‡Extractable P, Ca, and Mg (mg kg^{-1})

Table 5.3: Soil nutrient data of Olustee Agriculture plots. North, Central, and South indicate blocks.

Plot No.	Total C†	Total N†	C:N	pH††	P‡	Ca‡	Mg‡
1North	2.13	0.09	24.90	4.27	62.46	30.53	6.13
2	1.90	0.08	22.54	3.86	200.72	45.76	6.93
3	1.70	0.07	23.78	3.81	57.16	29.56	4.58
4	2.25	0.09	24.69	3.95	63.25	32.02	5.91
5	2.11	0.09	23.66	4.21	36.41	92.72	12.49
6	3.26	0.11	28.41	4.40	102.29	103.57	35.42
7	2.26	0.10	22.11	4.12	127.50	47.46	8.53
8	2.14	0.10	21.17	4.16	298.01	188.36	16.67
9	1.53	0.08	19.14	3.86	150.02	81.90	10.13
10	1.68	0.07	22.96	4.08	176.52	51.47	7.87
1Central	2.64	0.11	24.45	3.82	30.80	83.28	30.98
2	11.17	0.36	30.88	3.29	47.38	90.47	56.62
3	2.61	0.09	28.44	3.61	29.58	78.73	34.00
4	2.77	0.08	33.11	3.42	18.46	48.91	17.96
5	2.57	0.08	31.98	3.64	17.90	34.15	9.91
6	4.51	0.15	30.29	3.50	13.19	328.04	60.40
7	6.51	0.17	37.52	3.35	18.94	61.23	27.91
8	2.68	0.08	32.54	3.52	16.20	73.47	42.04
9	2.32	0.08	27.49	3.71	10.27	65.77	22.89
10	2.37	0.08	28.08	3.81	26.19	39.84	22.09
1South	2.94	0.10	30.68	3.82	22.04	29.56	10.76
2	3.43	0.12	29.84	3.97	33.91	55.15	18.44
3	2.41	0.09	26.36	4.07	23.08	41.32	9.91
4	4.96	0.18	28.29	3.44	32.03	90.75	41.51
5	1.88	0.07	26.35	3.81	11.68	24.53	9.60
6	2.69	0.08	32.21	3.51	14.41	74.92	54.58
7	1.83	0.07	25.55	3.83	16.30	36.16	13.38
8	2.00	0.10	20.96	3.55	32.31	284.66	46.44
9	2.13	0.08	25.25	3.90	20.35	30.73	14.98
10	1.93	0.08	25.71	4.06	17.68	43.56	11.96

†Total % carbon and nitrogen by mass

††1:1 water: soil pH extraction

‡Extractable P, Ca, and Mg (mg kg^{-1})

Table 5.4: Soil nutrient data of Olustee Reference plots. North, Central, and South indicate blocks.

