Investigating the Soil-Vegetation Interactions for Kentucky Ecosystems using Field Observations and Remote Sensing Data: Linking Climate Change to Carbon and Water Use Efficiency, and Soil properties

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Abstract

The increased deforestation and urbanization of Earth's surface changes how the soil system interacts with plants and understanding this relationship is vital in this time of climate change. Yet, how soil affects carbon and water use efficiency in plants is poorly understood. Studies show strong relationships between soil nutrient and vegetation carbon use efficiency (CUE) and water use efficiency (WUE) for different ecosystems; however, studies rarely have examined the combined effects of soil characteristics and nutrients on CUE and WUE. This study use both soil profile and satellite data to explore the role soil properties play in regulating water and carbon use by plants. Site and satellite multispectral and hyperspectral data are collected from 30 Kentucky terrestrial ecosystem sites and used to investigate the relationship between spectral reflectance and physical and chemical properties of soil. Results show strong relationship between CUE and phosphorus, soil organic carbon, and iron in the C-horizon for forests. On the contrary, a negative relationship was observed between CUE and SOC in the A-horizon for herbaceous biomes. Also, results show a strong relationship between δ13C and CUE for the forest sites. These types of data are timely and critical for accurate predictions of how terrestrial ecosystems will respond to climate change.

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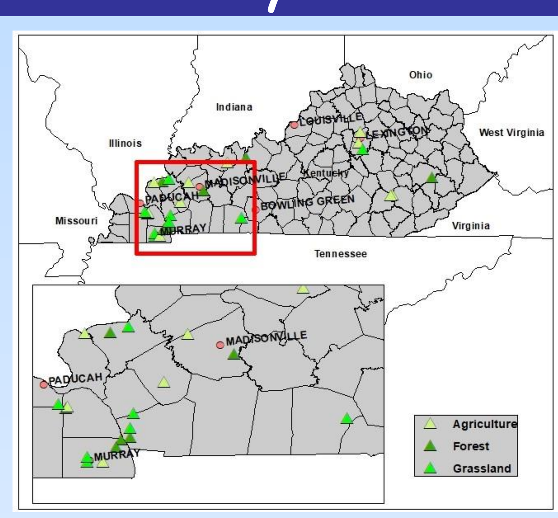
Abstract

The increased deforestation and urbanization of Earth's surface changes how the soil system interacts with plants and understanding this relationship is vital in this time of climate change. Yet, how soil affects carbon and water use efficiency in plants is poorly understood. This study use both soil profile and satellite data to explore the role soil properties play in regulating water and carbon use by plants. Site and satellite multispectral data are collected from 24 Kentucky terrestrial ecosystem sites and used to investigate the relationship between above ground vegetation efficiencies and physical and chemical properties of soil.

Study Sites



Methods

- Soil samples for a depth of 60 cm were collected from 24 sites: 8 Forest, 10 grassland, and 6 agriculture.
- Soil physical and chemical properties were measured including: Bulk density, particle size, loss in ignition, extractable P, K, Fe, Ca, Mg, Zn, total N, SOC, $\delta^{13}C$ and $\delta^{15}N$.
- Satellite data for GPP, NPP, and ET were acquired from the Moderate Resolution Imagining Spectroradiometer (MODIS) and LandSat. Sun-Induced Fluorescence (SIF) data were acquires from the Orbiting Carbon Observatory-2 (OCO-2).
- Water use efficiency (WUE) = GPP/ET or GPP-SIF/ET.
- Carbon use efficiency (CUE) = NPP/GPP or NPP/GPP-SIF.
- GPP-SIF was estimated for each land use type following Zhang et al., 2016.
- Classification and regression trees (CART) were constructed to determine which variables are significant in predicting WUE and CUE.

