DEVELOPMENT OF A SOIL TEST FOR DETERMINING THE IMPACT OF SOIL DISTURBANCE

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Abstract

United States Federal law requires land-managing agencies like the US Army to identify and take into account the impacts of their undertakings on archaeological resources. Development of a method that uses changes in the stratification of horizon interfaces to identify the onset of adverse impacts to archaeological deposits was investigated. This method will allow Cultural resource managers to identify types and levels of military training that risk adverse impacts to intact archaeological deposits. A study was initiated at Fort Benning, GA, and Fort Riley, KS with treatments including (1) archaeological habitation/no-training, (2) archaeological habitation/training, (3) non-habitation/no-training, and (4) non-habitation/training. Soil core samples for each treatment group were taken for 0-10, 10-20, 20-30, 30-50 cm increments for chemical analysis. Several promising elements were identified that may be useful as indicators for determining potential damage to archaeological deposits resulting from ground disturbing activities such as mechanized maneuver training. Differences between disturbed and undisturbed treatment groups were often evident at depths of 20-40 cm, indicating substantial soil inversion, displacement, or mixing. Soil C concentrations were always negatively impacted in disturbed treatment group soils, indicating that C might also be a reliable indicator of disturbance, especially when used in a ratio with another elements that accumulate in undisturbed surface soil horizons. Analyses of ratios, including the Top-to-Total (ratio of upper 10 cm to entire 50 cm profile), the Total-to-Soluble (ratio of total elemental to soluble elemental concentration), and the Leachable to Non-Leachable (ratio of leachable/mobile element to a non-leachable/immobile element) indicated promising results.

Introduction

Archaeological sites consist of artifacts and features (constructed facilities such as houses, hearths, and storage pits) that occur in soil and/or sediment matrices. Sites are the end results of multiple, diverse episodes of human behavior, and archaeologists use the patterning detected within sites as a basis for inferences about the nature and chronology of past behavior. A site's scientific and cultural value and eligibility for the National Register of Historic Places (NRHP) is closely related to its depositional integrity which is the degree to which the three-dimensional relationships between artifacts, features, soils and sediments are similar to those that existed when the site was formed. Depositional integrity is generally evaluated by means of careful hand excavation, which is time consuming, expensive, and itself destructive. Modern human activities (e.g., agriculture, infrastructure development, and military training) and natural processes can alter or destroy the spatial relationships and associations among artifacts and features, thereby reducing the site's integrity (1 and 2).

Archaeological deposits that occur at or very near the current ground surface have, in many cases, already been adversely impacted by historic or recent plowing, military training, infrastructure development and maintenance, or other actions. At many sites, however, archaeological deposits extend well below the maximum depth of such disturbances, and those deeper deposits are likely to be intact and have scientific value. Federal law (including the National Historic Preservation Act of 1966, as amended) requires land-managing agencies like the US Army to identify and take into account the impacts of their undertakings on archaeological resources that are or may be eligible for nomination to the NRHP.

The broad occurrence of archaeological sites across the landscape poses a serious obstacle to realistic military training. Agencies that oversee compliance with relevant historic preservation legislation (e.g., State Historic Preservation Offices, their tribal counterparts, and the Advisory Council on Historic Preservation) frequently assume that military training will have an adverse effect on most archaeological resources. To date, very little research has been done to refute or support such assumptions. Consequently, land managing agencies within the Department of Defense (DoD) must continue their practice of scheduling/locating training to avoid sites that may not be adversely impacted by many aspects of military training. Much of the land now managed by the Army was previously impacted by historic agriculture, timbering, or grazing. Although near-surface (A-horizon) soils have often been previously disturbed, archaeological features (pits, burials, architectural remains) that extend into the underlying B horizon may contain intact deposits with scientific or cultural value. The A-B horizon interface thus represents a threshold between disturbed and undisturbed deposits, and it is important that future military training does not impact below that threshold.