Plot No.	**Total C**†	**Total N**†	**C:N**	**pH**††	**P**‡	**Ca**‡	**Mg**‡
1North	3.85	0.13	29.65	3.50	24.18	90.75	61.64
2	2.60	0.09	29.04	3.99	10.24	45.55	20.40
3	3.42	0.13	26.97	4.23	19.31	91.48	57.64
4	6.74	0.27	25.03	3.63	26.52	272.32	50.40
5	2.11	0.07	29.45	3.91	12.52	35.17	12.89
6	3.28	0.11	30.60	3.90	17.66	102.34	36.31
7	3.16	0.10	30.44	3.78	17.77	35.01	15.29
8	2.89	0.09	30.84	4.09	20.15	39.10	17.78
9	4.46	0.13	34.51	3.82	11.30	54.19	19.78
10	2.15	0.08	25.76	3.82	9.98	57.61	27.78
1Central	2.49	0.08	30.98	3.66	8.79	238.25	39.51
2	4.75	0.13	36.16	3.34	8.79	75.56	62.76
3	3.45	0.10	33.14	3.47	80.15	144.21	45.16
4	1.88	0.07	26.60	3.66	41.13	55.78	16.31
5	1.90	0.07	27.73	3.95	17.13	23.57	7.91
6	2.58	0.10	26.75	3.67	64.95	79.96	31.24
7	3.75	0.12	30.59	3.87	9.16	44.36	19.64
8	3.50	0.11	33.05	3.50	4.44	28.20	17.20
9	3.69	0.13	29.40	3.58	23.71	305.57	52.93
10	3.46	0.12	29.96	3.64	18.18	62.31	37.73
1South	3.79	0.11	35.75	3.48	15.36	85.12	22.80
2	2.84	0.09	33.07	3.58	10.55	63.82	28.84
3	2.68	0.08	33.75	3.53	9.89	56.67	50.93
4	3.63	0.10	37.46	3.43	19.69	78.92	58.40
5	2.37	0.09	26.30	3.83	20.16	136.37	43.42
6	2.05	0.08	27.14	3.92	18.37	23.95	10.09
7	4.99	0.16	31.42	3.57	19.97	28.79	9.69
8	2.32	0.09	25.13	4.40	16.86	20.32	9.91
9	2.69	0.07	36.90	3.43	15.45	96.00	48.36
10	2.47	0.07	35.88	3.58	12.53	42.12	14.67

†Total % carbon and nitrogen by mass
††1:1 water: soil pH extraction
‡Extractable P, Ca, and Mg (mg kg^{-1})

Soil Profile and Site Data-Sample Plots

Table 5.5: Soil profile and site data of Chipley Agriculture plots. North (N), Central (C), and South (S) indicate blocks.

Plot #	A depth (cm)	Depth to Bh (cm)	Agriculture Periods††	DOV§	DUV§§	Elevation (m) ‡
1N	5	5	Depression	Oakpinesweet	Mix	3.35
2	10	25	Depression	Oakpinesweet	Sawpalm	3.05
3	17	160	Depression	Oakpinesweet	Sabalpalm	3.05
4	15	15	Depression	Oakmix	Sabalpalm	3.35
5	20	20	Depression	Oakpinesweet	Mix	2.13
6	5	17	Depression	Oakpinesweet	Sabalpalm	2.74
7	5	5	Civil War	Oakhickory	Mix	3.05
8	35	160	Depression	Oakpinesweet	Mix	2.26
9	15	15	Modern	Pinemix	Sabalpalm	3.66
10	13	13	Modern	Pinemix	Sabalpalm	2.74
1C	7	160	Modern	Oakpinesweet	Mix	3.32
2	10	10	Modern	Oakpinesweet	Sabalpalm	3.35
3	15	140	Civil War	Oakmix	Mix	4.57
4	13	13	Modern	Open	Open	3.05
5	10	133	Civil War	Wateroak	Mix	3.66
6	13	13	Depression	Wateroak	Mix	3.35
7	53	160	Depression	Oakpinesweet	Sabalpalm	1.52
8	5	5	Depression	Oakpinesweet	Mix	3.66
9	15	30	Civil War	Wateroak	Mix	3.66
10	23	160	Modern	Oakmix	Open	3.05
1S	7	7	Depression	Oakhickory	Sabalpalm	3.26
2	20	160	Depression	Oakpinesweet	Sabalpalm	3.54
3	7	7	Depression	Oakpinesweet	Sabalpalm	3.35
4	5	5	Depression	Oakmix	Mix	3.05
5	7	7	Depression	Oakhickory	Sawpalm	3.29
6	7	7	Depression	Wateroak	Sabalpalm	3.35
7	17	83	Depression	Oakpinesweet	Open	2.13
8	17	50	Depression	Oakpinesweet	Sabalpalm	3.05
9	15	160	Depression	Oakhickory	Sabalpalm	3.35
10	30	160	Depression	Oakpinesweet	Open	1.16

††Agricultural periods represent time since agricultural abandonment. Civil War (100 + yrs since agricultural abandonment), Depression (80 + yrs), Modern (still influenced by amendments/ open field), and No Agriculture (Reference areas).

