United States Department of Agriculture
Natural Resources Conservation Service

Pedotransfer Functions for Estimating Saturated Hydraulic Conductivity:

Opportunities for Minimizing Uncertainty

Gerard J. Kluitenberg

Kansas State University

NRCS North Central Regional Work Planning Conference
June 23-26, 2008
Manhattan, KS

K-STATE RESEARCH & EXTENSION
Kansas State University

Introduction

Saturated Hydraulic Conductivity

"The ease with which pores of a saturated soil transmit water. Formally, the proportionality coefficient that expresses the relationship of the rate of water movement to hydraulic gradient in Darcy's Law…" (National Soil Survey Handbook, Section 618.50)

Darcy's Law is

$$Q/At = K_s (\Delta H/L)$$

where Q/At is the rate of water flow, $\Delta H/L$ is the hydraulic gradient, and K_s is the saturated hydraulic conductivity.

Introduction

Saturated Hydraulic Conductivity

Saturated hydraulic conductivity used by NRCS for numerous interpretations:

- Suitability for irrigation and drainage systems
- Septic tank absorption fields
- Sewage lagoons
- Sanitary landfills
- Irrigation disposal of wastewater

Unfortunately, K_s data are available for relatively few soils because K_s is difficult to measure. Methods are costly, time-consuming, require specialized equipment, and subject to numerous sources of uncertainty.

Introduction

Estimation of Saturated Hydraulic Conductivity

Difficulties in obtaining K_s data have motivated effort to estimate K_s from more easily measured soil properties.

Efforts to estimate K_s dates back to at least the 1930s.

Substantial body of work on K_s estimation exists due to efforts of NRCS staff and research contributions from soil science community and related disciplines.

Despite progress, a critical need remains for algorithms that can be used to generate reliable estimates of K_s.

Introduction

Pedotransfer Functions for Estimation of K_s

The term pedotransfer function (PTF), coined by Bouma (1989), refers to statistical regression equations used to express relationships between soil properties.

In K_s context, PTFs are used to develop relationships between K_s and more easily measured soil properties.

Terminology is new, but concept is old. Many decades-old methods for K_s estimation can be considered PTFs.

Primary benefit of PTF concept?

- Renewed interest in estimation of hydraulic properties
- Focusing of effort in soil science community

Introduction

Pedotransfer Functions for Estimation of K_s

Strong interest in PTFs mainly a result of new methods and tools for PTF development:

- Statistical regression techniques
- Artificial neural networks
- Group method of data handling
- Regression tree modeling

Considerable interest in neural network PTF of Schaap et al. (1998) for K_s estimation.

Interest driven, in part, by availability of a graphical user interface (Rosetta) for implementing method.

Outline

- Evaluation of PTFs for Estimating Saturated Hydraulic Conductivity: Results from joint NRCS-KSU research project
- Opportunities for Minimizing Uncertainty
- Questions and Discussion

Evaluation of PTFs for Estimating K_s

Project Objective

Evaluate use of Rosetta for benchmark soils by comparing Rosetta K_s estimates with field-measured K_s data.

Methods

Physical property and K_s data measured at sites where NRCS descriptions of soil series had been completed.

The 16 sites (10 benchmark soils) included eight Mollisols, one Alfisol, one Vertisol, two Inceptisols, and one Entisol.

K-STATE Kansas State University RESEARCH & EXTENSION

Evaluation of PTFs for Estimating K_s

Methods – Soil series used in investigation

Soil series	Taxonomic description
Mollisols	
Albion*	Coarse-loamy, mixed, superactive, mesic Udic Argiustoll
Bourbonais	Coarse-silty over sandy or sandy-skeletal, mixed, mesic Fluventic Hapludoll
Dennis*	Fine, mixed, active, thermic Aquic Argiudoll
Geary*	Fine-silty, mixed, superactive, mesic Udic Argiustoll
Harney*	Fine, smectitic, superactive, mesic Pachic Argiustoll
Irwin*	Fine, mixed, superactive, mesic Pachic Argiustoll
Morrill	Fine-loamy, mixed, superactive, mesic Typic Argiudoll
Pawnee*	Fine, smectitic, superactive, mesic Aquic Argiudoll
Penden*	Fine-loamy, mixed, mesic Typic Calciustoll
Sibleyville	Fine-loamy, mixed, superactive, mesic Typic Argiudoll
Ulysses*	Fine-silty, mixed, mesic Aridic Haplustoll

