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# Characterization of Problematic Red Clay Soils in Arkansas for the Purpose of Onsite Wastewater System Placement

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Characterization of Problematic Red Clay Soils in Arkansas for the Purpose of Onsite Wastewater System Placement

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## Abstract

Distinguishing between red-clay soils that are non-expansive and can reduce and red-clay soils developing in problematic red parent material, which are expansive, but also non-reducing, is key for proper on-site wastewater system placement. The Arkansas Department of Health allows for the placement of on-site wastewater systems in certain red-clay soils that have the potential to reduce, but only in the Ozark Highlands [Major Land Resource Area (MLRA) 116A], which is referred to as the red-soil exception. There is currently little scientific data to support the geographic restriction of the red-soil exception. The objectives of this study were to: i) confirm the non-expansiveness and reducibility of select soils in the Ozark Highlands that meet the criteria for the red-soil exception for determining soil suitability for on-site wastewater system placement, and ii) compare the expansiveness and reducibility of the residual and colluvial, red-clay soils of the Ozark Highlands to those in other MLRA region groupings in Arkansas. Fresh soil samples were collected in conjunction with archived soil samples to create a 51-sample data set from the 38- to 50-cm soil depth interval for analyses. The alluvial soils of the Red and Arkansas Rivers region, which are known to be expansive and non-reducing, had a mean coefficient of linear extensibility (COLE) of 0.116 mm $mm^{-1}$, whereas soils from the other four MLRA regions evaluated, including the Ozark Highlands, had significantly lower ($P < 0.01$) COLE values. Based on a 1-hr reduction test, soils from the Red and Arkansas Rivers region changed red color the least (ΔA of -8.6 in the LAB color scheme; $P < 0.01$) compared to soil from all four other MLRA regions evaluated, including the Ozark Highlands. As an often-used indicator of expansiveness, the Mehlich-3-estimated cation exchange capacity (CEC-M), excluding any contribution from soil organic matter, was larger (24.5 $cmol_c$ $kg^{-1}$; $P < 0.01$) for soils from the Red and Arkansas Rivers region than for soils from all four other regions

evaluated. The CEC-M:clay ratio was also larger (0.46; $P < 0.01$) for soils from the Red and Arkansas Rivers region than for soils from all four other regions, which did not differ. Results of this study indicate the red-soil exception, used by the Arkansas Department of Health for determining on-site wastewater system suitability, could be expanded to include several additional MLRAs in Arkansas, excluding the alluvial, red-clay soils of the Arkansas and Red River valleys due to their expansive and reduction-resistant characteristics.

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## Dedication

This thesis is dedicated to my grandfather, Tommy Kitchens, who made many sacrifices so my siblings and I could have the opportunities afforded to us. My academic experience would not have been possible without his support.

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# INTRODUCTION

# Introduction

Over one in five households in the United States rely on individual on-site or community-cluster systems to treat wastewater (USEPA, 2002). Homes built in rural areas, without access to city sewer systems, rely on on-site wastewater treatment systems (OSWWTS). Arkansas is a mostly rural state, with 41% of Arkansans living in rural counties, compared to 14% of the United States population living in rural counties (Miller and Wheeler, 2021). The standard OSWWTS used is one that includes a septic tank and absorption field (CDCP, 2006). The suitability of OSWWTSs in Arkansas is governed by the Arkansas State Board of Health. To properly understand the hydrology of a soil, both historically, currently, and in the future, a determination must made whether the soil conducts water fast enough that reducing conditions do not exist or develop or whether the soil resists color changes that would indicate impeded water movement.

Determining if a soil may have problematic red parent material and testing the soil's ability to reduce ensures an OSWWTS is suitable for a location with clayey, red soil. It is important to distinguish between soils that are non-expansive, but can reduce from those derived in problematic red parent materials that resist color change. Despite large clay concentrations, certain red-colored soil parent materials do not develop redoximorphic features associated with prolong soil saturation (Mokma and Sprecher, 1994), thus making it difficult to use soil morphological features as reliable indicators of soil wetness.

The Arkansas Rules and Regulations Pertaining to Onsite Wastewater Systems allows for an exception for OSSWS to be placed in certain red soils with large clay contents, but only if the soils specifically occur in the Ozark Highlands major land resource area (MLRA; ASBH, 2019). The exception is referred to as the red-soil exception (ASBH, 2019). The Arkansas State Board of Health requires the following criteria for the red-soil exception to be used: i) ≥ 35% clay, ii) 5YR or redder hue, iii) no redoximorphic features, iv) from approximately the 38- (15 in) to 50-cm (20 in) depth range, and v) the soil resides in the Ozark Highlands (MLRA 116A). However, the Ozark Highlands may not be the only MLRA in Arkansas that contains soils that may meet the criteria for the red-soil exception.

The Natural Resources Conservation Service (NRCS) uses red parent material as an indicator for hydric soils in areas known to have red soils that are resistant to color change under reducing conditions (NRCS, 2018), specifically a color change propensity index (CCPI) value < 30 (Rabenhorst and Parikh, 2000). Some red soils, or soils derived from red parent materials, will develop hydromorphic features when exposed to anaerobic conditions (Rabenhorst and Parikh, 2000). Determining the reducibility of a soil can determine whether or not a soil will develop redoximorphic features. The Ozark Highlands (MLRA 116A) generally does not have soils with non-reducing red parent materials, but the non-reducing soils developed in red parent materials are present in other areas of Arkansas.

In addition to the ability of a soil to reduce to show morphological features that can be used as indicators of soil wetness, low shrink-swell capacity (i.e., low expansiveness) is also needed for OSWWS suitability. Soils with low shrink-swell capacity have little risk of expanding upon wetting, which renders a soil with restricted vertical water flow. If vertical water flow is restricted, then effluent dosed to absorption field trenches from a septic tank has the potential to surface, causing a major health hazard.

Recent observations from the on-site wastewater professional community in Arkansas have identified clayey, residual/colluvial soils outside of the Ozark Highlands that show little evidence of restricting water, have a moist soil color of 5YR or redder, and are only minimally expansive. Determining if there are soils that meet the red-soil exception outside of the Ozark Highlands will allow for the more effective use of certain soils and expanded placement options for on-site wastewater systems throughout Arkansas. Therefore, the goal of this thesis is to evaluate soils of various other regions outside the Ozark Highlands for their expansiveness and reducibility.

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# CHAPTER 1

# LITERATURE REVIEW

## Literature Review

### Managing On-site Wastewater

Over one in five households in the United States rely on individual on-site or community-cluster systems to treat wastewater (USEPA, 2002). Homes and business, not serviced by a centralized public sewer system, use on-site wastewater systems (USEPA, 2002). On-site wastewater treatment systems can be referred to as septic systems, cluster systems, or on-lot systems.

Raw domestic wastewater, referred to as sewage, is primarily water that contains 0.1% of impurities, which includes biodegradable organic materials and potentially pathogens. The purpose of an on-site wastewater system is to remove the impurities and release treated water back into the environment, and usually the soil (CDCP, 2006).

On-site wastewater systems (OSWWS) are typically installed near where the wastewater is generated. On-site wastewater systems are a part of the permanent infrastructure of a home or business and are managed as stand-alone facilities (USEPA, 2002). The standard in OSWWS used is one that includes a septic tank and absorption field (CDCP, 2006). The standard system consists of a septic tank, a distribution box, and a series of perforated pipes in trenches, referred to as the drain field.

Wastewater leaves a household or business and flows into the septic tank. The septic tank is a cylindrical or round container made of concrete, fiberglass, or polyethylene. In the septic tank, wastewater is held as solids fall out of suspension to the bottom of the tank and is referred to as sludge (USEPA, 2002). The sludge is decomposed by microbial action. Fats, grease, and oils float at the top of the effluent held in the septic tank and are referred to as the scum layer. The wastewater between the scum and sludge, termed effluent, flows out of the septic tank to the distribution box. The distribution box controls the flow of effluent to the perforated pipes in the drain field (USEPA, 2002).

**Properties that Affect Water/Wastewater Flow in Soil**

Hydraulic Conductivity

Hydraulic conductivity describes the ease at which the soil conducts water. The hydraulic conductivity of a soil determines the rate at which natural water, or effluent, will travel through the soil. Groundwater contamination is a concern if the soil conducts water too quickly and surfacing of effluent is a concern if effluent moves too slowly. For the purpose of wastewater system placement, hydraulic conductivity is divided into classes.

Hydraulic conductivity is determined within the zone extending 15.2 cm (6 in) above to 30.5 cm (12 in) below the planned depth of the absorption trench (ASBH, 2019). The hydraulic conductivity class is determined based on the soil horizon with the minimum hydraulic conductivity in the zone. Authorized and experienced officials observe features of the soil to determine the hydraulic conductivity (ASBH, 2019).

To describe a horizon as high hydraulic conductivity, the soil must not be compacted and must have sandy, fragmental, or sandy-skeletal particle size class (SSDS, 2017). A soil with low hydraulic conductivity will have a clay content of 40 to 60% and will have platy or massive structure (SSDS, 2017). Compacted horizons, or those that have a textural class of sandy clay, clay, and silty clay are classified as low hydraulic conductivity (SSDS, 2017). Soils with low hydraulic conductivity will not conduct effluent at a proper rate, leading to the soil holding the effluent, risking emergence at the soil surface. Effluent surfacing can lead to exposure to pathogens. Evidence of soils with low hydraulic conductivity includes redoximorphic features, such as iron and manganese depletions and concentrations.

The hydraulic conductivity classes used by the Natural Resources Conservation Service vary from very rapid (> 141 µm $s^{-1}$) to very slow (0 to 0.4 µm $s^{-1}$; Table 1; SSDS, 2017). Soils dominant in clay are expected to have a hydraulic conductivity of moderately slow (1.4 to 4.2 µm $s^{-1}$) to slow (0.4 to 1.4 µm $s^{-1}$; SSDS, 2017).

The hydraulic conductivity classes used by the Arkansas Department of Health are high, moderate, and low. Hydraulic conductivity class is assigned based on soil texture, soil structure, and the size and amount of rock fragments. For example, a soil with 40 to 60% clay or has a platy or massive structure would be classified as low hydraulic conductivity.

The hydraulic conductivity class of the soil determines the distance that is required from the bottom of the proposed absorption trench to the water table, either true or seasonal, and/or the underlying bedrock. For example, if a soil has moderate hydraulic conductivity, there must be 61 cm (24 in) between the bottom of the trench and the true water table and 46 to 61 cm to bedrock. (ASBH, 2019). Hydraulic conductivity class is also used to assign loading rate or system size. For example, a moderate hydraulic conductivity class soil will have a smaller system than a low hydraulic conductivity class soil.

## Soil Structure

The arrangement or organization of soil particles plus organic matter, which make up soil peds or aggregates, in the soil is referred to as soil structure (Hillel, 1998). Due to variations in shape, size, and orientation of soil peds, complex and irregular patterns are present in the soil. (Hillel, 1998). The formation and stabilization of aggregates in soil is primarily influenced by soil organic matter (Brady and Weil, 2008). Soil mineral particles are coated and encrusted with decomposed organic materials. The complex organic polymers, which are the result of decay, interact with silicate clays, iron oxides, and aluminum oxides. The organic polymers assist to orient the clays, forming bridges between individual soil particles, binding them together into aggregates (Brady and Weil, 2008). Soil structure has one of three broad categories- single-grained, massive, or aggregated. For non-aggregated soils, single-grained is used to describe soil with loose particles, while massive describes soil peds that are tightly packed in one large cohesive block. Aggregated structure is when stable aggregates are formed and maintained in the soil (Hillel, 1998). For OSWWS, soil structure contributes to how much effluent can be loaded into the soil, referred to as hydraulic loading rates (ASBH, 2019). By taking into consideration both the structure and texture, officials can determine the proper hydraulic loading rate for a soil, hence the effluent loading rate.

## Clay Mineralogy

The texture of the soil is comprised of the three soil separates, sand, silt, and clay. Clay is the smallest soil separate, measuring < 2 μm in characteristic dimension. The quantity and type of clay affect how a soil conducts water and if a soil expands or not. The type of clay is based on the mineralogy that makes up the clay particle. Clay minerals are divided into three categories based on their structure: 1:1, 2:1, and 1:2:1 clay minerals.

Large numbers of aluminum octahedra ($AlO_6$) condense to form octahedral sheets. The condensation of silicon tetrahedra ($SiO_4$) combine into tetrahedral sheets. Through oxide-ion sharing, tetrahedral sheets bind to octahedral sheets. One-to-one clay minerals, referred to as the kaolinitic group, are clays that are composed of one octahedral and one tetrahedral sheet.

Two-to-one clay minerals can be sub-categorized as smectite, vermiculite, and illite. Two-to-one clays are composed of two octahedral sheets and one tetrahedral sheet. Two-to-one clay minerals may or may not be expansive or may be semi-expansive based on differences in the crystallographic structure (Schulze, 2002).

Chlorites are a group of clay minerals that exhibit a 2:1:1 structural arrangement, which consists of a basic 2:1 structure with an interlayer brucite or gibbsite sheet. Due to lack of water absorption within the interlayer space, chlorites are not considered expansive (Barton and Karathanasis, 2002).