A study was undertaken to develop a reliable method for identifying the onset of new disturbance in a soil profile. The technical objectives of this research were 1) to demonstrate that naturally occurring and culturally induced stratigraphic differences in a suite of soil parameters such as SOC and chemical elements (e.g. P, Mg, Ca, Zn, Cu, Pb) at the interface of near-surface soil horizons can be disrupted to varying degrees by military training and other (e.g., agricultural) human actions and 2) to use this predictable stratification as the basis for an innovative, low-cost, widely applicable, reliable method to identify the onset and quantify the extent of adverse impacts to archaeological deposits that are associated with military training.

Materials and Methods

We selected prehistoric archaeological habitation sites at two Department of Defense (DoD) facilities that have different climates, soils, and ecosystems. These installations were Fort Benning, GA, and Fort Riley, KS, and encompass an adequate range of environmental conditions and soil types necessary to assess the suitability of selected soil compositional variables for use as indicators of horizon interface disturbance and potential damage to underlying archaeological resources. Archaeology sites were identified, surveyed, and subsequently selected following consultation with the installation Cultural Resources Manager and other relevant offices. A minimum of four habitation sites were selected at each installation to ensure a wide range of variability in topography, soil chemistry and texture, and plant community type. The habitation sites selected had been previously evaluated for NRHP eligibility status and adverse impacts from military training had been documented.

Each archeological site and adjacent non-site area was then surveyed to provide a floristic species and foliar cover inventory and evaluated for obvious mechanized maneuver training disturbances (vehicle ruts and tracks, disturbed/flattened vegetation communities, compacted staging areas, etc) and sub-divided based on level of training disturbance. This arrangement provided essentially four treatments per site: (1) archaeological site/no-training, (2) site/training, (3) non-site/no-training, and (4) non-site/training. The non-habitation site areas were contiguous or adjacent to archaeological sites, but were not archaeological sites per se.

For each selected archaeological site (and adjacent non-site area) at Fort Benning, GA, and Fort Riley, KS six soil core samples (8-cm diameter) for each treatment group to depths were collected. All cores were collected to a minimum depth of 65 cm, however, site conditions allowed some cores to be collected to deeper depths. Each core was collected using a butyrate probe liner for stability, ease of transport, and ease of sub-dividing. Cores were sub-divided into 5-cm increments, dried at 55 C, and processed to pass through a 0.15-mm mesh screen. Total N and C concentrations were determined using a LECO Truspec (3). Soil pH was measured with a Robotic pH meter (AS-3000 Dual pH Analyzer, LabFit, Burswood, Australia) using a 1:1 soil/solution ratio (0.01 M $CaCl_2$) (4). Soil lime buffer capacity and cation exchange capacity (CEC) were measured with $Ca(OH)_2$ titration (5). Soil samples were extracted using Mehlich extractants (6) and measured by an inductive coupled plasma spectrophotometer (Eviro I ICAP Spectrometer, Thermo Jarrell-Ash, Franklin, MA) for Al, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, and Zn. Soil samples were also processed to determine total digestible elements using HNO_3 Microwave Digestion procedures (EPA Method 3051) on a CEM Mars5 digester (CEM Corporation, Matthews, NC). Soil digest samples were analyzed for total P, K, Ca, Mg, S, Mn, Fe, Al, B, Cu, Zn, Na, Ni, Pb, and Cr using an inductive coupled plasma spectrophotometer (EPA Method 200.7).

A mixed model was utilized for statistical analyses with sites as random effects, treatment and depth as fixed effects, and soil cores as subsamples. The treatment by depth interaction was analyzed, and means of significant effects were compared using Tukey's LSD at an alpha of 0.05. Means for significant interactions were compared using a Bonferroni adjusted Tukey's LSD (controls experiment-wise error rate) at an alpha of 0.05. Treatment by depth interactions were used to identify divergence in distribution of soil variables with depth that could be attributed to physical disturbance (mixing, inversion, burial).

Results

Significant treatment group by depth interactions for C, pH, total phosphorus, and extractable calcium, magnesium, manganese, and nickel indicated divergence in distribution of soil variables with depth that could be attributed to physical disturbance (mixing, inversion, or burial). Soil C, pH, calcium, magnesium, manganese, nickel, and phosphorus values were different for disturbed treatment groups to depths ranging from 10 to 30 cm when compared to undisturbed treatment groups, suggesting these variables may have utility in estimating severity and depth of disturbance.