Evaluation of PTFs for Estimating K_s

Methods – Soil series used in investigation

Soil series	Taxonomic description
Alfisol	
Pratt*	Sandy, mixed, mesic, Lamellic Haplustalf
Vertisol	
Kenoma*	Fine, smectitic, superactive, thermic Typic Epiaquert
Inceptisols	
Basehor	Loamy, siliceous, superactive, mesic Lithic Dystrudept
Bismarckgrove	Fine-silty, mixed, superactive, mesic Fluventic Eutrudept
Entisols	
Belvue	Coarse-silty, mixed, superactive, nonacid, mesic Typic Udifluvent

Evaluation of PTFs for Estimating K_s

Methods

Pit excavated at each site and soil described by NRCS soil scientists.

Samples from each horizon sent to NSSC Soil Survey Laboratory for physical property analysis.

Evaluation of PTFs for Estimating K_s

Methods

Field measurements of K_s obtained using constant-head well permeameter method (Amoozemeter) with five replicates per horizon.

Where appropriate, horizons less than 15-cm thick were grouped to satisfy constraints of CHWP method.

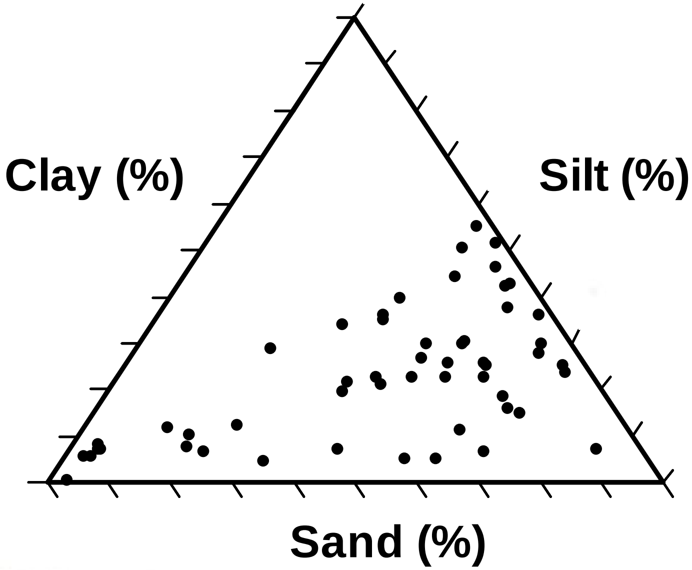
K·STATE RESEARCH & EXTENSION
Kansas State University

Evaluation of PTFs for Estimating K_s

Methods

The 16 sites yielded 53 samples including 14 A horizons, 29 B horizons, and 10 C horizons.

Relatively uniform distribution of textures with the exception of sandy clay.



Evaluation of PTFs for Estimating K_s

Methods

Estimation of K_s from physical property done using Rosetta (Schaap et al., 2001), and the methods of Ahuja et al. (1989) and Saxton et al. (1986).

Rosetta allows for five hierarchical levels of input data:

