Investigating Relationships Between Soil Morphology, Classification, and Hydraulic Properties

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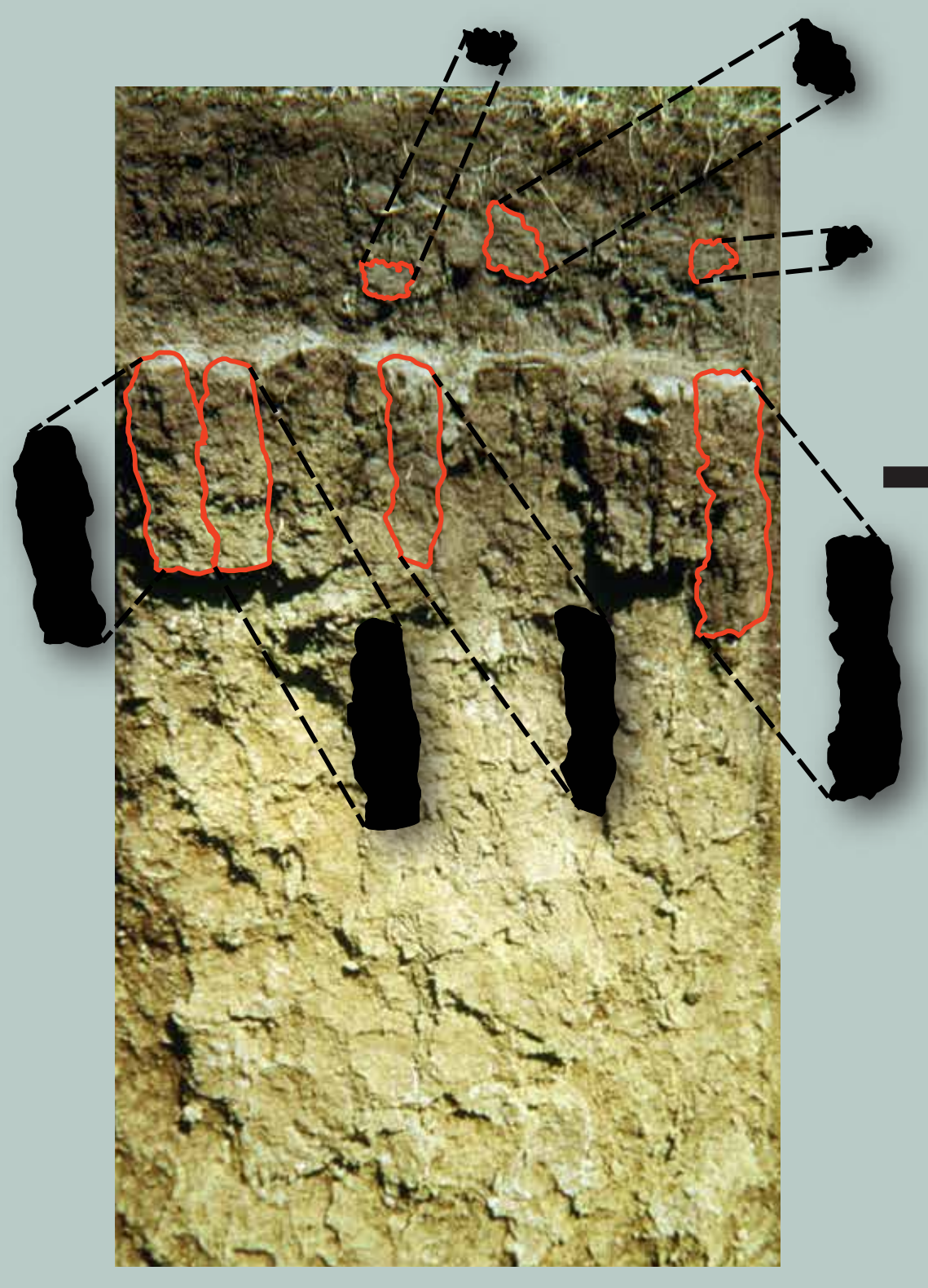
We quantified relationships between soil morphology, classification, and hydraulic properties using more than 78,000 samples in the National Cooperative Soil Survey (NCSS) database. Our goal was to (i) assess which morphological properties (soil structure, texture, organic carbon, and bulk density) significantly correlate with field capacity and wilting point and (ii) examine if the significance of the morphological properties differ by taxonomic order.