§DOV (Dominant Overstory Vegetation). Wateroak (*Quercus nigra*); Oakpinesweet (*Q. nigra*, *Pinus taeda*, *Liquidambar styraciflua*); Oakmix-(*Q. nigra*, *virginiana*, *hemisphaerica*, and *falcata*); Oakpinetupelo- (*Q. nigra*, *Q. virginiana*, *P. taeda*, *Nyssa biflora*); Pinemix- (*P. taeda*, *P. elliottii*); Oakhickory- (*Q. nigra*, *Q. virginiana*, *Magnolia grandiflora*, *Carya glabra*); and Open-field (no forest cover).

§§DUV (Dominant Understory Vegetation). Mix-(*Persia spp.*, *Symplocus tinctoria*, *Morella cerifera*, *Vaccinium aboreum. Serenoa repens*); Sawpalm- (*S. repens*, *Morella cerifera*); Galberry- (*Ilex glabra*, *S. repens*); Lyonia- (*Lyonia lucida*); Sabalpalm- (*Sabal minor*, *Morella cerifera*); Open- (grass)

‡Elevation obtained from a 2010 Chatham Cty, Georgia LIDAR map, conducted by NOAA.

Table 5.6: Soil profile and site data of Chipley Reference plots. North (N), Central (C), and South (S) indicate blocks.

Plot No.	**A depth**†	**Depth to Bh**†	**Agriculture Periods**††	**DOV**§	**DUV**§§	**Elevation**‡
1N	7	7	No Ag	Oakpinesweet	Mix	3.35
2	7	13	No Ag	Oakmix	Sabalpalm	1.22
3	13	13	No Ag	Oakpinesweet	Mix	3.96
4	15	15	No Ag	Wateroak	Mix	3.05
5	10	133	No Ag	Oakhickory	Sabalpalm	3.35
6	13	13	No Ag	Oakmix	Mix	3.05
7	7	17	No Ag	Oakmix	Mix	3.66
8	16	16	No Ag	Oakmix	Mix	4.27
9	13	13	No Ag	Oakpinesweet	Mix	3.05
10	17	17	No Ag	Oakpinesweet	Mix	3.35
1C	10	160	No Ag	Oakhickory	Sabalpalm	2.74
2	13	160	No Ag	Oakpinesweet	Mix	3.35
3	20	20	No Ag	Oakpinesweet	Mix	3.05
4	5	93	No Ag	Oakmix	Sabalpalm	2.74
5	15	15	No Ag	Oakmix	Mix	4.27
6	15	160	No Ag	Oakmix	Mix	2.44
7	13	30	No Ag	Oakpinesweet	Mix	3.81
8	15	113	No Ag	Oakpinesweet	Sawpalm	3.66
9	17	10	No Ag	Oakpinesweet	Sabalpalm	2.74
10	5	5	No Ag	Oakpinesweet	Mix	3.35
1S	10	10	No Ag	Oakpinesweet	Sabalpalm	3.54
2	17	17	No Ag	Oakpinesweet	Mix	3.72
3	10	17	No Ag	Oakpinetupelo	Mix	3.35
4	3	160	No Ag	Oakpinesweet	Sawpalm	2.07
5	10	160	No Ag	Oakhickory	Mix	3.35
6	5	13	No Ag	Oakpinesweet	Sawpalm	3.05
7	8	17	No Ag	Oakpinesweet	Mix	3.96
8	5	5	No Ag	Oakpinesweet	Sawpalm	3.87
9	5	160	No Ag	Oakpinesweet	Sawpalm	3.05
10	10	97	No Ag	Oakpinesweet	Sawpalm	2.74

†Both are measured in cm.

††Agricultural periods represent time since agricultural abandonment. Civil War (100 + yrs since agricultural abandonment), Depression (80 + yrs), Modern (still influenced by amendments/ open field), and No Agriculture (Reference areas).