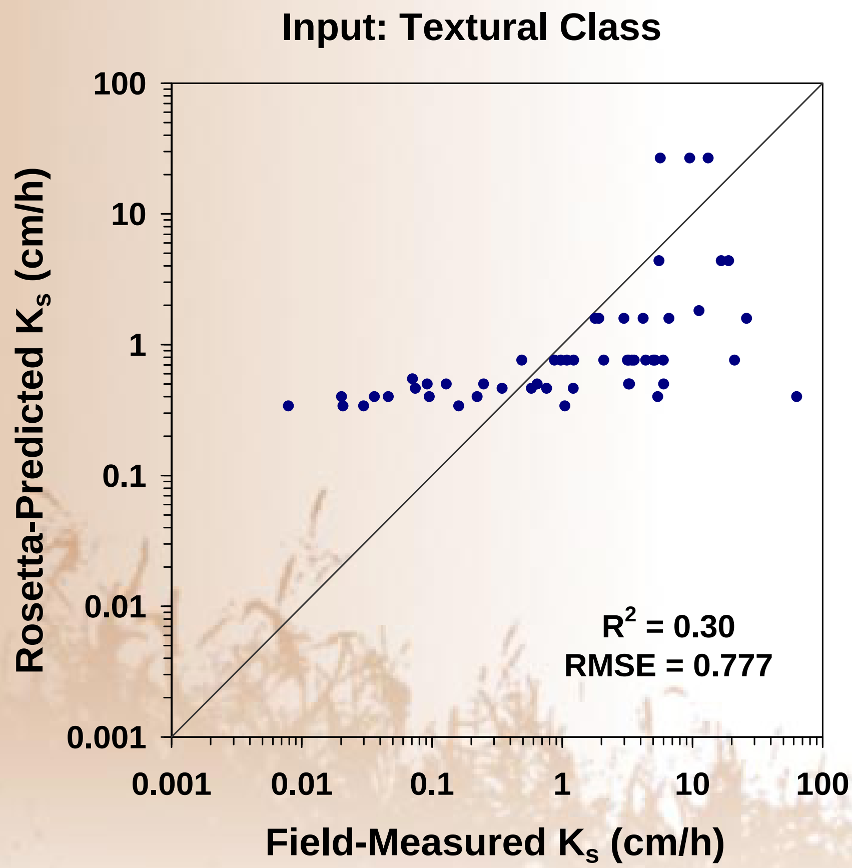
- Textural class
- Sand, silt and clay (SSC) percentages
- SSC and bulk density (BD)
- SSC, BD, and 33-kPa water content
- SSC, BD, and 33- and 1500-kPa water contents

Method of Ahuja et al. (1989) uses effective porosity.

Method of Saxton et al. (1986) uses sand and clay percentages and total porosity.