Soil Physical and Chemical Properties

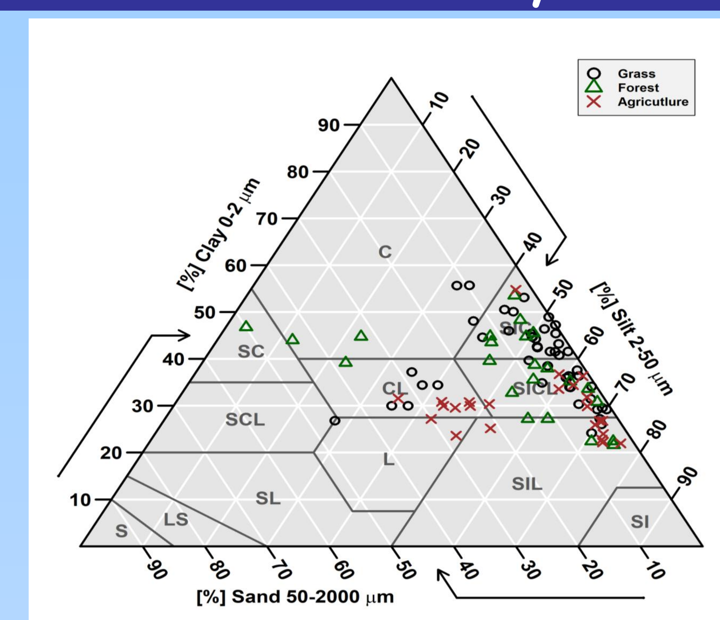


Figure 1. Soil texture for the study sites for all the soil depths.

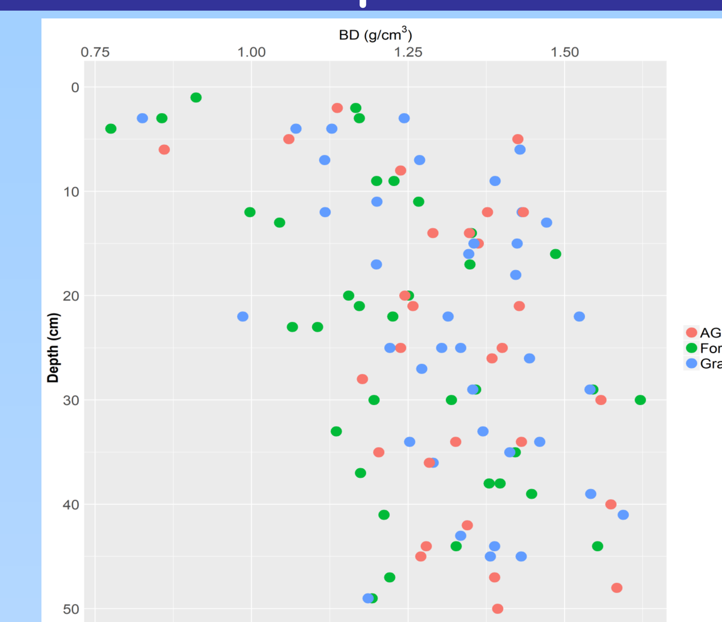


Figure 2. Soil bulk density with soil depth for the study sites.

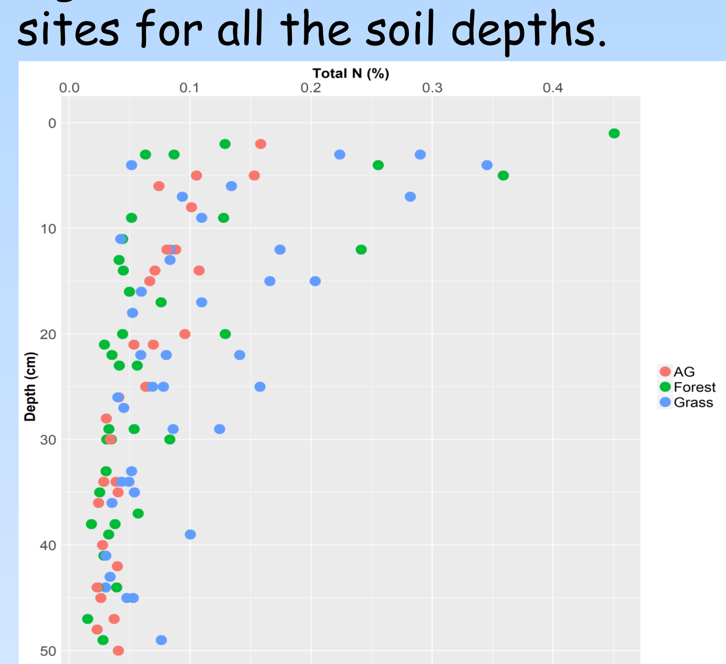


Figure 3. Total soil N with soil depth for the study sites.