§DOV (Dominant Overstory Vegetation). Wateroak (*Quercus nigra*); Oakpinesweet (*Q. nigra*, *Pinus taeda*, *Liquidambar styraciflua*); Oakmix-(*Q. nigra*, *virginiana*, *hemisphaerica*, and *falcata*); Oakpinetupelo- (*Q. nigra*, *Q. virginiana*, *P. taeda*, *Nyssa biflora*); Pinemix- (*P. taeda*, *P. elliottii*); Oakhickory- (*Q. nigra*, *Q. virginiana*, *Magnolia grandiflora*, *Carya glabra*); and Open-field (no forest cover).

§§DUV (Dominant Understory Vegetation). Mix-(*Persia spp., Symplocus tinctoria*, *Morella cerifera*, *Vaccinium aboreum. Serenoa repens*); Sawpalm- (*S. repens, Morella cerifera*); Galberry- (*Ilex glabra*, *S. repens*); Lyonia- (*Lyonia lucida*); Sabalpalm- (*Sabal minor, Morella cerifera*); Open- (grass)

‡Elevation, in meters, obtained from a 2010 Chatham Cty, Georgia LIDAR map, conducted by NOAA.

Table 5.7: Soil profile and site data of Olustee Agriculture plots. North (N), Central (C), and South (S) indicate blocks.

Plot No.	A depth†	Depth to Bh†	Agriculture Periods††	DOV§	DUV§§	Elevation‡
1N	5	5	Depression	Wateroak	Mix	3.96
2	10	10	Civil War	Wateroak	Mix	3.66
3	15	15	Depression	Wateroak	Mix	3.96
4	10	10	Depression	Wateroak	Mix	3.96
5	5	5	Depression	Wateroak	Mix	3.66
6	10	10	Depression	Oakpinesweet	Sawpalm	3.96
7	13	13	Civil War	Wateroak	Mix	3.96
8	5	5	Civil War	Oakmix	Sabalpalm	3.66
9	10	10	Civil War	Oakpinesweet	Mix	3.66
10	15	15	Civil War	Wateroak	Mix	3.96
1C	13	13	Civil War	Oakpinetupelo	Galberry	3.66
2	10	10	Civil War	Pinemix	Open	3.35
3	17	17	Civil War	Oakpinesweet	Mix	3.66
4	17	17	Civil War	Oakpinetupelo	Sawpalm	4.15
5	13	13	Civil War	Oakpinetupelo	Mix	3.96
6	15	15	Civil War	Oakpinetupelo	Galberry	3.96
7	13	13	Civil War	Wateroak	Galberry	3.51
8	10	25	Civil War	Oakpinetupelo	Mix	3.96
9	21	21	Civil War	Oakpinetupelo	Galberry	3.96
10	15	15	Civil War	Oakpinetupelo	Galberry	3.96
1S	15	15	Depression	Oakpinetupelo	Mix	3.35
2	7	7	Depression	Oakpinesweet	Mix	3.51
3	17	17	Depression	Oakpinesweet	Mix	3.35
4	13	13	Depression	Oakpinetupelo	Sabalpalm	2.74
5	14	14	Depression	Oakpinesweet	Sawpalm	3.66
6	10	20	Depression	Oakpinetupelo	Sawpalm	3.66
7	5	17	Depression	Oakpinetupelo	Mix	3.35
8	5	160	Depression	Oakpinesweet	Sabalpalm	2.26
9	15	15	Depression	Oakpinesweet	Open	3.35
10	5	13	Depression	Oakpinesweet	Mix	3.66

†Both are measured in cm.

††Agricultural periods represent time since agricultural abandonment. Civil War (100 + yrs since agricultural abandonment), Depression (80 + yrs), Modern (still influenced by amendments/ open field), and No Agriculture (Reference areas).