1 Quantitative Description of Structure Type

Why emphasize soil structure?

Soil structure has a considerable influence over hydraulic properties of the soil especially near saturation where interpedal pores are important. Because structure is characterized using qualitative categories, it has been difficult to include in previous studies attempting to predict hydraulic properties.

In order to include soil structure as a morphological variable in this study, we developed a method to quantify soil structure type, size, and grade.

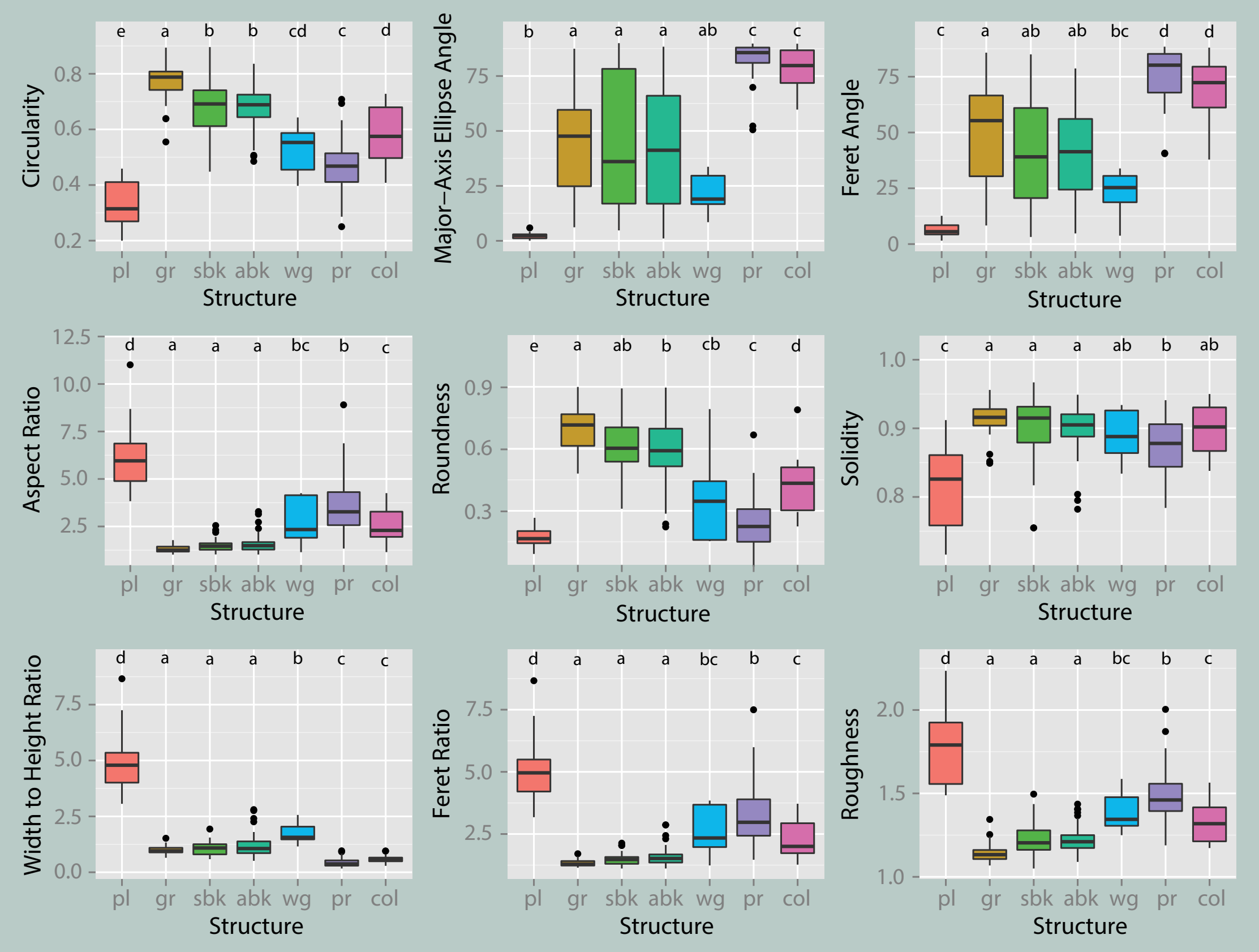


Digitized peds from a profile photograph

ImageJ 1.48

Shape metrics summary

Structure	Abbreviation	N	Circularity	MAE Angle	F angle	Aspect Ratio	Roundness	Solidity	WH Ratio	F ratio	Roughness
Platy	pl	14.00	0.33	2.30	6.14	6.28	0.17	0.82	5.00	5.16	1.79
Granular	gr	29.00	0.77	45.37	50.92	1.32	0.78	0.91	1.00	1.34	1.14
Subangular blocky	sbk	48.00	0.68	42.55	42.73	1.50	0.69	0.90	1.05	1.48	1.22
Angular blocky	abk	56.00	0.67	42.21	41.03	1.57	0.68	0.90	1.16	1.6	1.23
Wedge	wg	9.00	0.52	20.86	23.31	2.73	0.44	0.89	1.77	2.56	1.40
Prismatic	pr	57.00	0.47	83.08	75.61	3.56	0.32	0.87	0.42	3.16	1.48
Columnar	col	23	0.58	78.31	69.60	2.61	0.43	0.9	0.57	2.35	1.33

