**Supplemental Material**

**A soil health scoring framework for arable cropping systems in Saskatchewan Canada**

***Data distributions***

*Chemical attributes*

Soil EC and pH distributions were unimodal regardless of depth, with EC as highly right-skewed and pH as highly left-skewed (Fig. S1A). Soil EC averaged 0.33, 0.31, 0.39 ms cm-1 in the 0-15, 15-30, and 30-60 cm depth, respectively; soil pH averaged 7.24, 7.54, 7.93 in the same depth increments, respectively. Soil EC medians did not dramatically differ by soil zone, whereas pH medians were generally higher for the brown soil zone and lower for the gray zone (Fig. S1A).

Soil TC, SOC, and TN distributions were near normal with some extreme values (Fig. S1A). For all three attributes, the values decreased with increasing soil depth (Fig. S1A). Soil TC averaged 26.44, 19.28, 18.21g kg-1, for the 0-15, 15-30, 30-60 cm depths, respectively; whereas for the same respective depth increments, SOC averaged 24.16, 15.52, 12.20 g kg-1 and TN averaged 2.32, 1.48, 1.00 g kg-1. Some extremely high SOC values were observed, such as 71.28 g kg-1 from the gray soil. For TC, SOC, and TN the difference between medians among soil zones decreased with soil depth (Fig. S1A). The gray and black soil zones had higher medians in the top 0-15 cm depth, while the gray soil zone had the lowest medians in the 30-60 cm depth. The interquartile range of the gray soil zone was wider than other soil zones for the top 0-15 cm, but sharply reduced with depth (Fig. S1A).

The shape of NO3- and NH4+ distributions were unimodal and slightly right-skewed. For NO3-, the 0-15 and 15-30 cm depths resulted in flatter distributions than the deeper 30-60cm data (Fig. S1A). Soil NO3- generally decreased with depth, averaging 12.33, 9.31, 4.78 ug g-1 in 0-15, 15-30, and 30-60cm, respectively (Fig. S1A). Soil NH4+, on the other hand, showed little variation by soil depth, averaging 4.39, 3.61, 3.77 ug g-1 in the 0-15, 15-30, and 30-60 cm, respectively (Fig. S1A). Noticeably, the gray soil has the lowest NO3- values, while the dark brown soil zone had the widest variation. Soil NH4+ medians remained fairly consistent among soil zones (Fig. S1A).

Soil Na, P, and Mn were near normally distributed, with some outliers (Fig. S1B). Soil Na averaged 90.19, 87.97, 135.63 mg kg-1, for the 0-15, 15-30, 30-60 cm depths, respectively; whereas for the same respective depth increments, P averaged 532.35, 434.16, 419.41mg kg-1 and Mn averaged 482.86, 431.86, 408.58 mg kg-1. Some extremely high Na were observed, such as 850.21 mg kg-1 in the surface soil from black soil zone and 838.06 mg kg-1 in soil depth 30-60cm from brown soil zone. The highest Na and P values existed in surface soil, while the highest Mn was in the deeper 30-6 0cm.

Soil Ca, S, and Mg distributions were mostly unimodal and right-skewed regardless of depth. For these three nutrients, the 0-15 cm depth had narrower distributions than the deeper 15-30 and 30-60 cm depths (Fig. S1B). Soil Ca averaged 10218, 15878, 24799 mg kg-1 from the soil in 0-15, 15-30, 30-60 cm depth, respectively, whereas for the same respective depth increments, S averaged 574.08, 645.35, 900.73 mg kg-1 and Mg averaged 5398.80, 6607.83, 8510.87 mg kg-1. The black soil had highest median of soil Ca, S and Mg regardless of depth.

Soil Zn, Fe, and K distributions were bimodal with two distinct peaks (Fig. S1B). Soil Zn and K generally decreased with depth, which averaged 67.40, 63.16, 59.74 mg kg-1 of Zn and 3423.23, 2972.79, 2584.71 mg kg-1 of K in 0-15, 15-30, 30-60cm depth. Conversely, soil Fe generally increased with depth, averaging 17161, 17736, 17770 mg kg-1 in the same respective depth increments. No obvious differences were observed between soil zones by depth.

![Diagram, engineering drawing

Description automatically generated]()

Figure S1A). The distribution for common soil chemical attributes, presented using density plots. The y-axis is the probability density (kernel estimation) per unit on the x-axis. Box-plots show the interquartile range (solid bar), median (the line inside bars), minimum and the maximum excluding outliers (the extreme line), and outliers (dots) for each soil zone.