Soil C concentrations were always negatively impacted in disturbed treatment group soils, indicating that C is a reliable indicator of disturbance (Figure 1). Although soil C content is a predictable indicator of disturbance, its use as an indicator of both severity and depth of disturbance may be enhanced when used in combination or ratio with other metallic soil elements such as nickel, zinc, chromium, or lead which accumulate in undisturbed surface soil horizons.

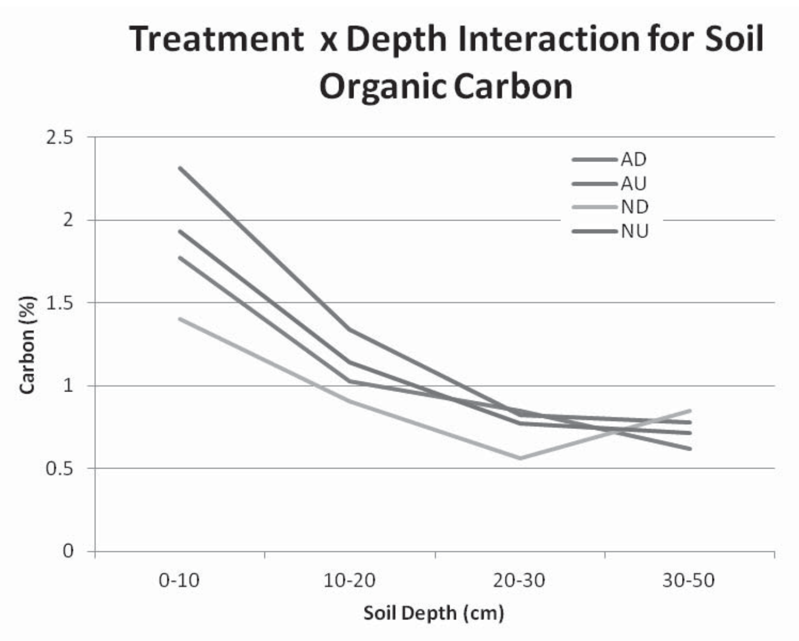

Figure 1. Percent C with depth from disturbed (D) and undisturbed (U) archaeological (A) and non-archaeological (N) treatment groups across all installations.

Soil pH, and extractable calcium, magnesium, and manganese were generally lower for disturbed treatment groups to depths of 10 to 20 cm when compared to undisturbed treatment groups. Use of soil pH as a sole indicator of disturbance would be inadvisable due to agricultural and timber production practices, such as liming and fertilization, which can quickly change pH in surface soils. The predictable decreases in soil pH with disturbance, however, suggest that use of soil pH in combination or ratio with other variables such as organic C or metallic elements may provide evidence to ascertain severity and depth of disturbance. Treatment by depth interactions for extractable calcium, magnesium, and manganese suggest that these variables exhibit similar distribution by depth patterns irrespective of treatment group and are probably not particularly useful as indicators of severity or depth of disturbance. This is not unexpected given that these elements are so common in most soils, but does not preclude their use in ratios with other variables such as pH or soil organic C where the ability to detect severity and depth of disturbance may be enhanced.

Extractable nickel concentrations were generally higher for disturbed treatment groups to depths of 10-30 cm when compared to undisturbed treatment groups, suggesting that extractable nickel concentrations may be useful for documenting disturbance and estimating depth of disturbance in soils with high natural levels of nickel. Undisturbed treatment groups exhibited increases in nickel concentration in the 0-30 cm depth increment, while disturbed treatment groups showed general declines to depths of 30 cm, suggesting that this divergent distribution pattern with depth may be a potential indicator of disturbance and depth of disturbance, warranting additional research.