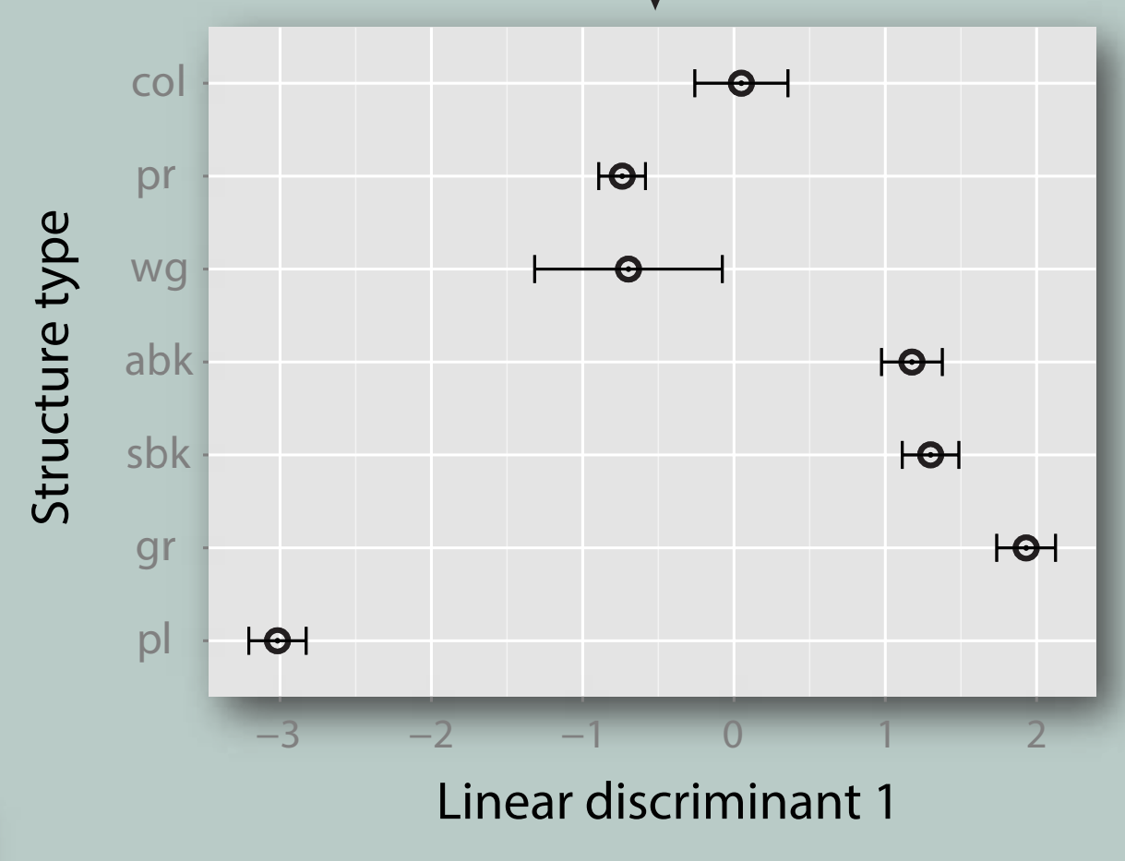


We quantified structure type using multiple shape metrics. A collection of photographs of soil profiles and samples was assembled. Easily recognizable examples of each structure type in the photographs were identified and outlined using Adobe® Illustrator® to create silhouettes that were analyzed using ImageJ 1.48 for a variety of shape metrics. Structure type means were separated using Tukey's Honest Significant Difference test; identical letters on the boxplots indicate means that are not significantly different at an α-level of 0.05.

Three independent shape metrics were identified (major-axis ellipse angle, roundness, and solidity) and run using discriminant analysis to compute a single comprehensive shape metric for each structure.