§DOV (Dominant Overstory Vegetation). Wateroak (*Quercus nigra*); Oakpinesweet (*Q. nigra*, *Pinus taeda*, *Liquidambar styraciflua*); Oakmix-(*Q. nigra*, *virginiana*, *hemisphaerica*, and *falcata*); Oakpinetupelo- (*Q. nigra*, *Q. virginiana*, *P. taeda*, *Nyssa biflora*); Pinemix- (*P. taeda*, *P. elliottii*); Oakhickory- (*Q. nigra*, *Q. virginiana*, *Magnolia grandiflora*, *Carya glabra*); and Open-field (no forest cover).

§§DUV (Dominant Understory Vegetation). Mix-(*Persia spp.*, *Symplocus tinctoria*, *Morella cerifera*, *Vaccinium aboreum. Serenoa repens*); Sawpalm- (*S. repens, Morella cerifera*); Galberry- (*Ilex glabra*, *S. repens*); Lyonia- (*Lyonia lucida*); Sabalpalm- (*Sabal minor, Morella cerifera*); Open- (grass)

‡Elevation, in meters, obtained from a 2010 Chatham Cty, Georgia LIDAR map, conducted by NOAA.

Table 5.8: Soil profile and site data of Olustee Reference plots. North (N), Central (C), and South (S) indicate blocks.

Plot No.	A depth†	Depth to Bh†	Agriculture Periods††	DOV§	DUV§§	Elevation‡
1N	15	15	No Ag	Oakmix	Mix	2.13
2	13	13	No Ag	Wateroak	Mix	3.66
3	10	10	No Ag	Oakmix	Mix	3.05
4	13	13	No Ag	Oakmix	Mix	2.44
5	7	17	No Ag	Wateroak	Mix	3.66
6	10	10	No Ag	Wateroak	Mix	3.87
7	17	17	No Ag	Wateroak	Mix	3.84
8	10	10	No Ag	Wateroak	Mix	3.96
9	5	5	No Ag	Oakmix	Mix	3.66
10	13	13	No Ag	Oakmix	Mix	3.05
1C	7	7	No Ag	Oakpinesweet	Mix	3.66
2	10	27	No Ag	Oakpinetupelo	Lyonia	3.35
3	10	25	No Ag	Oakmix	Mix	3.96
4	15	15	No Ag	Wateroak	Mix	4.27
5	10	10	No Ag	Oakpinetupelo	Mix	4.27
6	10	10	No Ag	Wateroak	Mix	3.96
7	10	10	No Ag	Oakpinetupelo	Lyonia	3.05
8	13	13	No Ag	Oakpinesweet	Lyonia	3.66
9	10	10	No Ag	Oakpinesweet	Mix	3.66
10	15	125	No Ag	Oakmix	Mix	3.96
1S	23	23	No Ag	Oakpinetupelo	Galberry	3.35
2	20	20	No Ag	Oakpinetupelo	Galberry	3.66
3	17	17	No Ag	Oakpinetupelo	Galberry	3.51
4	15	33	No Ag	Oakpinetupelo	Galberry	3.57
5	17	17	No Ag	Oakpinetupelo	Sawpalm	3.47
6	8	15	No Ag	Oakpinetupelo	Sawpalm	3.57
7	45	75	No Ag	Pinemix	Open	2.93
8	5	5	No Ag	Oakpinetupelo	Mix	3.66
9	15	35	No Ag	Oakpinetupelo	Galberry	3.96
10	10	15	No Ag	Oakpinetupelo	Sawpalm	3.81

†Both are measured in cm.

††Agricultural periods represent time since agricultural abandonment. Civil War (100 + yrs since agricultural abandonment), Depression (80 + yrs), Modern (still influenced by amendments/ open field), and No Agriculture (Reference areas).