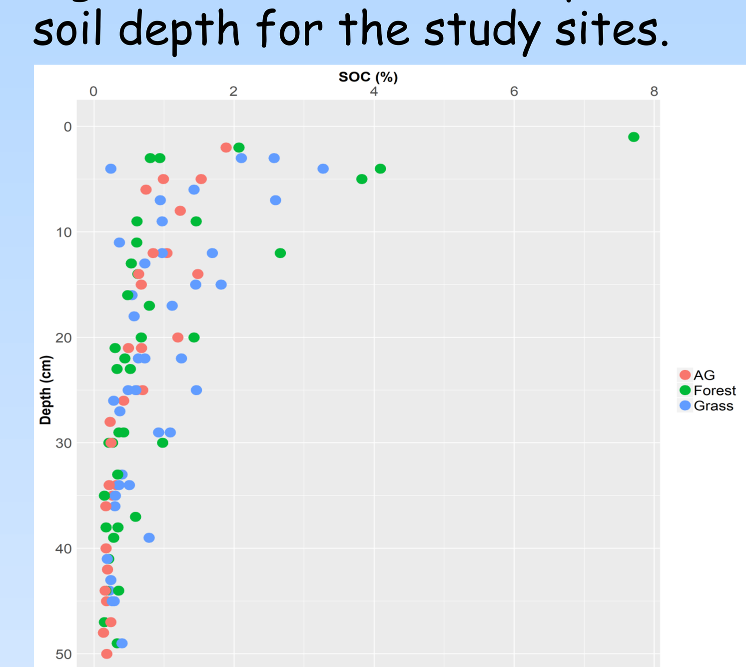


Figure 4. Soil organic carbon with soil depth for the study sites.

CUE and WUE vs. Soil Chemical Properties

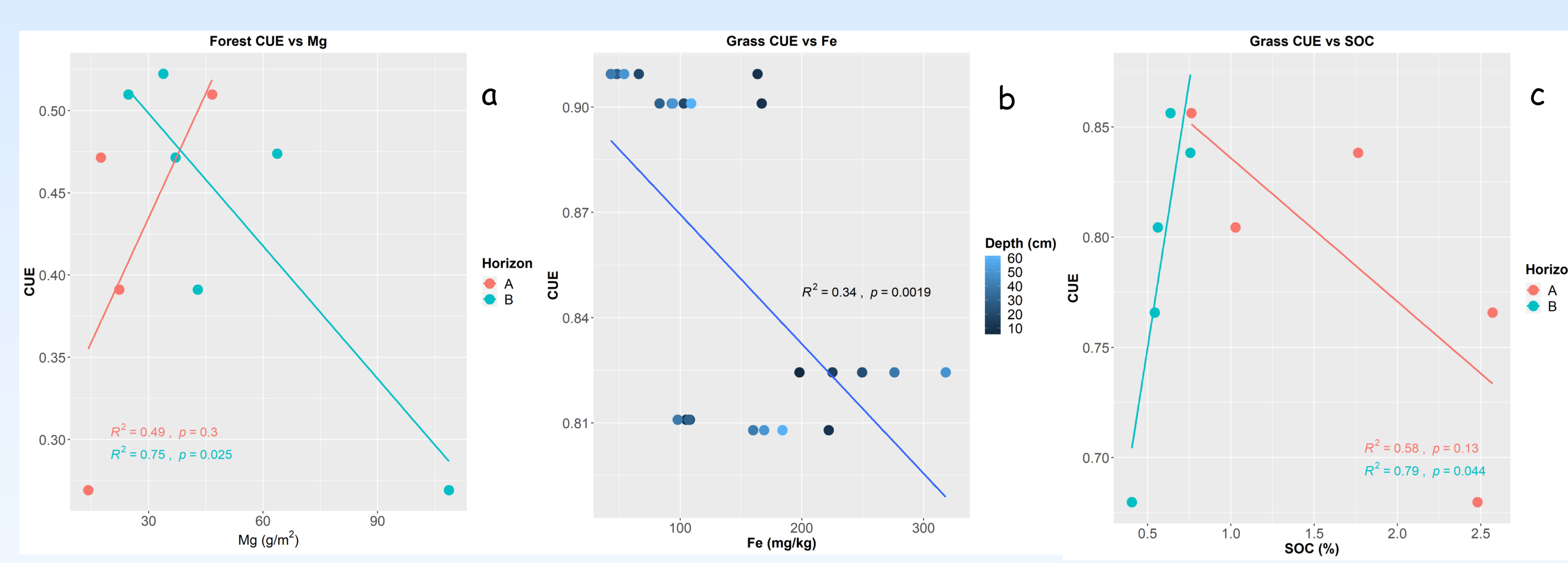


Figure 6. Correlation coefficient of (a) CUE and Mg for the forest sites; (b) CUE and Fe for the grassland sites; (c) CUE-SIF and SOC for the grassland sites per soil horizon.