Evaluation of PTFs for Estimating K_s

Results – Estimation using Rosetta

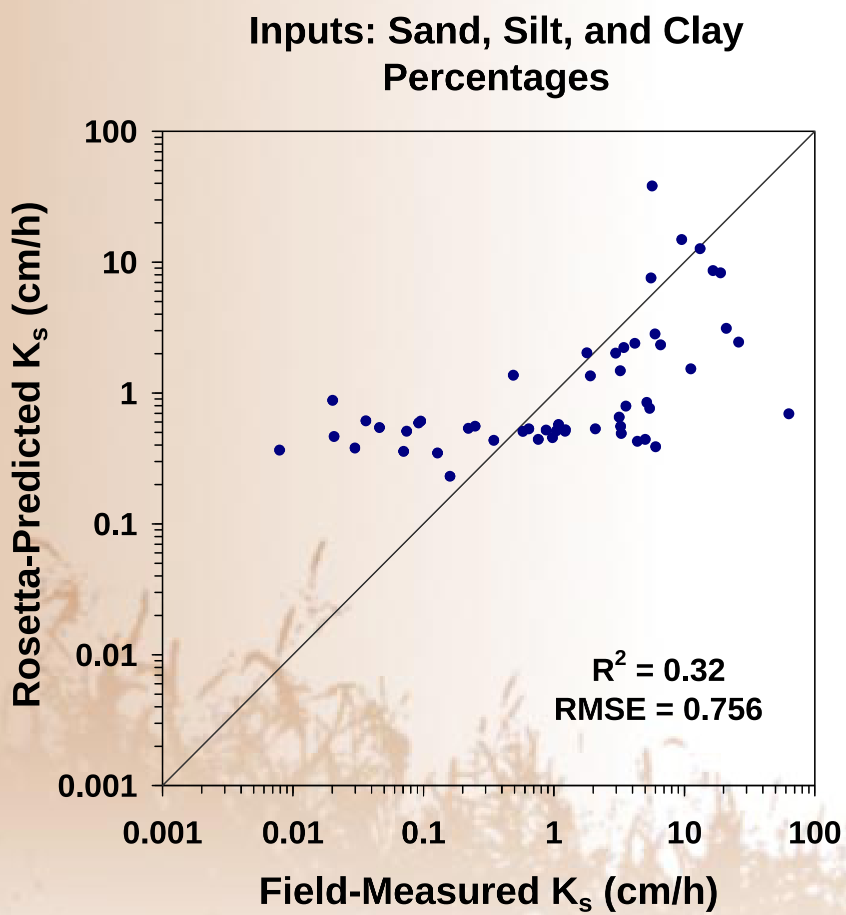


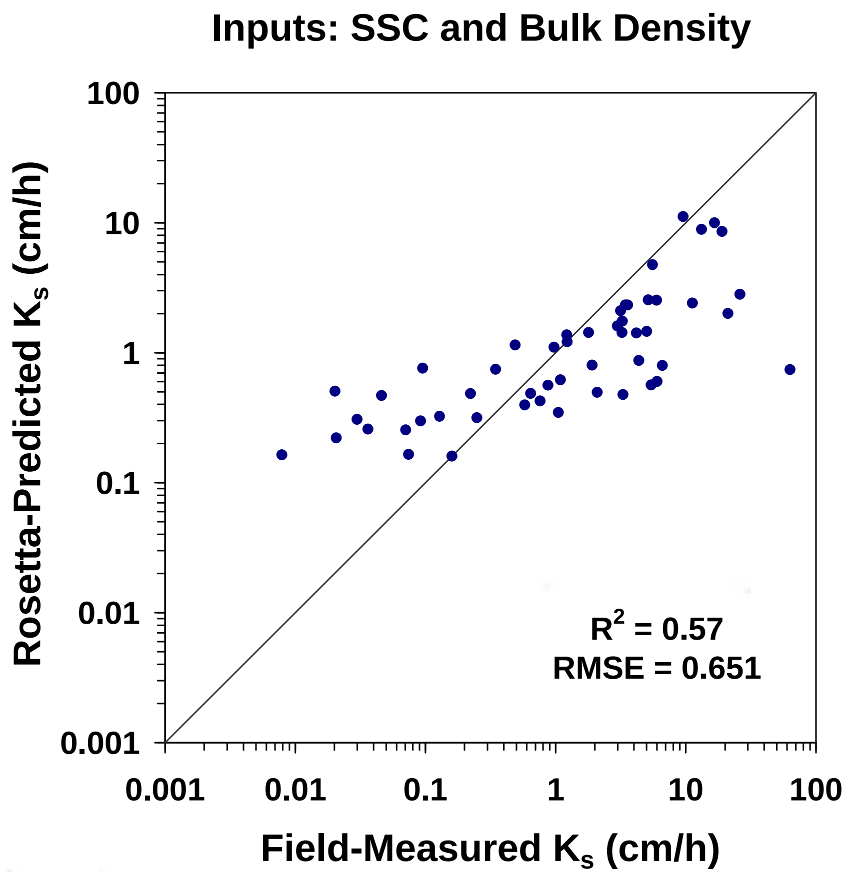
$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\log(K_s) - \log(K_s')\right]^2}$$

RMSE quantifies deviation from 1:1 line due to both scatter and bias (rotation & translation).