Ratios

Ratios of soil element concentrations have been used to develop soil process relationships that are applicable across multiple soil types and climate conditions. One of the better known and widely used of these ratios is the one between soil C and nitrogen. Soil C concentrations can be extremely variable across soil types, however, despite these large differences, the C:N ratio can be used to determine the basic levels of decomposition, mineralization, and immobilization processes that impact soil fertility and plant growth. Most soils in equilibrium will have a C:N ratio in the range of 10-12. Ratios above this indicate a recent influx of organic C into the system and elevated soil microbial activity. Rapid changes in C:N are commonly the result of tillage or some other disturbance and have important implications for soil fertility and plant production. Because the C:N ratio tends to normalize values across soil types and climatic regimes, our research team began initially investigating other types of soil property ratios that may serve as disturbance indicators and have implications for archeological integrity.

Because of the reliable and well established vertical distributions of soil C with respect to disturbance (7), the project team initiated evaluation of a series of ratios using soil C, extractable, and/or total soil metals in an attempt to highlight potential indicators of disturbance that may be more stable across varying soil types and geographic gradients. These types of ratios were considered potentially useful disturbance indicators as they would reflect recent (days to weeks) disturbance, based on changes in metal distributions, as well as longer timeframe (weeks to months) disturbances based on changes in soil C distributions. Other ratios of interest that may improve the stability and reliability of potential disturbance indicators across multiple soil types and geographic gradients include top-to-total metal concentrations, extractable-to-total metal concentrations, and simple elemental ratios. The concepts behind these ratios and some preliminary examples are discussed in the following sections.

Top to Total Ratio

One ratio of interest is the top-to-total ratio, which is the ratio of a given soil element concentration in the top 10 cm of the profile to the concentration of that element in the entire 50 cm profile (e.g. potassium in top 10 cm of profile : potassium in total 50 cm of profile). Natural soil forming processes lead to the development of soil layers, each having distinctive concentrations of soil elements that contribute to the overall vertical distribution pattern within the entire soil profile. Soil disturbance that results in soil mixing will consequently change the distribution of these elements with soil depth. Concentrations of any given soil element would be expected to change dramatically across different soil types, however, within soil types the concentration and vertical distribution patterns would be consistent. Therefore, any change in vertical distribution

for a given soil element (especially a stable soil element) would be a clear indication that disturbance has resulted in soil mixing. The ratio of concentration in the top 10 cm to the total concentration in the soil profile is an attempt to normalize changes in absolute soil concentrations and develop a more standardized measure of soil mixing.
An example of this ratio is presented for Fort Benning, where the sandy nature of the soils makes them vulnerable to deep mixing. Significant top-to-total ratios were observed for total phosphorus (p=0.005) and total sulfur (p=0.001) averaged over all sampled sites at Fort Benning (Figure 2). The change in the top-to-total ratios with disturbance clearly indicates that mixing has occurred and that this relationship holds promise as a measure that can indicate soil disturbance, especially if constructed using previously identified soil variables which exhibit significant treatment by depth interactions across multiple sites (i.e. extractable nickel, calcium, magnesium, manganese, total phosphorus, pH, C).

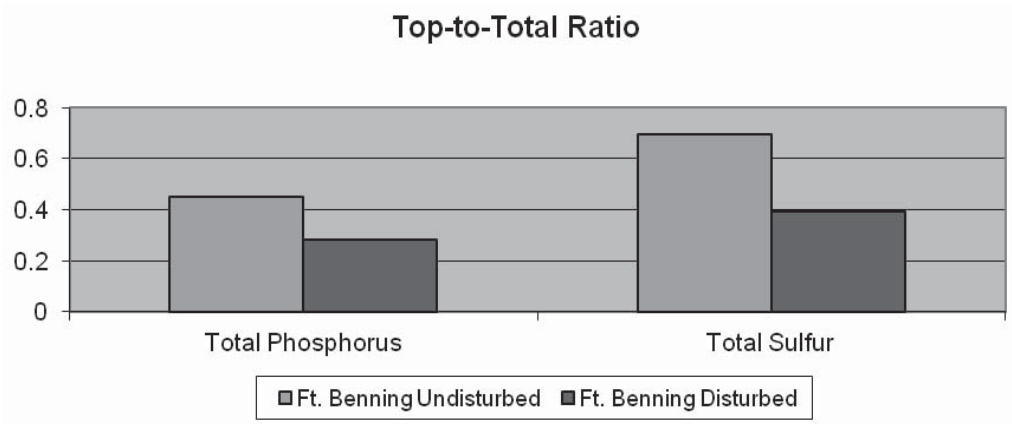

Figure 2. Ratio of total phosphorus and total sulfur concentrations in the upper 10 cm to the respective concentrations in the entire 50 cm soil profile.