Diagram

Description automatically generated  
Figure S1B). The distribution of several soil nutrients as chemical attributes (other than those shown in Figure S1A), presented using density plots. The y-axis is the probability density (kernel estimation) per unit on the x-axis. Box-plots show the interquartile range (solid bar), median (the line inside bars), minimum and the maximum excluding outliers (the extreme line), and outliers (dots) for each soil zone.

*Physical attributes*

In our database, the percentage of sand in the soil ranged widely from 1.1% to 81% with a bi-modal distribution—a form that was shared by clay, only to a lesser degree due to the clustering around ~20% and 60% (Fig. S2). The silt percentage, on the other hand, showed a unimodal distribution centered around ~40% and was more right skewed with depth (Fig. S2). For sand and clay there was a fair amount of overlap in the interquartile range among the soil zones tested, but the soil zones tended to differentiate by silt (Fig. S2).

The WAS distribution was unimodal and slightly left-skewed for the 0-15 and 15-30 cm depths, but more uniform for the 30-60 cm depth (Fig. S2). The WAS generally decreased with soil depth, averaging 53%, 48%, 44% in 0-15, 15-30, 30-60cm, respectively. For WAS, the dark brown soil and black zone showed wider distributions than the brown or gray soil zones (Fig. S2). Soil FC showed a bi-modal distribution at ~40% to 60% with similarities among the soil zones, and little change in distribution with soil depth (Fig. S2). Soil FC was nearly consistent among depths, and averaged 46, 44, 43% in 0-15, 15-30, 30-60cm.

![Chart, polygon

Description automatically generated]()

Figure S2. The distribution of soil physical attributes presented using density plots. The y-axis is the probability density (kernel estimation) per unit on the x-axis. Box-plots show the interquartile range (solid bar), median (the line inside bars), minimum and the maximum excluding outliers (the extreme line), and outliers (dots) for each soil zone.

*Biological attributes*

The data distribution for soil active C, CO2 production, and protein were similar to each other, with unimodal distributions and similar patterns across soil zones (Fig. S3). Nitrous oxide production, on the other hand, showed a highly right-skewed unimodal distribution with few differences between soil zones (Fig. S3).

Soil protein levels in the 0-15 cm soil ranged from 1 to 17 mg g-1, with a unimodal distribution that is normal and a mean of 6.9 mg g-1 (Fig. S3). The gray soil zone produced a median protein level that was exceptionally higher than the other soil zones in 0-15 cm depth (Fig. S3).

![Diagram, shape, polygon

Description automatically generated]()

Figure S3. The distribution of soil biological indictors in the 0-15 cm depths, presented using density plots. The y-axis is the probability density (kernel estimation) per unit on the x-axis. Box-plots show the interquartile range (solid bar), median (the line inside bars), minimum and the maximum excluding outliers (the extreme line), and outliers (dots) for each soil zone.

