A new pH depth function for agricultural soils

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Soil pH

- Is an important soil quality index.
- Controls plant nutrients availability, growth environment of plant roots, soil microbial activity, and affects many chemical processes.
- Determines various agricultural management decisions but based on surface soil measurements.

Depth function

- It quantitatively describes vertical variability of soil properties
- It plays an essential role in 3D digital soil mapping

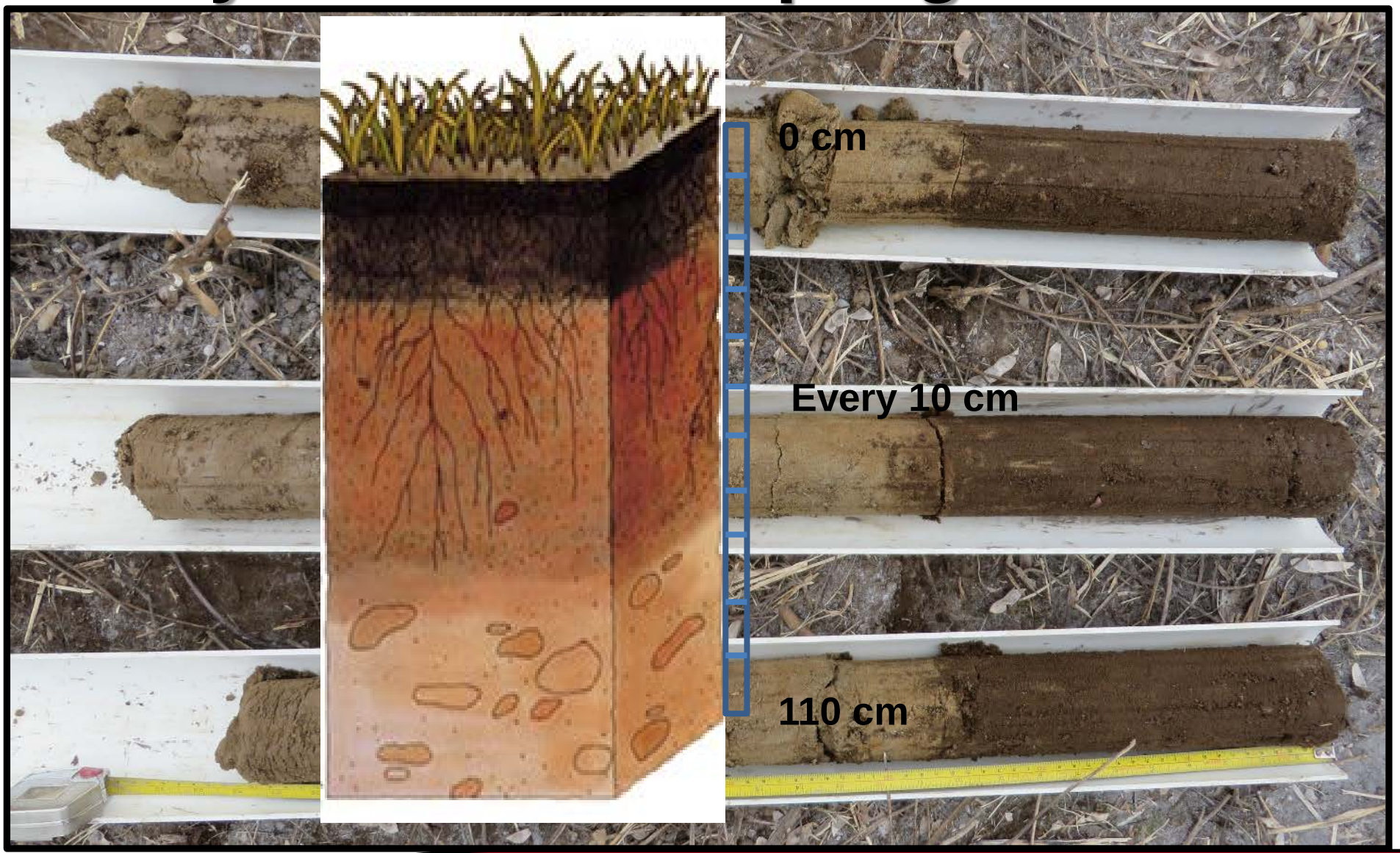
Limitations and Opportunities

- Equal-area quadratic spline function has high flexibility and accuracy for any soil properties while lacks physical explanation and general trend
- Exponential decay function is well developed to describe the decreasing trend of soil organic matter with depth.
- Other functions (power and polynomial functions) occasionally fit well for some properties while the feasibility and generality of these models need further explanation.
- Considering the physical condition of agricultural field, a more general model should be proposed to describe the vertical variability of soil pH.