$$LD1 = 1.53\, z_{round} + 0.403\, z_{angle} + 0.218\, z_{solidity}$$

Linear discriminant (LD1) values were added to the NCSS database to replace the qualitative description of structure type.



2 Quantitative Description of Structure Grade and Size

We calculated the geometric mean of each structure size class; grade was quantified using evenly spaced values from weak (1) to very strong (3.5). These values were added to the NCSS database to replace the qualitative description of structure size and grade; these were analyzed with the other morphological varaibles using multiple linear regression.

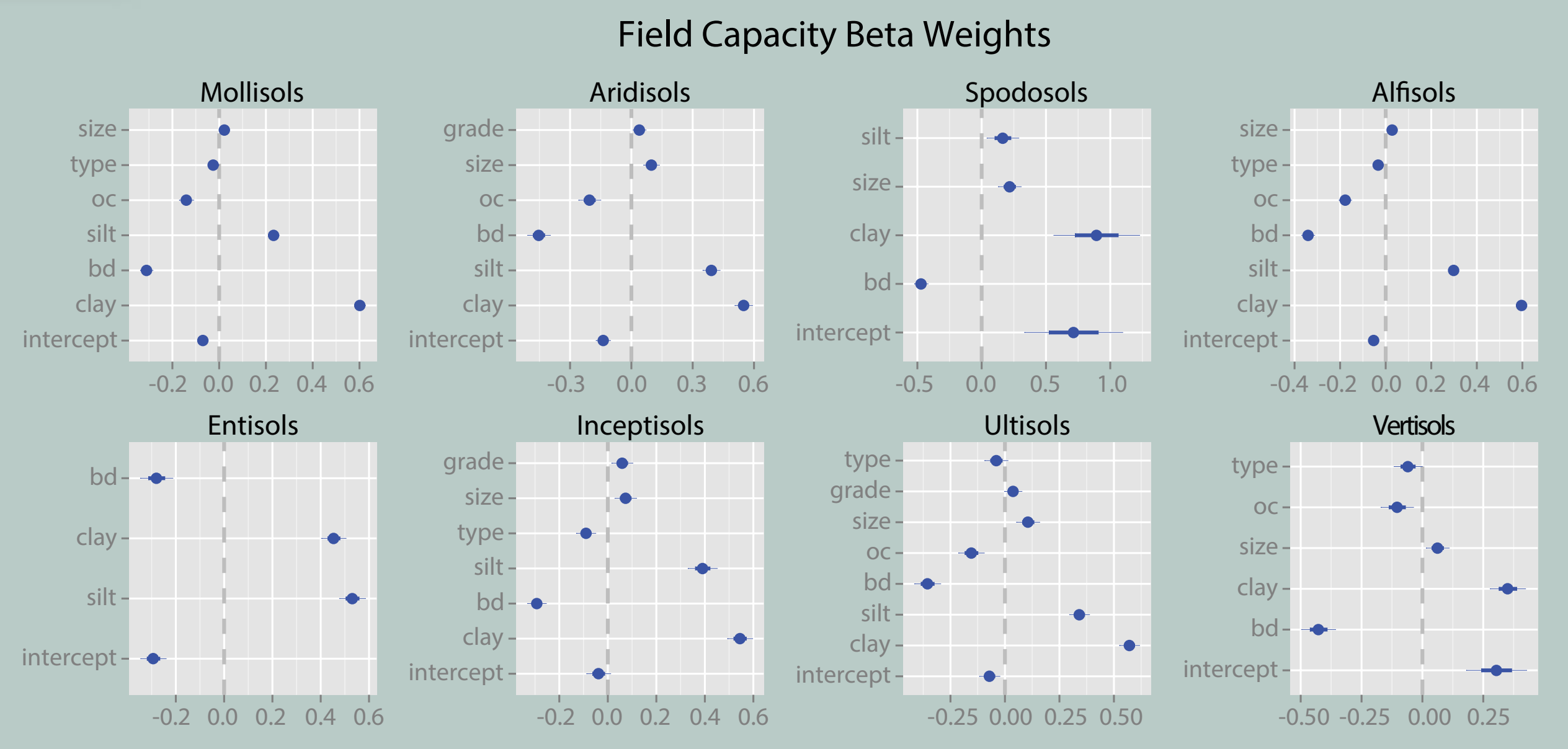
Grade	Value
Structureless	0
Weak	1
Weak and moderate	1.5
Moderate	2
Moderate and strong	2.5
Strong	3
Very strong	3.5

