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RESEARCH LETTER

Role of inherent soil characteristics in assessing soil health across Missouri

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Abstract

Soil health indicator values vary based on parent material, native vegetation, and other soil forming factors; therefore, useful interpretations require consideration of inherent soil characteristics. Our objective was to evaluate the distribution of soil health indicators across soil and climate gradients throughout the state of Missouri through a statewide cover crop cost-share program. Soil samples (0–7 cm) were collected from 5,300 agricultural fields and analyzed for several soil health indicators. Comparisons were made among six regions in the state based on Major Land Resource Area and county boundaries. Results varied for soil organic carbon (C), active C, potentially mineralizable nitrogen, water stable aggregates, and cation exchange capacity by region and corresponded with soil forming factors. Interpretation of soil health indicators must account for regional factors, recognizing that areas with different inherent values have a different potential for soil health.

1 | INTRODUCTION

Previous work has shown that interpretation of soil health indicators needs to account for inherent soil characteristics related to soil forming factors including parent material, native vegetation, climate, topography, and time (Andrews, Karlen, & Cambardella, 2004). We had the unique opportunity to evaluate the variation and distribution of soil health indicators in Missouri through a large,

statewide project that collected soil health samples to a depth of 7 cm from 5,300 agricultural fields across the state.

A primary goal in developing soil health testing for producers is identification of dynamic indicators that are sensitive to management in a short period of time (1–3 yr) while being commercially ready and relatively inexpensive (Stott, 2019). Perhaps even more important, indicators must be related to soil functions or processes while considering inherent soil properties (Andrews et al., 2004). The conditions under which a soil formed are the drivers of initial soil conditions, which then shift over time, in part through land use. For example, soils differ in inherent levels of organic matter due to soil forming factors; higher organic matter is often found under soils with prairie vegetation or loess parent material compared with forested soils or those with alluvium parent material. Other factors, such

Abbreviations: %BaseSat, base saturation; BTH, Bootheel; CEC, cation exchange capacity; ECP, Eastern Clay Pan; ERW, Eastern River/Wooded Slopes; NCT, North Central Till Plain; PMN, potentially mineralizable nitrogen; SMAF, Soil Management Assessment Framework; SOC, soil organic carbon; WCP, West Cherokee Prairies/Springfield Plain; WLR, Western Deep Loess/River; WSA, water stable aggregates.

as topography and soil texture, can influence drainage class and in turn influence organic matter accumulation.

Assessments of soil health vary in how soil and climate characteristics are taken into account. In the Soil Management Assessment Framework (SMAF), scoring curves are parameterized using multiple site characteristics, including soil textural class, mineralogy, precipitation, and temperature regime (Andrews et al., 2004). Currently, SMAF scoring curves are under revision using a nationwide dataset (Karlen, Veum, Sudduth, Obrycki, & Nunes, 2019).

This work focused on patterns within the state of Missouri to evaluate how the distribution of soil health indicators varied as a function of inherent soil and climate factors. Soil samples in this project were collected to a relatively shallow depth of 7 cm, in contrast with most studies where soil is sampled to a greater depth (≥15 cm). The shallow soil sampling may allow for greater sensitivity to management practices for indicators closely related to organic matter and microbial activity that is concentrated near the soil surface. The objective of this work was to provide a framework for the interpretation of soil health tests conducted in Missouri using the shallow soil sampling protocol.

2 | MATERIALS AND METHODS

Soil samples were collected in conjunction with a statewide cover crop cost-share program through the Missouri Department of Natural Resources. From 2015 to 2017, 5,300 fields were enrolled in the program and sampled, representing a total of 327,938 acres across the state, which is 1.2% of Missouri's 27.8 million agricultural acres (11 million ha; USDA-NASS, 2019). Individual landowners, producers, consultants, and conservation staff collected four subsamples to a depth of 7 cm with 7.2-cm-diameter bulk density rings from close proximity within a field. For each field, the subsamples were composited and shipped to the University of Missouri Soil Health Assessment Center for analysis. Additional information about location, landscape position, soil series, and agronomic management was collected for each sample.

Standard methods from Soil Survey Staff (2014) were used for analyses except for potentially mineralizable nitrogen (PMN), which was quantified using the 7-d anaerobic incubation method from Waring and Bremner (1964). Other measurements included particle size analysis (sand, silt, and clay content), water stable aggregates (WSA; wet-sieving method), cation exchange capacity (CEC; ammonium acetate at pH 7), exchangeable cations (including K, Ca, and Mg), base saturation (%BaseSat), Bray-1 phosphorus (Bray-1P), soil pH (1:1 soil/water), active C (potassium

Core Ideas

- Inherent soil characteristics can strongly influence soil health indicator values.
- Statewide soil health samples were collected from 5,300 fields across Missouri.
- Soil health indicator values varied across soil regions.
- Interpreting management impacts on soil health should consider regional soil characteristics.

permanganate oxidizable C), and soil organic C (SOC; dry combustion by LECO C-144 carbon analyzer).