Total to Soluble Ratio
Another ratio of interest is the total-to-soluble ratio, which is the ratio of the total element concentration to the extractable or soluble element concentration. All soils are subject to mineralogical weathering processes that convert insoluble elements/compounds to more soluble forms over time. This weathering process is fundamental to soil formation and leads to the development of soil layers with distinct elemental signatures that contribute to the overall vertical distribution pattern of elements within the entire soil profile. Over time, soil weathering processes reach an equilibrium state in any given soil that will be disrupted with disturbance. In addition to the actual physical disturbance, changes in soil surface area, soil moisture levels, pore space distributions, and microbial activity will alter the mineralogical weathering processes, causing changes in the concentration of soluble elements. Total and soluble concentrations of any given soil element would be expected to differ dramatically across dissimilar soil types, however, within soil types the concentration and vertical distribution patterns would be consistent. Therefore, any change in the ratio of total to soluble soil element concentration would be a clear indicator that mineralogical weathering processes have been altered and that disturbance is likely responsible. Since mineralogical weathering processes take place over longer time frames, any change in the total-to-soluble ratio would be a long term indicator of soil disturbance. Furthermore, these changes would seem to be a more sensitive measure of soil disturbance than could be expected from the changes in total or soluble elemental concentrations when considered alone.

An example of this total-to-soluble ratio is presented for Fort Riley, where the more complex mineralogy and age of the soils provided higher total and soluble concentrations of many elements, thereby enabling this relationship to be fully demonstrated. Significant total to soluble ratios were observed for both calcium (p=0.017) and potassium (p=0.048) when averaged over all sites at Fort Riley (Figure 3). The modest, but significant changes in the total-to-soluble ratio with disturbance clearly indicates that changes are detectable and that this relationship holds promise as a measure that can indicate soil disturbance over time, especially if constructed using previously identified soil variables which exhibit significant treatment by depth interactions across multiple sites (i.e. extractable nickel, calcium, magnesium, manganese, total phosphorus, pH, C).

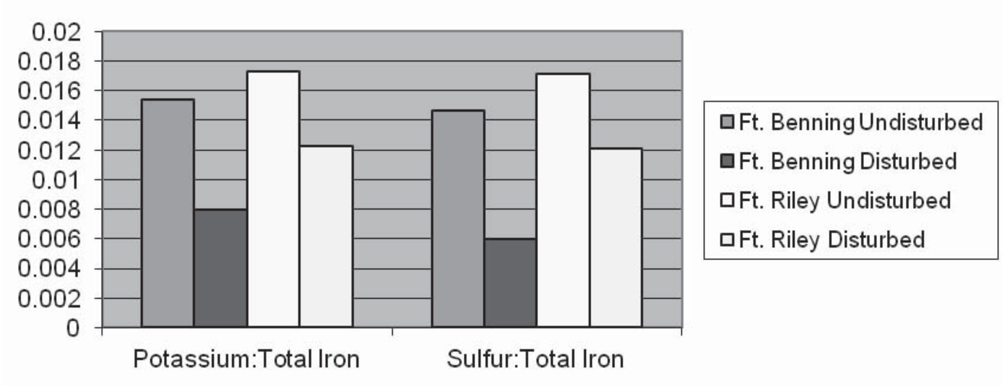

Figure 3. Ratio of total to soluble calcium and potassium concentrations at Fort Riley, KS, in the 0-10 cm depth increment.