Objectives

- to develop a new closed form sigmoid model and test its ability in predicting soil pH in agricultural fields
  - Test the sigmoid function in a small agricultural field (local dataset).
  - Test the sigmoid function in global dataset.
  - Compare the predictive capability of sigmoid function with polynomial and spline function.

Study area and sampling



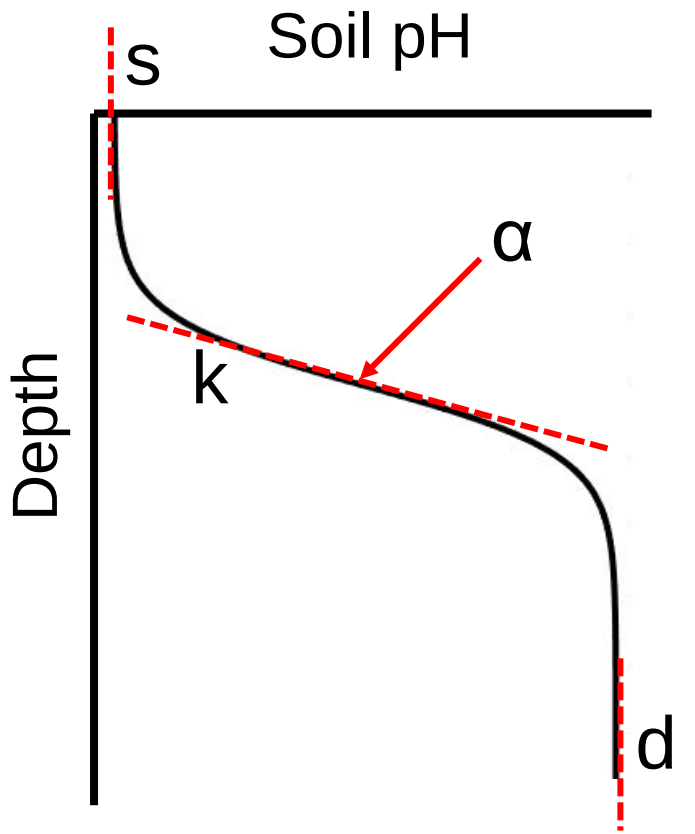
Global dataset

- 432 profiles (non-uniform depths) of agricultural soils (Batjes, 2000).
- pH values were measured in soil-water suspension with a ratio of 1:2.5.
- The fitting results were further categorized and compared according to various soil class, land use, drainage, and altitude.

Sigmoid function (pH depth function)

$$f(x) = s + \frac{d - s}{1 + \left(\frac{x}{\alpha}\right)^{-k}}$$

- f(x) – soil pH; x - soil depth;
- s – soil pH at the top of soil profile;
- d – soil pH at the bottom of soil profile;
- α – inflection point;
- k – steepness of the curve.



Polynomial and Spline functions

- 3rd order polynomial function

$$f(x) = a + b \times x + c \times x^2 + d \times x^3$$

- Equal-area quadratic spline function (Bishop et al., 1999)

$$\frac{1}{n}\sum_{i=1}^{n}\left(y_i - \overline{f}_i\right)^2 + \lambda \int_{x_0}^{x_n} f'(x)^2 dx$$

goodness roughness

Bishop, T.F.A., McBratney, A.B., Laslett, G.M., 1999. Modelling soil attribute depth functions with equal-area quadratic smoothing splines. Geoderma 91(1–2), 27-45.