Location information for each sample was primarily limited to the county of collection. We developed seven soil regions of Missouri based on Major Land Resource Area and modified to align with county boundaries. Of these seven regions, the Ozark Highlands has little row crop agricultural land and therefore was not included in the analysis. For the remaining six regions, names were based on Major Land Resource Area, location within the state, and/or landform features. Details of the soil regions, including number of observations, soil forming factors of parent material, native vegetation (USDA-NRCS, 2006), and 30-yr mean annual temperature and precipitation (NOAA, 2020), are provided in Table 1. A map of the regions is provided in Figure 1.

Soils in the north-central and western side of Missouri (North Central Till Plain [NCT], Western Deep Loess/River [WLR], West Cherokee Prairies/Springfield Plain [WCP]) tend to be Mollisols with some Alfisols and Entisols. The remainder of the state is dominated by Alfisols, Entisols, and Inceptisols as well as some Ultisols and Vertisols in the southern part of the state, particularly in the Bootheel (BTH) (USDA-NRCS, 2006). The northern half of the state was glaciated and has a layer of loess over till as parent material with some loess and residuum in the rest of the state. Alluvium dominates along the Missouri and Mississippi Rivers and in the southeastern BTH region of the state. The BTH is characterized by a uniquely wide alluvial plain over 60 km in width with more diversified cropping systems compared with the rest of the state, as well as a greater proportion of tilled acreage with less livestock compared with other regions of Missouri. The majority of soils measured across the state were classified as silt loams, but greater texture variability was observed in the BTH region (Figure 1). Over half of the soils in BTH contained less than 20% sand, but ranged up to 95% sand. Likewise, the silt content of BTH varied greatly,

TABLE 1 Soil, climate, and cropping system details for Missouri soil regions, based on Major Land Resource Area and modified to align with county boundaries. Soil information includes parent material and native vegetation. Mean annual temperature (MAT) and mean annual precipitation (MAP) are climate normal averages from 1981 to 2010 from NOAA weather stations within the soil regions. The number of observations were included from each soil region in the study from 2015 to 2017 along with a description of the most common cropping systems within the regions

Missouri soil regions		n	Parent materials	Native vegetation	Climate MAT (°C)	MAP (mm)	Cropping systems[a]
WCP	West Cherokee Prairies/ Springfield Plain	511	Residuum, loess, alluvium	Prairie to the west; transitional and forested to east and south	13.3	1,151	Primarily soybean with some wheat, corn, and hay
WLR	Western Deep Loess/River	1,102	Deep loess over till	Prairie and forest	12.1	1,034	Mix of corn and soybean with some pasture and forest
NCT	North Central Till Plain	813	Loess, loess over till	Prairie; waterways and lowlands are forested	11.2	1,014	Mix of corn/soybean with some pasture, hay, and forest
ECP	Eastern Clay Pan	746	Loess over till	Prairie on some uplands; otherwise, forested	11.8	1,012	Mix of corn/soybean with some pasture, hay, and forest
ERW	Eastern River/Wooded Slopes	1,522	Loess over till	Primarily forested	12.9	1,104	Mix of pasture, forest, and corn/soybean
BTH	Bootheel	561	Alluvium, some loess, loess over paleosols	Forest	14.5	1,216	Diversified corn, soybean, cotton, winter wheat, and rice

[a]Corn, *Zea mays* L.; cotton, *Gossypium* spp.; rice, *Oryza sativa* L.; soybean, *Glycine max* (L.) Merr.; wheat, *Triticum aestivum* L.

but the range of clay content was similar to that of the other regions.

Statistical analysis was conducted in R to perform an ANOVA for each soil health indicator to evaluate the effect of soil region. Due to lack of normality of residuals, transformations were selected on the basis of Box-Cox power transformation series. The transformations used were square root for SOC, active C, WSA, PMN, Mg, CEC, %BaseSat, and Ca; logarithmic for P and K; and squared for soil pH. Least square means were separated using a Tukey adjustment with $\alpha = .05$.