Table S1. Shapiro-Wilk probability values indicating the distribution normality for each soil attribute. Where *P* values are < 0.05, a log or square root transformation was applied to improve normality.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Attributes | Dataset |  | Soil depth (cm) | | |
|  |  |  | 0-15 | 15-30 | 30-60 |
| Wet aggregate stability (%) | Original |  | 0.38 | 0.30 | 0.16 |
| Soil organic C (g kg-1) | Original |  | 0.48 | 0.73 | 0.78 |
| Total C (g kg-1) | Original |  | 0.73 | 0.08 | 0.14 |
| Total N (g kg-1) | Original |  | 0.22 | 0.07 | 0.09 |
| Protein (mg g-1) | Original |  | 0.15 | 0.73 | 0.96 |
| Active C (mg kg-1) | Original |  | 0.93 | - | - |
| CO2 (µg g-1 24hr-1) | Original |  | 0.53 | - | - |
| EC (mS cm-1) | Original |  | 0.00 | 0.01 | 0.58 |
|  | Log transformation | | 0.16 | 0.43 |  |
| N2O (ng g-1 24hr-1) | Original |  | 0.00 | - | - |
|  | Log transformation | | 0.20 |  |  |
| pH | Original |  | 0.00 | 0.00 | 0.00 |
|  | Square root |  | 0.05 | 0.04 | 0.08 |
| Sand (%) | Original |  | 0.06 | 0.04 | 0.00 |
|  | Square root |  |  | 0.45 |  |
| Silt (%) | Original |  | 0.82 | 0.69 | 0.22 |
| Clay (%) | Original |  | 0.00 | 0.00 | 0.00 |
|  | Log transformation | | 0.06 | 0.14 | 0.02 |
| NO3-1-N (µg g-1) | Original |  | 0.00 | 0.00 | 0.00 |
|  | Log transformation | | 0.22 | 0.04 | 0.73 |
| NH4+-N (µg g-1) | Original |  | 0.70 | 0.24 | 0.50 |
| PMN (µg g-1) | Original |  | 0.01 | - | - |
|  | Log transformation |  | 0.38 | - | - |
| Field capacity (%) | Original |  | 0.49 | 0.66 | 0.18 |
| Na (mg kg-1) | Original |  | 0.15 | 0.04 | 0.04 |
|  | Log transformation | |  | 0.58 | 0.56 |
| P (mg kg-1) | Original |  | 0.43 | 0.58 | 0.73 |
| Mn (mg kg-1) | Original |  | 0.90 | 0.27 | 0.14 |
| Ca (mg kg-1) | Original |  | 0.00 | 0.00 | 0.00 |
|  | Log transformation | | 0.67 | 0.08 | 0.05 |
| S (mg kg-1) | Original |  | 0.33 | 0.00 | 0.00 |
|  | Log transformation | |  | 0.84 | 0.07 |
| Mg (mg kg-1) | Original |  | 0.00 | 0.00 | 0.00 |
|  | Log transformation | | 0.29 | 0.28 | 0.26 |
| Zn (mg kg-1) | Original |  | 0.45 | 0.04 | 0.01 |
|  | Log transformation | |  | 0.33 | 0.03 |
| Fe (mg kg-1) | Original |  | 0.01 | 0.02 | 0.00 |
|  | Log transformation | | 0.07 | 0.11 | 0.00 |
| K (mg kg-1) | Original |  | 0.00 | 0.00 | 0.00 |
|  | Log transformation | | 0.11 | 0.14 | 0.05 |

- , data not available because only the surface-most depth increment was analyzed