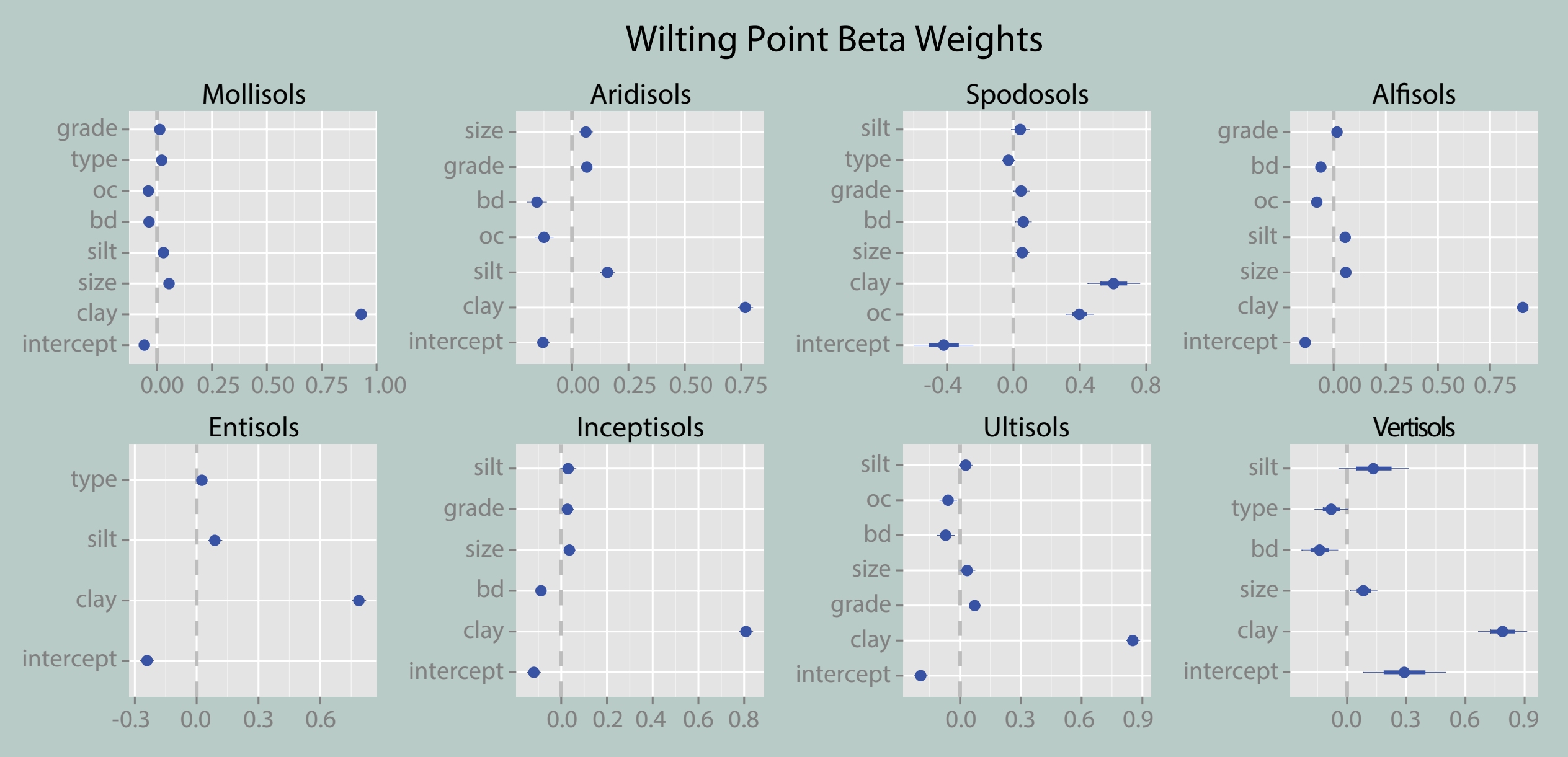
Size Class	Upper Boundary (mm)	Lower Boundary (mm)	Geometric Mean (mm)
Granular/Platy			
Fine	1	2	1.4
Medium	2	5	3.2
Coarse	5	10	7.1
Very coarse	10	-	10.0
Columnar/Prismatic/Wedge			
Very fine	0.1	10	1.0
Fine	10	20	14.1
Medium	20	50	31.6
Coarse	50	100	70.7
Very coarse	100	500	223.6
Extremely coarse	500	-	500.0
Angular/Subangular Blocky			
Very fine	0.1	5	0.7
Fine	5	10	7.1
Medium	10	20	14.1
Coarse	20	50	31.6
Very coarse	50	-	50.0