Accuracy and efficiency

- Root mean squared error

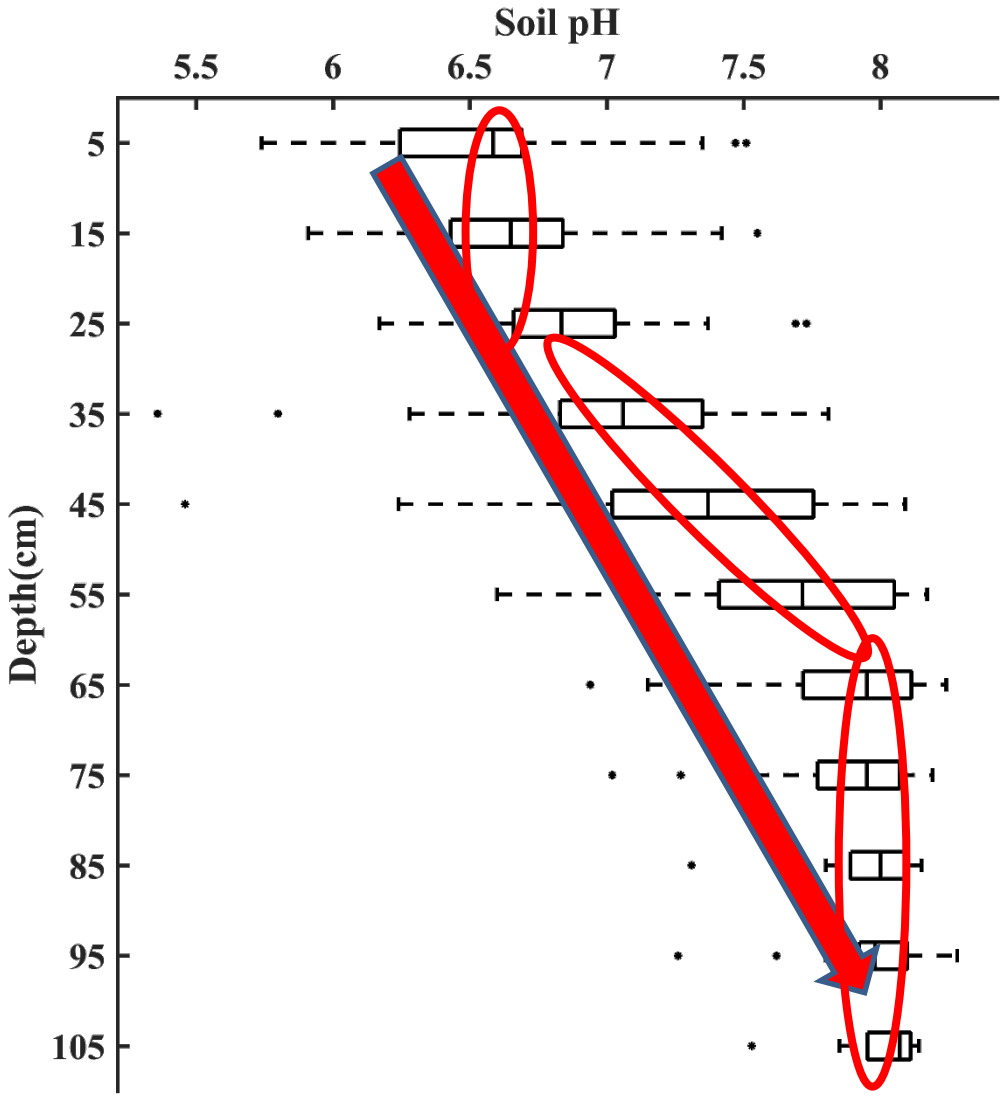
$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - f_i)^2}$$

- Coefficient of determination

$$\mathrm{R}^2 = 1 - \frac{SS_{res}}{SS_{tot}} = 1 - \frac{\sum_{i=1}^{n}(y_i - f_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

