Reference Ecological Unit: A Land Classification Unit for Comparative Soil Studies

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Abstract

There is a growing consensus on a need for comparing the cropland with a reference state or native land in a prime soil health state to determine soil health management goals in croplands. However, the complex soil heterogeneity and climate variations make soil health potential variable and confound the land-use and management practices while comparing soils from different sites. Identifying a discrete landmass unit where all soils have similar health potential will be instrumental in conducting meaningful comparative studies. This methodological paper proposes and discusses a land unit, Reference Ecological Unit (REU), that accounts for soil and climate variabilities and covers the area with similar soil health potential. The REU is developed for one Major Land Resource Area in Nebraska based on the USDA-NRCS hierarchical land classification system. A true difference in soil health for different land use and agronomic management practices such as no-till and cover crops can be determined by comparing sites within an individual REU. Evaluation of management effects on soil health indicators in an REU will adequately illustrate the beneficial impact of such practices without being confounded by agroecological variations.

Keywords: Soil Health, Reference Ecological Unit, Reference State, Soil Health Potential

Concerns over the sustainability of the soil ecosystem that provides food, fiber, and fuel to the ever-increasing world population have helped coalesce efforts around soil health and conservation. Soil health is the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans (NRCS - USDA, 2021) and is measured via indicators that are measurable soil properties that can provide inferences about soil functions. Numerous research report soil health in terms of soil physicochemical and biological indicators and identify different management practices that can improve it.

There is a growing consensus that soil health in cropland needs to be compared to a reference state to understand its status and how much it can be improved (Morgan and Cappellazzi, 2021). For example, Maharjan et al. (2020) proposed a term "Soil Health Gap" that compares soil health in cropland and native undisturbed land, providing a measure of decline in soil health in croplands since cultivation began and simultaneously setting potential soil health management goals in croplands. Many other researchers have suggested using native virgin or undisturbed land as the reference state, considering the theoretical prime health status. However, defining and selecting a benchmark reference site comparable to cropland of interest is intricate and should account for the heterogeneity in soil and climate.

Significant changes in soil bio-physicochemical properties can be observed across different soil series and associations (Caudle, 2019). Climate, especially precipitation, defines soil biological functions and the biogeochemistry of nutrients. Precipitation gradient and individual soil entities based on pedogenetic differences can create differences in soil health potential. For that reason, the response of soil health indicators to different management practices is site-specific (Nunes et al., 2021). Therefore, compared soils should belong to an ecologically discrete unit that accounts for soil and climate variability and have similar soil health potential.

In this paper, we propose a landmass unit*, **Reference Ecological Unit*** **(REU)**, that accounts for agroecological variability and wherein croplands can be compared among themselves and with native lands for their soil health statuses. If measured in the same REU, soil health indicators in different soils will provide true differences due to land use or management practices. The REU will provide a leveled platform for comparative studies where soil health can be assessed and compared for a group of soils with similar soil health potential.

Definition of Reference Ecological Unit

Reference ecological unit is defined as a landmass unit with uniform pedogenetic and climatic properties in a hierarchical land classification system. Below, we present how to carve out REUs within ecological sites (ES) in each major land resource area (MLRA) in the USDA-NRCS Hierarchical Land Classification System (HLCS) (**Figure 1(a**)). The REU can be created to achieve the desired resolution by adjusting boundary conditions of pedogenetic and climatic factors.

In the USDA-NRCS HLCS, MLRA is a broad classification of geographically associated land considering the geology (parental material), climate (precipitation, temperature), water, soils (dominant soil orders), biological resources (plants and animals), and land-use types (NRCS-USDA, 2021). The MLRA is then divided into ecological sites (ES), which are distinctive lands with specific soil and physical characteristics (climate, geology, hydrology) that differ from each other to produce distinct kinds of vegetation and respond to management practices and natural disturbances. From ES, Benchmark Ecological Sites (BES) are selected for their potential to yield data and information about ecological functions, processes, and climate change which are important to characterize an area or critical ecological zones.

Methodology to determine REU

To determine REU, BES were categorized based on their crop cover area, and the top BES cumulatively representing >90% crop covers were selected and are referred to as Dominant Ecological Sites (DES) (**Figure 1(b)**). Individual DES was divided into discrete landmass units as a function of soil associations and precipitation range (≥ 3 in; 7.6 cm) to determine the REU. Thus, theoretically, REU represents uniformity from perspectives of soil genesis (geology), biotic community (plant community), physical properties (topology and hydrology), and climate (precipitation). Selecting a group of soils within each REU will provide a leveled platform for comparison as they all would have similar soil health potential.

