IOWA STATE UNIVERSITY

Department of Agronomy

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Digital Hillslope Position as an Alternative Method for Soil Mapping: A Case Study for Soil Surface Properties and Topsoil Thickness in Iowa

Introduction

- **Soil-landscape paradigm:** Fundamental concept for soil mapping by which local soil property variation in texture and profile development is strongly governed by topography metrics (i.e. slope, profile curvature, relative slope position) under similar soil-forming environments (Hudson, 1992) (Figs. 1 & 2).

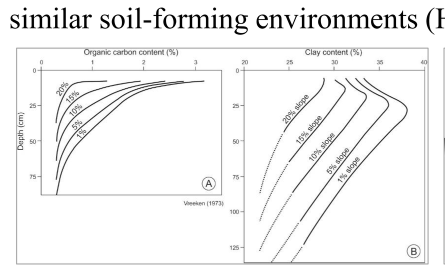


Figure 1. Depth functions of soil organic carbon (A) and clay content (B) for the hillside of an Iowa Mollisol in relationship with slope gradient (from Schaetzl and Thompson, 2015; pg. 462).

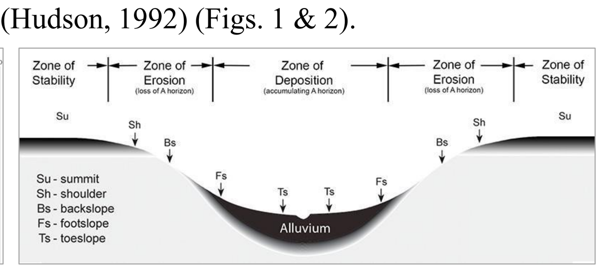


Figure 2. Hillslope position controls thickness of A horizon which is governed by hillslope topography metrics with differing erosion and deposition regimes (Miller and Schaetzl, 2015).

- By developing a soil-landscape model for a particular region (Fig. 3), traditional soil mappers could effectively delineate bodies of soil on the landscape by observing **less than one-thousandth** of the soil below. But, they were limited by relying on aerial stereophotographs to interpret topography. Ability to delineate was biased and limited by 1) resolution of the aerial photo, 2) cartographic scale (~1:24,000), and 3) the individual soil surveyor's interpretation of the landscape (Smith and Hudson, 2002) (Fig. 4).

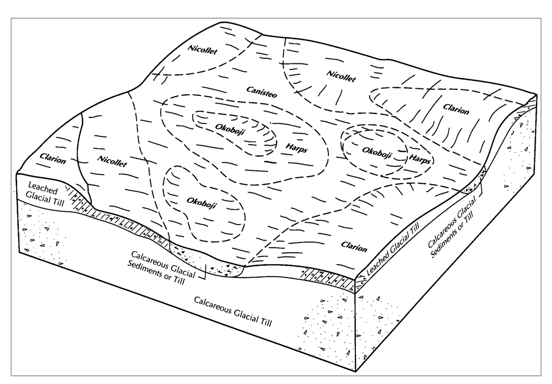


Figure 3. The conceptual soil-landscape model used in traditional soil mapping for the soil-forming region of the Bemis Till Plain in Polk Co., Iowa, also known as a soil block diagram (NCSS, 2000).

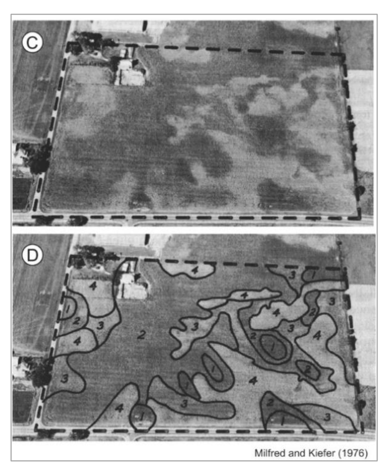


Figure 4. Soil map unit lines drawn based on aerial photographs in traditional soil mapping (from Schaetzl and Thompson, 2015; pg. 157).

- The Digital Hillslope Position (DHP) algorithm (Miller and Schaetzl, 2015) is a tool used to classify the five fundamental units of hillslope position (Figs. 2 & 5) based on three terrain metrics calculated from Digital Elevation Model (DEM) (Fig. 6). The DHP is a quantifiable and repeatable terrain classification technique that can be extended to different soil-forming environments (available for ArcGIS at www.geographer-miller.com/relief-analysis-toolbox).