Kaolinite and halloysite are the most common 1:1 clay mineral, referred to as kaolin minerals. Kaolin minerals typically have a small surface area and low cation and anion exchange capacities. Only two layers of water molecules can enter the interlayer space of halloysite, and no water enters the interlayer space of kaolinite (Dixon, 1989). In kaolinite, hydroxyl hydrogens and oxide ions are hydrogen-bonded so tightly together that water cannot enter the interlayer space (Mitchell, 1993). In addition, halloysite differs from kaolinite, as halloysite is often tubular in contrast to the platy morphology of kaolinite (Bates et al., 1950). Both kaolinite and halloysite are produced by acid weathering (Grossman and Reinsch, 2002) and are non-expansive clay minerals.

Kaolinite is the most common mineral in the kaolin group. Kaolinite is composed of a tetrahedral and an octahedral sheet. Sheets in kaolinite are held tightly together by hydrogen bonding, which restricts expansion and limits the reactive area to only external surfaces. The surface area, as well as the chemical and physical activity of kaolinite, is dependent on the particle size and crystal perfection. Kaolinite crystallites are sub-micro-sized and platy in morphology. Plates are roughly hexagonal shaped. In well-developed soils, the predominant size of kaolinite is < 2 µm. In residual soils, stacks of structural layers, referred to as books, may also form (Dixon, 1989).

Expansive Soils

An expansive soil is any soil that has the potential to shrink and swell under changing soil moisture conditions (Nelson and Miller, 1992). Expansive soils will experience a three-dimensional (3-D) increase in volume when wetted and a 3-D decrease in volume when dried (Azam et al., 2000). Shrink-swell clays are commonly abundant with smectite clays, which are 2:1 expanding clay minerals. Many Major Land Resource Areas (MLRAs) in Arkansas have a wide variety of shrink-swell soils that are present as Vertisols. There are 20 soil series mapped as Vertisols in Arkansas and they represent close to 1% of the mapped land area in Arkansas (Brye et al., 2013). Many shrink-swell soils reside in the Red River Alluvium MLRA (Brye et al., 2013).

**On-site Wastewater Management in Arkansas**

The placement of OSWWSs in Arkansas is governed by the Arkansas State Board of Health. The "Rules and Regulations Pertaining to Onsite Wastewater Systems" (ASBH, 2019) provides guidelines in all steps of the process of site evaluation and installing an OSWWS. The first step is to perform an on-site evaluation for the suitability of the site for an OSWWS. In order for a designated representative (DR) to evaluate the soil on site, a minimum of two soil pits are dug, one in the primary location, and one in a secondary location. Soil properties that specifically relate to OSWWS suitability include, but are not limited to, color, texture, structure, redoximorphic features, and depth to bedrock (ASBH, 2019).

## Soil Color

Soil color is a typical soil morphological property associated with most soil descriptions. Soil color is most often determined visually using moist, field soil (SSDS, 2017). The most common system for determining soil color is the Munsell Color System. Soil color is traditionally determined by using a Munsell color book and matching the moist soil color by eye to the correct color chip with the corresponding hue, value, and chroma (SSDS, 2017).

A Munsell color notation is recorded as hue, value/chroma, for example: 5YR 3/3. Hue describes the chromatic composition of light that reaches the eye (Lynn and Pearson, 2000). Red, yellow, and green are examples of hue. Value describes the lightness or darkness of a color in relation to a neutral gray scale (Lynn and Pearson, 2000). Zero is a pure black value, while 10 is a pure white value. Chroma describes the purity, strength, or intensity of the color (Brady and Weil, 2008).

The LAB system is another tool that can be used to determine soil color. In the LAB system, LAB refers to the three axes used to identify colors. In the LAB color space, L is the black-white axis, A is the red-green axis, and B is the yellow-blue axis (Konica Minolta, 2018). All three axes combine to form a theoretical sphere. Each color has three numeric values, one for each axis. All three points combine to form a coordinate in a sphere (Konica Minolta, 2018).

For the LAB system, the L parameter correlates to the dark pigment (humus) of the soil. The A parameter correlates to the red pigment of the soil. The B parameter relates to the yellow pigment of the soil (Vodyanitskii and Kirillova, 2016).

## Soil Redoximorphic Features

In addition to organic matter, iron (Fe) and manganese (Mn) are the primary color-producing agents in the soil that creates redoximorphic features as a result of fluctuating oxidizing-reducing conditions (SSDS, 2017). When a soil becomes saturated with water for significant periods of time, dissolved oxygen gets used up rather quickly and anaerobic conditions develop. In anaerobic conditions, ferric iron ($Fe^{3+}$), which has low solubility, in oxide minerals begins to be reduced to the ferrous state ($Fe^{2+}$), which has much greater solubility. When Fe is reduced to the soluble ferrous state in saturated conditions, Fe becomes mobilized (Rabenhorst and Parikh, 2000).

Manganese (Mn) oxides give rise to dark brown or black pigments in the soil. Oxidized Mn, often precipitated with Fe, can be visible in soils as concentrations, such as coatings, nodules, or concretions (Rabenhorst and Parikh, 2000), and is an indicator of moisture fluctuations in the soil.

Redoximorphic features consist of color patterns in a soil that are caused by the loss (depletion) or gain (concentration) of color or pigment in the soil compared to the soil matrix color. Redoximorphic features result in distinct patterns of color in the soil and are used to infer soil drainage and hydrologic conditions (Veneman et al., 1998). A zone of depletion is interpreted as uncoated mineral grains, which exhibits a gray or white color, with a color chroma $\leq 2$. The areas of concentration will appear redder or browner than the matrix soil color and can be observed as masses, coatings, or pore linings (Vepraskas, 1992).

Different soil samples can be compared under reducing conditions using the color change propensity index (CCPI; Rabenhorst and Parikh, 2000). The CCPI is used to differentiate between soils that do or do not have resistance to developing redoximorphic color changes

(Rabenhorst and Parikh, 2000). The more resistant a soil is to color change, the lower the CCPI value will be (Rabenhorst and Parikh, 2000).

**Depth to Bedrock**

Depth to bedrock is a crucial soil feature due to the impact on internal water dynamics and direction (SSDS, 2017). Bedrock refers to continuous and coherent rock. If close to the base of the solum, bedrock affects the presence and the preferential flow direction of groundwater (SSDS, 2017). Due to the generally non-porous nature, water will not percolate through bedrock as water will through soil with aggregation and structure. A septic system placed in soil without adequate distance to bedrock can risk groundwater contamination or system failure.

**Shrink-Swell Properties of Soil**

The shrink-swell capacity of a soil, or the change in volume relative to moisture condition, determines whether a soil is considered expansive or not and is inferred in order to decide the suitability of a soil for an OSWWS. To determine if the soil has expansive properties, DRs fill the pre-dug holes with water to a depth of 30 cm and maintain this level overnight (ASBH, 2019). The time period gives the soil time to swell and represent the conditions the soil will be in during wet seasons (ASBH, 2019).

The shrinkage limit is reached when the soil is in a hard, rigid, and dry state (Grossman and Reinsch, 2002). The plastic limit is reached when the water content transforms the soil into a malleable, plastic mass (Grossman and Reinsch, 2002). When soil moisture is abundant enough to cause the soil to transform into a viscous liquid, the soil has passed the liquid limit (Grossman and Reinsch, 2002). Collectively, the shrinkage, plastic, and liquid limits are referred to as

Atterberg limits (Grossman and Reinsch, 2002). The difference between the plastic and liquid limit is referred to as the plasticity index (Grossman and Reinsch, 2002). The plasticity index is the range in which a soil exhibits plastic properties. Expansive clay soils that have a plasticity index of 25 or greater are not suitable for certain uses, such as for roadbeds or foundations (Grossman and Reinsch, 2002).

The coefficient of linear extensibility (COLE) is a comparison of the one-dimensional change in length of a soil sample between two moisture conditions. The COLE measurement is often used to determine the shrink-swell capacity of a soil (Grossman et al., 1968). One method to determine COLE is the $COLE_{rod}$ method. Using the $COLE_{rod}$ method, soil is mixed with water into a paste and extruded as rods (Schafer and Singer, 1976). The $COLE_{rod}$ value is determined by the length of the oven-dry rod of soil subtracted from the length of the moist soil rod length. The resulting length difference is then divided by the length of the moist rod and expressed as a percentage (Schafer and Singer, 1976).

**Standard System Specifications in Arkansas**

There are a variety of OSWWSs that can be used to renovate household wastewater. Examples of systems include drip dispersal systems, in which drip laterals are inserted in the top 15 to 30cm (6 to 12 in) of the soil and effluent is discharged in timed doses (USEPA, 2019). Chamber systems are another option for Arkansans. A chamber system utilizes a gravel-less drain field. Chamber systems can utilize fabric wrapped pipes, recycled materials, or synthetic materials such as polystyrene media (USEPA, 2019).

In Arkansas, the standard system for OSWWS is the pipe-and-gravel system. Effluent from the septic tank travels by pipe, via gravity flow or pressure from a pump, to a distribution box that divides the effluent among the series of perforated pipes in the drain field. Each pipe is often no more than 30.5-m (100 ft) long and are set into trenches. The standard trench is 45.7-cm (18 in) deep and roughly 70-cm (24 in) wide (Figure 1). Drain field pipes have a diameter of 10 cm (4 in) with 15 cm (6 in) of gravel separating the bottom of the perforated pipe and the bottom of the trench (Figure 1).

**Problematic Red Parent Materials**

In order to properly understand the hydrology of a soil, both historically, currently, and in the future, a determination must made whether the soil conducts water fast enough that reducing conditions do not exist, or if the soil resists color changes that would indicate impeded water movement. Despite large clay concentrations, certain red-colored soil parent materials do not develop redoximorphic features associated with prolong soil saturation (Mokma and Sprecher, 1994). An example of non-reducing, red soils are the clayey, alluvial deposits developed from the red beds in Louisiana (Rabenhorst and Parikh, 2000). In Arkansas, non-reducing, alluvial, clayey deposits are located in the southwest portion of the state along the Red River and are also located in the Arkansas River alluvium in east-central Arkansas (Figure 2; Mack et al., 2018). The Arkansas River originates in the Sawatch Range of the Rocky Mountains near Leadville, CO (Bradly, 1968), while the Red River originates in Randall County, Texas (LSUS, 2019). The geographic areas where the Arkansas and Red Rivers originate have geologic materials containing iron minerals that are mostly resistant to reduction in typical ambient soil/environmental conditions.

The Natural Resources Conservation Service (NRCS) uses red parent material as an indicator for hydric soils in areas known to have red soils resistant to color change, specifically a

CCPI value < 30 (Rabenhorst and Parikh, 2000). Some red soils, or soils derived from red parent materials, will develop hydromorphic features when exposed to anaerobic conditions (Rabenhorst and Parikh, 2000). Consequently, the red, non-reducing sediments have been recently referred to as problematic red parent materials (Rabenhorst and Parikh, 2000).

Determining if a soil may have problematic red parent material and testing the soil's ability to reduce ensures an OSSWS is suitable for a location with red soil. The Arkansas Rules and Regulations (ASBH, 2019) allows for an exception for OSSWS to be placed in certain red soils with large clay contents, but only if the soils specifically reside in the Ozark Highlands major land resource area (ASBH, 2019). However, the Ozark Highlands may not be the only region in Arkansas that contains soils that meet the red-soil exception criteria but no research has been conducted to characterize properties or the potential geographic distribution of problematic red parent materials in Arkansas.

**Red Clay Soils with Moderate Hydraulic Conductivity**

Red clay soils (i.e., sandy clay, clay, or silty clay textures) exist in the Ozark Highlands that have moderate hydraulic conductivity and low shrink-swell capacity. The red clay soils are formed over limestone or chert and exhibit a hue of 5YR or redder (ASBH, 2019). On-site wastewater systems may be installed in these soils, but only if the site is in the Ozark Highlands (ASBH, 2019). The exception to allow OSWWSs to be placed on these red clay soils does not include alluvial soils deposited by the Arkansas or Red Rivers or soils formed over other parent materials in other parts of Arkansas (ASBH, 2019). Some of the red clay soils with moderate hydraulic conductivity do not have the problematic red parent materials and will reduce if exposed to anaerobic conditions for extended periods of time (ASBH, 2019), but do not have a large shrink-swell capacity, therefore may still be suitable for OSWWS use.

**Ozark Highlands**

The Ozark Highlands [major land resource area (MLRA) 116A; Brye et al., 2013] is in the northern part of Arkansas along the Arkansas-Missouri state line. The extent of MLRA 116A is approximately 1.9 million hectares (4.7 million acres; Brye et al., 2013) (Figure 3). The elevation ranges from 152 to 437 m (500 to 1400 ft) above sea level (Brye et al., 2013). Slopes in the Ozark Highlands range from nearly level to very steep (Brye et al., 2013). The soil temperature regime for the Ozark Highlands is mesic (mean annual temperature of 8 to 15 □), with a udic soil moisture regime (not dry for more than 90 cumulative days) being most common (Brye et al., 2013), but some areas of aquic soil moisture regime exist at local low elevations. Limestone and dolomite are the most common soil parent materials present in the Ozark Highlands. Due to the presence of underlying soluble carbonate rocks, karst features, such as springs, caves, and sinkholes, are present in some places.

**Justification**

There is a lack of prior research on the soils that meet the red-soil exception in the "Rules and Regulations for Onsite Wastewater Systems" (ASBH, 2019). Recent observations from the on-site wastewater professional community have identified residual soils outside of the Ozark Highlands that show little evidence of restricting water and have a moist soil color of 5YR or redder. Determining if there are soils that meet the red-soil exception outside of the Ozark Highlands will allow for the more effective placement of on-site wastewater systems. By making clear distinctions between the problematic, non-reducing red soils present in the Arkansas and Red River alluvium, and the reducing soils developed from residuum in the exception, DRs will be able to make scientifically informed decisions on the placement of on-site wastewater systems on red soils in Arkansas.