Table S2. Model selection for predicting soil health scores from soil attribute measurements according to the “more is better” function. For all models, *x* is the observed soil score and *y* is the modelled soil health score. Models are selected based on R2 and root mean square error (RMSE), indicated in bold.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Model** | | | | | | | | |
| **Soil depth (cm)** | **Attributes** |  | **Polynomial with intercept (order =2)** | **polynomial without intercept (order =2)** | **polynomial (order=1)** | **Power** | **Inverse power** | **Square root** | **Hoerl's** | **Logarithmic** |
| 0-15 | Wet aggregate stability (%) | R2 | **0.96** | 0.95 | - | 0.86 | 0.98 | 0.92 | 0.97 | 0.85 |
|  | RMSE | **5.59** | 6.60 | - | 10.72 | 3.80 | 8.33 | 4.76 | 11.29 |
| Soil Organic C (g kg -1) | R2 | **0.96** | 0.94 | 0.96 | 0.89 | - | 0.93 | 0.95 | 0.85 |
|  | RMSE | **5.68** | 7.45 | 5.69 | 9.95 | - | 7.64 | 6.27 | 11.36 |
| Total C (g kg -1) | R2 | **0.97** | 0.93 | 0.97 | 0.87 | - | 0.96 | 1.00 | 0.92 |
|  | RMSE | **5.34** | 7.82 | 5.41 | 11.06 | - | 6.24 | 1.56 | 8.50 |
| Total N (g kg -1) | R2 | **0.95** | 0.94 | - | 0.88 | - | 0.89 | - | 0.77 |
|  | RMSE | **6.26** | 7.42 | - | 10.24 | - | 9.55 | - | 14.21 |
| Protein (mg g-1) | R2 | **0.95** | 0.91 | 0.95 | 0.85 | - | 0.92 | 0.95 | 0.81 |
|  | RMSE | **6.60** | 8.99 | 6.82 | 11.19 | - | 8.34 | 6.83 | 12.67 |
| CO2 (mg g-1 24hr-1) | R2 | **0.97** | 0.92 | 0.96 | 0.86 | 0.98 | 0.96 | 0.99 | 0.92 |
|  | RMSE | **5.04** | 8.31 | 5.58 | 11.02 | 4.18 | 5.80 | 3.02 | 8.05 |
| Active C (mg kg -1) | R2 | **0.97** | 0.95 | 0.97 | 0.92 | - | 0.94 | 0.97 | 0.86 |
|  | RMSE | **5.05** | 6.77 | 5.05 | 8.52 | - | 7.20 | 5.16 | 11.29 |
|  | Potential mineralizable N (ug g-1) | R2 | - | 0.94 | 0.76 | 0.71 | 0.96 | **0.94** | 0.96 | 0.91 |
|  |  | RMSE | - | 6.87 | 14.01 | 15.37 | 5.61 | **7.15** | 5.97 | 8.81 |
| 15-30 | Wet aggregate stability (%) | R2 | **0.98** | 0.96 | 0.97 | 0.87 | 0.97 | 0.94 | 1.00 | 0.90 |
|  | RMSE | **4.47** | 5.47 | 5.09 | 10.32 | 4.87 | 6.97 | 0.97 | 9.36 |
| Soil Organic C (g kg -1) | R2 | **0.97** | 0.93 | 0.97 | 0.88 | 0.99 | 0.95 | 0.98 | 0.90 |
|  | RMSE | **5.49** | 8.01 | 5.60 | 10.56 | 3.71 | 6.74 | 4.50 | 9.76 |
| Total C (g kg -1) | R2 | **0.98** | 0.91 | 0.94 | 0.83 | 0.98 | 0.96 | 0.99 | 0.95 |
|  | RMSE | **4.43** | 9.08 | 6.99 | 12.34 | 4.01 | 5.58 | 2.71 | 6.77 |
| Total N (g kg -1) | R2 | **0.98** | 0.95 | 0.98 | 0.92 | 0.99 | 0.97 | 0.98 | 0.92 |
|  | RMSE | **4.65** | 7.20 | 4.82 | 8.61 | 3.15 | 5.78 | 4.14 | 8.76 |
| Protein (mg g -1) | R2 | **0.97** | 0.94 | 0.97 | 0.88 | 0.98 | 0.95 | 0.99 | 0.91 |
|  | RMSE | **5.10** | 7.34 | 5.13 | 10.16 | 3.80 | 6.33 | 2.32 | 9.13 |
| 30-60 | Wet aggregate stability (%) | R2 | **0.98** | 0.98 | 0.97 | 0.98 | - | 0.90 | 0.94 | 0.73 |
|  | RMSE | **4.24** | 4.69 | 4.83 | 4.26 | - | 9.38 | 7.41 | 15.64 |
| Soil Organic C (g kg -1) | R2 | **0.98** | 0.94 | 0.97 | 0.90 | 0.99 | 0.96 | 0.99 | 0.91 |
|  | RMSE | **4.75** | 7.12 | 4.83 | 9.43 | 3.30 | 5.98 | 3.09 | 8.87 |
| Total C (g kg -1) | R2 | **0.98** | 0.95 | 0.97 | 0.93 | - | 0.97 | 0.98 | 0.91 |
|  | RMSE | **4.19** | 6.49 | 5.18 | 8.05 | - | 5.35 | 4.05 | 8.79 |
| Total N (g kg -1) | R2 | 0.98 | 0.91 | 0.95 | 0.85 | 0.98 | **0.97** | 0.99 | 0.95 |
|  | RMSE | 4.23 | 8.61 | 6.88 | 11.37 | 3.79 | **5.43** | 2.70 | 6.78 |
| Protein (mg g -1) | R2 | **0.96** | 0.94 | 0.96 | 0.92 | 0.92 | 0.92 | 0.93 | 0.81 |
|  | RMSE | **5.56** | 6.98 | 5.56 | 8.39 | 8.56 | 8.17 | 7.55 | 12.74 |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
| Average |  | R2 | **0.97** | 0.94 | \* | 0.89 | \* | 0.94 | \* | 0.88 |
|  |  | RMSE | **5.10** | 7.31 | \* | 9.78 | \* | 6.94 | \* | 10.23 |

-, the curve created by particular model doesn’t follow the scoring type; \*, the model is not applicable for all selected attributes.