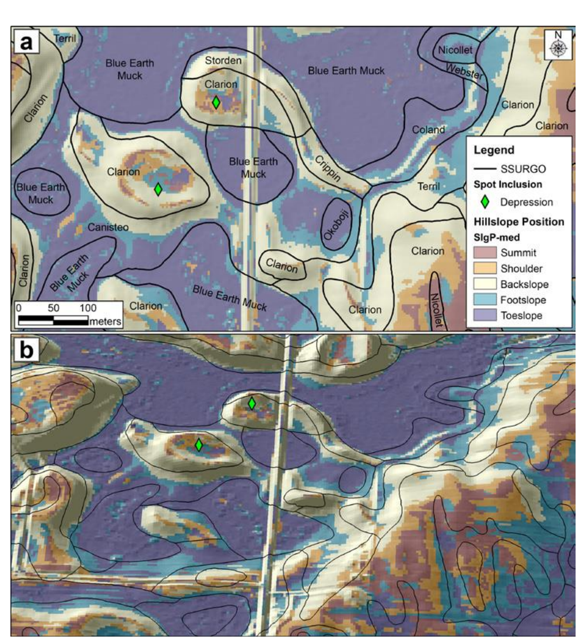


Figure 5. DHP terrain classification with overlain soil map unit boundaries in Dickinson Co., IA -Bemis Till Plain (Miller and Schaetzl, 2015; pg. 143).

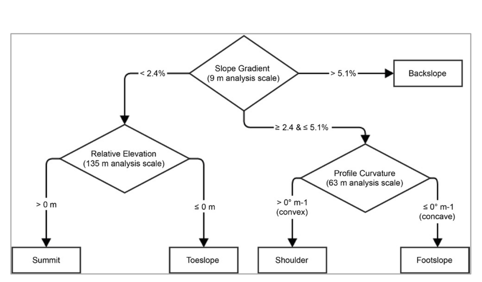


Figure 6. DHP classification decision tree workflow from Miller and Schaetzl (2015).

Objectives

- Determine if DHP classes improve soil maps by reducing the variation within soil map classes for surface soil properties, i.e. clay, silt, organic matter (OM) and soil A horizon thickness.
- Explore the distribution of soil properties by DHP class for each soil-forming environment, i.e. for Iowa and each physiographic region (Fig. 7) to determine effectiveness of DHP to explain soil property variation associated with hillslope processes.

Methods

- The DHP classification algorithm does not differentiate floodplain positions in the landscape. Therefore, classification of a floodplain was determined by the mean vertical distance to channel network of mapped alluvium per physiographic region on slopes (9-m analysis scale) < 1.4 degrees.
- Vertical Distance to Channel Network (VDCN) was calculated with SAGA GIS 6.4.1 (Conrad et al., 2019) on a 10-m resolution DEM of Iowa (NED, 2018) for channels with a Strahler stream order ≥ 3 (Iowa DNR, 2019).
- Zonal statistics were performed in ArcGIS 10.6 on generalized alluvium to calculate mean VDCN.
- The physiographic regions were delineated by McDanel et al., (unpublished data, 2019) based on soil parent material and physiography. The alluvium was from a 10-m classified parent material raster developed by McDanel and Miller (unpublished data, 2018) which originated from the dominant component of each soil map unit in the gSSURGO database (Soil Survey Staff, 2018).
- The modified DHP algorithm was subsequently computed for floodplain classification via raster calculator in ArcGIS 10.6 to produce a 10-m resolution raster (Figs. 7 & 8).
- Iowa pedons with surface horizon clay, silt, pH (1:1 H_2O) (n ≈ 1,300), OM (n ≈ 86) , and soil A horizon thickness (n ≈ 14,000) were collected from the NCSS Soil Characterization Database (Soil Survey Staff, 2018a) and the National Soil Information System (Soil Survey Staff, 2018b). Data manipulation, statistical summaries, and data distribution graphic generation were performed in Microsoft Excel 2016 (Microsoft, Redmond WA, 2016) and Rstudio 1.1.463 (RStudio Team, 2018) with the AQP (Beaudette et al., 2013) and ggplot2 packages (Wickham, 2016).
- Soil map unit components for comparison with the DHP classification were extracted based on the dominant component of delineation from the gSSURGO 2018 database (Soil Survey Staff, 2018c).