**Objectives**

The objectives of this study were to: i) confirm the reducibility and non-expansiveness of select soils in the Ozark Highlands that meet the criteria for the red-soil exception for determining soil suitability for on-site wastewater system placement and ii) compare the reducibility and expansiveness of the residual red soils of the Ozark Highlands to those in other MLRA groupings in Arkansas.

**Hypotheses**

It is hypothesized that soils that meet the current criteria for the red-soil exception in the Arkansas Rules and Regulations Pertaining to On-site Wastewater Systems (ASBH, 2019) both quantitatively reduce (i.e., change color upon chemically induced reducing conditions) and have relatively low COLErod values (i.e., non-expansive). It is hypothesized that there are soils that meet the current criteria for the red-soil exception outside of the Ozark Highlands that should be considered for inclusion in the red-soil exception. It is also hypothesized that, based on expected soil mineralogical composition differences, the residual red soils of the Ozark Highlands will show reducible and non-expansive characteristics, while the alluvial red soils of the Arkansas River Alluvium and Red River Alluvium will show non-reducible and expansive characteristics.

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Table 1. The texture of the soil determines the rate at which water moves through the soil profile. Using the soil texture, the hydraulic conductivity (HC) class and the hydraulic conductivity rate (µm $s^{-1}$) can be estimated (SSDS, 2017).

| **Soil Texture Group** | **General Textural Class** | **General Textural Description** | **HC Class** | **HC Rate (µm $s^{-1}$)** |
|---|---|---|---|---|
| Coarse sand | Coarse | Sandy | Very rapid | > 141.1 |
| Sand<br>Loamy sand | Coarse | Sandy | Rapid | 42.3 - 141.1 |
| Sandy loam<br>Fine sandy loam | Moderately coarse | Loamy | Moderately rapid | 14.1 - 42.3 |
| Very fine sandy Loam<br>Loam<br>Silt loam<br>Silt | Medium | Loamy | Moderate | 4.2 - 14.1 |
| Clay loam<br>Sandy clay loam<br>Silty clay loam | Moderately fine | Loamy | Moderately slow | 1.4 - 4.2 |
| Sandy clay<br>Silty clay<br>Clay | Fine<br>Very fine | Clayey | Slow | 0.4 - 1.4 |

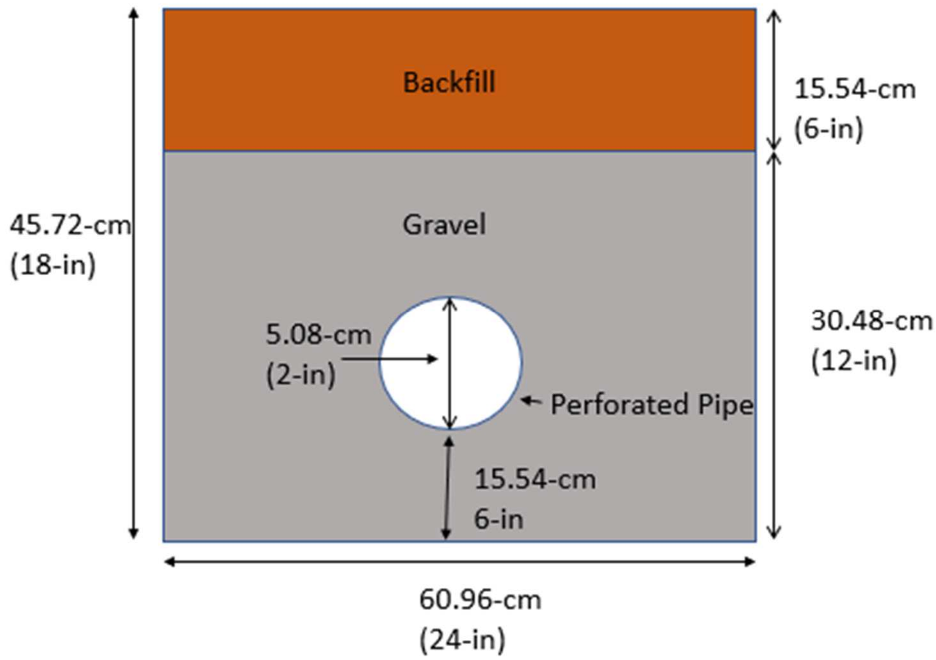


Figure 1. Cross-sectional view of a standard drainfield trench with a perforated pipe, through which effluent is discharged, surrounded in gravel (ASBH, 2019).

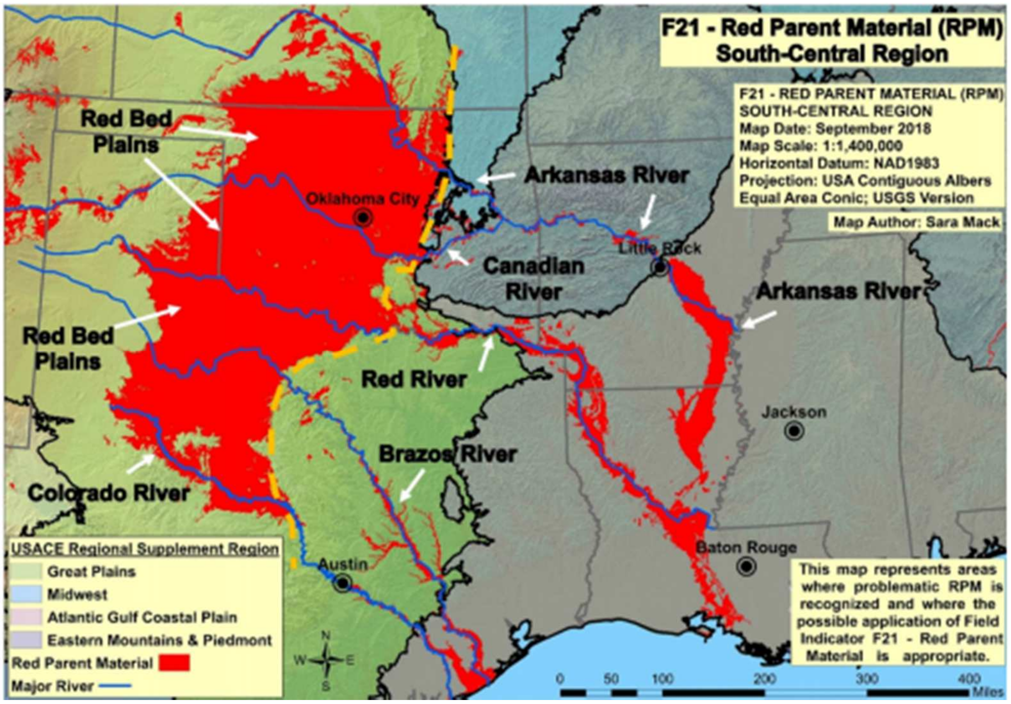


Figure 2. Red soils that do not reduce and fall under the Natural Resources Conservation Services' hydric soil indicator F21 that are known to be present in Arkansas River and Red River alluvium in Arkansas (Mack et al., 2018).

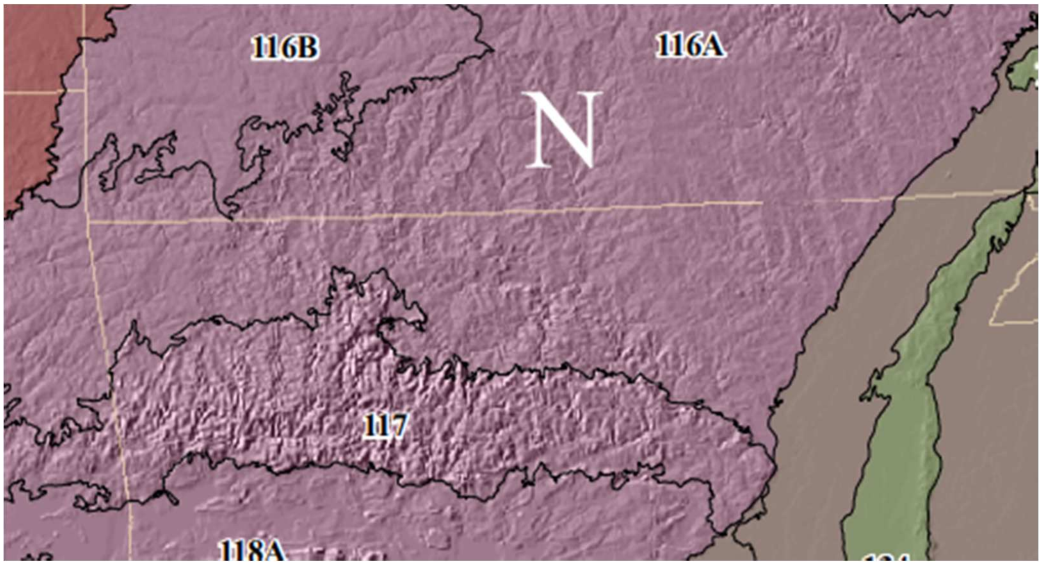


Figure 3. The Ozark Highlands (Major Land Resource Area 116A) includes the northern border of Arkansas, much of southern Missouri, and extends west into Oklahoma (NRCS, 2006).

# CHAPTER 2

# CHARACTERIZING EXPANSIVENESS AND REDUCIBILITY OF ARKANSAS' RED-CLAY SOILS FOR THE PURPOSE OF ON-SITE WASTEWATER SYSTEM PLACEMENT

**Abstract**

The Arkansas Department of Health allows for the placement of on-site wastewater systems in certain red-clay soils that have the potential to reduce, but only in the Ozark Highlands [Major Land Resource Area (MLRA) 116A], which is referred to as the red-soil exception. The objectives of this study were to: i) confirm the non-expansiveness and reducibility of select soils in the Ozark Highlands that meet the criteria for the red-soil exception for determining soil suitability for on-site wastewater system placement, and ii) compare the expansiveness and reducibility of the residual, red-clay soils of the Ozark Highlands to those in other MLRA region groupings in Arkansas. Fresh soil samples were collected in conjunction with archived soil samples to create a 51-sample data set from the 38- to 50-cm soil depth interval for analyses. The alluvial soils of the Red and Arkansas Rivers region, which are known to be expansive and non-reducing, had a mean coefficient of linear extensibility (COLE) of 0.116 mm $mm^{-1}$, whereas soils from the other four MLRA regions evaluated had lower ($P < 0.01$) COLE values. Based on a 1-hr reduction test, soils from the Red and Arkansas Rivers region changed red color the least (ΔA of -8.6 in the LAB color scheme; $P < 0.01$) compared to soils from the other four MLRA regions evaluated. Results of this study indicate the red-soil exception, used by the Arkansas Department of Health for determining on-site wastewater system suitability, could be expanded to include several additional MLRAs in Arkansas.

## Introduction

Over 20% of households in the United States rely on individual on-site or community-cluster systems to treat wastewater (USEPA, 2002). Homes built in rural areas, without access to city sewer systems, rely on on-site wastewater treatment systems (OSWWTS). Arkansas is a mostly rural state, with 41% of Arkansans living in rural counties, compared to 14% of the United States population living in rural counties (Miller and Wheeler, 2021). The standard OSWWTS used is one that includes a septic tank and absorption field (CDCP, 2006). The suitability of OSWWTSs in Arkansas is governed by the Arkansas State Board of Health. To properly understand the hydrology of a soil, both historically, currently, and in the future, a determination must made whether the soil conducts water fast enough that reducing conditions do not exist or develop or whether the soil resists color changes that would indicate impeded water movement.

Determining if a soil may have problematic red parent material and testing the soil's ability to reduce ensures an OSWWTS is suitable for a location with clayey, red soil. It is important to distinguish between soils that are non-expansive, but can reduce from those derived in problematic red parent materials that resist color change. Despite large clay concentrations, certain red-colored soil parent materials do not develop redoximorphic features associated with prolong soil saturation (Mokma and Sprecher, 1994), thus making it difficult to use soil morphological features as reliable indicators of soil wetness.

The Arkansas Rules and Regulations Pertaining to Onsite Wastewater Systems allows for an exception for OSSWS to be placed in certain red soils with large clay contents, but only if the soils specifically reside in the Ozark Highlands major land resource area (MLRA; ASBH, 2019). The exception is referred to as the red-soil exception (ASBH, 2019). The Arkansas State Board of Health requires the following criteria for the red-soil exception to be used: i) ≥ 35% clay, ii) 5YR or redder hue, iii) no redoximorphic features, iv) from approximately the 38- (15 in) to 50-cm (20 in) depth range, and v) the soil resides in the Ozark Highlands (MLRA 116A). However, the Ozark Highlands may not be the only MLRA in Arkansas that contains soils that may meet the criteria for the red-soil exception.

The Natural Resources Conservation Service (NRCS) uses red parent material as an indicator for hydric soils in areas known to have red soils that are resistant to color change (NRCS, 2018), specifically a color change propensity index (CCPI) value < 30 (Rabenhorst and Parikh, 2000). Some red soils, or soils derived from red parent materials, will develop hydromorphic features when exposed to anaerobic conditions (Rabenhorst and Parikh, 2000). Determining the reducibility of a soil can determine whether or not a soil will develop redoximorphic features. The Ozark Highlands (MLRA 116A) generally does not have soils with non-reducing red parent materials, but non-reducing soils developed in red parent material are present in other areas of Arkansas.