Leachable to Non-Leachable Ratio

Another ratio of interest is the leachable to non-leachable ratio, which is the ratio between elements that are considered leachable or mobile to those elements that are considered non-leachable or immobile. Due to mineralogical weathering processes present during soil development, soil elements and compounds distribute themselves in the soil profile as a function of their leaching potential. These weathering processes are fundamental to soil formation and lead to the development of soil layers with distinct elemental signatures that contribute to the overall vertical distribution pattern of elements within the entire soil profile. Over time, soil weathering processes reach an equilibrium state in any given soil that will be disrupted with disturbance, causing physical mixing, displacement of elements in the soil profile, and alterations in mineralization processes which affect the leachable element concentration in soil solution. Leachable and non-leachable element concentrations would be expected to differ significantly across dissimilar soil types, however, within soil types the concentration and vertical distribution patterns would be consistent. Therefore, any change in the ratio of leachable to non-leachable soil element concentrations may be a potential indicator of disturbance and depth of disturbance. The ratio between leachable and non-leachable elemental concentrations at various depths is an attempt to normalize changes in absolute soil concentrations and would seem to be a more sensitive measure of soil disturbance than could be expected from the changes in leachable or non-leachable elemental concentrations when considered individually.

An example of this leaching to non-leaching element ratio is presented for both Fort Benning and Fort Riley. Significant (p<0.05) leachable to non-leachable element ratios were observed for potassium (leachable) to total iron (non-leachable) and sulfur (leachable) to total iron for soil disturbance averaged across all sites at each installation (Figure 4). The change in the ratio with disturbance clearly indicates that a change in the leachable to non-leachable element concentrations has occurred and that this relationship holds promise as a measure that can indicate soil disturbance and depth of disturbance, especially if constructed using previously identified soil variables which exhibit significant treatment by depth interactions across multiple sites (i.e. extractable nickel, calcium, magnesium, manganese, total phosphorus, pH, C).

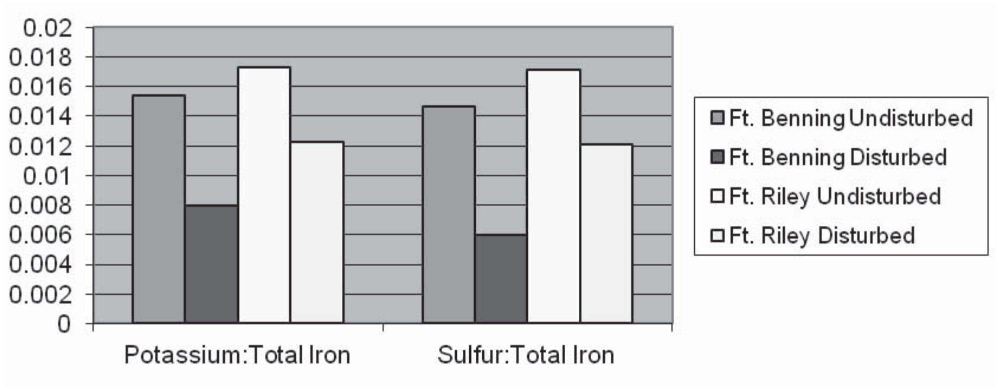

Figure 4. Ratio of leachable (potassium and sulfur) to non-leachable (total iron) element concentrations at Fort Benning, GA, and Fort Riley, KS, in the 0-10 cm depth increment.

Conclusion

The recognition that ratios or combinations of soil variables might be more stable indicators of disturbance across wide geographic and edaphic ranges than single variables led to the development of several small scale validation tests involving the concept of top to total ratios, total to soluble ratios, and leachable to non-leachable elemental ratios. Significant top-to-total, total to soluble, and leachable to non-leachable ratios were observed for total phosphorus and total sulfur, calcium and potassium, and potassium:iron/sulfur:iron, respectively, indicating that soil mixing to depths between 10 to 20 cm had occurred and that these ratios may hold promise as measures of severity and depth of soil disturbance. Top to total, total to soluble, and leachable to non-leachable ratios were only developed on small subsets of data from each installation as proof of concept exercises; however, preliminary analyses indicate these types of derived ratios may be promising areas for continued research.

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Keywords
Archaeological resources, soil disturbance, soil profile