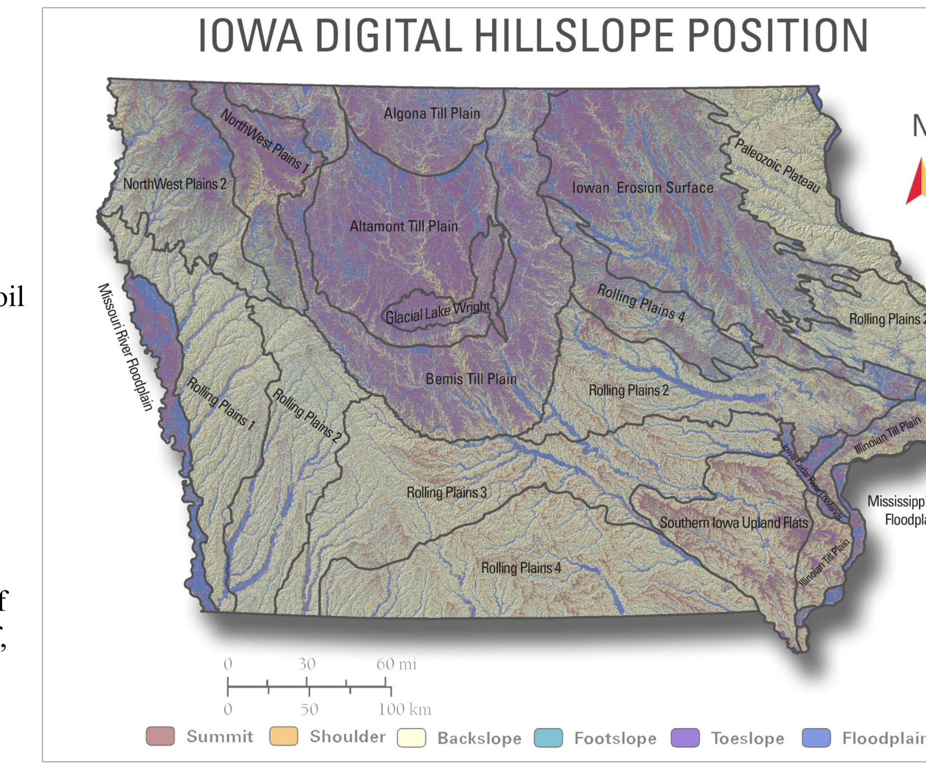


Figure 7. DHP modified classification algorithm for floodplain and physiographic regions for the state of Iowa.

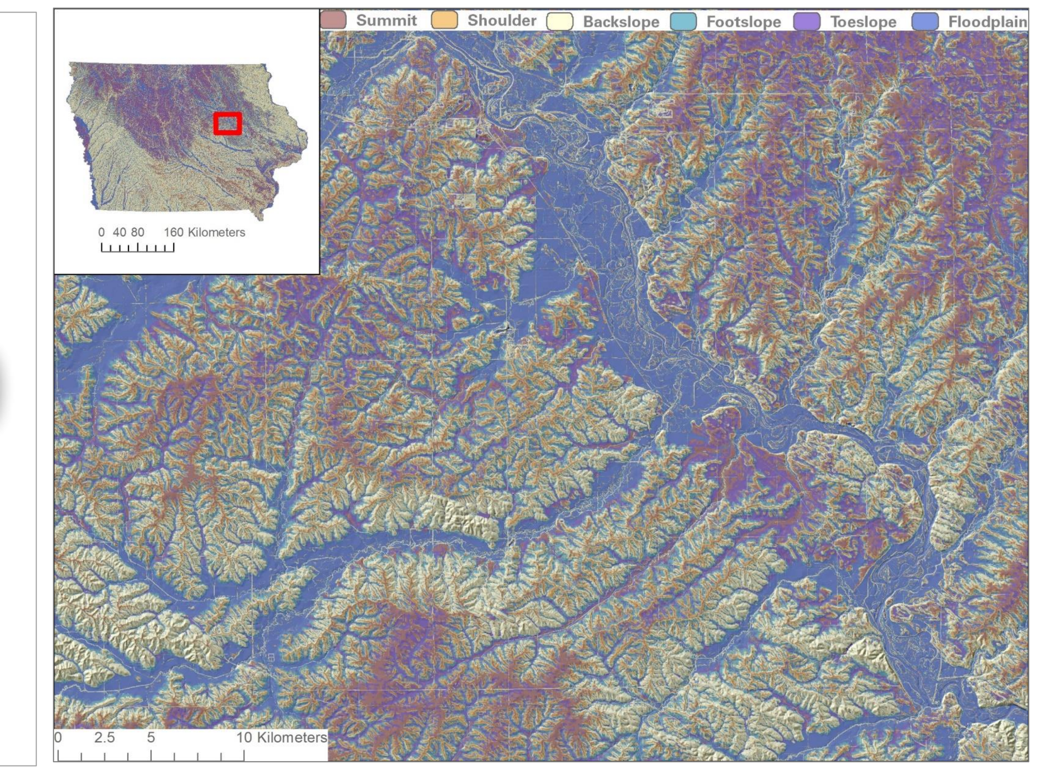


Figure 8. DHP modified classification algorithm for floodplain zoomed in on a portion of the Iowan Erosion Surface and Rolling Plains 4.

