A Novel Method for Estimation of Root Zone Moisture Content from EO-1 Hyperion Hyperspectral Imagery

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Introduction

- Excess irrigation in arid and semiarid regions poses risks for contamination of environmental resources.
- The development and application of sustainable and environmentally friendly irrigation strategies requires knowledge of the root zone moisture distribution, which is challenging to obtain for large areas with standard sensor technology.
- Remote sensing provides excellent means for estimation of large-scale surface moisture distributions, but limitations still exist, especially with extending surface moisture information to the root zone.

Objectives

- Find an appropriate method to obtain topsoil moisture from EO-1 Hyperion hyperspectral imagery.
- Evaluate different methods for estimating root zone soil moisture from surface moisture distributions with a limited number of experimental data.

Materials and Methods

- Soil sampling was conducted in a square field of 81 ha located in the Hetao Irrigation District in China (Fig. 1).
- Two hyperspectral datasets were also collected. The first dataset was obtained with the EO-1 Hyperion sensor before spring sowing; the second dataset was obtained with a hyperspectral camera (400-2500 nm) before soil sampling.

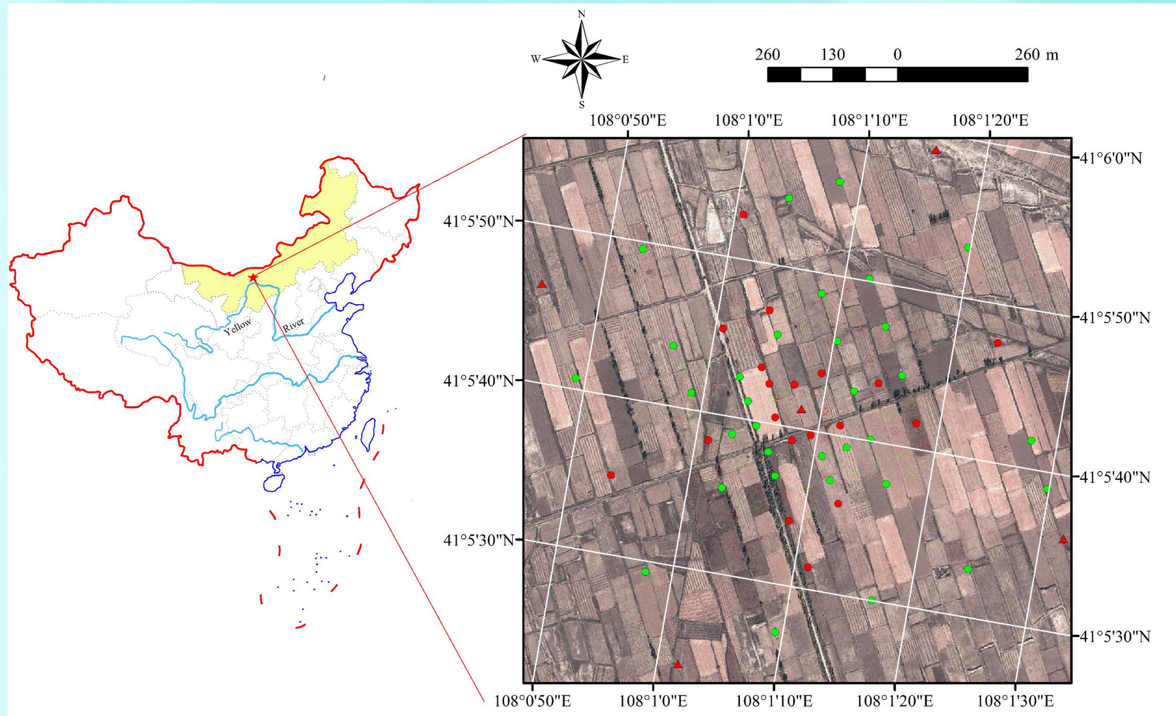

Fig 1: Field site in the Hetao Irrigation District and applied sampling scheme. Soil samples were extracted both on April 6 and 26, 2013.

