Investigating the Spatial Variability in Soil Geochemical and Colour Properties Across Two Contrasting Land Uses

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Abstract

Quantification and accurate assessment of the spatial variability and distribution of soil physical and biogeochemical properties (fingerprints) are vital components of agri-environmental research and modeling, including sediment source fingerprinting. Understanding the distribution of soil properties at a range of spatial scales is crucial in the development of appropriate, reliable, and efficient sampling campaigns. This study was aimed to investigate the spatial variability in soil geochemical and colour (i.e., spectral reflectance) fingerprints across two contrasting land uses. The main objectives of this study are to: 1) quantify the spatial variability of geochemical and colour fingerprint properties at a field-scale (~ 40 ha) across agricultural and forested sites; 2) evaluate the spatial variability and distribution of soil fingerprint properties and its relation to a range of terrain attributes (e.g., slope); and 3) identify the possible sources of variation in each land use, primarily environmental factors. A combination of univariate analysis and geostatistical methods were applied to analyze the soil geochemistry and colour properties. This information was used to both quantify and assess the variability in commonly used fingerprints. Terrain attributes derived from digital elevation model (DEM) were used to investigate spatial variation of soil geochemical and colour fingerprint properties. The ability of terrain attributes to explain the observed variability in soil fingerprints played an important role across all properties. The present study suggest that kriging interpolation can directly reveal the spatial distribution of soil fingerprint properties and quantify the variability at a field-scale.

## 1 Introduction

## 2 Methods

### 2.1 Site description

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| Figure 1: Map showing the location of the study sites within Canada, and the regional land use and topography. |

Source: [Research Site Locations](https://alex-koiter.github.io/spatial-variability-soil-manuscript/notebooks/location_map.qmd.html#cell-fig-location_map)

## 3 Results

### 3.1 Univariate summary

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| Table 1: Summary statistics for for six examples of for six examples of geochemical and colour soil properties, specific surface area, and organic matter content for each site.   | Element | Mean | SD | Max | Min | Skewness | CV | | --- | --- | --- | --- | --- | --- | --- | | Forest | | | | | | | | Li | 6.47 | 0.90 | 8.60 | 4.30 | −0.02 | 13.89 | | Nb | 0.37 | 0.06 | 0.56 | 0.17 | −0.68 | 17.10 | | Zn | 109.55 | 53.27 | 318.00 | 42.00 | 1.43 | 48.62 | | *h*\* | 1.13 | 0.05 | 1.23 | 1.06 | 0.34 | 4.13 | | *L* | 47.45 | 6.35 | 59.48 | 34.34 | −0.02 | 13.37 | | *v*\* | 4.79 | 1.04 | 6.62 | 2.77 | 0.31 | 21.74 | | SSA | 763.48 | 133.48 | 1,032.61 | 492.59 | −0.08 | 17.48 | | Org | 11.55 | 5.99 | 26.99 | 1.37 | 0.37 | 51.89 | | Agriculture | | | | | | | | Ca | 4.00 | 2.19 | 8.78 | 0.95 | 0.28 | 54.66 | | Mo | 0.93 | 0.41 | 2.35 | 0.47 | 1.18 | 43.95 | | U | 1.48 | 0.19 | 1.94 | 1.20 | 0.59 | 12.64 | | *a*\* | 3.38 | 0.32 | 4.15 | 2.59 | −0.03 | 9.53 | | *c*\* | 9.47 | 1.02 | 11.32 | 7.17 | −0.19 | 10.74 | | *h*\* | 1.20 | 0.01 | 1.23 | 1.18 | 0.19 | 1.12 | | SSA | 1,853.02 | 187.32 | 2,195.72 | 1,458.53 | 0.00 | 10.11 | | Org | 8.51 | 1.37 | 11.36 | 5.86 | 0.07 | 16.13 | |

Source: [Univariate summary](https://alex-koiter.github.io/spatial-variability-soil-manuscript/notebooks/univariate_summary.qmd.html#cell-tbl-univariate-summary)