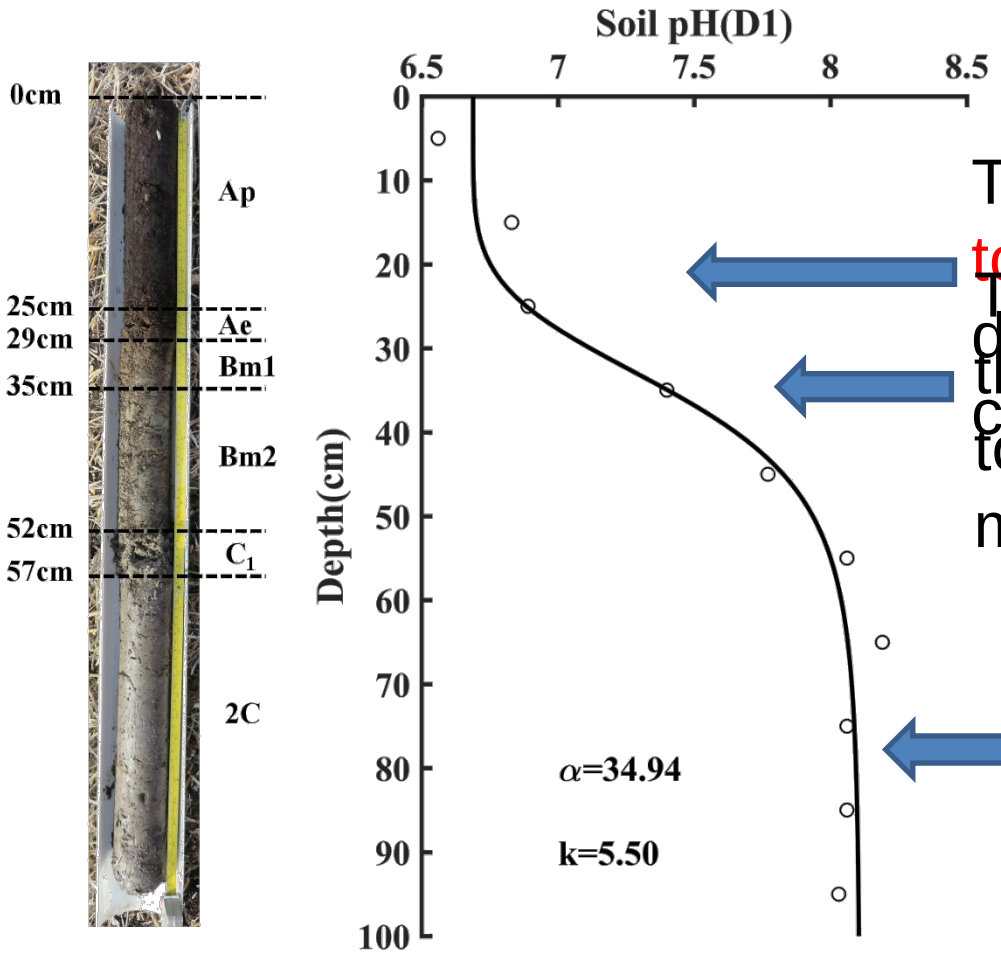
- Standard deviation

Profile description- local dataset



- Increasing trend with depth.
- Uniform distribution at top layers and bottom layers.
- A transition zone in between