3 | RESULTS AND DISCUSSION

The patterns across the state for SOC, active C, WSA, and PMN were similar, with the highest levels in the north- ern part of the state in NCT, followed by the other western regions. These four indicators are all directly related to organic matter content (Stott, 2019). Active C measures the labile portion of SOC, whereas PMN is closely related to the amount of N stored within SOC. Stable aggregates, as measured by WSA, are held together by organic matter "glue." The western and northern regions (NCT, WLR, and WCP) are dominated by Mollisols with high organic matter content in the characteristic mollic epipedon, which is less common in Alfisols and other soil orders in the remainder of the state. With the exception of WSA, the eastern regions of the state were generally lower and followed a pattern of decreasing values from north to south, presumably due to the temperature gradient with greater mineralization and lower accumulation of carbon in soils under warmer climate. While NCT had the greatest WSA values, there were no significant differences among the other regions.
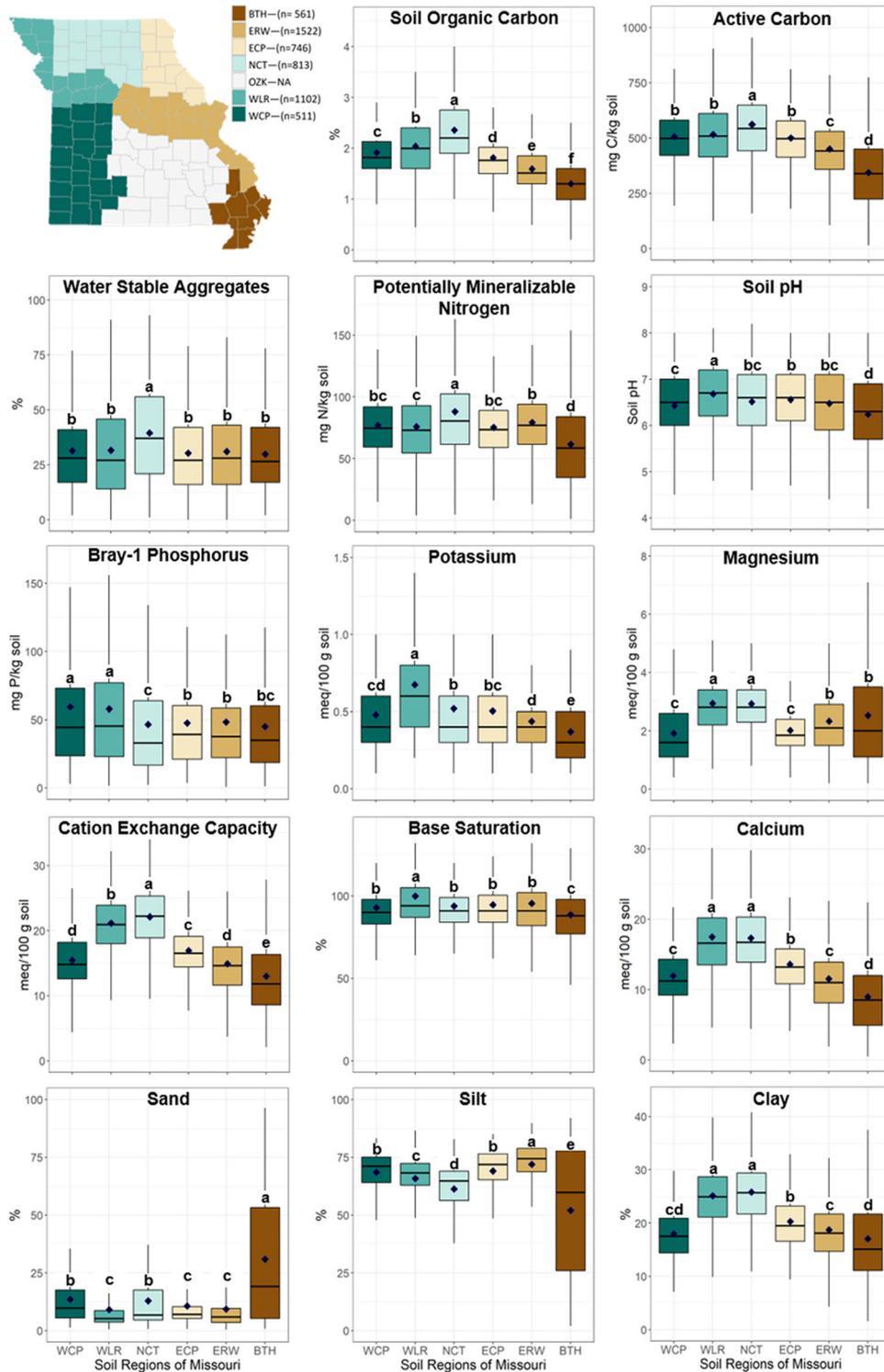
FIGURE 1 Map of Missouri soil regions based on Major Land Resource Areas modified by county boundaries and box plots by soil region for 11 soil health and fertility indicators as well as particle size analysis. For each soil region, the median is indicated by the box midline and the mean by a diamond symbol. The bottom and top lines of the box represent the 25th and 75th percentiles. The whiskers extend to the smallest or largest values that are no more than 1.5 times the interquartile range beyond the edges of the box; extreme values beyond that point are not shown, although they were included in the analysis. Means among soil regions that are significantly different based on the ANOVA of transformed data are indicated by letters at α = .05 with Tukey adjustment. BTH, Bootheel; ECP, Eastern Clay Pan; ERW, Eastern River/Wooded Slopes; NCT, North Central Till Plain; OZK, Ozark Highlands; WCP, West Cherokee Prairies/Springfield Plain; WLR, Western Deep Loess/River.