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| Table 2: Summary statistics for the interpoloated values (10m resolution) for six examples of geochemical and colour soil properties, specific surface area, organic matter content, and seven terrain attributes for each site.   | Property | Mean | SD | Max | Min | Skewness | CV | | --- | --- | --- | --- | --- | --- | --- | | Forest | | | | | | | | Li | 6.44 | 0.63 | 8.57 | 4.34 | −0.16 | 9.73 | | Nb | 0.37 | 0.03 | 0.43 | 0.29 | −0.32 | 8.32 | | Zn | 111.46 | 43.21 | 317.76 | 42.15 | 1.11 | 38.76 | | *h*\* | 1.13 | 0.04 | 1.23 | 1.06 | 0.30 | 3.38 | | *L* | 47.25 | 4.72 | 59.48 | 34.38 | 0.10 | 9.98 | | *v*\* | 4.78 | 0.73 | 6.62 | 2.77 | 0.28 | 15.28 | | SSA | 760.40 | 120.58 | 1,102.95 | 483.70 | 0.12 | 15.86 | | Org | 11.53 | 1.97 | 16.13 | 7.37 | −0.12 | 17.10 | | Elevation | 369.28 | 3.34 | 377.24 | 358.29 | −0.21 | 0.90 | | Rel. Slope Position | 0.22 | 0.26 | 1.00 | −0.12 | 1.55 | 116.75 | | Vert. Dist. Channel | 0.47 | 0.57 | 4.90 | −0.67 | 2.75 | 122.69 | | SAGA Wetness Index | 6.00 | 1.26 | 9.96 | 0.09 | −0.86 | 20.92 | | Catchment Area | 565.06 | 5,109.73 | 209,263.22 | 0.67 | 17.83 | 904.28 | | Profile Curvature | 0.00 | 0.03 | 0.45 | −0.47 | −0.34 | −15,245.25 | | Plan Curvature | 0.00 | 0.01 | 0.30 | −0.26 | 0.56 | 3,382.34 | | Agriculture | | | | | | | | Ca | 4.10 | 2.09 | 9.11 | 1.03 | 0.09 | 51.01 | | Mo | 0.89 | 0.31 | 1.96 | 0.51 | 0.76 | 35.03 | | U | 1.46 | 0.14 | 1.81 | 1.24 | 0.25 | 9.24 | | *a*\* | 3.34 | 0.22 | 3.93 | 2.77 | 0.03 | 6.60 | | *c*\* | 9.35 | 0.76 | 11.08 | 7.39 | −0.16 | 8.17 | | *h*\* | 1.20 | 0.01 | 1.23 | 1.18 | −0.13 | 0.72 | | SSA | 1,867.79 | 129.71 | 2,056.35 | 1,579.16 | −0.43 | 6.94 | | Org | 8.62 | 0.68 | 10.30 | 7.08 | 0.34 | 7.89 | | Elevation | 309.92 | 0.59 | 311.82 | 309.01 | 0.62 | 0.19 | | Rel. Slope Position | 0.72 | 0.34 | 28.79 | −33.19 | −3.62 | 47.84 | | Vert. Dist. Channel | 0.06 | 0.04 | 0.33 | 0.00 | 1.07 | 73.73 | | SAGA Wetness Index | 9.64 | 0.72 | 11.27 | 7.63 | −0.11 | 7.43 | | Catchment Area | 475.21 | 1,884.43 | 41,848.99 | 1.05 | 10.24 | 396.55 | | Profile Curvature | 0.00 | 0.00 | 0.00 | 0.00 | −0.15 | −5,332.23 | | Plan Curvature | 0.00 | 0.00 | 0.00 | 0.00 | 0.23 | 27,643.82 | |

Source: [Univariate summary](https://alex-koiter.github.io/spatial-variability-soil-manuscript/notebooks/univariate_summary.qmd.html#cell-tbl-univariate2-summary)

### 3.2 Spatial analysis

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| Table 3: Geostatistical parameters of the fitted semivariogram models for six examples of geochemical and colour fingerprint properties for each site.   | Property | Model1 | Nugget (Co) | Sill (Co) | Range (m) | C/(C + Co) (%) | Class2 | R2 | RMSE | | --- | --- | --- | --- | --- | --- | --- | --- | --- | | Agriculture | | | | | | | | | | Ca | Exp | 0 | 1.49 | 72.52 | 0 | S | 0.27 | 1.8 | | Forest | | | | | | | | | | Ca | Exp | 0 | 1.49 | 72.52 | 0 | S | 0.27 | 1.8 | | 1 Models are all isotropic. | | | | | | | | | | 2 S = strong spatial dependency (C/(C + Co) % >75); M = moderate spatial dependency (C/(C + Co) % between 75 and 25). | | | | | | | | | |

Source: [Semivariograms](https://alex-koiter.github.io/spatial-variability-soil-manuscript/notebooks/semivariogram.qmd.html#cell-tbl-geochem-semivariogram)

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| Figure 2: Kriged map of select colour (*a\**, *c\**, *h\**) and geochemical (Ca, Mo, U) properties across the agricultural site. |

Source: [Soil property mapping](https://alex-koiter.github.io/spatial-variability-soil-manuscript/notebooks/soil_property_maps.qmd.html#cell-fig-ag_map)

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| --- |
| Figure 3: Kriged map of organic matter content (%), specific surface area (m2 kg-1), and elevation (m) across the agricultural site. |