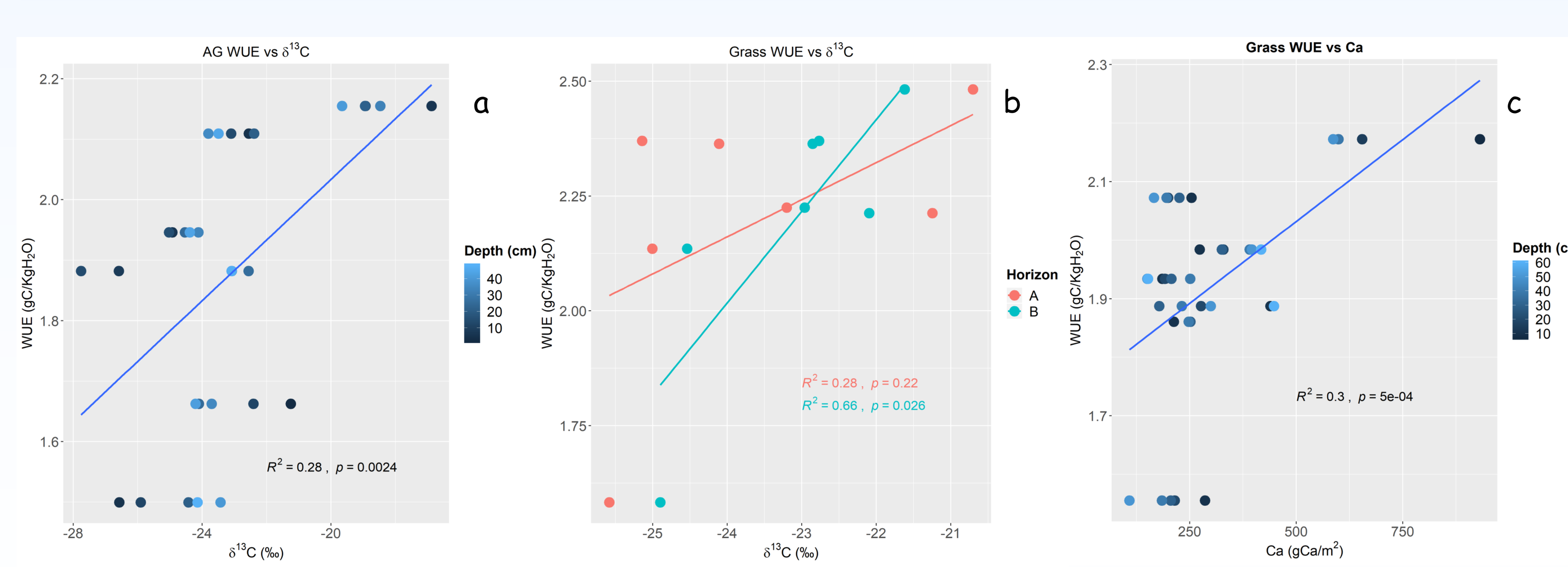


Figure 7. Correlation coefficient of (a) WUE and $\delta^{13}C$ for the agricultural sites; (b) WUE-SIF for the grassland sites per soil horizon; (c) WUE and C for the grassland sites.