The model with bolding values is the selected model for the attributes in table. Polynomial with intercept (order =2), y=a+bx+cx2. Polynomial without intercept (order =2), y=ax+bx2. Polynomial with intercept (order =1), y=a+bx. Power, y=axb. Inverse power, y=a\*e(b/x). Square root, y=a+b\*. Hoerl’s, y=a\*xb\*e(C\*x) . Logarithmic, y=a+b\*In(x).

Table S3. Model selection for predicting soil health scores for each soil attribute of “less is better” type in the 0-15, 15-30, and 30-60 cm depth, based on R2 and root mean square error (RMSE). For all models, *x* is the observed soil health score and *y* is the modelled soil health score. Bolded R2 and RMSE values indicate the selected model.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | **Modal** | | | | | | | |
| **Soil depth (cm)** | **Attributes** |  | **Polynomial with intercept (order =2)** | **Polynomial without intercept (order =2)** | **Polynomial (order=1)** | **Power** | **Inverse power** | **Square root** | **Hoerl's** | **Logarithmic** |
| 0-15 | EC (mS cm -1) | R2 | - | - | - | - | - | **0.97** | - | 0.99 |
|  |  | RMSE | - | - | - | - | - | **5.30** | - | 3.75 |
|  | N2O (ng g-1 24hr-1) | R2 | - | - | - | - | - | **0.95** | - | 0.95 |
|  |  | RMSE | - | - | - | - | - | **6.48** | - | 6.77 |
| 15-30 | EC (mS cm -1) | R2 | - | - | 0.89 | 0.72 | 0.51 | **0.95** | - | - |
|  |  | RMSE | - | - | 9.59 | 15.41 | 20.39 | **6.24** | - | - |
| 30-60 | EC (mS cm -1) | R2 | - | - | 0.97 | - | - | **0.96** | - | 0.90 |
|  |  | RMSE | - | - | 5.21 | - | - | **5.98** | - | 9.32 |
|  |  |  |  |  |  |  |  |  |  |  |
| Average |  | R2 | \* | \* | 0.93 | \* | \* | **0.96** | \* | 0.95 |
|  |  | RMSE | \* | \* | 7.51 | \* | \* | **5.62** | \* | 6.38 |

-, the curve created by particular model doesn’t follow the scoring type;

\*, the model is not applicable for all selected attributes.

Polynomial (order=1), y=a+bx. Polynomial with intercept (order =2), y=a+bx+cx2. Polynomial with intercept (order =2), y=ax+bx2. Power, y=axb. Inverse power, y=a\*e(b/x). Square root, y=a+b\*. Hoerl’s, y=a\*xb\*e(C\*x). Logarithmic, y=a+b\*In(x);