Evaluation of PTFs for Estimating K_s

Results – Estimation using Rosetta

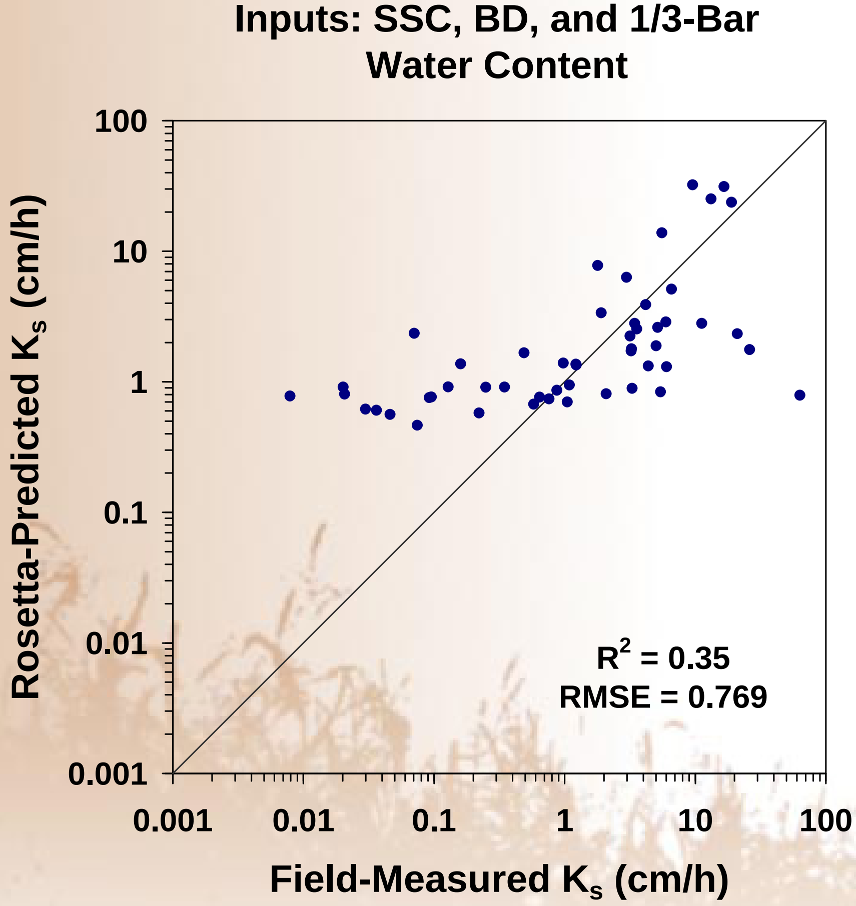


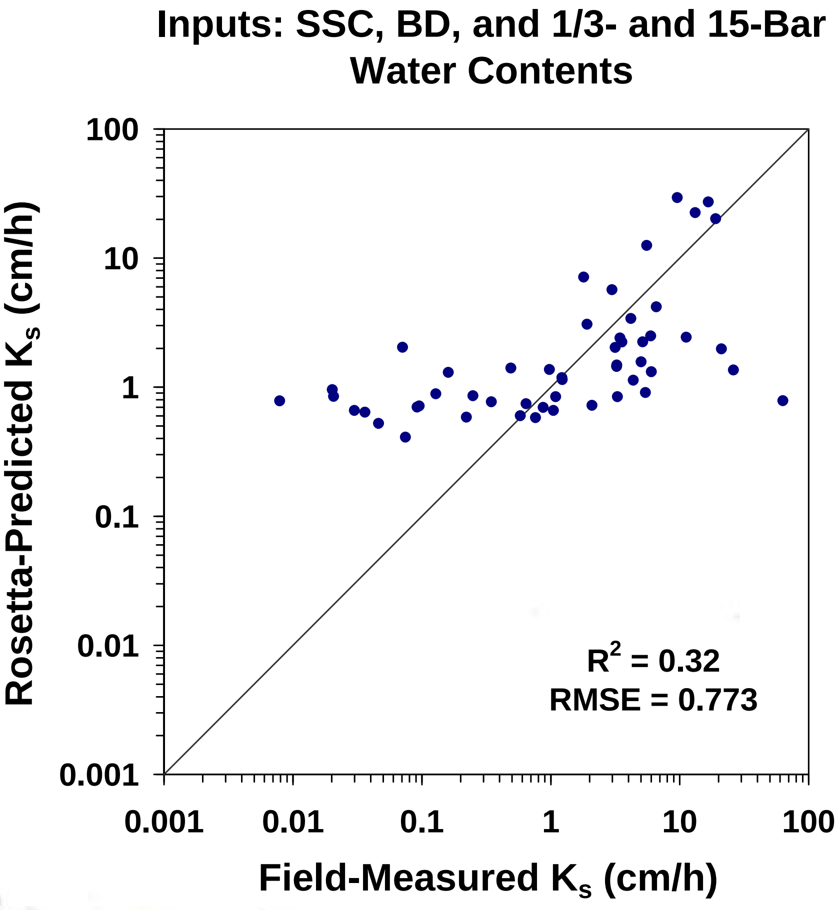


K-STATE RESEARCH & EXTENSION
Kansas State University

Evaluation of PTFs for Estimating K_s

Results – Estimation using Rosetta





K-STATE RESEARCH & EXTENSION
Kansas State University

Evaluation of PTFs for Estimating K_s

Results – Estimation using Rosetta

Results show only modest correlation between measured and Rosetta-predicted saturated hydraulic conductivity.