Regression Tree Analysis

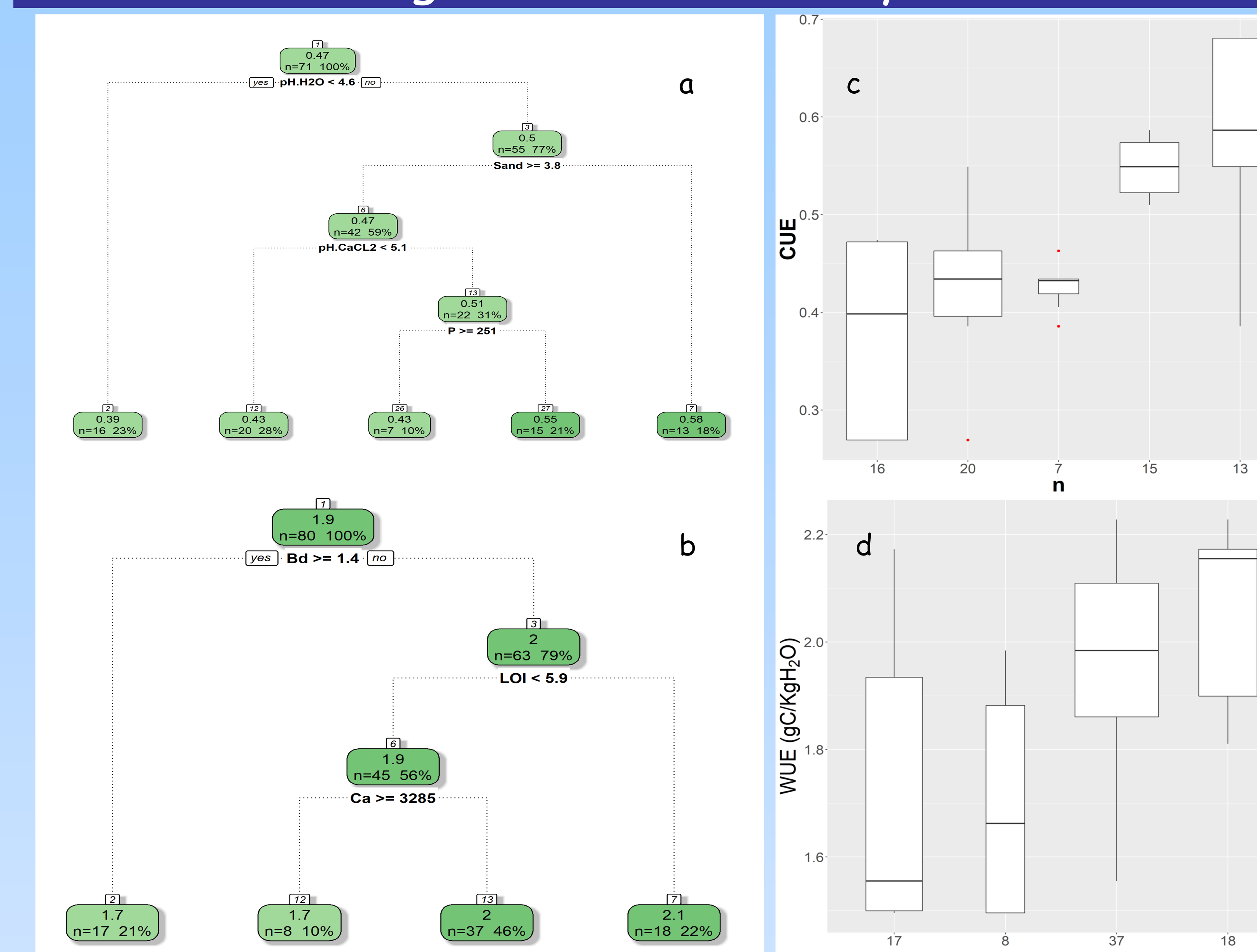


Figure 8. Left Panel: Pruned Regression tree for (a) CUE; and (b) WUE. Right panel: Terminal node boxplots showing the mean and distribution of (c) CUE; and (d) WUE at each branch in the regression tree. The models has a predictive error of ±0.05 for CUE and ±0.15 gC/KgH_2O for WUE.

Conclusions

- Correlation coefficient are significant for CUE and Mg, SOC and Fe and WUE and soil $\delta^{13}C$ and Ca.
- Land cover/land use types and soil horizons has a significant impact on the relationship between soil chemical properties and CUE and WUE.
- The correlation between WUE and $\delta^{13}C$ for the grassland sites highlights grassland adaptation to high fluctuation in soil water availability due to high evaporation rates.
- The correlation for WUE and $\delta^{13}C$ for the agricultural sites could be a reflection of the land management practices to maximize yield.
- Pruned regression tree analysis shows that bulk density, loss on ignition (LOI), and Ca are important predictors of WUE. While, pH, sand content, and P are the important variables for prediction of CUE.
- Further analysis in needed to understand the role of soil development and soil chemical properties and the observed ranges in CUE and WUE.

Acknowledgements

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References

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