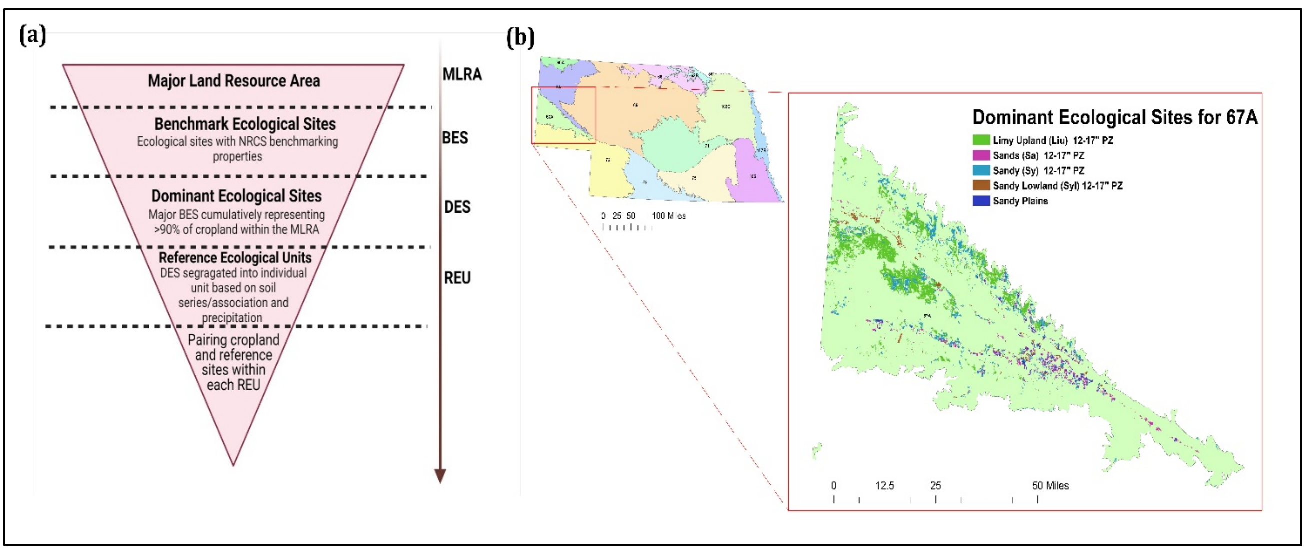

__Figure 1__. (a) Hierarchical land classification leading to Reference Ecological Units where soils can be compared, (b) Dominant ecological sites identified based on >90% crop cover for the MLRA 67A, one of 13 MLRAs in Nebraska.

Geo-spatial analyses were conducted to determine REUs in ArcGIS 10.8 (Esri, CA). The USA Contiguous Albers Equal Area Conic was used as a reference projection model for geo-spatial analysis and methodology development. Available shapefiles and layer files such as MLRA, Land Cover and Land Use were downloaded from the USDA - Geospatial Data Gateway (USDA – GDW) by generating a request form from the website. In this study, the MLRA 67A in

Nebraska is used for an example to demonstrate the determination of REUs. The REU selection methodology was performed in the following order:

i. A layer of MLRA for Nebraska was created from USA – MLRA shapefile obtained from USDA - GDW by clipping with NE state shapefile.

ii. A layer of the Land-Cover-Land-Use was created from NASS land cover data. All the land use properties were removed from the layer attributes except for the cropland to create the cropland layer file.

iii. A layer of BES was created from the polygon data of ES as provided by the USDA – NRCS based on the benchmarking attributes determined by NRCS.

iv. MLRA layer was intersected with the cropland layer (from step ii) and BES (from step iii) using ArcGIS intersect function of geo-spatial analysis. Output shapefile was split into 13 discrete MLRA units for Nebraska using intersect layer as the primary input and MLRA layer as the split unit.

v. Each MLRA at this point has multiple polygons for each BES as they are segregated based on the cropland cover. Dissolve function from the generalized tool of ArcMap was used to aggregate the attributes of each BES feature class to represent each BES as single unit in the MLRA attribute.

vi. Using field value calculator, area of cropland for each BES was calculated for individual MLRA. Percentage of land cover for each BES was calculated by dividing the individual area of cropland for each BES to the total area of cropland for the MLRA.

vii. A cumulative percentage of cropland cover was calculated. Top BES cumulatively covering > 90% of the cropland was selected as the DES. For MLRA 67A, there were 5 DES.

viii. The layer of DES for each MLRA was intersected with the *Soil associations Layer* and *Precipitation Layer*. Each intersected map unit was grouped by unique DES and Soil associations and then discretized over two or three inches (5.1 or 7.6 cm) of precipitation gradient to determine the ***Reference Ecological Unit*** for each MLRA (**Figure 2**). For MLRA 67A, there were 45 REUs.

ix. For soil health comparative studies, the native grassland site (~rangeland) and cropland should be present in the same REU for determination of true differences in soil health statuses or the Soil Health Gap in croplands. **Figure 2** has an enlarged section of reference ecological unit (REU-8) from the MLRA 67A to illustrate the concept. Here, in **Figure 2**, the shaded background in the enlarged section is the REU, and the blue and pink shared area represents the croplands and rangelands, respectively. Croplands in the blue-shaded area should be comparable to determine soil health differences due to management practices. Soils from croplands and rangelands in the REU can be compared to determine the Soil Health Gap and set potential soil health management goals in those croplands.