Best estimation achieved with combination of sand, silt and clay percentages and bulk density.

The use of 33- and 1500-kPa water contents did not enhance predictive ability over SSC and bulk density.

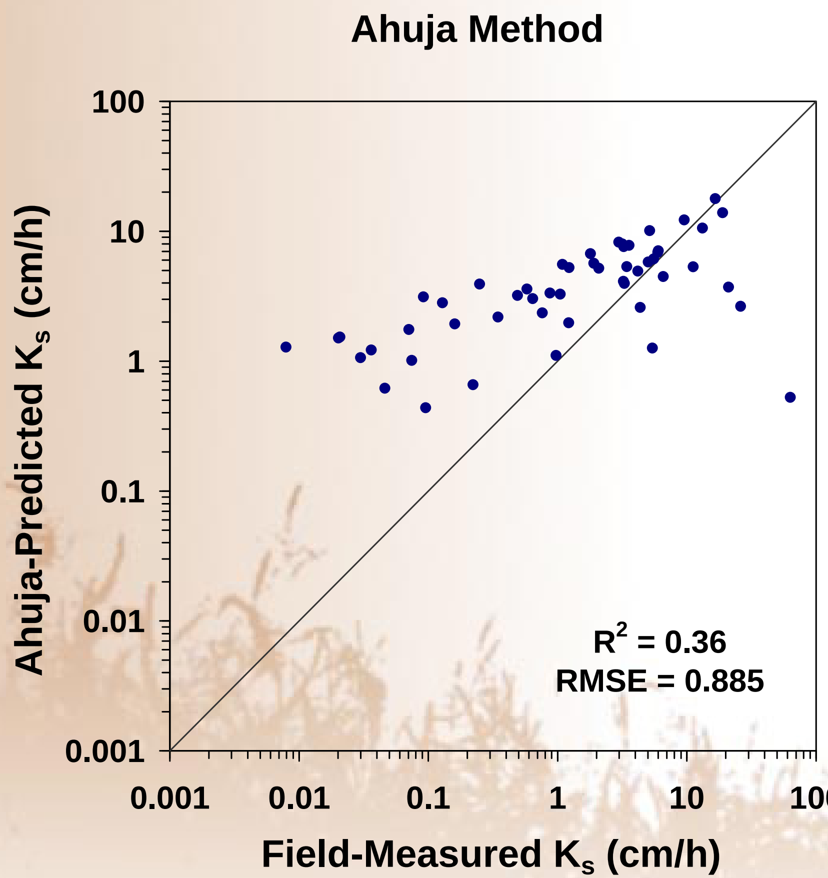
Rosetta estimates were biased (rotational) towards overestimation at low K_s and underestimation at high K_s.