Results

Physiographic Region

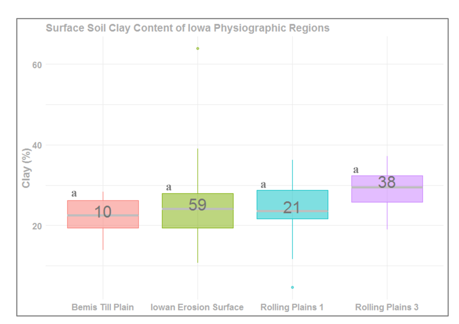
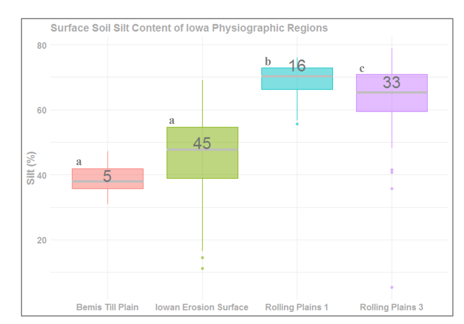


Figure 9.



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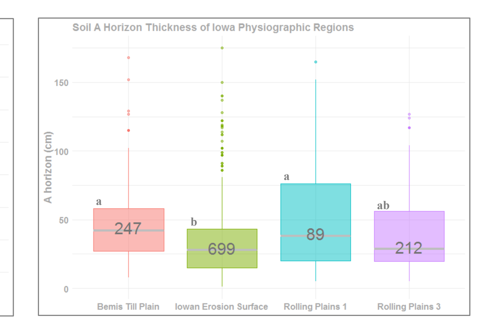
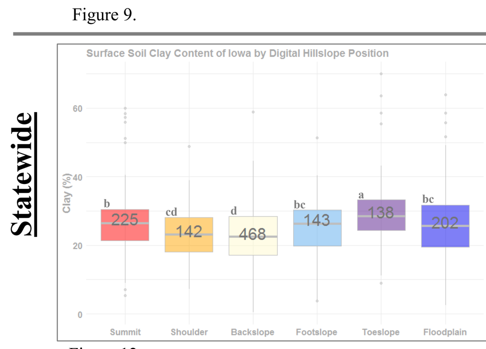


Figure 11.

Statewide



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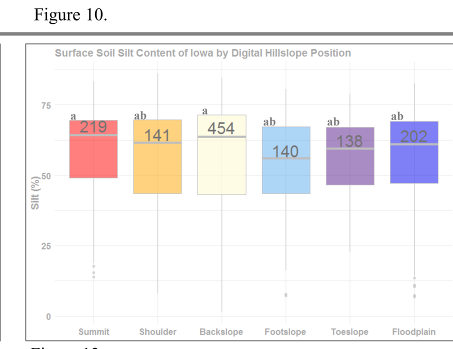


Figure 13.

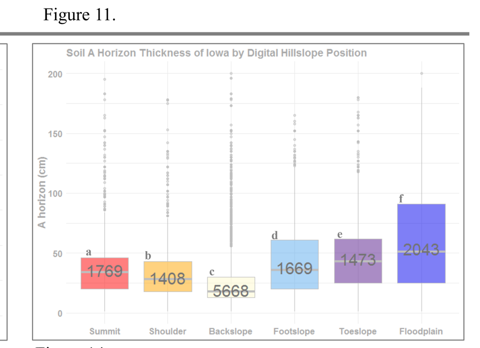
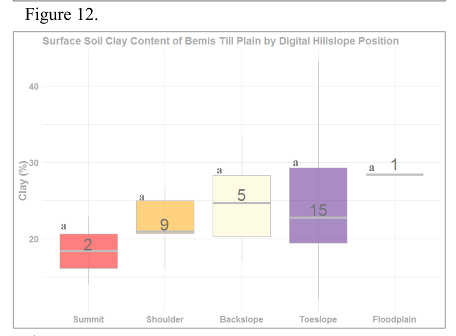


Figure 14.