Sigmoid function- local dataset

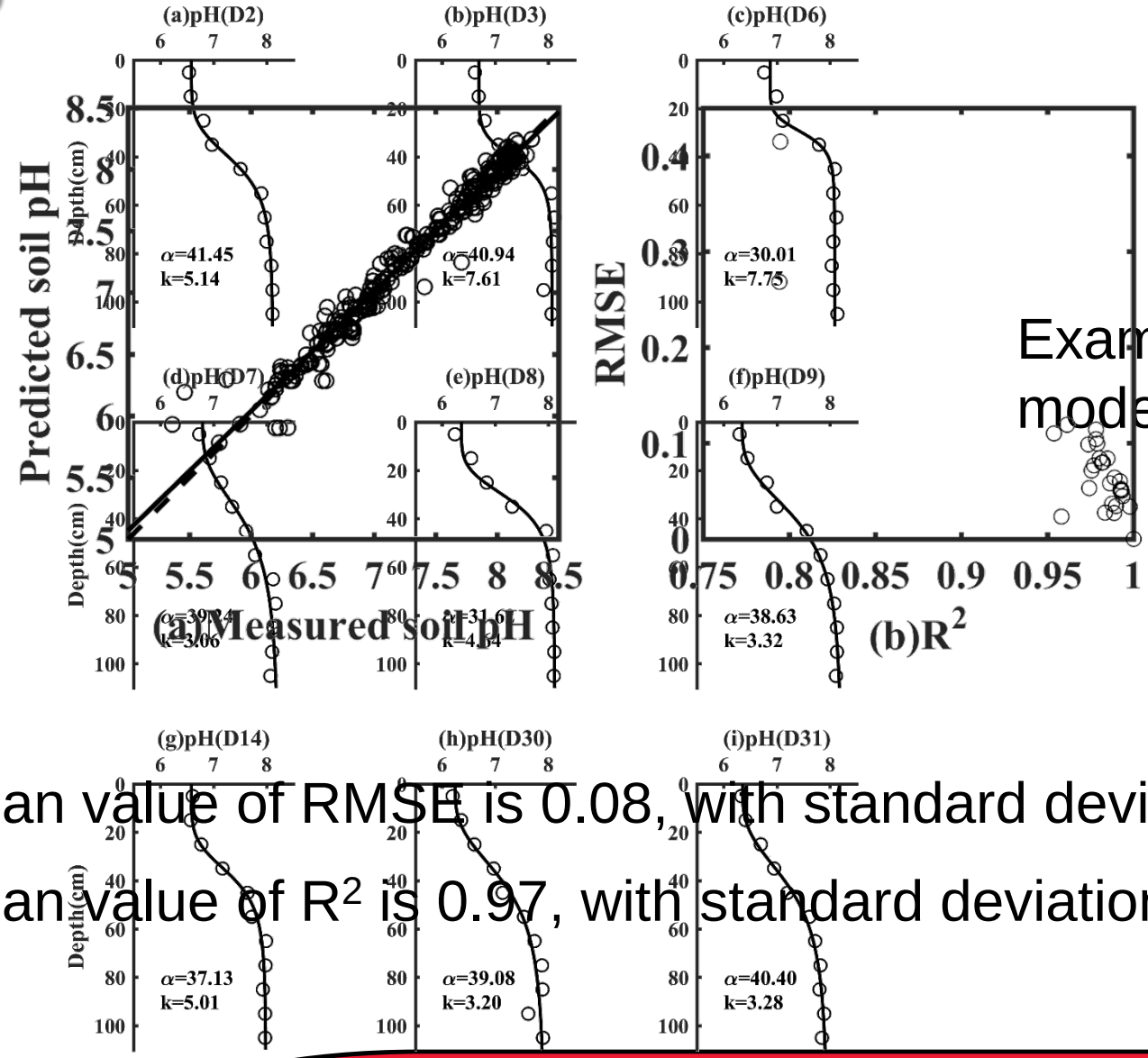


The uniform distribution in top soil (plough layers) is due to mixing from tillage, corresponding to Ap horizon.

The transition zone is from the bottom of tillage layers to the bottom of root zone, mainly in B horizons.

The uniform distribution in deep soil is due to less disturbance and groundwater movement, corresponding to C horizons.