For soil fertility measurements, Bray-1 P levels were the highest in the western regions (WLR, WCP). Phosphorus availability is particularly pH dependent, with decreasing P availability in soils with pH below 5.5 or above 7.5. The northwestern WLR region demonstrated significantly higher pH compared with the other regions, and BTH had the lowest. However, the higher P levels in WLR and WCP compared with other regions were not likely related to soil pH, as the majority of the samples from all regions fell within this range. Potassium levels were highest in northwestern WLR region but also showed a large variation in K levels; the lowest K levels were found in the east-central Eastern River/Wooded Slopes (ERW) and southeastern BTH. Magnesium was the highest in WLR and NCT and lowest in WCP in the southwest and the Eastern Clay Pan (ECP) in the northeast part of the state; in BTH, there was a large variation in Mg measurements and the highest Mg content overall. For Ca, the pattern was similar to Mg, except with less variability in BTH and no exceptionally high values. Cation exchange capacity followed the same general trend of SOC and clay content due to the dependence of CEC on the negative exchange sites on the surface of clay minerals and organic matter. Base saturation is closely related to pH, and the highest %BaseSat and highest pH were found in NCT. All regions had a substantial number of samples with %BaseSat values above 100%, corresponding to samples with pH over 7.0, likely due to recent liming or proximity to limestone gravel roads.

It is important to understand the potentials and limitations of a particular soil when interpreting soil health results. Soils in the north-central and western parts of Missouri will likely have higher values in soil health tests related to organic matter, such as C and microbial measurements, because of the influence of parent material and native vegetation. For example, a soil health test result may be high compared with the state average but reflect room for improvement at the regional scale. Further, it may take longer or be more difficult to detect changes in soil health measurements in soils with higher inherent values. In contrast, soil health in ECP, ERW, and BTH may show improvement more rapidly, but values may remain relatively low compared with the state mean due to inherent regional differences.

These results provide the framework for the next steps in evaluating the impacts of agronomic management on soil health within the state of Missouri. Interpretation of soil health results needs to consider the potential within a region to accurately understand and explain the impact of management practices. The unique shallow sampling depth of this project may provide greater sensitivity to management practices, particularly for soil health indicators directly related to microbial cycling of carbon and nutrients.

CONFLICT OF INTEREST
The authors declare no conflict of interest.

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REFERENCES

Andrews, S. S., Karlen, D. L., & Cambardella, C. A. (2004). The Soil Management Assessment Framework. *Soil Science Society of America Journal*, *68*(6), 1945–1962. https://doi.org/10.2136/sssaj2004.1945

Karlen, D., Veum, K. S., Sudduth, K. A., Obrycki, J. F., & Nunes, M. R. (2019). Soil health assessment: Past accomplishments, current activities, and future opportunities. *Soil & Tillage Research*, *195*, 104365. https://doi.org/10.1016/j.still.2019.104365

Stott, D. E. (2019). *Recommended soil health indicators and associated laboratory procedures* (Soil Health Technical Note No. 450-03). Washington, DC: USDA-NRCS.

NOAA. (2020). Climate data online. National Oceanic Atmospheric Administration. Retrieved from https://www.ncdc.noaa.gov/cdo-web/

Soil Survey Staff. (2014). *Kellogg soil survey laboratory methods manual* (Soil Survey Investigations Report 42). Washington, DC: USDA-NRCS.

Waring, S. A., & Bremner, J. M. (1964). Ammonium production in soil under waterlogged conditions as an index of nitrogen availability. *Nature*, *201*(4922), 951–952. https://doi.org/10.1038/201951a0

USDA-NASS. (2019). *2017 Census of agriculture: United States summary and state data. Vol. 1. Geographic Information Series, Part 51* (AC-17-A-51). USDA. Retrieved from https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf

USDA-NRCS. (2006). *Land resource regions and major land resource areas of the United States, the Caribbean, and the Pacific Basin* (Agriculture Handbook 296). Washington, DC: USDA-NRCS.