§DOV (Dominant Overstory Vegetation). Wateroak (*Quercus nigra*); Oakpinesweet (*Q. nigra*, *Pinus taeda*, *Liquidambar styraciflua*); Oakmix-(*Q. nigra*, *virginiana*, *hemisphaerica*, and *falcata*); Oakpinetupelo- (*Q. nigra*, *Q. virginiana*, *P. taeda*, *Nyssa biflora*); Pinemix- (*P. taeda*, *P. elliottii*); Oakhickory- (*Q. nigra*, *Q. virginiana*, *Magnolia grandiflora*, *Carya glabra*); and Open-field (no forest cover).

§§DUV (Dominant Understory Vegetation). Mix-(*Persia spp.*, *Symplocus tinctoria*, *Morella cerifera*, *Vaccinium aboreum*. *Serenoa repens*); Sawpalm- (*S. repens*, *Morella cerifera*); Galberry- (*Ilex glabra*, *S. repens*); Lyonia- (*Lyonia lucida*); Sabalpalm- (*Sabal minor*, *Morella cerifera*); Open- (grass)

‡Elevation, in meters, obtained from a 2010 Chatham Cty, Georgia LIDAR map, conducted by NOAA.

NRCS Soil Map of Wormsloe

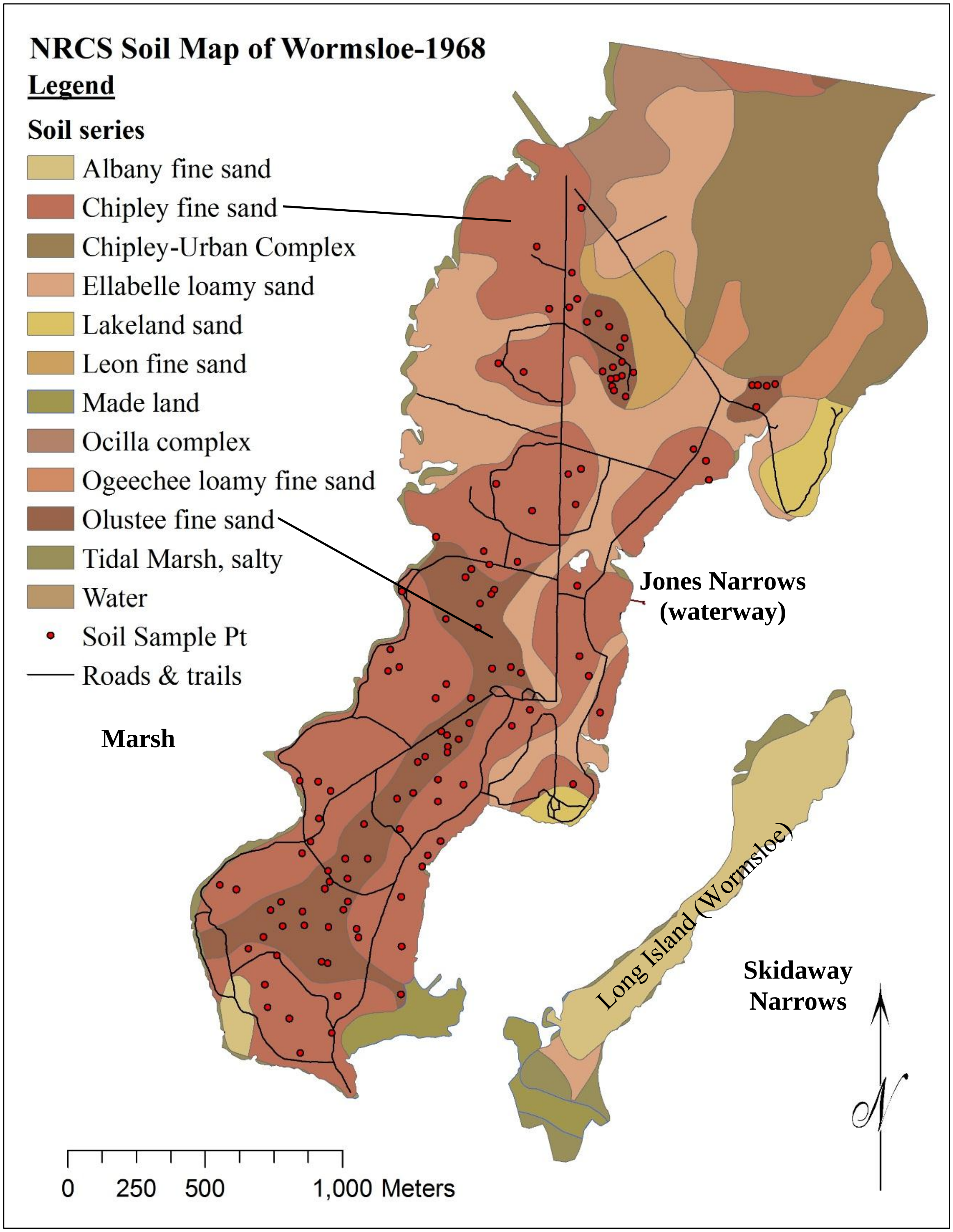

Figure 5.1: Soil series at Wormsloe mapped by the Natural Resource Conservation Service (NRCS) in the 1970s. Map made by author in ArcGIS using data from the NRCS and the UGA CGR.

Long Term Vegetation Plots- Soil Data- Soil Data

Table 5.9: Soil nutrient data at Wormsloe Long Term Vegetation Plots.

Plot No.	Total C†	Total N†	C:N	pH††	P	Ca	Mg
1	1.78	0.10	17.71	4.90	126.92	1624.00	44.000
2	2.09	0.09	23.28	3.76	5.61	137.02	46.222
3	6.42	0.31	20.58	3.53	31.19	93.47	47.156
4	4.00	0.19	21.12	3.48	36.36	147.56	70.311