In addition to the ability of a soil to reduce to show morphological features that can be used as indicators of soil wetness, low shrink-swell capacity (i.e., low expansiveness) is also needed for OSWWS suitability. Soils with low shrink-swell capacity have little risk of expanding upon wetting, which renders a soil with restricted vertical water flow. If vertical water flow is restricted, then effluent dosed to absorption field trenches from a septic tank has the potential to surface, causing a major health hazard.

Recent observations from the on-site wastewater professional community in Arkansas have identified residual soils outside of the Ozark Highlands that show little evidence of restricting water, have a moist soil color of 5YR or redder, and are only minimally expansive.

Determining if there are soils that meet the red-soil exception outside of the Ozark Highlands will allow for the more effective use of certain soils and expanded placement options for on-site wastewater systems throughout Arkansas. Therefore, the objectives of this study were to: i) confirm the reducibility and non-expansiveness of select soils in the Ozark Highlands that meet the criteria for the red-soil exception for determining soil suitability for on-site wastewater system placement and ii) compare the reducibility and expansiveness of the residual red soils of the Ozark Highlands to those in other MLRA groupings in Arkansas. It was hypothesized that soils that meet the current criteria for the red-soil exception (ASBH, 2019) both quantitatively reduce (i.e., change color upon chemically induced reducing conditions) and have relatively low coefficient of linear extensibility values (i.e., are non-expansive). It was also hypothesized that there are soils that meet the current criteria for the red-soil exception outside of the Ozark Highlands that should be considered for inclusion in the red-soil exception. In addition, it was hypothesized that, based on expected soil mineralogical composition differences, the residual red soils of the Ozark Highlands will show reducible and non-expansive characteristics, while the alluvial red soils of the Arkansas River Alluvium and Red River Alluvium will show non-reducible and expansive characteristics.

## Materials and Methods

### Archived Sample Collection

Archived soil samples, saved over years of activity associated with the Arkansas Soil Characterization Laboratory, were searched for their properties that correspond to the combination of properties required for the red-soil exception for use for an OSWWTS. The Arkansas State Board of Health requires the following criteria for the red-soil exception: i) ≥

35% clay, ii) 5YR or redder hue, iii) no redoximorphic features, and iv) from approximately the 38- (15 in) to 50-cm (20 in) depth range, which contains the typical 46-cm (18 inch) depth of a standard pipe-and-gravel OSWWTS trench depth (ASBH, 2019). Archived soil samples from the specified Ozark Highlands region (ASBH, 2019), which is a region known to contain soils developed in non-reducible, non-expansive, red parent materials, as well as soils from numerous other MLRAs in Arkansas that met the above criteria were targeted for potential inclusion in this study. Archived samples had previously been oven-dried, ground, and sieved to < 2 mm prior to storage. Due to settlement in the containers during storage, archived samples were well mixed, by inverting the storage containers multiple times, prior to removing soil for use in any procedures.

To date, 41 archived samples have been retrieved, representing 24 different Arkansas counties and seven different MLRAs, that meet the red-soil-exception criteria for soil properties (i.e., clay content, color, redoximorphic features, and soil depth). Samples include those both in and not in the geographic requirement (i.e., Ozark Highlands only). Table 1 summarizes the retrieved soil samples and their numerous, relevant properties.

New Soil Samples

To supplement archived soil samples, assistance was solicited from active professionals in the field of on-site wastewater systems throughout Arkansas (i.e., professional soil classifiers, DRs, and Environmental Health Specialists with the Department of Health). Specific assistance requested was for obtaining and saving an approximate 10 L of soil from sites where active on-site wastewater work was being conducted that meet the red-soil-exception criteria for soil properties (i.e., clay content, color, redoximorphic features, and soil depth), but not the geographic requirement (i.e., Ozark Highlands only). Only one new sample was provided from the requested outside assistance, which was from the Ozark Highlands (MLRA 116A), thus it was necessary to collect several additional, fresh samples. Between 20 September 2019 and 17 August 2020, 12 new soil samples were collected from within Arkansas, including six samples from the Red River (MLRA 131C) and Arkansas River (MLRA 131B) areas and seven from the Ouachita Mountains (MLRA 119) area.

In total, 13 new samples were obtained, representing five different Arkansas counties and four different MLRAs (Table 2), to supplement the archived soil sample set. Sub-samples of any new samples were oven-dried at 70°C for at least 48 hours and ground and sieved to pass a 2-mm mesh screen for subsequent physical property determinations (i.e., reducibility, COLE, and particle-size analyses).

Soil Reducibility

To determine if archived and new soil samples were non-reducible (i.e., resistant to color change in reducing conditions), a recently developed, rapid, 1-hr reducibility test was performed following procedures described by Rabenhorst et al. (2020). Two, 45-mL plastic test tubes (2.49-cm diameter and 13.97-cm height) with screw caps were prepared for each soil sample. Tests was performed on a minimum of two replications of each soil sample when possible due to low soil mass. Tests were performed in triplicate. One test tube was used to record the soil color without reduction ($T_0$), while the second test tube was used to record the soil color after 1 hour of exposure to reducing conditions ($T_1$).

Approximately 5 to 8 g (i.e., 1 teaspoon) of oven-dried, ground, and sieved soil was added to both test tubes. Approximately 5 to 7 g (i.e., 1 teaspoon) of sodium chloride (NaCl) was then added to both test tubes. To one test tube, approximately 5 g (i.e., 1 teaspoon) of sodium dithionite ($Na_2O_4S_2$) powder was added as the reducing agent. Deionized water (25 mL) was then be added to both test tubes. The screw caps were secured, and the test tubes were manually, vigorously shaken for approximately 15 seconds in an up-down motion until well mixed. The test tubes will be subsequently shaken every 10 minutes for 1 hour. After 1 hour, the moist soil color of both mixtures was determined visually under florescent lighting and through the plastic test tube using a Munsell color book to the nearest color chip. A conversion table, sourced from Vodyanitskii and Kirillova (2016), was used to convert the Munsell color to the LAB color format. The individual L, A, and B values was used for statistical analyses.

The reduction in Munsell soil color was also evaluated using the Color Change Propensity Index (CCPI; Rabenhorst and Parikh, 2000) using the formula modifications for the 1-hour reduction test (Rabenhorst et al., 2020):

$$\text{1 Hour Chroma Index (CI)} = \Delta \text{Chroma}_{(0h-1h)} \quad [1]$$

$$\text{1 Hour Hue Index (HI)} = \Delta \text{Hue}_{(1h-0h)} \quad [2]$$

$$\text{1 Hour Color Index} = 9\,(\text{HI}) + 18\,(\text{CI}) \quad [3]$$

The average CCPI of the three replications for each sample was used for statistical analyses.

## Shrink-swell Potential

To assess the shrink-swell potential of archived and new soils meeting the red-soil-exception criteria for soil properties, the $COLE_{rod}$ method was performed following procedures described in Schafer and Singer (1976) and Vaught et al. (2006). Samples for $COLE_{rod}$ were oven-dried, ground, and sieved to < 2 mm. Approximately 100 g of soil was added to small, plastic sample cups with 50 mL of deionized water and mixed to wet thoroughly. The soil paste was left to equilibrate for 24 hours, covered in the plastic cups. After the 24-hour equilibration period, any excess free-water at the surface was poured off the top and the soil slurry was stirred for approximately 10 seconds.

A 25-$cm^3$, plastic syringe was modified so the orifice has a diameter of 1 cm. The modified orifice was created using a drill press, the edges were smoothed to make the opening symmetrical, and plastic spurs and irregularities were removed using tweezers. The soil slurry was loaded into the modified syringe using a metal spatula. The first 100 mm of soil manually extruded from the syringe was discarded due to the compaction created within the syringe (Vaught et al., 2006).

The soil slurry will then be extruded in 60-mm-long rods onto a Teflon-coated baking sheet. Using one prepared soil slurry, eight replicate rods was extruded for each sample. A caliper was used to measure the rod length to 60 mm, excess material was removed using a damp, plastic spatula, and the resulting moist rod length were remeasured and recorded to the nearest 0.1 mm. Extruded rods were oven-dried for 2.5 hours at 105□ in a forced-draft oven. After oven-drying, rod lengths were measured again using the caliper and recorded. Any abnormal rods, such as excessively cracked or curled rods, were discarded. The $COLE_{rod}$ value were calculated using Equation 1:

$$COLE_{rod} = (l_m - l_d) / l_d \qquad [4]$$

where $l_m$ is the moist-rod length (mm) and $l_d$ is the dry-rod length (mm) (Schafer and Singer, 1976).

Particle-size Analyses

Particle-size analyses was conducted on any new soil samples collected or obtained to determine the distribution of sand, silt, and clay, and the resulting soil textural class. Particle-size analyses was conducted on oven-dried, ground, sieved soil using a modified 12-hr hydrometer method (Gee and Or, 2002).

Cation Exchange Capacity Evaluation

Archived soil samples had laboratory data associated with them, including exchangeable cation concentrations (i.e., Ca, Mg, K, and Na), where ammonium acetate was the extracting solution. Exchangeable acidity was measured by the barium chloride ($BaCl_2$)-triethanol amine procedure at pH 8.2. The ammonium-acetate-estimated CEC for these samples was the sum of basic cations plus exchangeable acidity measured at pH 8.2. However, the present, convenient soil-test method, which would be available and used by active professional in the on-site wastewater industry (i.e., DRs and Health Department Environmental Specialists), is based on a Mehlich-3 soil extraction (Mehlich, 1984; Tucker, 1992). Consequently, both new/fresh soil samples collected and all archived soil samples had Mehlich-3 extractable nutrient concentrations determined. Using the archived soil samples with both Mehlich-3- and ammonium-acetate-extractable base cations (i.e., Ca, Mg, K, and Na), the sum of the base cations was calculated for both the ammonium-acetate- and Mehlich-3-extractable base cations to compare their relationship. Cation exchange capacity for the archived soils was based on based on the sum of extractable bases plus extractable acidity (pH 8.2). The CEC for the new/fresh soil samples was the sum of the Mehlich-3-extractable bases and an estimate of exchangeable acidity based on the measured Mehlich-3 Ca concentration and soil pH (Cheri

Villines, personal communication, 28 October, 2020). The soil-test estimated CEC is an estimate of CEC at the soil's natural pH (< 7.5 [<7.3 for new samples] for all samples). Thus, the ammonium-acetate CEC would be expected to be greater than the soil-test estimated CEC because of additional charge from variable-charge components at the larger measurement pH. In addition, the CEC estimates ignored the contribution of SOM to exchange sites based on the similarity of sub-soil depths from which all soils samples were derived (i.e., 38 to 50 cm) and the generally low SOM concentration at depth (Oades et al., 1989). Estimated CECs were also used for statistical analyses.

## Statistical Analyses

For the purposes of statistical analysis, the soil sample dataset assembled from archived and new samples was divided into five regions based on similar soil parent materials, geographic location, and MLRA (Table 4). Based on a completely random design, an analysis of variance (ANOVA) was performed using the PROC GLIMMIX procedure of SAS (version 9.4, SAS Institute, Inc., Cary, NC) to evaluate the effect of region on the change in the L, A, and B values associated with soil color from the reducibility test, $COLE_{rod}$, CCPI, and the estimated CEC based on Mehlich-3-extractable soil cations. Studentized residuals were examined to confirm data normality. Linear regression analyses were performed to examine the relationships between Mehlich-3- and ammonium-acetate-derived sum of base cations, Mehlich-3- and ammonium-acetate-derived CEC, and $COLE_{rod}$ and CEC:clay ratio using Minitab (version 13.31, Minitab, Inc., State College, PA). When appropriate, means were separated by least significant difference at the $P < 0.05$ level.

**Results and Discussion**

Overview of Assembled Dataset

The complete dataset used for this study was comprised of 51 total soil samples assembled from both archived (Table 1) and new/freshly collected soil samples (Table 2). There were 37 archived and 13 new soil samples that made up the complete dataset (Table 3). The archived samples represented seven different MLRAs and 24 counties in Arkansas (Table 1). The new samples were collected from five counties representing four different MLRAs (Table 2). Percent clay ranged from 28.5 to 87.4% for archived soils (Table 1) and from 36.7 to 64.4% for new soils (Table 2) and represented clay loam, silty clay loam, sandy clay, silty clay, and clay textural classes. The majority of soils in the complete dataset were sampled from an argillic (Bt) horizon (Table 1).

To evaluate the geographic specificity of the red-soil exception, currently limited to only soils from the Ozark Highlands (MLRA 116A), all soils in the complete dataset were categorized into five regions based on geographic proximity to one another and soil similarities. The regions were comprised of the following MLRA groupings: Region 1: Ozark Highlands (MLRA 116A), Region 2: Boston Mountains (MLRA 117) and Arkansas Valley and Ridges (MLRA 118A), Region 3: Red River Alluvium (MLRA 131C) and Arkansas River Alluvium (131B), Region 4: Western Coastal Plain (MLRA 133B) and Cretaceous Western Coastal Plains (MLRA 135B), and Region 5: Ouachita Mountains (MLRA 119) (Table 3). Table 3 summarizes the number of archived and new soil samples in the complete dataset among the five region categories. Soils from Region 1 had clay ranging from 29.8 to 87.4% (Tables 1 and 3). Soils from Region 2 had clay ranging from 28.5 to 54.0% (Tables 1 and 3). Soils from Region 3 had clay ranging from

36.7 to 64.4% (Tables 1 and 3). Soils from Region 4 had clay ranging from 30.1 to 70.4% (Tables 1 and 3). Soils from Region 5 had clay ranging from 40.8 to 58% (Tables 1 and 3).