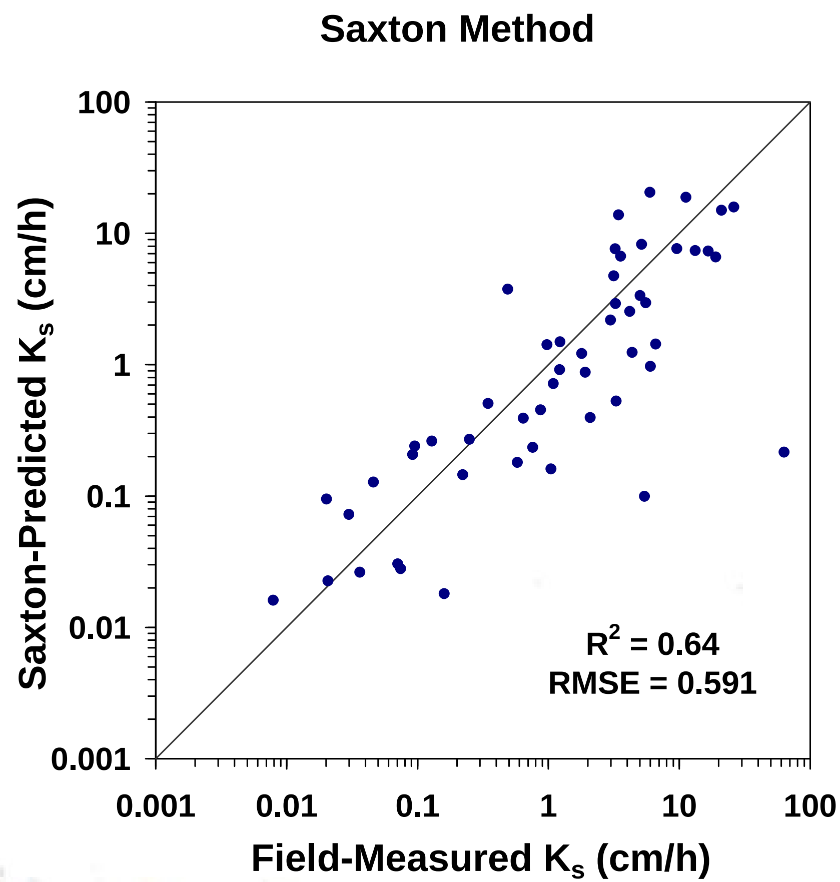
Bias and modest correlation likely a result of the data set used for calibration of Rosetta.

K-STATE RESEARCH & EXTENSION
Kansas State University

Evaluation of PTFs for Estimating K_s

Results – K_s from Ahuja and Saxton Methods





K-STATE RESEARCH & EXTENSION
Kansas State University

Evaluation of PTFs for Estimating K_s

Results – K_s from Ahuja and Saxton Methods

Ahuja Method

Rotational bias in K_s estimates similar to that for Rosetta.

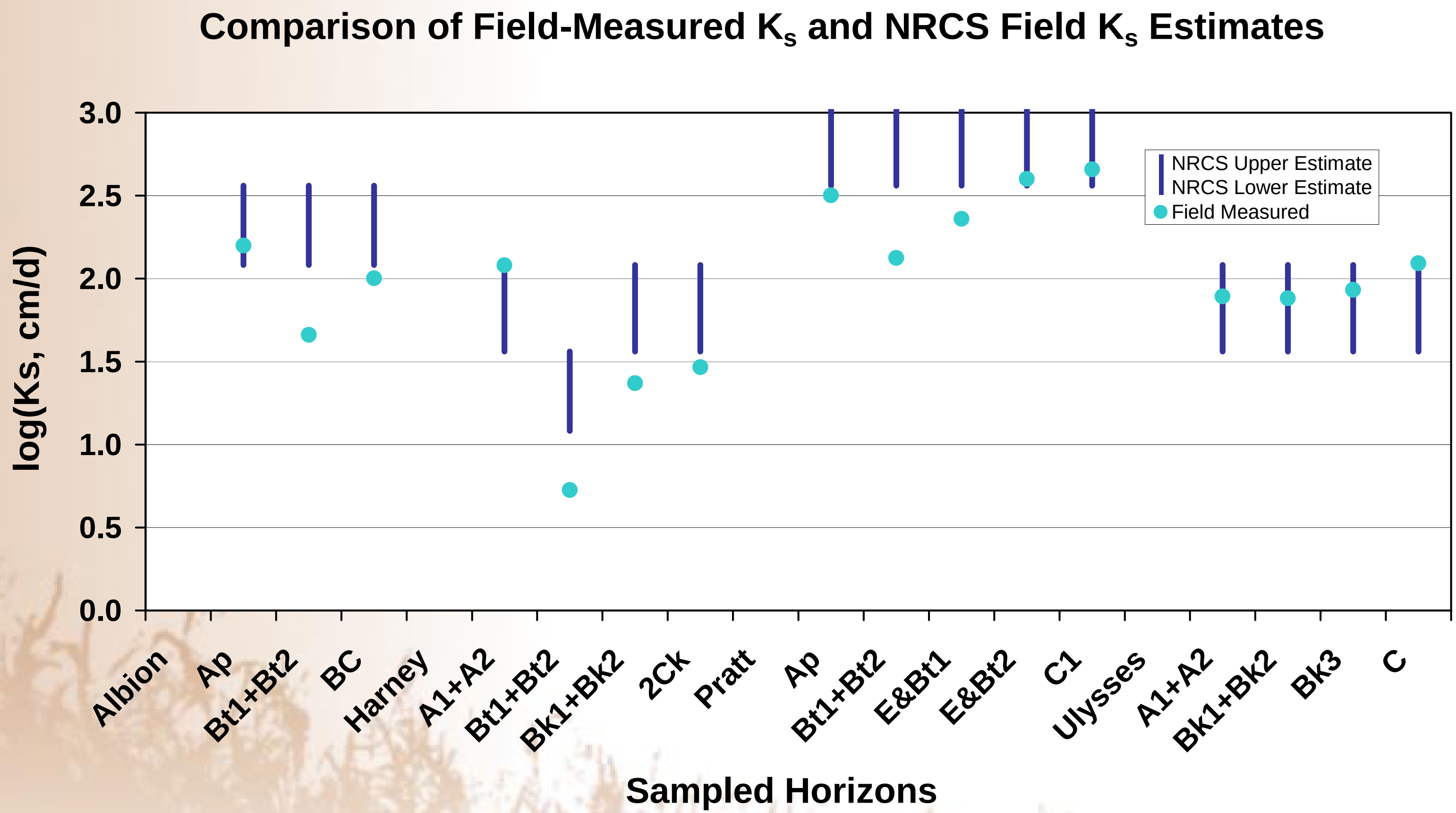
Did not perform as well as Rosetta (larger RMSE) due to translational bias.