Bemis Till Plain



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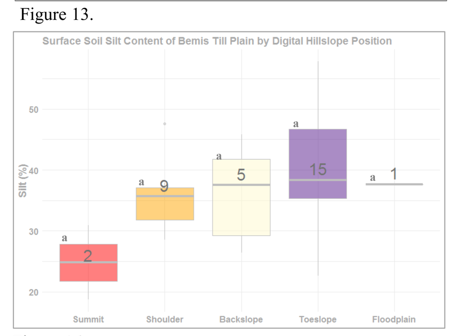

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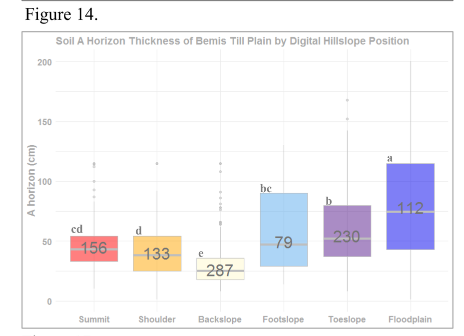
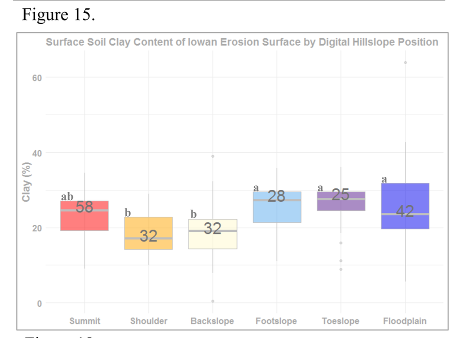


Figure 17.

Iowan Erosion Surface



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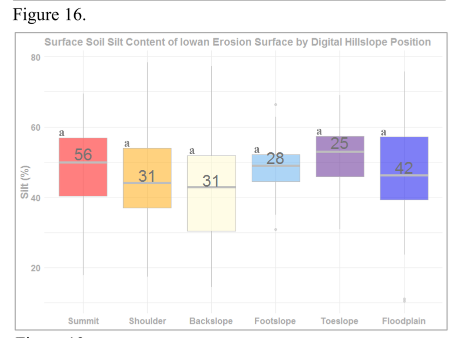

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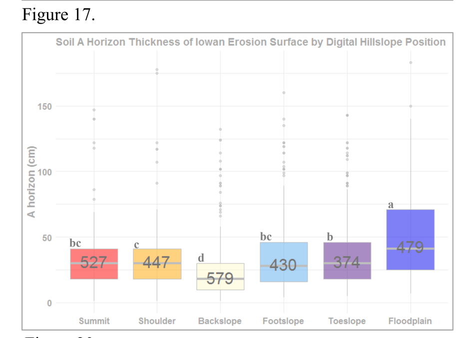
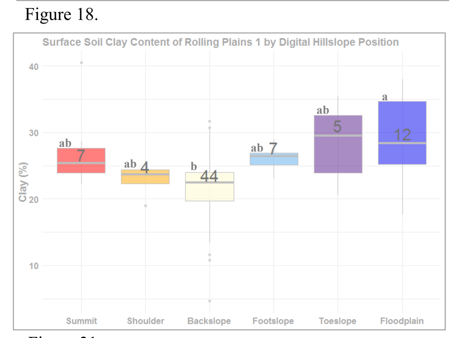


Figure 20.

Rolling Plains 1



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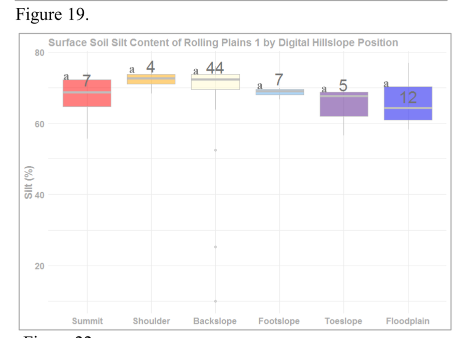


Figure 22.

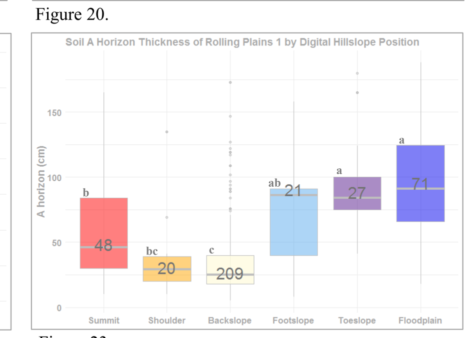
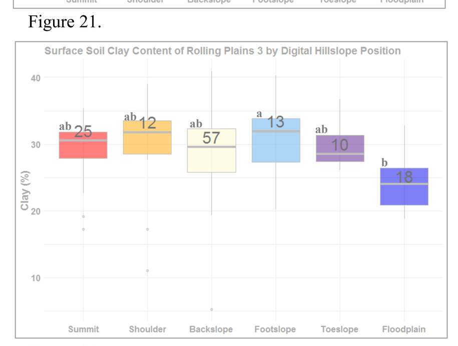


Figure 23.