Despite the criteria of ≥ 35% clay, seven of the 51 total soils, all from the archived samples, had clay percentages less than 35% (Table 1), thus technically did not meet the criteria for the red-soil exception (ASBH, 2019). However, when DRs and other professionals investigate sites for potential on-site wastewater systems in the field, soil from the appropriate depth is hand-textured to estimate percent clay. Results of hand-texturing do not always correspond exactly to laboratory-determined clay fractions from standard methods, such as the hydrometer or pipette methods, and are frequently over- and under-estimated in the field until they are adjusted with formal laboratory data. Furthermore, three soil textural class, sandy clay loam, clay loam, and silty clay loam, have lower clay ranges that extend below 35%, thus accurately determining a soil's textural class in the field based on hand-texturing can be somewhat variable, particularly when the actual clay percentage is near a textural class boundary. For these reasons, the several soils with < 35 % clay, but that met all other red-soil-exception requirements, were retained in the complete dataset and included for all subsequent analyses.

Soils in Region 1 (MLRA 116A) are those that meet the geographic requirement for the red-soil exception, while soils in Regions 2, 4, and 5 do not currently meet the geographic requirement for the red-soil exception. However, based on interactions and communications with on-site wastewater professionals working in these areas because the frequency of on-site wastewater systems are expanding due to rural population growth, some soils in Regions 2, 4, and 5 possess some of the characteristic requirements for the red-soil exception (i.e., > 35% clay at in the 38 to 50 cm depth and 5YR or redder moist colors), but may or may not have mineralogical compositions that would show distinct redoximorphic features (i.e., may or may not show evidence of reducibility) and may or may not have shrink-swell potential. Consequently, soils in Regions 2, 4, and 5 warrant further investigation as to whether they could potentially contain soils that could qualify for a red-soil exception to allow on-site wastewater system expansion into areas not currently suitable for an on-site wastewater system. Further investigation includes, but is not limited to, examining structure or performing a percolation test.

In contrast to soils in Regions 1, which are known to have non-expansive and reducible red-clay soils for which the red-soil exception pertains, soils in Regions 2, 4, and 5 have not been sufficiently evaluated to date, and soils in Region 3 are alluvial and are known to have mineralogical compositions that show shrink-swell capacity (i.e., expansiveness) and resist reduction using the relatively rapid reduction-test methods (i.e., do not display redoximorphic features like depletions that are used for on-site wastewater system evaluation in Arkansas). Therefore, soils of Region 3 in this study represented somewhat of a known control group.

**Region Effects on Soil Properties**

Based on the complete, 51-sample dataset, quantification of expansiveness (i.e., $COLE_{rod}$) and reducibility (i.e., specifically ΔA from the LAB color scheme and 1-hr reducibility test) varied among samples in the dataset. Measured $COLE_{rod}$ ranged from 0.00 to 0.26 mm $mm^{-1}$ across all replications, while ΔA ranged from -27.1 to -4.1. Measured CCPI ranged from 18 to 155 across all replications.

Expansiveness

Formal statistical evaluation demonstrated $COLE_{rod}$ differed ($P < 0.01$) among regions (Table 4). Despite the resulting small magnitudes, all mean measured $COLE_{rod}$ values among regions were greater ($P < 0.05$) than zero (Table 4). Measured $COLE_{rod}$ differed ($P < 0.01$) among regions (Table 4). As expected, measured $COLE_{rod}$ from Region 3 was at least 1.2 times greater than that for all four other regions (Table 4), meaning that the alluvial soils compromising Region 3 were most expansive or had the most shrink-swell capacity. Soils in Regions 1 and 4 had similar measured $COLE_{rod}$, which were greater than in Region 2 (Table 4). Soils in Region 2 had the numerically lowest measured $COLE_{rod}$ among all regions, but did not differ from that in Region 5, while mean $COLE_{rod}$ in Region 5 also did not differ from that in Region 4 (Table 4).

Results showed that soils of Region 1 (i.e., the Ozark Highlands, MLRA 116A) have more than minimal expansiveness, with a mean $COLE_{rod}$ of 0.095, which would just barely fall in the "very high" shrink-swell class (Soil Science Division Staff, 2017; Table 5). However, soils in Regions 2, 4, and 5 had similar or lower $COLE_{rod}$ values than from Region 1. In addition, soils from Regions 1, 2, 4, and 5 had lower $COLE_{rod}$ values that from Region 3, which have soils that had previously been known to have high shrink-swell capacity and was confirmed by measurements made in this study (Table 5). Thus, soils from Region 3 were confirmed to have the greatest expansiveness and that soil the other four regions demonstrated less expansiveness.

Relative to the current limitation of the red-soil exception to the Ozark Highlands MLRA, soils of Regions 2, 4, and 5 were similar or less expansive than those included in the Ozark Highlands. Consequently, based on shrink-swell capacity, Regions 2, 4, and 5 could be included in the red-soil exception. However, Region 3 (MLRAs 121C and 131B) should not be included in the red-soil exception due to the expansive nature of the alluvial soils from the region.

Reducibility

Similar to $COLE_{rod}$, measured soil color changes (i.e., ΔL, ΔA, and ΔB) also differed ($P < 0.01$) among regions (Table 4). All mean measured soil color changes from the 1-hour reducibility test were statistically greater ($P < 0.05$) than zero (Table 4). The A value in the LAB color scheme relates to the degree of soil redness, thus results for ΔA are most pertinent for assessing soil reducibility. As expected, the mean measured ΔA for Region 3 was larger (i.e., less negative) than that for all four other regions, meaning that the alluvial soils comprising Region 3 reduced the least or were the most resistant to reduction (Table 4). Soils in Regions 1 and 2 had similar mean measured ΔA, while that for Region 2 was also similar to Regions 4 and 5, which did not differ. Soils in Region 5 had the numerically smallest ΔA (Table 4).

Though not directly related to the degree of redness or reducibility and similar to ΔA, mean measured ΔL differed ($P < 0.01$) among regions (Table 4), where a large ΔL meant the soil decreased or increased in degree of lightness. Region 3 had the numerically largest ΔL, which did not differ from that for Region 4 (Table 4). Region 1 and 4 had similar ΔL, both of which were greater than that for Region 2, while ΔL for Region 5 was smallest among all five regions (Table 4).

Similar to ΔA and ΔL, mean measured ΔB differed ($P < 0.01$) among regions (Table 4), where a large ΔB meant the soil appeared more yellow (positive change) or appeared more blue (negative change). Region 3 had the smallest decrease in B, which did not differ from Region 1 (Table 4). Regions 1 and 4 had similar ΔB (Table 4). Region 5 had the numerically largest decrease in B, which did not differ from that in Regions 2 and 4 (Table 4).

The ΔA results showed that the red soils from Region 1 (i.e., the Ozark Highlands) actually reduced, while soils in Regions 2, 4, and 5 reduced at least similarly to those in Region 1. Results demonstrate that soils from Regions 1, 2, 4, and 5 have mineralogical compositions that could reduce and would show evidence of redoximorphic depletions under reducing conditions in the field. Consequently, DRs and other on-site wastewater professionals could use soil color as a reliable, in-situ soil morphological feature in the field to make an accurate assessment of a site for on-site wastewater system suitability. In contrast, soils in Region 3, the known non-reducing soils, showed the least reducibility, thus DRs and other on-site wastewater professionals clearly cannot use soil color as a reliable, in-situ morphological feature in the field to make an accurate assessment of a site for on-site wastewater system suitability.

The CCPI combines the change in chroma and hue color components from the 1-hour reduction test. Similar to COLE and the LAB color changes, CCPI differed ($P < 0.01$) among regions (Table 4). All mean measured CCPI values were greater ($P < 0.05$) than zero. Soils in Region 4 had the numerically largest CCPI, which similar to that in Region 1, and was at least 1.4 times greater than that in the other three regions (Table 4). The CCPI in Regions 2, 3, and 5 were lower than that in Regions 1 and 4 and did not differ (Table 4). Region 3 had the numerically smallest CCPI (Table 4).

Soils derived from problematic red parent materials resist color changes produced by redox reactions in saturated conditions due to the inherent characteristics of their hematite-rich parent material (Rabenhorst et al., 2020). The large size of hematite crystals in problematic red parent material is the most likely cause of the phenomenon of resisting color change (Rabenhorst et al., 2020). The smaller the CCPI, the less likely a soil will show redoximorphic features indicating hydric or saturated conditions. A CCPI of less than 30 indicates a soil has likely developed from problematic red parent materials (Rabenhorst et al., 2020). However, the CCPI threshold reported by Rabenhorst et al. (2020) was developed for soils from the Atlantic coast and the northeastern US, which have different parent materials (i.e., glacial till) and climatic, hence weathering, conditions than those present in the more weathered mid-southern, southwestern, and southern US. The measured CCPI data from the current study support the interpretation that soils from Region 3 are more likely to be formed in problematic red parent materials than the soils from the other four regions based on the numerically smallest CCPI value associated with soils from Region 3. Thus, results support the conclusion that the red-soil exception should not be extended to include the alluvial soils of the Red River Valley (MLRA 131C) or the Arkansas River Alluvium (MLRA 131B), but could potentially be extended to include soils from MLRAs other than just the Ozark Highlands if more site-specific information was obtained.

**Inferences from CEC and Clay**

Cation exchange capacity is often used as a surrogate for making interpretations about a soil's expansiveness. Soils with large smectitic, or 2:1 expanding clay, concentrations are more expansive than those with kaolinitic, 1:1 clays (Dixon, 1989). Smectite clays (i.e., montmorillonite and vermiculite) are considered high-activity clays, whereas kaolinites and hydroxy-interlayered vermiculites are low-activity clays and micas and chlorites are intermediate activity clays (National Soil Survey Laboratory Staff, 1983). Two-to-one clays also generally have more exchange sites associated with individual clay particles than kaolinitic, 1:1 clays (Dixon, 1989), where the increase in exchange sites also increases the soil's CEC. Consequently, a common inference made is that a clay soil with a large CEC is more likely to be richer in smectitic clays and therefore more expansive than a clay soil with a lower CEC.

The archived soil samples used in the study had an estimated CEC associated with them, where the base cation concentrations (i.e., Ca, Mg, K, and Na) were determined by extraction with ammonium acetate. However, an ammonium acetate (pH 7.0) extraction is not a routine procedure at many soil testing labs, particularly in Arkansas. Instead, a Mehlich-3 extraction (Mehlich, 1984; Tucker, 1992) is routine in many state-operated, soil-testing laboratories in the southern US due to the Mehlich-3-extractable nutrient concentrations being well correlated with plant-available nutrient concentrations (Mehlich, 1984). If a DR needed CEC data as supplemental information associated with an on-site wastewater investigation, the DR would be able to obtain a Mehlich-3-estimated CEC much more readily than an ammonium-acetate-estimated CEC. Consequently, it was necessary to evaluate the sum of base cation concentrations from extraction by Mehlich-3 and ammonium acetate.

Figure 1 demonstrates a large correlation between Mehlich-3- and ammonium-acetate-measured sum of base cation concentrations ($R^2 = 0.94$, $P < 0.01$), where the slope of the resulting linear relationship was nearly 1 (0.89). Thus, it was reasonably concluded that the sum of the base cation concentrations from the more-easily-obtainable Mehlich-3 extraction was a reasonable approximation of that from an ammonium-acetate extraction.

In Arkansas, CEC is estimated from the Mehlich-3-extractable sum of base cations and an estimation of exchangeable acidity from the Mehlich-3-extractable calcium (Ca) concentration and soil pH (Cheri Villines, personal communication, 11 November 2020). The contribution from soil organic matter is also added in based on an assumed concentration of 0.75% (Cheri Villines, personal communication, 11 November 2020). However, the organic matter contribution to the estimated CEC is based on agricultural top soils rich in organic matter, while the SOM contribution to the estimated CEC is not calibrated for sub-soils (i.e., from the

38- to 56-cm depth interval) with comparatively much lower SOM concentrations. Figure 2 depicts the relationship between estimated CEC using the Mehlich-3 and the ammonium-acetate sum of base cation concentrations available for the archived samples. The two CEC estimation methods were linearly related ($R^2 = 0.40$, $P < 0.01$; Figure 2). The relationship, however, indicates that the ammonium-acetate CEC is about twice the CEC estimated by the soil-test laboratory (slope of line = 0.48). The CEC difference is likely due to too differences in the two procedures. First, the ammonium-acetate CEC is the CEC buffered to pH 8.2. The CEC buffered at 8.2 would be larger than the CEC for soils at their native pH due to contributions from variable-charge components. Second, the ammonium-acetate CEC includes the contribution of organic matter to the CEC. Since organic matter was not measured for the new samples, organic matter's contribution to the overall CEC was not included in the CEC estimates. Because the samples were from subsoils, however, the organic matter contribution to the overall CEC would likely be low. Despite the rather weak correlation and lower CEC estimate from the soil-test procedure (Figure 2), results support that the more-easily-obtainable estimated CEC from a Mehlich-3 extraction was a reasonable approximation of an ammonium-acetate-derived CEC and would be useful for evaluation of clay activity.