5	3.84	0.20	19.41	3.79	18.89	345.33	26.800
6	3.55	0.11	31.17	3.92	13.45	134.31	27.289
7	2.19	0.07	32.75	3.47	11.49	82.45	23.422
8	4.03	0.14	28.62	4.09	11.31	249.24	15.600
9	2.49	0.09	26.89	4.00	8.64	67.88	20.133
10	2.17	0.07	30.22	4.04	16.85	58.13	13.689
11	2.46	0.07	33.28	4.20	103.04	85.73	24.133
12	2.56	0.07	39.17	3.62	15.38	185.51	74.533
13	3.51	0.11	32.61	3.56	9.95	46.08	30.622
14	30.13	1.78	16.88	-------	-------	-------	-------
15	3.39	0.21	15.83	4.45	23.48	1836.00	38.400
16	1.99	0.09	22.90	4.24	57.62	144.22	18.711
17	2.13	0.09	24.30	4.44	220.78	89.86	19.022
18	1.38	0.04	32.98	4.27	260.53	83.11	26.444
19	12.94	0.36	36.17	3.86	28.86	79.27	34.533
20	5.30	0.15	34.41	3.85	58.46	35.41	12.711
21	1.96	0.09	21.37	4.21	230.22	462.53	18.400
22	2.49	0.12	21.14	4.03	26.72	207.20	22.000
23	2.54	0.08	32.31	3.25	14.51	49.07	27.822
24	2.00	0.08	23.58	3.74	84.51	48.24	22.444
25	1.75	0.08	20.84	3.90	12.34	47.17	22.578
26	1.28	0.06	22.54	4.80	15.69	191.87	9.200
27	1.68	0.07	24.03	4.16	116.49	46.44	18.578
28	5.88	0.17	34.58	3.89	10.99	36.17	19.867
29	2.03	0.08	24.18	4.00	13.07	44.86	15.867
30	3.17	0.11	29.16	4.27	27.01	301.60	141.200
31	2.96	0.14	21.18	4.15	17.12	0.22	1.733
32	2.71	0.11	23.96	4.44	14.40	6.21	15.822
33	3.45	0.13	25.78	4.52	218.58	0.57	3.156

†Total % carbon and nitrogen by mass

††1:1 water: soil pH extraction

Table 5.10: Arithmetic mean and standard error (Std Er) at Wormsloe Long Term Vegetation Plot soil nutrients.