Rolling Plains 3



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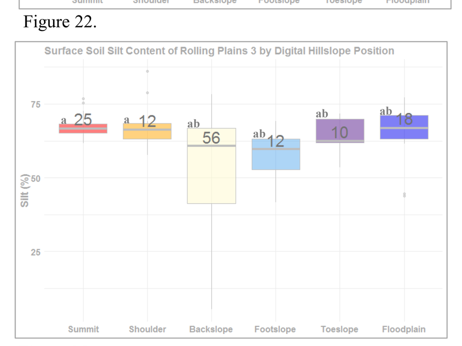


Figure 25.

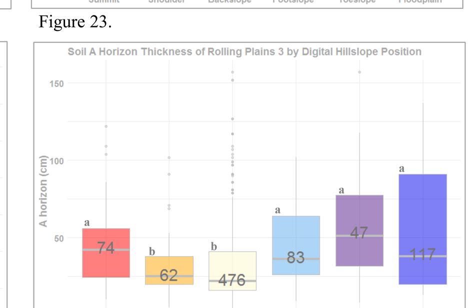


Figure 26.

Table 1. Summary statistics for surface soil clay content (%) of the six most frequently sampled soil map units and associated DHP classes.

Soil Map	DHP	n	mean	std. dev.	min	max
Fayette		**62**	**19**	**5**	**6**	**32**
	1-Summit	7	17	2	15	20
	2-Shoulder	5	19	4	15	26
	3-Backslope	48	19	5	6	30
	4-Footslope	2	25	10	18	32
Colo		**54**	**30**	**4**	**21**	**40**
	1-Summit	2	30	1	29	31
	2-Shoulder	1	29		29	29
	3-Backslope	8	31	6	21	40
	4-Footslope	8	28	4	22	33
	5-Toeslope	14	29	3	24	37
	6-Floodplain	21	30	5	24	38
Marshall		**32**	**31**	**3**	**25**	**36**
	1-Summit	14	30	2	27	35
	2-Shoulder	5	30	3	25	32
	3-Backslope	12	32	2	28	36
	5-Toeslope	1	31		31	31
Clyde		**27**	**28**	**6**	**11**	**36**
	1-Summit	4	24	9	11	30
	2-Shoulder	2	28	0	28	29
	3-Backslope	1	24		24	24
	4-Footslope	9	29	5	20	36
	5-Toeslope	11	29	5	16	36
Tama		**26**	**26**	**3**	**18**	**33**
	1-Summit	11	25	4	18	33
	2-Shoulder	6	24	3	19	27
	3-Backslope	4	26	4	23	30
	4-Footslope	5	28	1	26	30
Downs		**26**	**23**	**4**	**13**	**28**
	1-Summit	3	24	1	22	25
	2-Shoulder	11	21	5	16	28
	3-Backslope	10	23	4	13	28
	4-Footslope	1	17		17	17
	5-Toeslope	1	27		27	27

Table 2. Summary statistics for surface soil silt content (%) of the six most frequently sampled soil map units and associated DHP classes.

Soil Map	DHP	n	mean	std. dev.	min	max
Colo		**54**	**64**	**7**	**38**	**73**
	1-Summit	2	67	0	66	67
	2-Shoulder	1	69		69	69
	3-Backslope	8	64	8	48	72
	4-Footslope	8	57	11	38	69
	5-Toeslope	14	68	6	53	73
	6-Floodplain	21	63	6	48	72
Fayette		**49**	**71**	**14**	**22**	**85**
	1-Summit	6	80	3	77	83
	2-Shoulder	5	75	3	71	79
	3-Backslope	36	70	16	22	85
	4-Footslope	2	61	16	50	72
Marshall		**32**	**64**	**8**	**33**	**71**
	1-Summit	14	67	3	63	71
	2-Shoulder	5	67	1	66	69
	3-Backslope	12	60	12	33	71
	5-Toeslope	1	67		67	67
Clyde		**27**	**51**	**8**	**22**	**66**
	1-Summit	4	46	16	22	56
	2-Shoulder	2	55	2	54	56
	3-Backslope	1	55		55	55
	4-Footslope	9	51	6	45	63
	5-Toeslope	11	51	7	41	66
Tama		**26**	**71**	**4**	**64**	**79**
	1-Summit	11	71	5	64	79
	2-Shoulder	6	71	4	64	77
	3-Backslope	4	72	5	67	76
	4-Footslope	5	69	1	68	69
Downs		**26**	**71**	**8**	**40**	**81**
	1-Summit	3	72	1	72	73
	2-Shoulder	11	71	11	40	80
	3-Backslope	10	72	4	67	81
	4-Footslope	1	80		80	80
	5-Toeslope	1	61		61	61

Table 3. Summary statistics for surface soil pH (1:1 H2O) of the six most frequently sampled soil map units and associated DHP classes.