Similar to COLE, soil color changes, and CCPI, the Mehlich-3-estimated CEC, without accounting for SOM, differed ($P < 0.01$) among regions. Estimated CEC means were all greater ($P < 0.05$) than zero (Table 4). Mehlich-3-estimated CEC for Region 3 was at least 1.8 times greater than that for all four other regions. Regions 1, 4, and 5 had similar estimated CECs, while Regions 2, 4, and 5 also had similar estimated CECs (Table 4). Region 2 had the numerically smallest estimated CEC (Table 4). The largest estimated CEC associated with Region 3 supported earlier interpretations that soils from Region 3 were likely more expansive than those from any of the other four regions.

In addition to CEC alone, the CEC:clay ratio offers useful information about clay mineralogy and is to separate soils among activity classes as part of the family level of soil taxonomic classifications (Soil Survey Staff, 2011; Soil Survey Staff, 2014). A CEC at pH 7 (CEC-7):clay ratio of 0.5 to 0.7 indicates a smectitic or mixed clay minerology, and > 0.7 indicates a soil with smectitic minerology (Soil Survey Staff, 2011). A CEC-7:clay ratio of 0.3 to 0.5 indicates mixed clay minerology, 0.2 to 0.3 indicates kaolinitic or mixed clay mineralogy, and < 0.2 indicates kaolinitic clay minerology (Soil Survey Staff, 2011). According to the Keys of Soil Taxonomy (Soil Survey Staff, 2014), the CEC:cay ratio, where the CEC accounts for base cations, exchangeable acidity, and the contribution from SOM, is used to divide mixed or siliceous mineralogy soils into several activity classes. Soils with a CEC:cay ratio > 0.60 are superactive, soils with a ratio of 0.40 to 0.60 are active, soils with a ratio of 0.24 to 0.40 are semiactive, and soils with a ratio < 0.24 are subactive (Soil Survey Staff, 2014). However, in both cases, the CEC is derived from an ammonium acetate extraction buffered at a pH of 7, which is less obtainable from a typical state soil testing laboratory than a Mehlich-3-estimated CEC. Consequently, the Mehlich-3-estimated CEC (CEC-M):clay ratio was calculated for all soil samples in the dataset. The resulting CEC-M:clay ratio was linearly related to $COLE_{rod}$ ($R^2$ = 0.24, $P$ = 0.01; Figure 3), suggesting that the CEC-M:clay ratio can be used by DRs to make interpretations regarding soil expansibility. Furthermore, the CEC-M:clay ratio differed ($P$ < 0.01) among regions and was 1.8 times larger for Region 3 than for all four other regions, which did not differ (Figure 4). Based on results of this study, it appears that a red soil with a CEC-M:clay ratio < 0.30 could be consider suitable for an on-site wastewater system (Figure 4), as soils with a CEC-M:clay ratio < 0.30 were similar to those of the Ozark Highlands that are known to have non-expansive clays. In contrast, a red soil with a CEC-M:clay ratio > 0.30 should be considered unsuitable for an on-site wastewater system (Figure 4), as soils with a CEC-M:clay ratio > 0.30 behaved similar to the alluvial soils of Region 3, which are known to be comprised of expansive clays.

**Implications**

The results of this study indicate that are soils that meet the red-soil exception (≥ 35% clay, 5YR or redder hue, no redoximorphic features, and from approximately the 38- to 50-cm depth range) outside of the Ozark Highlands (MLRA 116A). Consequently, the red-soil exception could be extended to the following MLRAs in Arkansas: Ouachita Mountains (MLRA 119), Boston Mountains (MLRA 117), Western Coastal Plains (MLRA 133B), Arkansas Valley and Ridges (MLRA 118A), and Cretaceous Western Coastal Plains (MLRA 135B), provided that additional information, such as a CEC-M:clay ratio < 0.30, supports the decision. If the geographic boundary is extended to include additional MLRAs, DRs must be able to distinguish between soils that would qualify for the red-soil exception and soils derived from problematic red parent materials, such as the alluvial soils of the Arkansas and Red Rivers.

When a DR encounters a soil that may qualify for the red-soil exception, a sample should be sent to a soil testing laboratory for chemical analyses, including Mehlich-3 extractable soil nutrients and clay content. The DR should then estimate the CEC without accounting for SOM by summing the base cation concentrations (i.e., Ca, Mg, K, and Na) and added the estimated exchangeable acidity based on the Mehlich-3 Ca concentration and soil pH. The DR should divide the estimated CEC-M by the clay percentage. The resulting CEC-M:clay ratio should be compared to the CEC:clay ratio threshold of 0.3, which will tell the if the soil is likely to be too expansive (i.e., CEC-M:clay ratio > 0.3) or if the soil is suitable for placement of an on-site wastewater system (i.e., CEC-M:clay ratio < 0.3). If the soil of the proposed on-site wastewater system location is red and exhibits redox concentrations or depletions, even with a CEC-M:clay ratio below the threshold value, the recommendation is to not use the soil for an on-site wastewater system.

**Conclusions**

The goal of this study was to provide scientific evidence in support of the red-soil exception outlined in the Arkansas Rules and Regulations Pertaining to On-site Wastewater Systems (ASBH, 2019). One objective of this study was to confirm the reducibility and non-expansiveness of select soils in the Ozark Highlands that meet the criteria for the red-soil exception for determining soil suitability for on-site wastewater system placement. Based on $COLE_{rod}$ measurements, the clayey soils from the Ozark Highlands were not the least expansive, but were significantly less expansive than the alluvial soils of the Arkansas and Red Rivers, which are known to be expansive due to their specific clay mineralogies from which they are developing. Furthermore, based on a 1-hr reducibility test, results showed that soils from the Ozark Highlands exhibited a large propensity for color change. The combined expansiveness and reducibility results indicate that the red, clayey Ozark Highlands soils are only minimally prone to swelling when wetted, posing little risk of limiting water and/or household wastewater/effluent to potentially cause a septic system failure, and will reduce and show wetness-related redoximorphic features (i.e., depletions and/or a depleted matrix) when subjected to reducing conditions, which are characteristics of soils that are not developing in problematic red parent materials. Consequently, the hypothesis that soils that meet the current criteria for the red-soil exception in the Arkansas both exhibit minimal shrink-swell potential and quantitatively reduce (i.e., change color upon chemically induced reducing conditions) was supported by the results of this study.

The second objective of this study was to compare the expansiveness and reducibility of residual and colluvial, red, clay soils of the Ozark Highlands (Region 1) to those in other MLRA groupings in Arkansas. The red, clay soils from Regions 2, 4, and 5 shared similar expansiveness and reducibility characteristics to that of the Ozark Highlands, suggesting that there are soils from outside the Ozark Highlands (Region 1) that are not developing in problematic red parent materials, exhibit minimal shrink-swell potential, and would develop redoximorphic features in reducing conditions. Consequently, the hypothesis that there are soils that meet the current criteria for the red-soil exception outside of the Ozark Highlands that should be considered for inclusion in the red-soil exception was supported by the results of this study. The results of this research project suggest that red, clay soils from the Ouachita Mountains (MLRA 119), Boston Mountains (MLRA 117), Western Coastal Plains (MLRA 133B), Arkansas Valley and Ridges (MLRA 118A), and Cretaceous Western Coastal Plains (MLRA 135B) could be included in the red-soil exception provided additional information is generated to show the soil at a specific location does not have combination of estimated CEC and measured percent clay that would lead to soil swelling to limit water and/or effluent transmission below a septic system absorption field trench.

Based on $COLE_{rod}$ and reducibility tests, the alluvial, red, clay soils of the Arkansas and Red River valleys (Region 3) had the numerically lowest CCPI, meaning, of the sample set, soils from Region 3 were least likely to exhibit a change in color under reducing conditions. Soils of

Region 3 also had the numerically largest $COLE_{rod}$, meaning Region 3 soils were the most expansive within the evaluated data set and classified, by NRCS standards, as having very high shrink-swell capacity. Consequently, the hypothesis that, based on expected soil mineralogical composition differences, the residual and colluvial, red, clay soils of the Ozark Highlands will show non-expansive, but reducible characteristics, while the alluvial, clay red soils of the Arkansas and Red River valleys will show expansive and non-reducible characteristics was also confirmed by the results of this study.

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Table 1. Summary of soil samples, and relevant properties, obtained from the University of Arkansas (UA) Soils Archive based on the following characteristics i) ≥ 35% clay, ii) 5YR or redder hue, iii) no redoximorphic features, and iv) from approximately the 38- (15 in) to 50-cm (20 in) depth range.

| UA ID | Pedon | Arkansas County | MLRA† | Series | Horizon | Color | Depth (cm) | Clay (%) | Texture Class | pH | Base Sat† (%) | Na (%) | CEC† ($cmol_c$/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5413 | 68BO02 | Boone | 116A | Corydon | Bt3 | 2.5YR 4/6 | 38-56 | 85.4 | C†† | 5 | 41 | 4 | 40 |
| 5496 | 69FL01 | Fulton | 116A | Talbott | Bt2 | 2.5YR 4/6 | 43-58 | 57.1 | C | 4.8 | 26 | 1 | 20 |
| 5526 | 69JA07 | Jackson | 117 | Enders | Bt2 | 2.5YR 5/8 | 28-51 | 54.0 | C | 4.7 | 7 | 1 | 32 |
| 6331 | 70HP07 | Hempstead | 133B | Kirvin | Bt2 | 2.5 YR 4/8 | 25-51 | 56.5 | C | 5.2 | 13 | 1 | 20 |
| 6338 | 70HP08 | Hempstead | 133B | Sacul | Bt2 | 2.5YR 4/6 | 36-56 | 54.2 | C | 4.9 | 21 | 1 | 27 |
| 6358 | 69PY01 | Perry | 118A | Georgeville | Bt2 | 2.5YR 5/6 | 28-71 | 41.2 | SIC | 5 | 9 | 1 | 17 |
| 6391 | 70JH06 | Johnson | 117 | Enders | Bt2 | 5YR 4/6 | 36-71 | 43.2 | C | 5 | 5 | 1 | 20 |
| 6419 | 70JH11 | Johnson | 117 | Enders | Bt2 | 2.5YR 4/6 | 43-66 | 38.2 | CL | 4.9 | 7 | 1 | 28 |
| 6445 | 70DR03 | Drew | 133B | Sacul | Bt1 | 5YR 4/6 | 30-53 | 49.8 | C | 4.8 | 15 | 1 | 28 |
| 6534 | 70LW03 | Lawrence | 116A | Dewey | Bt1 | 2.5YR 4/6 | 30-61 | 78.8 | C | 4.7 | 32 | 1 | 24 |
| 6792 | 71JF01 | Jefferson | 133B | Sacul | Bt2 | 2.5YR 5/5 | 46-64 | 58.4 | C | 4.6 | 9 | 1 | 39 |
| 6955 | 71FL01 | Fulton | 116A | Dewey | Bt2 | 2.5YR 4/6 | 30-74 | 86.5 | C | 5.1 | 40 | 0 | 22 |
| 7012 | 71HP16 | Hempstead | 131C | Latanier | Bw1 | 5YR 3/2 | 18-48 | 56 | C | 7.9 | 92 | 0 | 36 |
| 7033 | 72BX01 | Baxter | 116A | Gassville | Bt1 | 2.5YR 4/6 | 28-66 | 77 | C | 4.9 | 33 | 1 | 25 |
| 7041 | 72BX03 | Baxter | 116A | Gassville | Bt2 | 2.5YR 4/8 | 43-66 | 85.4 | C | 4.9 | 33 | 1 | 25 |
| 7046 | 72BX04 | Baxter | 116A | Corydon | Bt2 | 5YR 4/6 | 41-53 | 71.7 | C | 5.2 | 50 | 1 | 32 |
| 7050 | 72IZ01 | Izard | 116A | Talbott | Bt1 | 5YR 4/6 | 23-56 | 87.4 | C | 4.9 | 36 | 0 | 26 |
| 7903 | 74BN10 | Benton | 116A | Peridge | Bt1 | 5YR 4/6 | 30-64 | 30.9 | CL | 5 | 17 | 1 | 17 |
| 7109 | 72FL02 | Fulton | 116A | Corydon | Bt2 | 2.5YR 3/6 | 43-71 | 83.7 | C | 5 | 41 | 1 | 32 |
| 7634 | 73FK06 | Faulkner | 118A | Allen | Bt1 | 5YR 5/6 | 18-53 | 28.5 | CL | 5.1 | 27 | 1 | 14 |
| 7741 | 74HP29 | Hempstead | 135B | Oktibbeha | Bt2 | 2.5YR 4/6 | 43-66 | 70.4 | C | 4.8 | 40 | 1 | 43 |
| 7792 | 74HP36 | Hempstead | 135B | Oktibbeha | Bt2 | 2.5YR 4/6 | 41-74 | 52.0 | C | 4.8 | 29 | 1 | 42 |
| 7823 | 74RO02 | Randolph | 116A | Boden | 2Bt1 | 2.5YR 5/8 | 33-61 | 41.6 | SC | 4.9 | 26 | 1 | 18 |
| 7878 | 74RO06 | Randolph | 116A | Gepp | Bt1 | 2.5YR 4/8 | 33-71 | 70.2 | C | 5.1 | 28 | 1 | 22 |

Table 1. Cont.