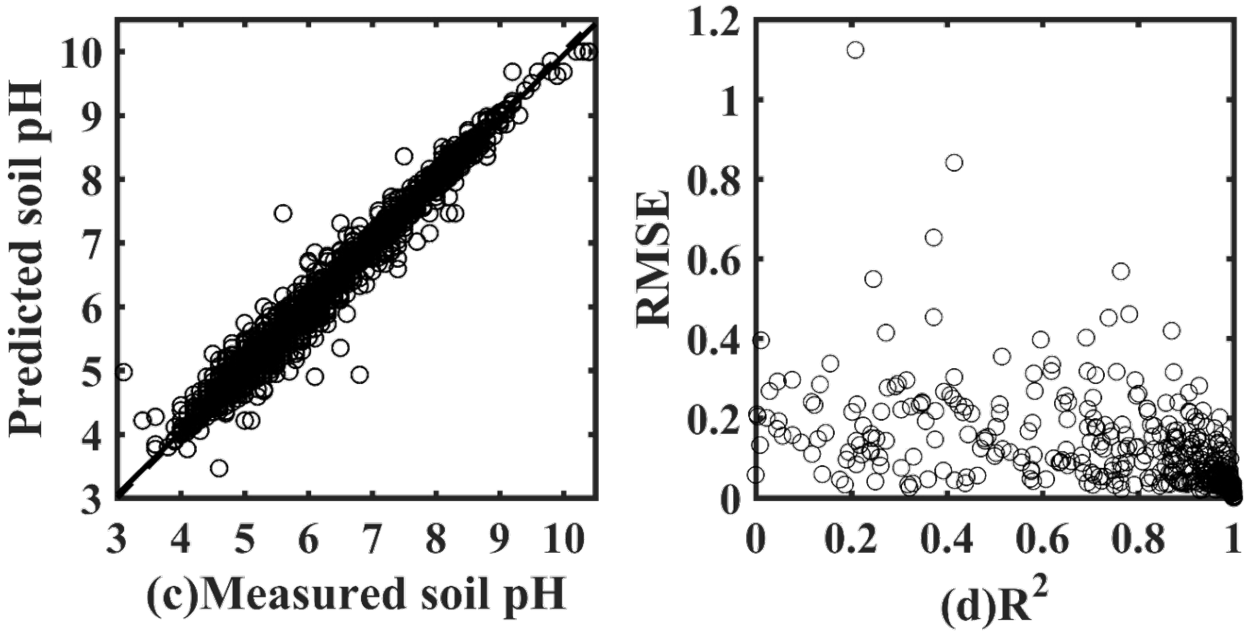
Sigmoid function- local dataset



Examples of model fitting

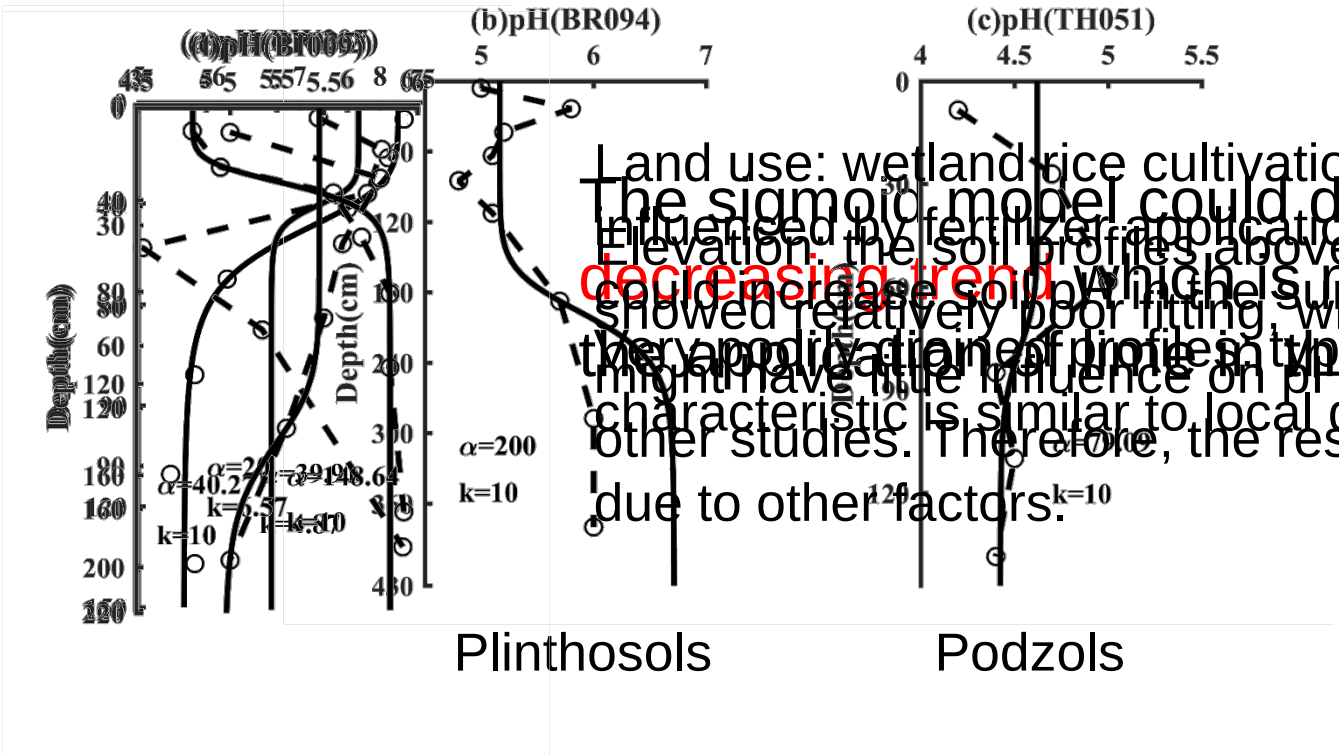
- Mean value of RMSE is 0.08, with standard deviation of 0.08.
- Mean value of R^2 is 0.97, with standard deviation of 0.05.

Sigmoid function- Global dataset



- Mean value of RMSE is 0.11, with standard deviation of 0.12.
- Mean value of R^2 is 0.76, with standard deviation of 0.29.

Sigmoid function- Global dataset



Plinthosols Podzols

Land use: wetland rice cultivation, highly influenced by fertilizer application which could increase soil pH in the surface layer and modify the profile type.