	Total C	Total N	C:N	pH	P	Ca	Mg
Mean Std Er	4.01 ± 0.90	0.17 ± 0.05	26.21 ± 1.07	4.03 ± 0.067	58.14 ± 12.94	217.71 ± 71.53	29.76 ± 4.52

Soil Monolith Construction at Wormsloe

Introduction

Soil monoliths are representative samples sample of soil profiles set in frames that are used as educational displays for museums and educational institutions. A monolith is representative of a specific soil, or named soil series, sharing soil characteristics, such as color, texture, structure, horizon depth and boundaries to a specified depth. Monoliths can also provide information on soil genesis and human influences on soil.

Wormsloe State Historic Site, located on a mainland peninsula outside of Savannah, Georgia, contains nearly three centuries of post-colonial human land use. Near residential areas and within some agricultural fields, significant accumulation of household debris, charcoal, or shells are evident. From our soil investigations on site, this debris has led to changes in surface soil structure and chemistry.

Objective

To make a soil monolith of a typical Wormsloe soil that also captures the influence of human land use on soil profile characteristics.

Methods

After examining nearly 200 soil profiles on the property, one site was chosen that met three necessary criteria to build a soil monolith: accessibility to water, clearance for a backhoe and other tools, and evidence of human activity within the profile.

One 122 X 15.24 X 3.81 cm (4 ft X 6 in X 1.5 in) frame was constructed from cypress to permanently display the monolith (Fig. 5.2). This frame size was based on recommendations from Soil Survey Staff at the NRCS. Screws 1.27 cm in length (0.5 in) were screwed through the back of the frame every 3 to 4 inches using a drill (to provide support for the monolith). Next, a layer of cheese cloth was placed over the screws in the bottom of the frame and Elmer's glue was poured liberally over the cheese cloth (Fig. 5.3) to provide further adherence of the soil to the frame.

To prepare the soil for excavation, two days before the soil pit was dug, a ten foot diameter area was moistened to field capacity (a moist soil is preferable for monolith construction). Using Darcy's Law, saturated hydraulic conductivity and depth of a wetting front were calculated for the selected soil's texture. Over four hours were necessary to moisten the soil to field capacity.

A soil pit was excavated to a depth of 152 cm (5 ft), one foot deeper than the depth of the wooden frame that would contain the monolith and 15.24 cm above the water table, which was at a 168 cm (5.5 ft) depth (Fig. 5.4). Because the soil had a high sand content with single grain structure, the monolith could not be extracted in one piece (Fig. 5.5). Instead, we extracted the monolith in sections and pieced them together in the frame (Fig. 5.6 and 5.7). After all pieces were in place in the frame (Fig. 5.8), the monolith was carefully wrapped with plastic wrap and transported back to the author's residence for final preparation.

Final preparation of the monolith includes removing excess soil to the top of the frame, so no soil extends beyond the frame (to be completed in January of 2015). The monolith will then dry completely before adding an acrylic hardening agent (a clear, acrylic floor wax). The acrylic will be added full strength in small amounts, until the profile is saturated. After fully drying, the soil monolith will solidify in the frame and later a plexi-glass cover will be placed over the frame for long term protection of the soil face. The soil series name (Echaw) will then be mounted on the top of the monolith frame.

Figure 5.2: Soil monolith frame.

Figure 5.3: Adding a layer of cheese cloth and glue to the bottom of the frame, before adding soil.

Figure 5.4: Excavation of the soil pit.

Figure 5.5: Assessing the best way to extract the soil profile chosen for making the monolith.

Figure 5.6: Removing the fragile profile piece by piece.

Figure 5.7: Placing the fragile pieces of the soil profile into the frame.

Figure 5.8: The entire profile is pieced within the frame and ready for final preparation.