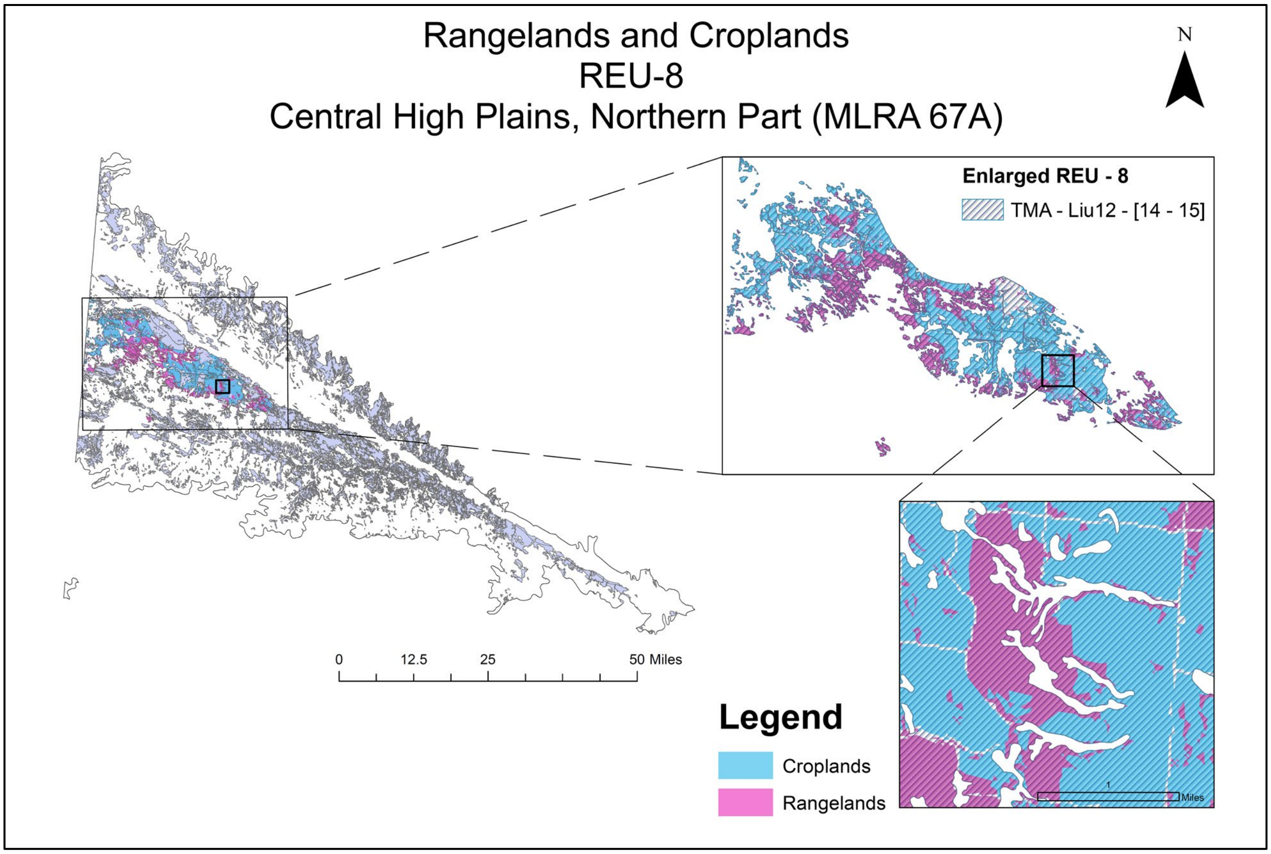

Figure 2. *Reference ecological units for MLRA 67A (left) and one of 45 identified REUs (REU-8) is enlarged and layered with cropland and rangeland (right). The REU identifier consists of soil association- DES- [pz; precipitation zone in inches]. TMA = Trip-Mitchell-Alice soil association, Liu12 = Limy upland 12 – 17 pz ecological site, and [14 – 15] is the precipitation zone.*

Relevance and Future Prospect of REU in Soil (Health) Research

Determining REU based off the existing USDA NRCS Hierarchical Land Classification System allows to find some levels of homogeneity in a land mass that otherwise has dynamic soil pedogenetic properties and climatic variability. As majority of the soil health researches attempt at understanding and determining management effects on soil health and the degree of gain in soil health over time, it is essential to be able to compare cropland soil health to an soil in a prime health state, or a reference state (Morgan and Cappellazzi, 2021). It is equally important, if not more, to select the soils from the same REU that would have similar soil health potential. Otherwise, the differences in pedology and climate among comparing sites create confounding effects on soil health indicators. In such cases, measurement of soil health indicators and comparative studies of soils with different potentials do not represent the true like-for-like comparison. Thus, REU will provide a unique leveled platform in soil science research for its functional attributes like:

- It will provide a land unit for comparative study with similar soil health potential as it accounts for site-specificity.
- A true quantitative difference in soil health for different land use and agronomic management practices can be determined by comparing sites within an individual REU. Evaluation of management effects on soil health properties in REU will provide the true understanding of beneficial effect of such practices, unconfounded by agroecological variations.
- Implementation of REU will help in comprehensive correlative understanding for soil health matrices for different agroecological regions.

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