Table S4. The formulas and threshold limits that correspond to the models presented in Figures 7 to 9.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **0-15 cm depth** | | | **15-30 cm depth** | | | **30-60 cm depth** | | |
| **Attribute** | **Equation** | **Upper threshold** | **Lower threshold** | **Equation** | **Upper threshold** | **Lower threshold** | **Equation** | **Upper threshold** | **Lower threshold** |
|  | **More is better** | | | | | | | | |
| Wet aggregate stability (%) | y= =-30.752 +1.077\*x+0.008\*x2 | 84.16 | 16.69 | y=-36.408 +1.1296\*x+0.011\*x2 | 73.53 | 21.58 | y=-9.442 +1.071\*x +0.006\*x2 | 79.94 | 2.12 |
| Soil organic C (g kg-1) | y=-42.350+3.967\*x+0.006\*x2 | 3.85 | 0.54 | y=-46.456+6.950\*x -0.035\*x2 | 27.06 | 4.11 | y=-38.912 +8.107\*x -0.042\*x2 | 20.74 | 3.69 |
| Total C (g kg-1) | y=-62.579+5.014\*x -0.016\*x2 | 4.19 | 0.89 | y=-46.464+6.388\*x-0.064\*x2 | 42.41 | 6.24 | y=-25.786+4.864\*x -0.036\*x2 | 39.04 | 4.04 |
| Total N (g kg-1) | y=-34.953+30.982\*x+3.820\*x2 | 0.34 | 0.04 | y=-44.239+72.271\*x -4.622\*x2 | 2.48 | 0.39 | y=-84.735+138.353\* | 2.20 | 0.32 |
| Protein (mg g-1) | y=-44.708 +16.897\*x^1 -0.272\*x^2 | 12.31 | 1.11 | y=-47.697+27.304\*x -0.363\*x2 | 6.33 | 1.16 | y=-23.544 +32.625\*x+0.110\*x2 | 4.14 | 0.36 |
| Active C (mg kg-1) | y=-30.213+0.139\*x | 1026.02 | 108.67 |  |  |  |  |  |  |
| CO2 (μg g-1 24hr-1) | y=-56.012 +25.727\*x -0.751\*x2 | 8.79 | 1.57 |  |  |  |  |  |  |
| Potential mineralizable N (μg g-1) | y=-54.072+25.581 |  |  |  |  |  |  |  |  |
|  | **Less is better** | | | | | | | | |
|  |  |  |  |  |  |  |  |  |  |
| EC (mS cm -1) | y=178.487-261.560\* | 0.53 | 0.10 | y=172.103-256.986\* | 0.55 | 0.07 | y=182.305-273.560\* | 0.47 | 0.06 |
| N2O (ng g-1 24hr-1) | y=148.330-188.642\* | 0.74 | 0.04 |  |  |  |  |  |  |
|  | **Optimum is best** | | | | | | | | |
| pH | y= | 8.45 | 5.15 | y= | 8.48 | 5.94 | y= | 8.82 | 6.49 |
| Sand (%) | y= | 80.59 | 4.06 | y= | 75.18 | 1.09 | y= | 70.30 | 4.37 |
| Silt (%) | y= | 58.86 | 14.45 | y= | 62.79 | 18.29 | y= | 60.72 | 16.27 |
| Clay (%) | y= | 66.25 | 4.96 | y= | 71.60 | 4.98 | y= | 72.76 | 10.03 |
| NO3-1-N (μg g-1) | y= | 25.11 | 1.19 | y= | 22.89 | 0.28 | y= | 28.36 | 0.04 |
| NH4+-N (μg g-1) | y= | 7.08 | 1.56 | y= | 5.54 | 1.71 | y= | 6.93 | 1.31 |
| Field capacity (%) | y= | 61.12 | 29.99 | y= | 56.84 | 30.85 | y= | 53.51 | 32.94 |
| Na (mg kg-1) | y= | 113.29 | 29.16 | y= | 152.52 | 28.82 | y= | 245.63 | 32.20 |
| Ca (mg kg-1) | y= | 24698.46 | 1615.49 | y= | 78616.06 | 1842.94 | y= | 81258.63 | 2099.80 |
| P (mg kg-1) | y= | 747.99 | 315.01 | y= | 706.88 | 232.08 | y= | 592.75 | 230.86 |
| S (mg kg-1) | y= | 892.06 | 178.02 | y= | 2043.56 | 100.63 | y= | 2471.25 | 105.64 |