Saxton Method

Best of the three PTFs examined (lowest RMSE) due to minimal bias in K_s estimates.

Evaluation of PTFs for Estimating K_s

Results - Additional comparisons…



Evaluation of PTFs for Estimating K_s

Results - Additional comparisons…

Field-measured K_s values fell outside the NRCS assigned range for more than half of the sampled horizons.

Where there was lack of agreement, assigned ranges were generally greater than the field-measured K_s values.

Agreement between field-measured K_s values and assigned range appears to be poorest for Bt horizons.

Evaluation of PTFs for Estimating K_s

Conclusions

A high-quality data set has been assembled for evaluating pedotransfer functions for K_s estimation.

The results suggest that Rosetta is not well suited for estimating K_s due to modest correlation with measured values and substantial bias.

Of the PTFs evaluated, the Saxton method proved to be the most effective for estimating K_s.

Problems with bias in K_s estimation were most likely a result of the data sets used for PTF calibration.

Opportunities for Minimizing Uncertainty

Database Development

There exists a critical need for a database that contains field-measured K_s data as well as corresponding soil descriptions and physical properties data.

There appears to be widespread agreement in the soil physics community that pedotransfer functions are not working out all that well. Principle problem appears to be lack of data for testing and development.

Most of the existing databases contain little in the way of field-measured K_s data…

Opportunities for Minimizing Uncertainty

Database Development

Perspective needs to be broader than simply developing a database that NRCS can use to evaluate/screen existing pedotransfer functions.

Database is critically needed by the soil science research community to calibrate existing PTFs and guide the development of new tools and methods for estimating K_s.

K-STATE RESEARCH & EXTENSION
Kansas State University

Opportunities for Minimizing Uncertainty

PTF Development

We can expect significant advances in the tools and methods for developing pedotransfer functions.

Advances in tools and methods will likely improve our ability to incorporate the expert knowledge of field soil scientists (e.g., identification of “overriding conditions” in Section 618.50 of Handbook).

Soil science research community needs the expertise of NRCS soil scientists to keep this process focused and moving in the right direction.

Opportunities for Minimizing Uncertainty

K_s Measurement

Improved methods for measuring K_s are needed…

Opportunities for Minimizing Uncertainty

Summary

- Databases for evaluating <u>and</u> developing PTFs
- Advances in tools and method for PTF development
- Advances in method for K_s measurement

K-STATE RESEARCH & EXTENSION
Kansas State University


Questions & Discussion