Soil Map	DHP	n	mean	std. dev.	min	max
Fayette		**60**	**6.3**	**0.8**	**2.1**	**7.5**
	1-Summit	7	6.5	0.6	5.5	7.4
	2-Shoulder	4	6.4	0.6	5.6	6.9
	3-Backslope	47	6.2	0.8	2.1	7.2
	4-Footslope	2	7.2	0.4	6.9	7.5
Colo		**49**	**6.2**	**0.7**	**4.1**	**7.6**
	1-Summit	2	6.0	0.2	5.8	6.1
	2-Shoulder	1	6.6		6.6	6.6
	3-Backslope	8	6.4	0.5	5.9	7.3
	4-Footslope	8	6.0	1.0	4.1	7.3
	5-Toeslope	13	5.9	0.7	4.8	7.6
	6-Floodplain	17	6.6	0.6	5.8	7.6
Marshall		**29**	**6.0**	**0.8**	**4.8**	**7.8**
	1-Summit	12	6.0	0.7	5.2	7.0
	2-Shoulder	5	6.4	0.8	5.6	7.6
	3-Backslope	11	5.9	0.8	4.8	7.8
	5-Toeslope	1	5.3		5.3	5.3
Downs		**29**	**6.5**	**0.7**	**5.2**	**7.6**
	1-Summit	5	6.3	0.6	5.5	7.2
	2-Shoulder	11	6.6	0.7	5.2	7.6
	3-Backslope	11	6.4	0.8	5.2	7.4
	4-Footslope	2	6.7	0.1	6.6	6.7
Tama		**24**	**6.2**	**0.6**	**5.3**	**7.2**
	1-Summit	10	6.6	0.5	5.6	7.2
	2-Shoulder	6	5.9	0.7	5.3	7.1
	3-Backslope	4	5.9	0.4	5.3	6.3
	4-Footslope	4	6.1	0.4	5.7	6.4
Monona		**23**	**6.6**	**0.9**	**4.4**	**7.7**
	1-Summit	4	5.7	1.0	4.4	6.9
	2-Shoulder	2	6.4	0.5	6.0	6.7
	3-Backslope	17	6.8	0.8	4.6	7.7

Table 4. Summary statistics for soil A horizon thickness of the six most frequently sampled soil map units and associated DHP classes.

Soil Map	DHP	n	mean	std. dev.	min	max
Fayette		**748**	**21**	**26**	**1**	**183**
	1-Summit	30	30	43	7	183
	2-Shoulder	79	15	12	2	74
	3-Backslope	579	21	26	1	183
	4-Footslope	55	26	22	3	114
	5-Toeslope	5	25	3	20	28
Colo		**598**	**77**	**33**	**1**	**183**
	1-Summit	7	102	22	71	130
	2-Shoulder	7	75	40	33	130
	3-Backslope	72	69	38	18	183
	4-Footslope	178	72	33	15	132
	5-Toeslope	111	84	29	13	152
	6-Floodplain	223	80	33	1	152
Shelby		**458**	**26**	**17**	**3**	**122**
	1-Summit	3	25	9	20	36
	2-Shoulder	6	22	6	18	33
	3-Backslope	440	26	17	3	122
	4-Footslope	9	31	23	10	88
Downs		**442**	**25**	**19**	**2**	**130**
	1-Summit	54	30	20	9	127
	2-Shoulder	81	31	20	8	89
	3-Backslope	277	23	19	2	130
	4-Footslope	25	29	22	10	121
	5-Toeslope	3	25	7	20	33
	6-Floodplain	2	19	8	13	25
Dubuque		**347**	**14**	**13**	**1**	**114**
	1-Summit	7	13	5	8	20
	2-Shoulder	19	19	4	6	23
	3-Backslope	307	14	14	1	114
	4-Footslope	14	20	6	4	24
Dickinson		**344**	**38**	**13**	**1**	**135**
	1-Summit	51	37	13	18	86
	2-Shoulder	64	34	12	1	58
	3-Backslope	103	34	13	10	66
	4-Footslope	35	42	21	17	135
	5-Toeslope	33	43	8	30	61
	6-Floodplain	58	45	8	30	61

Red data indicate **standard deviation** of the DHP class was **greater** than the soil map unit population and **green data** indicate the **standard deviation** of the DHP class was **less** than the soil map unit.