| Mg (mg kg-1) | y= | 11970.17 | 1526.70 | y= | 18870.92 | 1535.62 | y= | 20371.58 | 1970.63 |
| Zn (mg kg-1) | y= | 108.65 | 26.35 | y= | 109.31 | 29.26 | y= | 100.57 | 28.72 |
| Fe (mg kg-1) | y= | 28111.60 | 7152.07 | y= | 28392.45 | 7879.71 | \* | 27860.79 | 10050.85 |
| K (mg kg-1) | y= | 6593.32 | 866.90 | y= | 6213.33 | 991.55 | y= | 4724.46 | 763.12 |
| Mn (mg kg-1) | y= | 791.37 | 183.10 | y= | 728.37 | 195.35 | y= | 960.86 | 223.63 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Table S5. Summary of the principal component analysis (PCA) and the resulting eigenvectors for each soil attribute. | | | | | | | | | | | | | | | | | | | | | | | |
|  |  | 0-15 cm depth | | | | | | | |  | 15-30 cm depth | | | | | |  | 30-60 cm depth | | | | | |
| Indicator type | Attribute | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 | *w* |  | PC1 | PC2 | PC3 | PC4 | PC5 | *w* |  | PC1 | PC2 | PC3 | PC4 | PC5 | *w* |
| Chemical | SOC | 0.27 | 0.25 | 0.08 | -0.11 | -0.09 | -0.1 | -0.07 | 0.14 |  | 0.19 | 0.12 | 0.47 | -0.06 | -0.2 | 0.17 |  | 0.09 | 0.3 | 0.35 | -0.04 | 0.21 | 0.17 |
|  | Total C | 0.27 | 0.21 | 0.18 | -0.17 | -0.09 | -0.03 | -0.02 | 0.15 |  | 0.16 | 0.35 | 0.26 | -0.08 | -0.19 | 0.18 |  | 0.03 | 0.42 | 0.15 | -0.07 | 0.05 | 0.14 |
|  | Total N | 0.29 | 0.22 | 0.02 | -0.1 | -0.02 | -0.09 | -0.09 | 0.14 |  | 0.22 | -0.04 | 0.47 | -0.07 | -0.18 | 0.14 |  | 0.22 | -0.05 | 0.39 | 0.11 | 0.18 | 0.16 |
|  | NO3- | -0.02 | 0.11 | 0.13 | 0.38 | 0.44 | 0.11 | 0.21 | 0.12 |  | -0.09 | 0.22 | 0.19 | 0.4 | -0.06 | 0.06 |  | -0.12 | 0.09 | 0.23 | 0.09 | 0.62 | 0.05 |
|  | NH4+ | 0.13 | 0.06 | -0.06 | 0.3 | 0.51 | -0.06 | -0.1 | 0.11 |  | 0.21 | -0.07 | 0.02 | 0.43 | 0.02 | 0.12 |  | 0.22 | 0.01 | 0.02 | 0.07 | 0.24 | 0.12 |
|  | P | 0.16 | 0.2 | 0.13 | 0.07 | 0.22 | 0.34 | -0.12 | 0.16 |  | 0.03 | 0.25 | 0.38 | -0.12 | 0.31 | 0.14 |  | -0.08 | 0.27 | 0.28 | 0.21 | -0.22 | 0.08 |
|  | K | 0.23 | -0.27 | -0.15 | 0.04 | 0.08 | 0.03 | -0.12 | 0 |  | 0.31 | -0.09 | -0.06 | -0.08 | -0.05 | 0.11 |  | 0.34 | 0 | 0 | -0.09 | -0.05 | 0.13 |
|  | S | 0.17 | 0.01 | 0.47 | -0.1 | -0.01 | -0.16 | 0.13 | 0.12 |  | 0.05 | 0.46 | -0.07 | 0.09 | 0 | 0.13 |  | -0.04 | 0.4 | -0.24 | 0.14 | 0.09 | 0.08 |
|  | Ca | 0.03 | -0.15 | 0.49 | -0.08 | -0.04 | 0.12 | 0.18 | 0.05 |  | 0.03 | 0.45 | -0.18 | -0.01 | 0.02 | 0.1 |  | -0.05 | 0.43 | -0.12 | -0.1 | 0 | 0.07 |
|  | Na | 0.21 | 0.05 | -0.02 | -0.35 | 0.19 | 0.28 | 0.21 | 0.09 |  | 0.19 | 0.03 | -0.24 | 0.37 | 0.04 | 0.09 |  | 0.13 | 0.03 | -0.44 | 0.34 | 0.11 | 0.05 |
|  | Mg | 0.13 | -0.31 | 0.29 | -0.03 | -0.02 | 0.12 | 0.05 | 0.02 |  | 0.17 | 0.34 | -0.24 | -0.19 | 0.06 | 0.12 |  | 0.04 | 0.43 | -0.11 | -0.18 | -0.08 | 0.09 |
|  | Mn | 0.13 | -0.09 | -0.11 | 0.32 | -0.19 | 0.44 | 0.13 | 0.05 |  | 0.28 | -0.09 | 0.02 | 0 | 0.01 | 0.11 |  | 0.25 | -0.01 | 0.21 | 0.15 | 0.2 | 0.16 |