Source: [Soil property mapping](https://alex-koiter.github.io/spatial-variability-soil-manuscript/notebooks/soil_property_maps.qmd.html#cell-fig-ag_map2)

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| Figure 4: Kriged map of select colour (*h\**, *c\**, *v\**) and geochemical (Li, Nb, Zn) properties across the forested site. |

Source: [Soil property mapping](https://alex-koiter.github.io/spatial-variability-soil-manuscript/notebooks/soil_property_maps.qmd.html#cell-fig-forest_map)

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| --- |
| Figure 5: Kriged map of organic matter content (%), specific surface area (m2 kg-1), and elevation (m) across the forested site. |

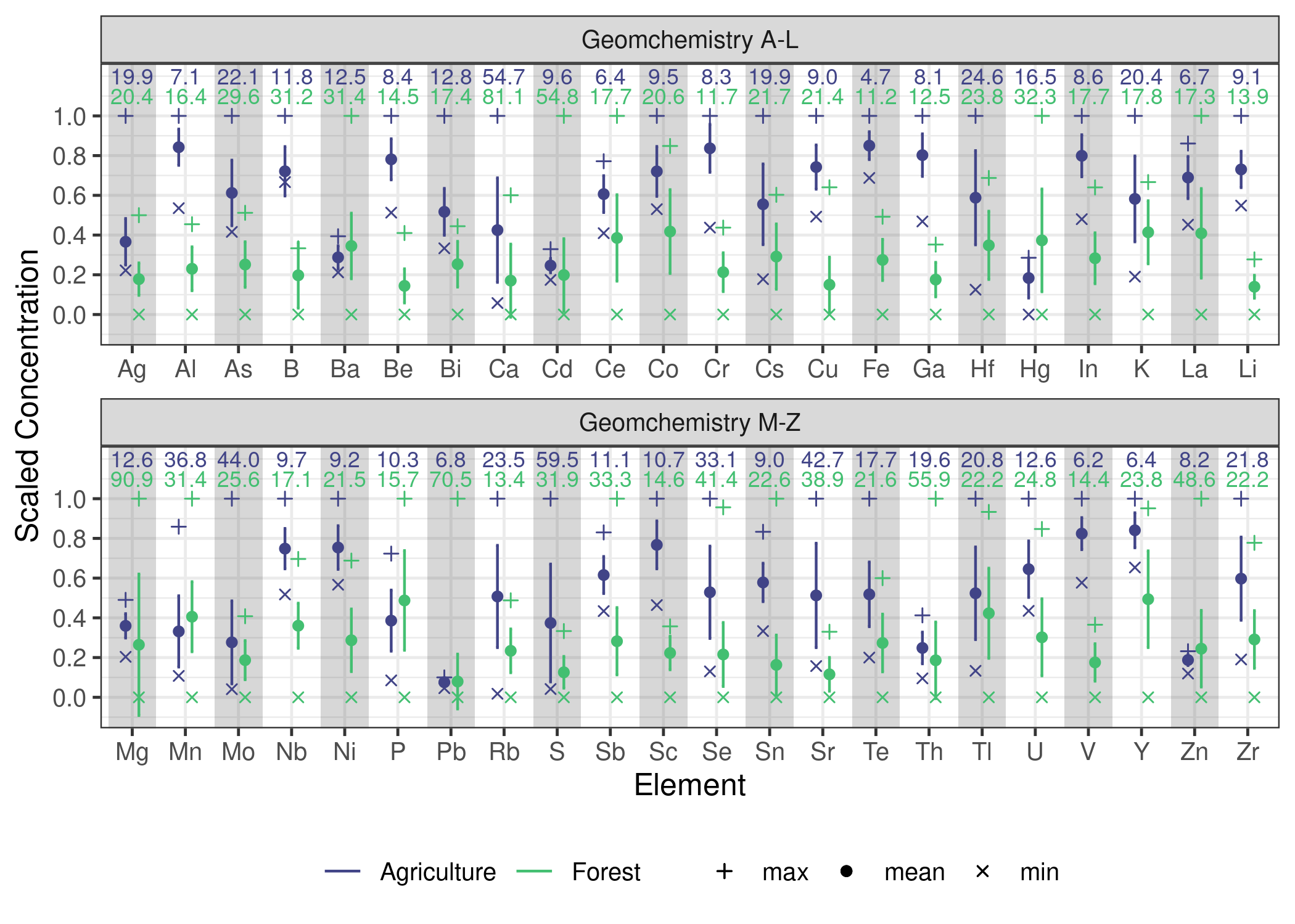
Source: [Soil property mapping](https://alex-koiter.github.io/spatial-variability-soil-manuscript/notebooks/soil_property_maps.qmd.html#cell-fig-forest_map2)