3 Soil Orders and Morphological Properties

These plots show the *beta* weights of the forward-selection standard regressions for 8 widely-distributed soil orders using all morphological variables for field capacity (-33 kPa) and wilting point (-1500 kPa). Variables that significantly correlate to hydraulic properties are shown on the y-axis; those furthest away from zero explain more of the variability in the dependent variable than values closer to zero. Soil orders retaining the same variables after the selection process have similar relationships between morphology and hydraulic properties.

Clay content explains most of the variability in wilting point and less so in field capacity. Bulk density, silt content, and organic carbon show strong relationships with field capacity for most of these soil orders. Structure showed significant relationships between both field capacity and wilting point. Morphological properties of Entisols, Spodosols, and Vertisols appear to have unique relationships with field capacity and wilting point compared to other soil orders.

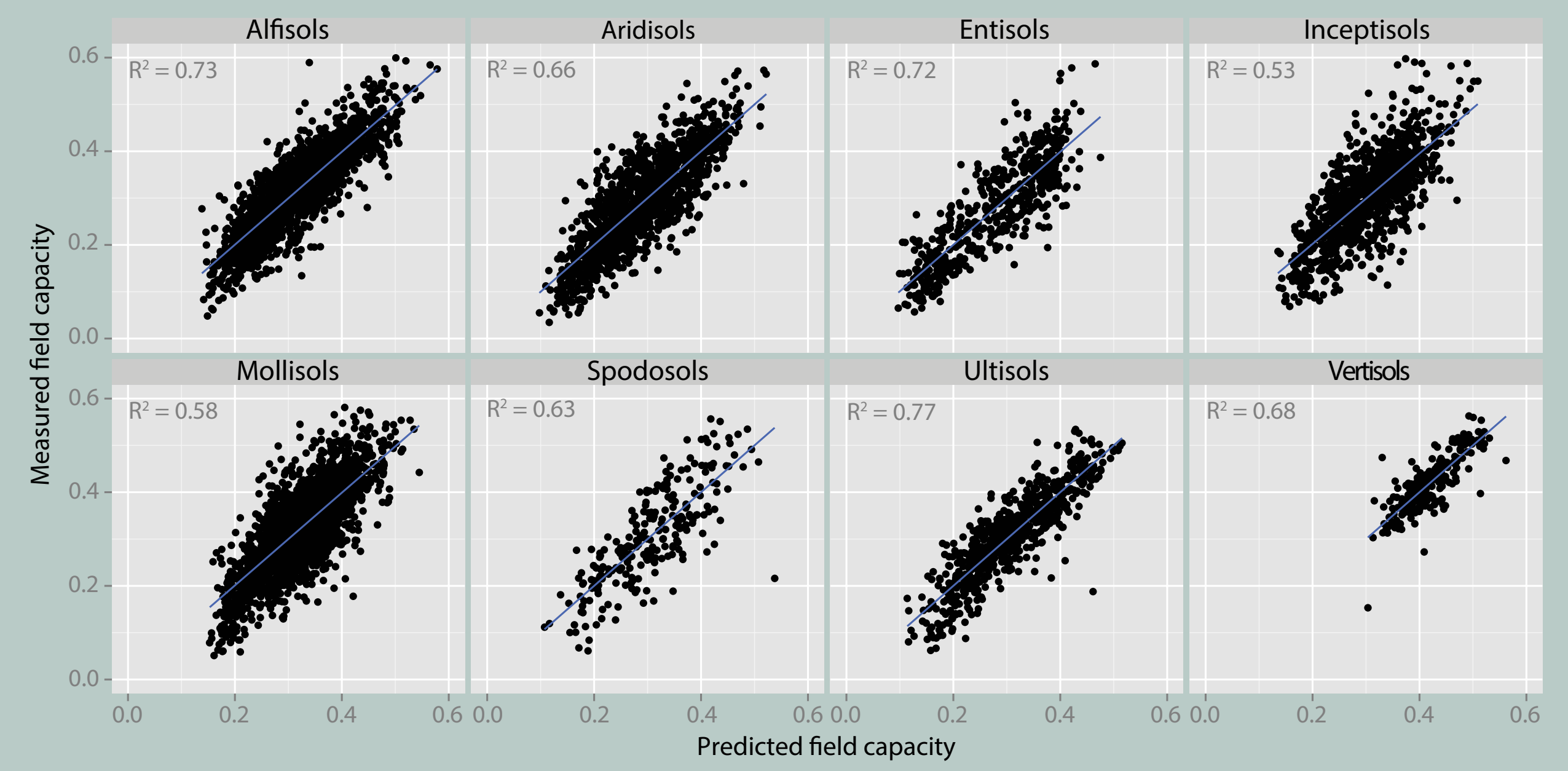


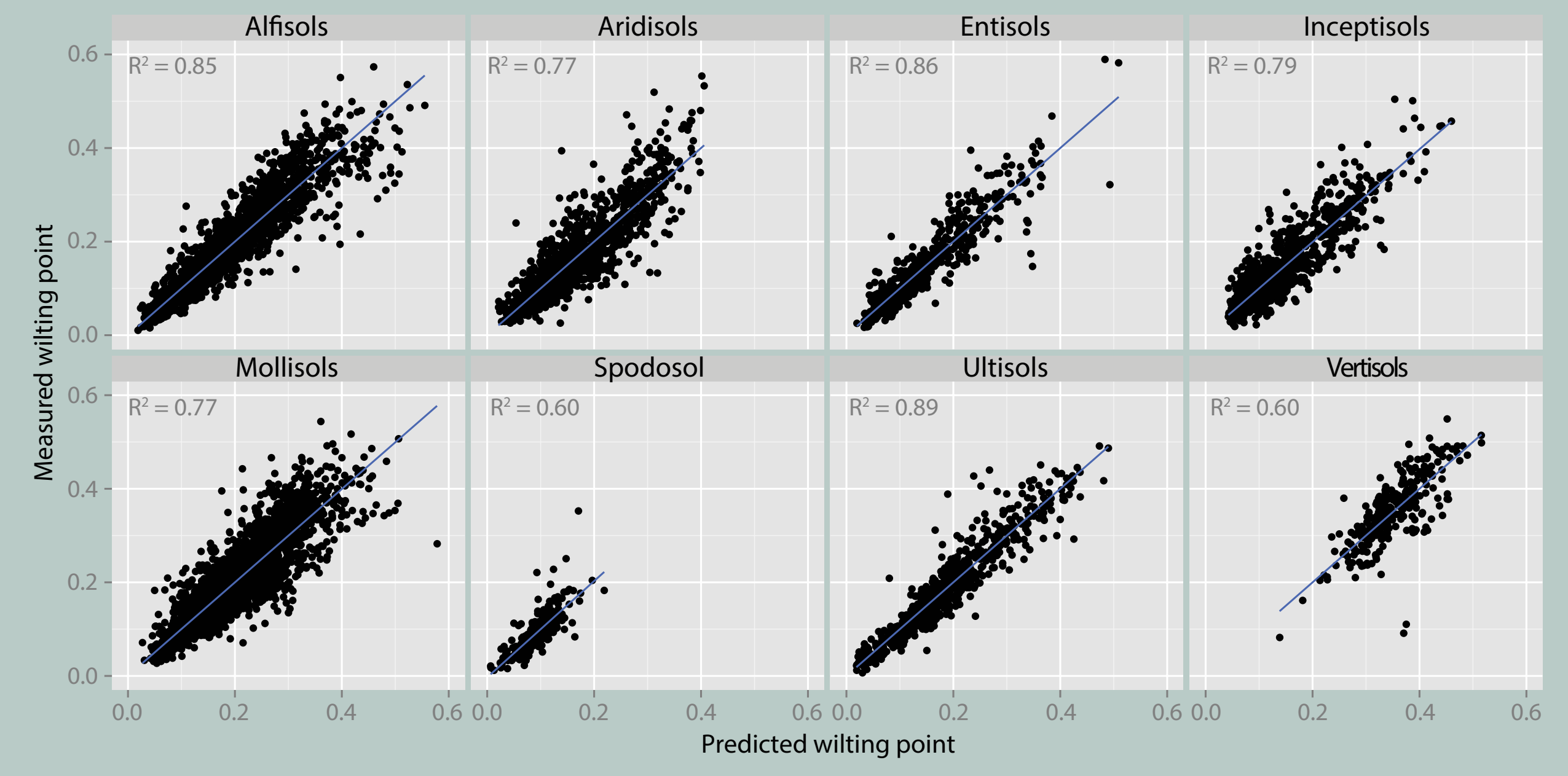


oc = organic carbon
bd = bulk density (1/3 bar)

4 Multivariate Analysis Results

Predicted field capacity and wilting point from the regressions were plotted against measured values to evaluate the fit of each regression model. The models showed strong coefficients of determination ranging between ($0.53 \leq R^2 \leq 0.89$) and slightly weaker relationships with field capacity ($0.53 \leq R^2 \leq 0.77$) compared to wilting point ($0.60 \leq R^2 \leq 0.89$) likely due to factors unaccounted for in this study such as land use and the abundance of plant roots and soil fauna. Two exceptions to this trend were seen in Spodosols and Vertisols where the model did better in predicting wilting point than field capacity. The best overall fits were observed with Alfisols, Entisols, and Ultisols.





5 Summary and Future Work

Our conclusions are that: (1) Not surprisingly, clay content is the most important morphological property for predicting field capacity and wilting point. (2) Entisols, Spodosols, and Vertisols appear to have unique relationships between morphology and hydraulic properties compared to other soil orders. This suggests that hydrologic interpretations might be better drawn from relationships established with those soil orders independently of the others examined in this study. (3) Future work is warranted to better understand the relationship between factors that affect soil structure and macropores such as land use and root distribution and their effect on field capacity. We propose that soil orders can be grouped based on the relationships between morphology and hydraulic properties by statistically comparing regression models.

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