|  | Fe | 0.24 | -0.27 | -0.17 | 0 | 0.02 | -0.01 | -0.06 | 0 |  | 0.32 | -0.14 | -0.12 | -0.05 | -0.06 | 0.09 |  | 0.35 | -0.06 | -0.06 | -0.09 | -0.05 | 0.12 |
|  | Zn | 0.27 | -0.16 | -0.13 | -0.04 | 0.14 | -0.19 | -0.08 | 0.04 |  | 0.32 | -0.15 | -0.02 | -0.04 | -0.02 | 0.1 |  | 0.35 | -0.04 | 0.04 | 0.05 | -0.12 | 0.14 |
|  | pH | 0 | -0.18 | 0.35 | 0.2 | -0.15 | 0.09 | -0.01 | 0.02 |  | 0.09 | 0.33 | -0.15 | -0.05 | 0.41 | 0.12 |  | 0 | 0.33 | -0.03 | 0.18 | -0.29 | 0.08 |
|  | EC | 0.16 | -0.04 | 0.22 | 0.23 | 0.26 | -0.44 | 0 | 0.1 |  | 0.13 | 0.09 | 0.02 | 0.6 | -0.18 | 0.12 |  | 0.07 | 0.02 | -0.37 | 0.49 | 0.32 | 0.06 |
| Biological | Active C | 0.23 | 0.27 | 0.04 | 0.06 | -0.14 | -0.05 | 0 | 0.15 |  | - | - | - | - | - | - |  | - | - | - | - | - | - |
|  | CO2 | 0.14 | 0.18 | -0.05 | 0.38 | -0.27 | 0.09 | -0.19 | 0.09 |  | - | - | - | - | - | - |  | - | - | - | - | - | - |
|  | N2O | 0.21 | 0.17 | -0.11 | -0.11 | 0.23 | 0.34 | 0.12 | 0.13 |  | - | - | - | - | - | - |  | - | - | - | - | - | - |
|  | PMN | 0.11 | 0.15 | 0.08 | 0.37 | -0.24 | -0.07 | -0.24 | 0.08 |  | - | - | - | - | - | - |  | - | - | - | - | - | - |
|  | Protein | 0.17 | 0.3 | -0.11 | -0.17 | -0.07 | -0.04 | 0.02 | 0.1 |  | - | - | - | - | - | - |  | - | - | - | - | - | - |
| Physical | Sand | -0.25 | 0.23 | 0.17 | -0.06 | 0.04 | 0.12 | -0.27 | 0 |  | -0.31 | 0.11 | 0.03 | -0.04 | -0.26 | 0 |  | -0.34 | -0.03 | -0.03 | -0.09 | 0.17 | 0 |
|  | Silt | 0.07 | 0.11 | -0.17 | 0.2 | -0.17 | -0.2 | 0.76 | 0.06 |  | -0.03 | -0.16 | 0.26 | 0.21 | 0.67 | 0.05 |  | -0.05 | -0.06 | 0.27 | 0.54 | -0.29 | 0.03 |
|  | Clay | 0.22 | -0.31 | -0.08 | -0.05 | 0.05 | -0.02 | -0.14 | 0 |  | 0.32 | -0.02 | -0.18 | -0.08 | -0.13 | 0.11 |  | 0.34 | 0.06 | -0.12 | -0.19 | 0 | 0.13 |
|  | WAS | 0.26 | -0.14 | 0.02 | 0.08 | -0.2 | 0.27 | 0.01 | 0.07 |  | 0.3 | 0.02 | -0.05 | -0.05 | 0.03 | 0.14 |  | 0.29 | 0.01 | -0.09 | -0.25 | 0.13 | 0.1 |
|  | FC | 0.27 | -0.14 | -0.1 | -0.03 | -0.11 | -0.19 | -0.04 | 0.03 |  | 0.29 | -0.02 | 0.08 | -0.14 | 0.22 | 0.15 |  | 0.31 | 0.05 | 0.07 | 0.2 | -0.15 | 0.16 |
| *Eigenvalue* |  | 7.88 | 5.36 | 3.00 | 1.87 | 1.70 | 1.18 | 1.00 |  |  | 8.14 | 4.15 | 2.39 | 1.35 | 1.14 |  |  | 7.37 | 4.49 | 2.22 | 1.67 | 1.24 |  |
| *% variation* |  | 30.32 | 20.6 | 11.54 | 7.20 | 6.54 | 4.55 | 3.84 |  |  | 38.76 | 19.77 | 11.36 | 6.42 | 5.45 |  |  | 35.12 | 21.39 | 10.57 | 7.95 | 5.93 |  |
| *Cumulative % variation* | | 30.32 | 50.92 | 62.47 | 69.66 | 76.2 | 80.75 | 84.59 |  |  | 38.76 | 58.53 | 69.89 | 76.31 | 81.76 |  |  | 35.12 | 56.51 | 67.08 | 75.03 | 80.96 |  |
|  |  | 0.36 | 0.24 | 0.14 | 0.09 | 0.08 | 0.05 | 0.05 |  |  | 0.47 | 0.24 | 0.14 | 0.08 | 0.07 |  |  | 0.43 | 0.26 | 0.13 | 0.1 | 0.07 |  |

-, data not available