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| Figure 6: Heat map of the Random Forest regresssion results showing the ranking of the importance of terrain attributes (based on % increase in Mean Squared Error) in explaining the spatial variabilty of selected colour and geochemical properties within the agricultural and forested sites. Top panel shows an average ranking for each site and across both sites. |

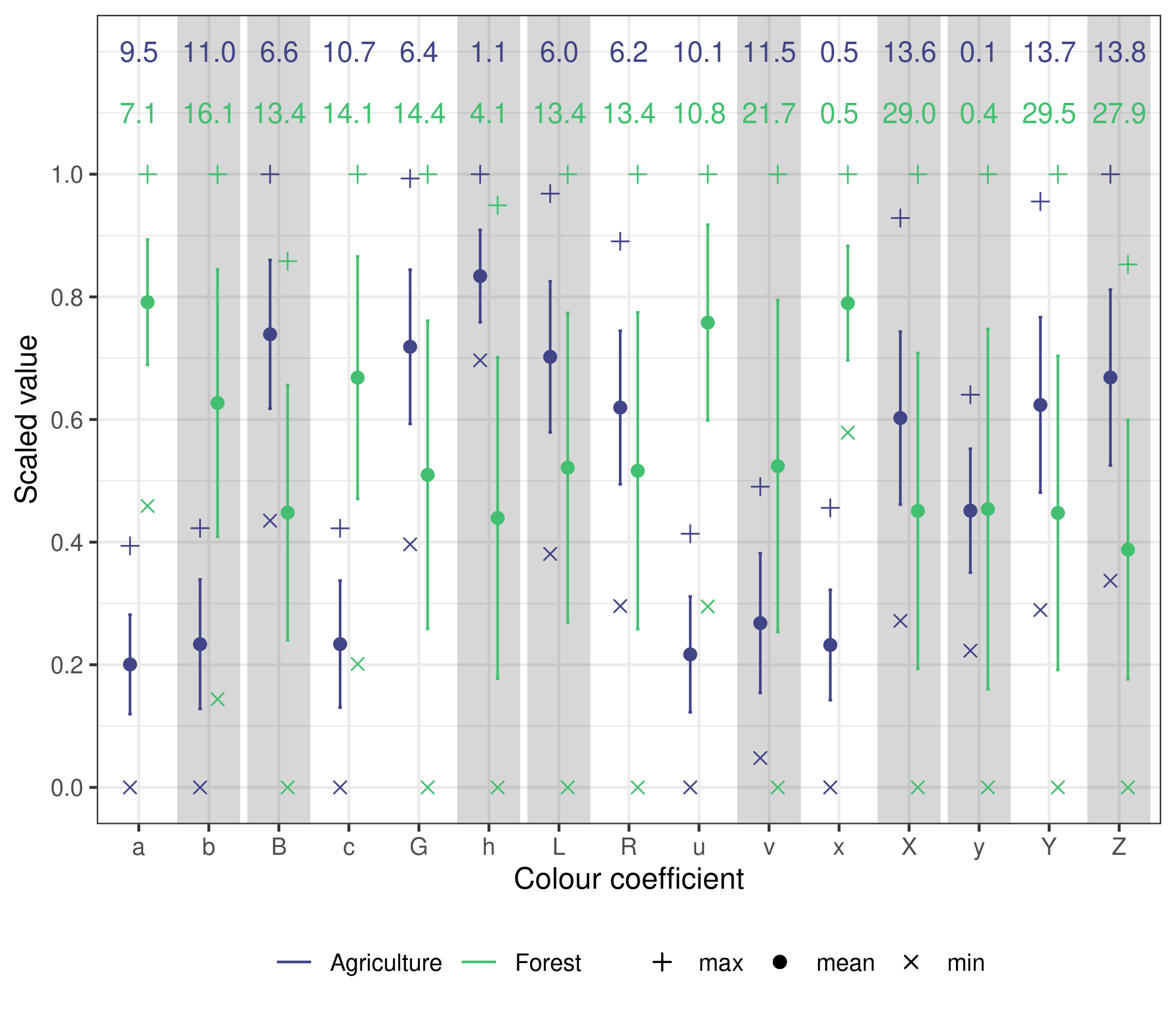
Source: [Random Forest results](https://alex-koiter.github.io/spatial-variability-soil-manuscript/notebooks/RF_results.qmd.html#cell-fig-RF-results)

## References

## Supplemental materials



Summary statistics of all measured geochemical soil properties at both sites. Error bars represent 1SD and the numeric values indicate the CV.



Summary statistics of all measured colour soil properties at both sites. Error bars represent 1SD and the numeric values indicate the CV.