| UA ID | Pedon | Arkansas County | MLRA† | Series | Horizon | Color | Depth (cm) | Clay (%) | Texture Class | pH | Base Sat† (%) | Na (%) | CEC† ($cmol_c$/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8485 | 76OT01 | Ouachita | 133B | Sacul | Bt1 | 2.5YR 4/6 | 23-56 | 54.6 | C | 5.5 | 53 | 0 | - |
| 8621 | 77BN01 | Benton | 116A | Britwater | Bt1 | 5YR 4/6 | 41-66 | 30.7 | SICL | 4.7 | 35 | 1 | - |
| 8628 | 77BN02 | Benton | 116A | Noark | Bw | 5YR 4/6 | 30-48 | 39.8 | SICL | 4.6 | 38 | 0 | - |
| 8651 | 77BN05 | Benton | 116A | Peridge | Bt2 | 2.5YR 3/6 | 41-76 | 34.5 | SICL | 5.1 | 40 | 1 | 15 |
| 8842 | 78FL01 | Fulton | 116A | Gepp | Bt1 | 2.5YR 4/6 | 36-66 | 71.6 | C | 4.8 | 26 | 0 | 31 |
| 8876 | 78BX02 | Baxter | 116A | Arkana | Bt2 | 5YR 5/6 | 38-53 | 67.5 | C | 4.8 | 45 | 0 | - |
| 8982 | 79ST01 | Stone | 116A | Estate | Bt1 | 2.5YR 4/6 | 25-71 | 55 | C | 6.4 | 55 | 0 | 34 |
| 9453 | 5WS01 | Washington | 116A | Razort | Bt2 | 5YR 3/4 | 46-76 | 29.8 | CL | 5.2 | 44 | 0 | 14 |
| 9874 | 90SV01 | Sevier | 135B | Beatrice | Bt1 | 5YR 4/8 | 25-69 | 70.1 | C | 5 | 17 | 0 | 35 |
| 9880 | 90SV02 | Sevier | 135B | Beatrice | Bt1 | 5YR 5/6 | 30-51 | 58.9 | C | 4.9 | 32 | 0 | 30 |
| 10373 | 98PK01 | Pike | 135B | Pikeville | Bt1 | 2.5YR 4/6 | 8 to 56 | 30.1 | CL | 4.4 | 12 | 2 | 12 |
| 10447 | 98PU06 | Pulaski | 118A | Carnasaw | 2Bt1 | 5YR 5/6 | 30-58 | 29.6 | CL | 4.5 | 20 | 1 | 13 |
| 8206 | 74ML04 | Miller | 131C | Moreland | Bss | 5YR 3/2 | 38-66 | 61.3 | C | 7.1 | - | - | - |
| 7619 | 73FK03 | Franklin | 131B | Moreland | A2 | 5YR 2/2 | 38-63 | 54.3 | SIC | 6.7 | 76 | 1 | 37 |

† MLRA, Major Land Resource Area; Base Sat, base saturation; CEC, cation exchange capacity
† C, clay; CL, clay loam; SICL, silty clay loam

Table 2. Summary of new samples collected and/or obtained from outside assistance and their relevant properties.

| Sample Number | Arkansas County | MLRA† | Mapped Series | Soil Texture† | Clay (%) | Moist Color |
|---|---|---|---|---|---|---|
| ST01 | Stone | 116A | Nixa-Noark Complex | C†† | 42.9 | 2.5 YR 3/6 |
| SL01 | Saline | 119 | Carnasaw | C | 58 | 5YR 4/6 |
| SL02 | Saline | 119 | Carnasaw | C | 58 | 5YR 5/6 |
| SL03 | Saline | 119 | Carnasaw | C | 53 | 5YR 5/6 |
| SL04 | Saline | 119 | Carnasaw | C | 57.3 | 5YR 4/6 |
| MO01 | Montgomery | 119 | Octavia-Carnasaw | C | 54.6 | 5YR 4/6 |
| MO02 | Montgomery | 119 | Carnasaw-Sherless Complex | C | 49 | 5YR 5/6 |
| MO03 | Montgomery | 119 | Carnasaw-Sherless Complex | C | 40.8 | 2.5YR 4/6 |
| LF01 | Lafayette | 131C | McKamie | C | 47 | 5YR 4/6 |
| LF02 | Lafayette | 131C | Bosier | CL | 36.7 | 5YR 4/6 |
| LF03 | Lafayette | 131C | Latanier | C | 64.4 | 2.5 YR 3/4 |
| PL01 | Pulaski | 131B | Moreland | C | 61.4 | 5YR 4/3 |
| PL02 | Pulaski | 131B | Moreland | SICL | 36.7 | 5YR 4/3 |

† MLRA, Major Land Resource Area
†† C, clay; CL, clay loam; SICL silty clay loam

Table 3. Summary of the five regions Arkansas was divided into based on similar soil parent materials, geographic location, and major land resource area (MLRA) and the number of archived, new, and total soil samples included in the dataset for each region.

| | | Number of Samples | | |
|---|---|---|---|---|
| **Region #** | **MLRA† Combinations** | **Archive** | **New** | **Total** |
| 1 | Ozark Highlands (116A) | 18 | 1 | 19 |
| 2 | Boston Mountains (117)<br>Arkansas Valley and Ridges (118A) | 6 | 0 | 6 |
| 3 | Red River Alluvium (131C)<br>Arkansas River Alluvium (131B) | 2 | 5 | 7 |
| 4 | Western Coastal Plain (133B)<br>Cretaceous Western Coastal Plains (135B) | 12 | 0 | 12 |
| 5 | Ouachita Mountains (119) | 0 | 7 | 7 |

† MLRA, Major Land Resource Area

Table 4. Summary of region effects on the coefficient of linear extensibility (COLE), the change in the L (ΔL), A (ΔA), and B (ΔB) soil color values from the LAB soil color system (Vodyanitskii and Kirillova, 2016), the color change propensity index (CCPI), and cation exchange capacity as calculated from Mehlich-3 extractable cations (CEC-M).

| **Region #** | **MLRA[†] Combinations** | **COLE[††] (mm mm$^{-1}$)** | **ΔL** | **ΔA** | **ΔB** | **CCPI** | **CEC-M (cmol$_c$ kg$^{-1}$)** |
|---|---|---|---|---|---|---|---|
| 1 | Ozark Highlands (116A) | 0.095 b* | 17.5 b$^{*}$ | -16.3 b$^{*}$ | -14.2 ab$^{*}$ | 109.4 a$^{*}$ | 13.6 b$^{*}$ |
| 2 | Boston Mountains (117)<br>Arkansas Valley and Ridges (118A) | 0.061 d* | 11.4 c$^{*}$ | -16.8 bc$^{*}$ | -18.1 c$^{*}$ | 77.0 b$^{*}$ | 6.0 c$^{*}$ |
| 3 | Red River Alluvium (131C)<br>Arkansas River Alluvium (131B) | 0.116 a* | 22.3 a$^{*}$ | -8.6 a$^{*}$ | -11.3 a$^{*}$ | 51.2 b$^{*}$ | 24.5 a$^{*}$ |
| 4 | Western Coastal Plains (133B)<br>Cretaceous Western Coastal Plain (135B) | 0.089 bc* | 19.0 ab$^{*}$ | -18.1 c$^{*}$ | -16.6 bc$^{*}$ | 112.2 a$^{*}$ | 12.4 bc$^{*}$ |
| 5 | Ouachita Mountains (119) | 0.076 cd* | 4.3 d$^{*}$ | -18.3 c$^{*}$ | -19.7 c$^{*}$ | 73.7 b$^{*}$ | 9.6 bc$^{*}$ |
| | *P*-value | < 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 |

[†] Major Land Resource Area, MLRA
[††] Different letters after means in the same column are different at $P < 0.05$
[*] Asterisks (*) indicate mean value differs from 0 at $P < 0.05$

Table 5. Shrink-swell classes used by the United States Department of Agriculture, Natural Resources Conservation Service to classify expansive soils (Soil Science Division Staff, 2017).

| **Shrink-swell Class** | **COLE (mm mm$^{-1}$)†** |
|---|---|
| Low | < 0.03 |
| Moderate | 0.03 to 0.06 |
| High | 0.06 to 0.09 |
| Very high | ≥ 0.09 |

† COLE, coefficient of linear extensibility

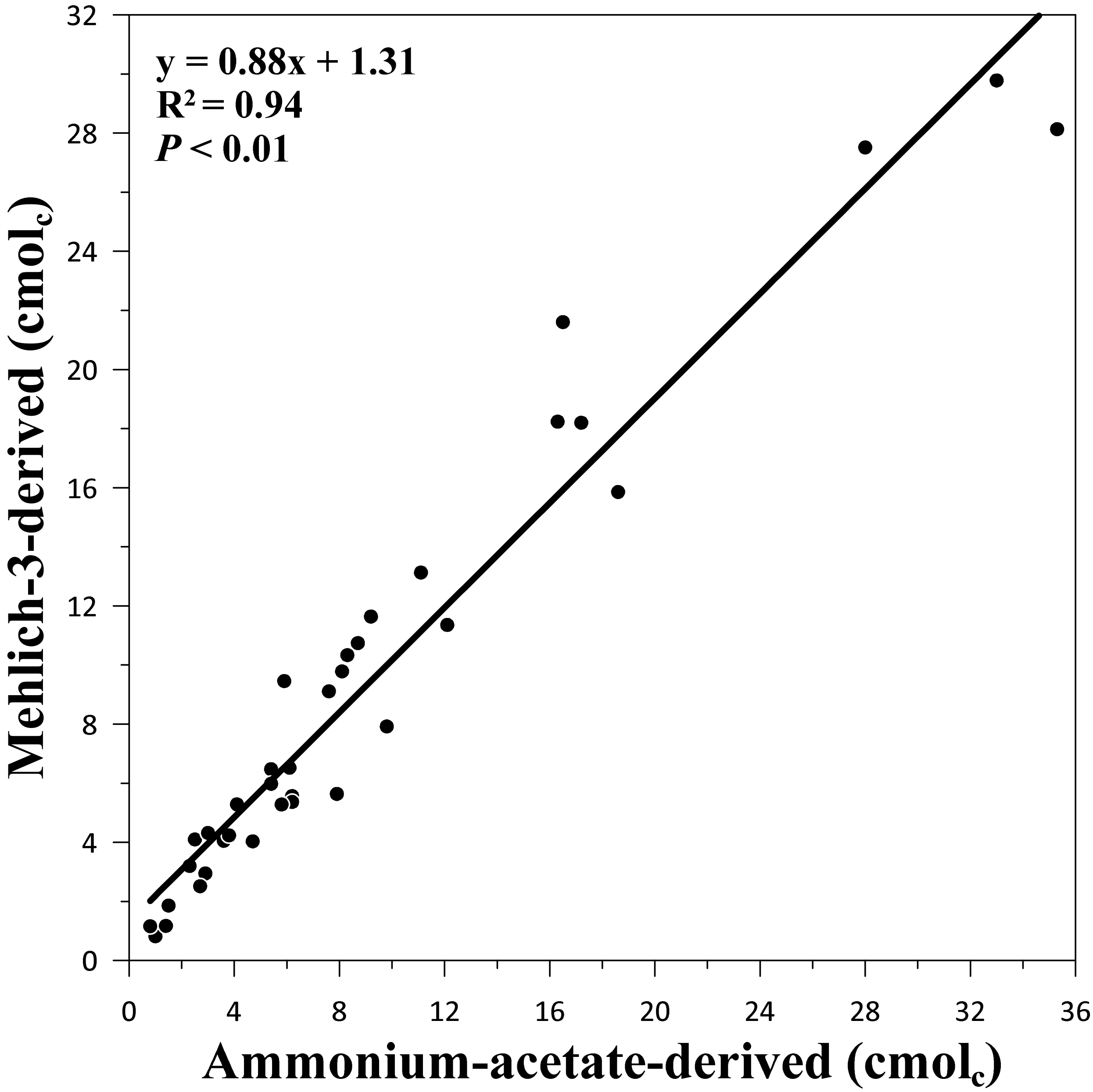


Figure 1. Relationship between the Mehlich-3- and ammonium-acetate-derived sum of base cations (i.e., Ca, Mg, K, and Na) from archived soil samples (n = 36).