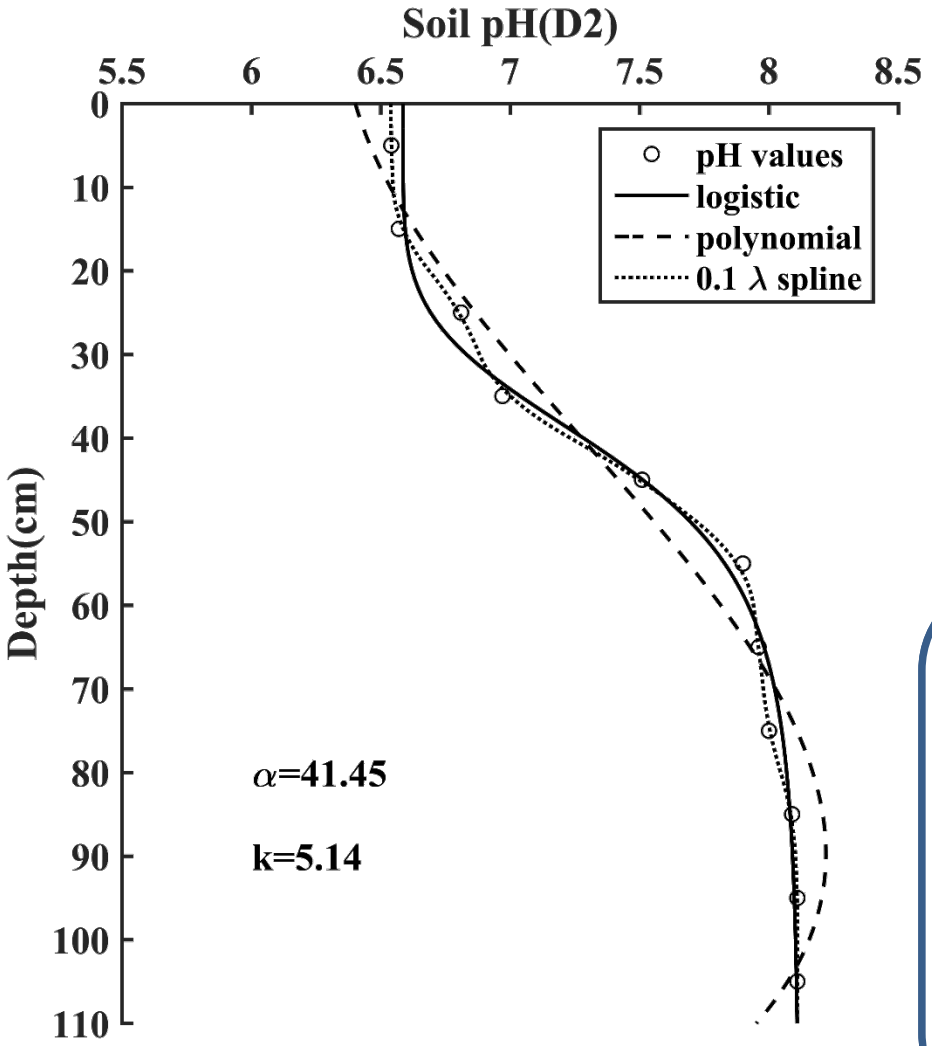
The sigmoid model could describe a decreasing trend which is mainly due to the application of lime on the soil surface.

Elevation: the soil profiles above 1300m showed relatively poor fitting, while elevation might have little influence on pH according to other studies. Therefore, the results might be due to other factors.

Parent material: the local soil characteristic is similar to local dataset.

- Plinthosols: highly weathered soil; the hardpan formation might cause discontinuity and non-monotonic feature of pH in soil profile.
- Podzols: sandy and acidic soil; Ae horizon with less Al and Fe might result in peak feature of pH distribution.

Comparison



Accuracy, interpretability, simplicity, generality, number of parameters, mass balance.

Spline

good accuracy

highest accuracy

no physical explanation

good generality

poor generality

4 parameters

cannot keep mass balance

non-monotonic at bottom

Conclusion

- The **sigmoid model** obtained good fitting performance in a local dataset and reasonably moderate performance for the majority of profiles in a more complex and changeable global dataset.

- The **spline function** had the highest accuracy but lacked a general trend in its shape and parameters

- The **polynomial function** had good accuracy and displayed a non-monotonic trend, which can also be used as a substitute for some profiles with complex variability.

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Thank You

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