Conclusions

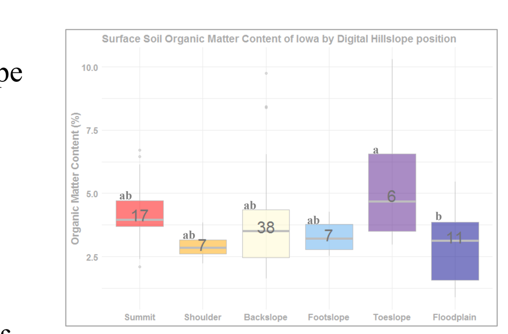
Six Major Map Unit Comparisons with DHP

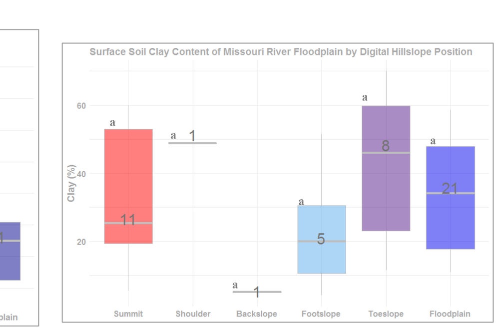
- The highest number of hillslope position observations corresponded with the typical landscape position of soil map units. Floodplain delineation seemed to be effective based on high observations for the alluvial Colo soil map unit (Tables 1-4).
- Mean surface clay content tended to be higher in depositional hillslope positions (Table 1.)
- In loess-derived soils, mean surface silt content was generally higher in the upland hillslope positions (Table 2).
- The mean surface pH was lowest in Backslope positions of the Fayette, Tama, and Marshall for a majority of all hillslope positions. The Downs and Fayette soils had highest mean surface pH values in depositional hillslope positions (Table 3).
- Thinner mean soil A horizons for soil map units corresponded with erosional hillslope positions with the exception of Shelby – Bs, Downs – Sh, and Dubuque – Sh & Bs (Table 4).

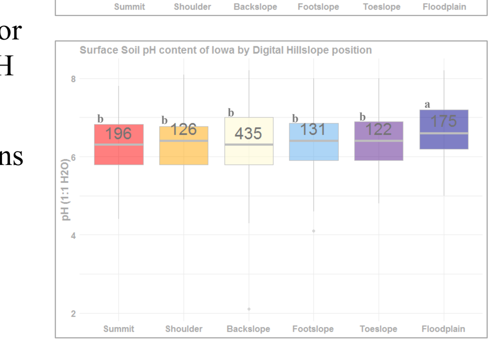
DHP Soil Property Boxplots by State and Physiographic Region

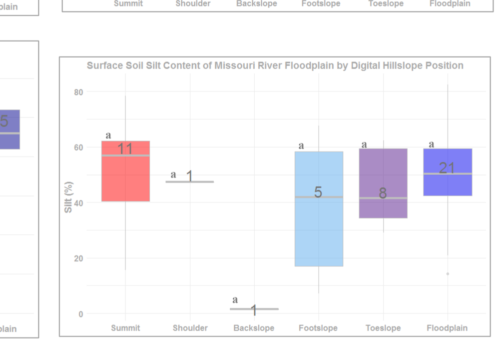
- Statewide median soil A horizon thickness and clay content directly corresponded with anticipated hillslope processes (Fig. 14). Median A horizon thickness patterns with associated with hillslope processes were apparent in the Bemis Till Plain (Fig. 17) and Rolling Plains 1 & 3 (Figs. 23 & 26).
- Hillslope particle-sorting processes (accumulation of fine particles in depositional zones and coarse particles in erosional zones) were apparent in the Iowan Erosion Surface (Figs. 18-19), Rolling Plains 1 (Figs. 19-20), and Rolling Plains 3 (Fig. 24-25). The Bemis Till Plain has a general accumulation of fine particles increasing downslope.

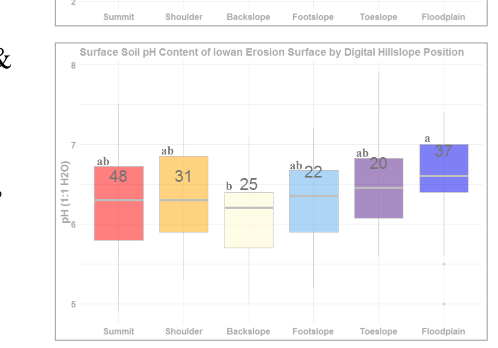
Future Prospects

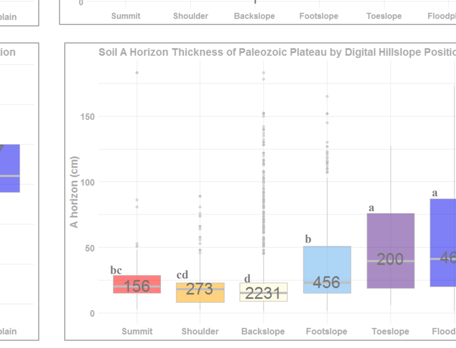












Geospatial Laboratory for Soil Informatics