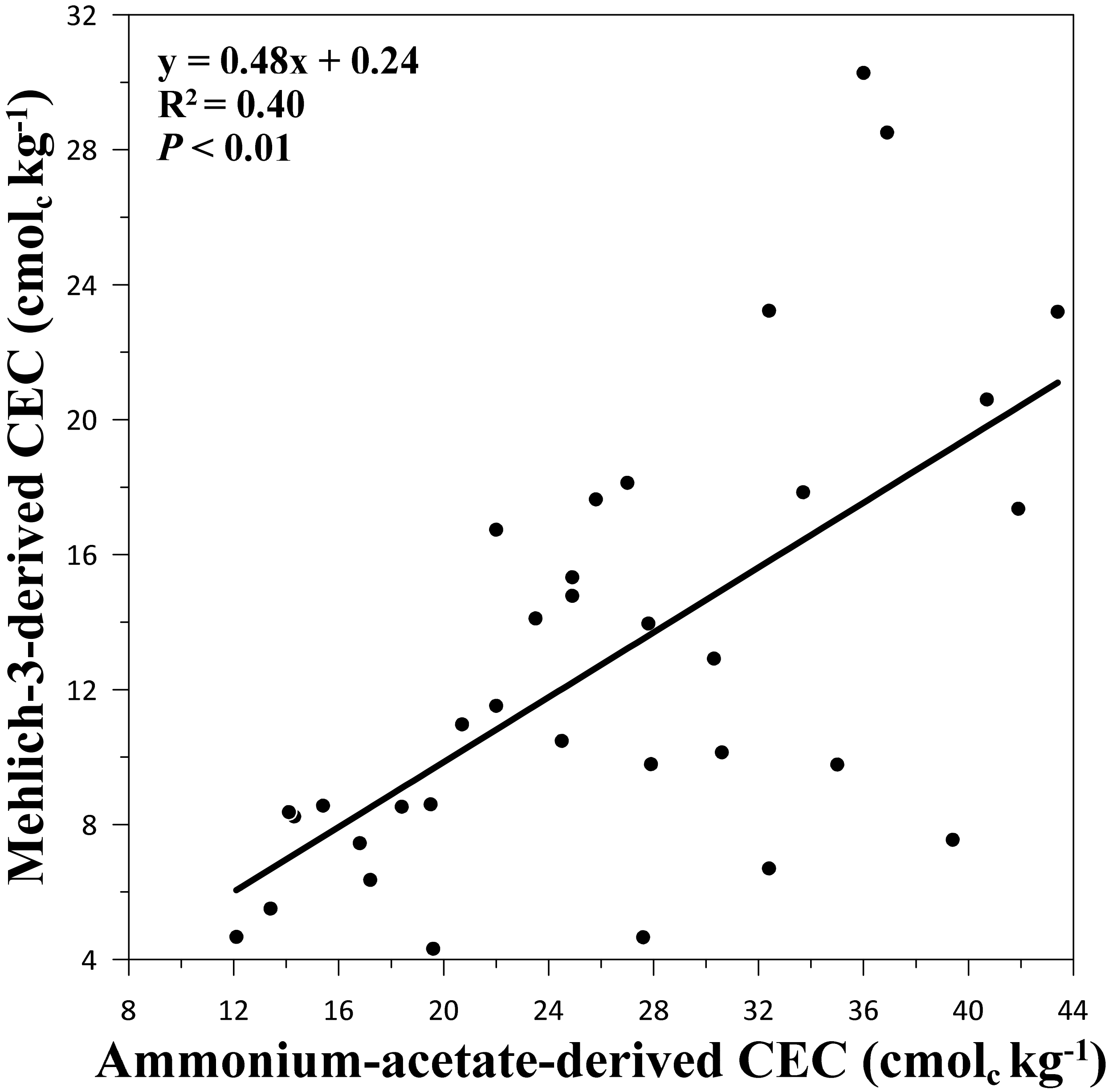


Figure 2. Relationship between the Mehlich-3- and ammonium-acetate-estimated cation exchange capacity (CEC) from archived soil samples (n = 34).

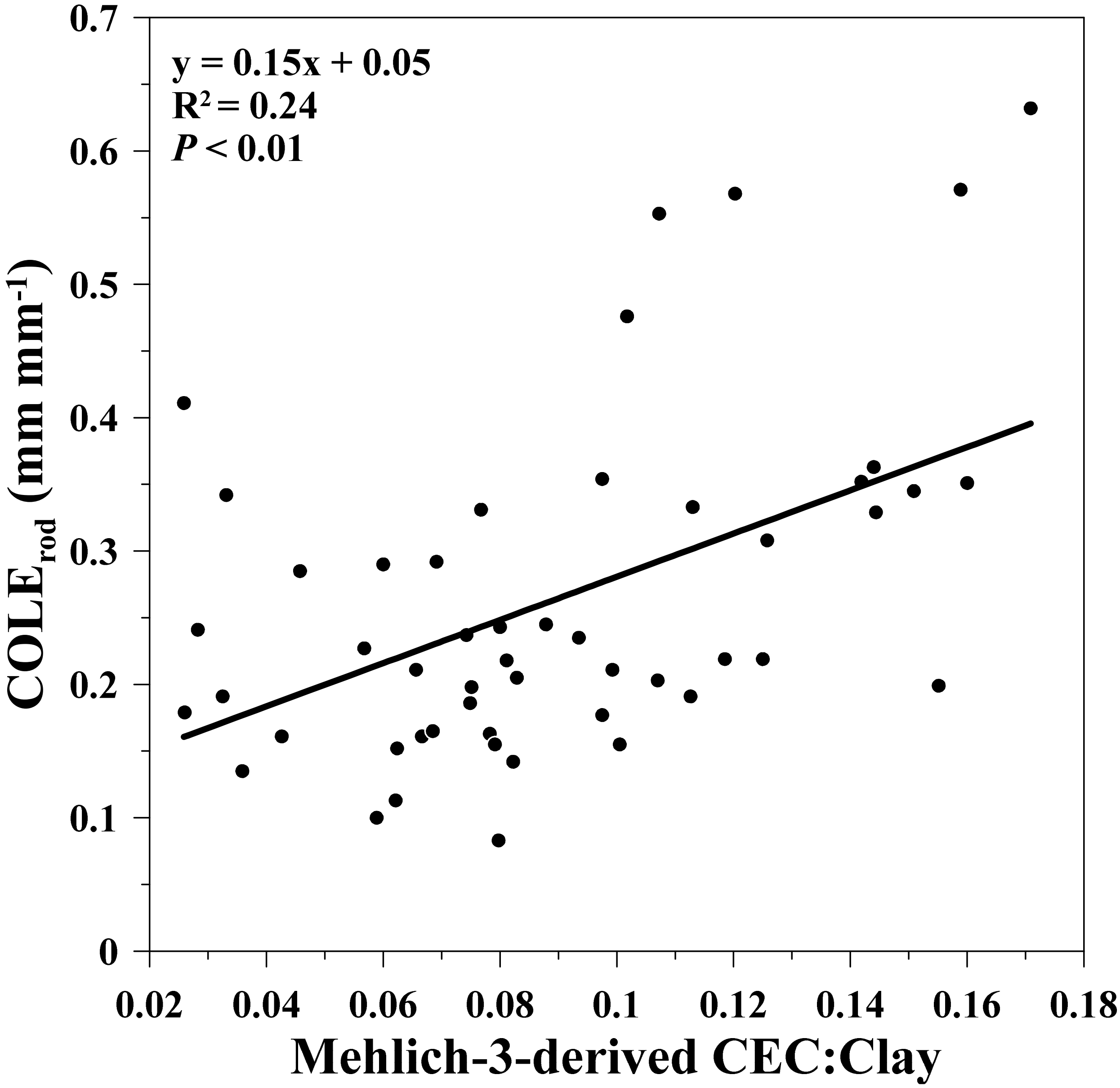


Figure 3. Relationship between the coefficient of linear extensibility rod method ($COLE_{rod}$) and the Mehlich-3-derived cation exchange capacity (CEC, $cmol_c\ kg^{-1}$) to clay (%) ratio (n = 51).

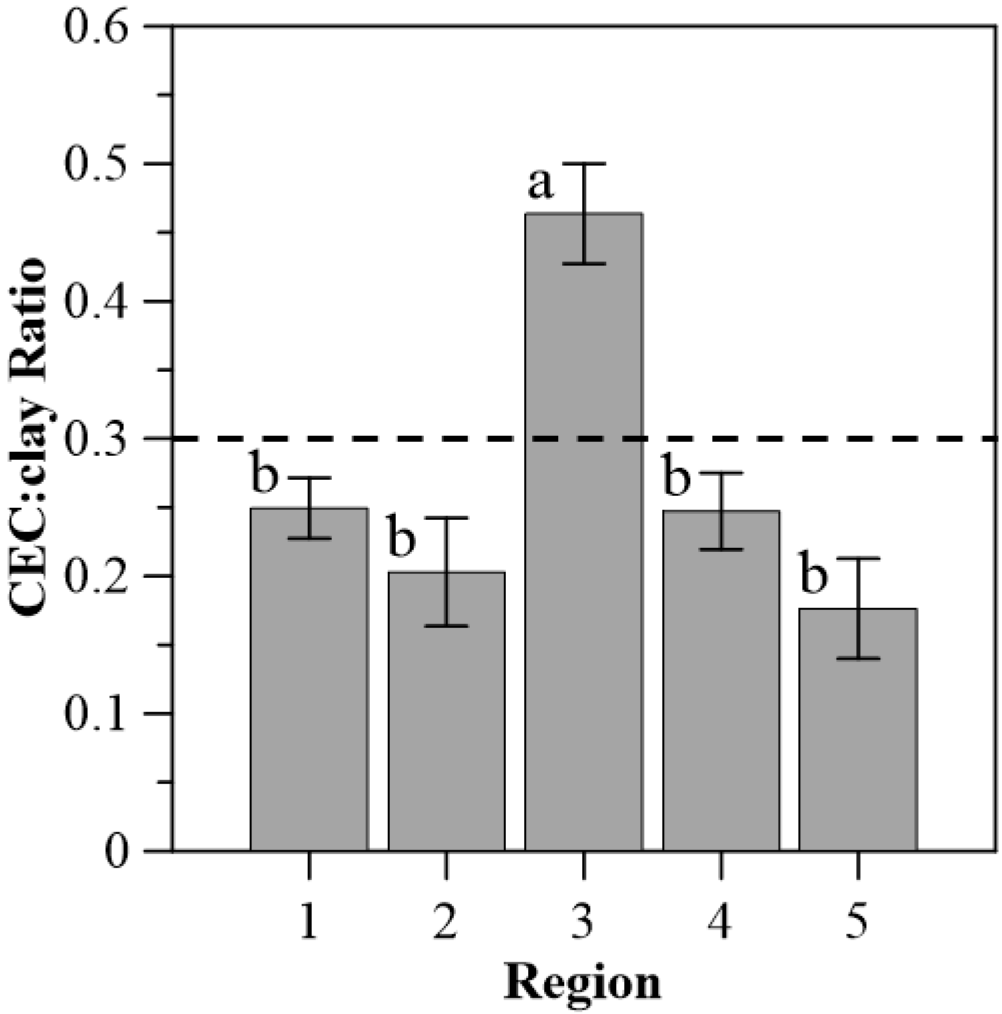


Figure 4. Region effect on Mehlich-3-estimated cation exchange capacity (CEC, $cmol_c$ $kg^{-1}$) to clay (%) ratio. Error bars represent the standard error of the means. Lower-case letters atop bars are different at $P < 0.05$. The dashed line represents the recommended threshold CEC:clay ratio value to use for deciding whether a soil may or may not be suitable for an on-site wastewater system. Table 3 summarized the combination of Major Land Resource Areas within the five regions.

## CONCLUSIONS

# CONCLUSIONS

The goal of this study was to provide scientific evidence in support of the red-soil exception outlined in the Arkansas Rules and Regulations Pertaining to On-site Wastewater Systems (ASBH, 2019). One objective of this study was to confirm the reducibility and non-expansiveness of select soils in the Ozark Highlands that meet the criteria for the red-soil exception for determining soil suitability for on-site wastewater system placement. Based on $COLE_{rod}$ measurements, the clayey soils from the Ozark Highlands were not the least expansive, but were significantly less expansive than the alluvial soils of the Arkansas and Red Rivers, which are known to be expansive due to their specific clay mineralogies from which they are developing. Furthermore, based on a 1-hr reducibility test, results showed that soils from the Ozark Highlands exhibited a large propensity for color change. The combined expansiveness and reducibility results indicate that the red, clayey Ozark Highlands soils are only minimally prone to swelling when wetted, posing little risk of limiting water and/or household wastewater/effluent to potentially cause a septic system failure, and will reduce and show wetness-related redoximorphic features (i.e., depletions and/or a depleted matrix) when subjected to reducing conditions, which are characteristics of soils that are not developing in problematic red parent materials. Consequently, the hypothesis that soils that meet the current criteria for the red-soil exception in the Arkansas both exhibit minimal shrink-swell potential and quantitatively reduce (i.e., change color upon chemically induced reducing conditions) was supported by the results of this study.

The second objective of this study was to compare the expansiveness and reducibility of residual and colluvial, red, clay soils of the Ozark Highlands (Region 1) to those in other MLRA groupings in Arkansas. The red, clay soils from Regions 2, 4, and 5 shared similar expansiveness and reducibility characteristics to that of the Ozark Highlands, suggesting that there are soils from outside the Ozark Highlands (Region 1) that are not developing in problematic red parent materials, exhibit minimal shrink-swell potential, and would develop redoximorphic features in reducing conditions. Consequently, the hypothesis that there are soils that meet the current criteria for the red-soil exception outside of the Ozark Highlands that should be considered for inclusion in the red-soil exception was supported by the results of this study. The results of this research project suggest that red, clay soils from the Ouachita Mountains (MLRA 119), Boston Mountains (MLRA 117), Western Coastal Plains (MLRA 133B), Arkansas Valley and Ridges (MLRA 118A), and Cretaceous Western Coastal Plains (MLRA 135B) could be included in the red-soil exception provided additional information is generated to show the soil at a specific location does not have combination of estimated CEC and measured percent clay that would lead to soil swelling to limit water and/or effluent transmission below a septic system absorption field trench.

Based on $COLE_{rod}$ and reducibility tests, the alluvial, red, clay soils of the Arkansas and Red River valleys (Region 3) had the numerically lowest CCPI, meaning, of the sample set, soils from Region 3 were least likely to exhibit a change in color under reducing conditions. Soils of Region 3 also had the numerically largest $COLE_{rod}$, meaning Region 3 soils were the most expansive within the evaluated data set and classified, by NRCS standards, as having very high shrink-swell capacity. Consequently, the hypothesis that, based on expected soil mineralogical composition differences, the residual and colluvial, red, clay soils of the Ozark Highlands will show non-expansive, but reducible characteristics, while the alluvial, clay red soils of the Arkansas and Red River valleys will show expansive and non-reducible characteristics was also confirmed by the results of this study.