- The soil moisture index (SMI, Eq. 1), the IG function (IG, Eq. 2), and the PLS method were used to obtain surface moisture from hyperspectral data.
- Geostatistics were applied to randomly generate 2000 soil particle size distributions (PSDs) based on measured textures (Fig. 2). The PSDs were then used in ROSETTA to obtain soil hydraulic properties to parameterize HYDRUS-1D and simulate root zone moisture distributions.
- Four different methods for obtaining root zone soil moisture were evaluated (Fig. 3).

$$SMI = \frac{R_{\lambda_1} - R_{\lambda_2}}{R_{\lambda_1} + R_{\lambda_2}} \quad (1)$$

$$R(\lambda) = R_{\lambda_i} + (R_{\lambda_0} - R_{\lambda_i})\exp\left(\frac{-(\lambda_i - \lambda_0)^2}{2\sigma^2}\right) \quad (2)$$

$R_{\lambda 1}$ and $R_{\lambda 2}$ represent reflectance in specific wavelengths.

λ_i is the maximum wavelength, λ_0 is the peak position wavelength, $R_{\lambda i}$ is the maximum reflectance, $R_{\lambda 0}$ is the minimum reflectance at function center, and σ is the Gaussian function deviation parameter describing the width of the Gaussian peak.

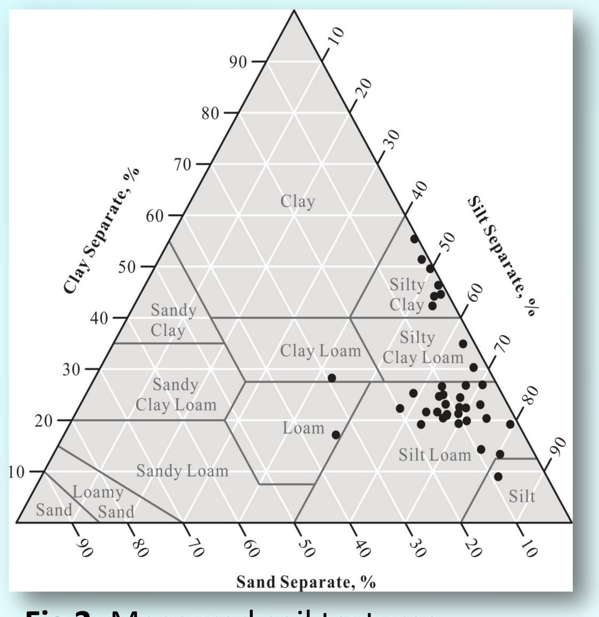

Fig 2: Measured soil textures

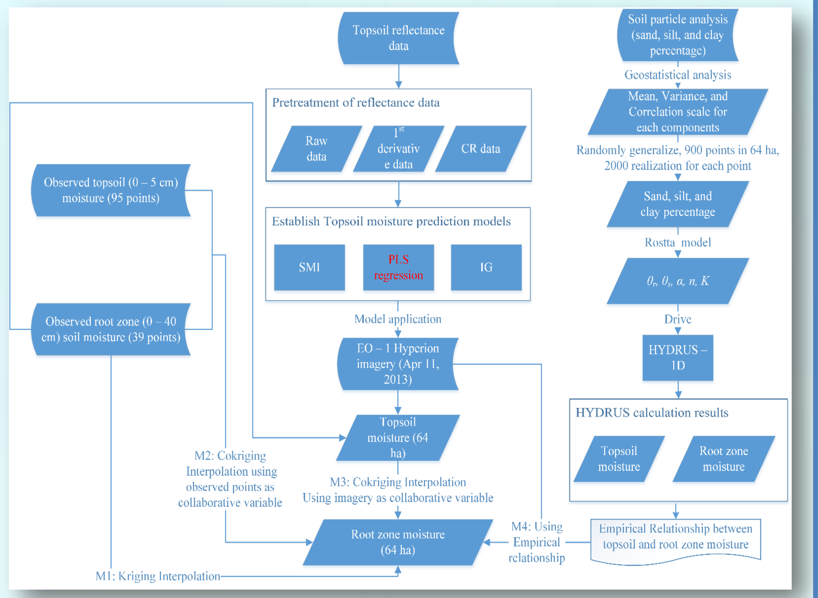

Fig 3: Modeling framework

Preliminary Results

Geostatistical Analysis of PSDs

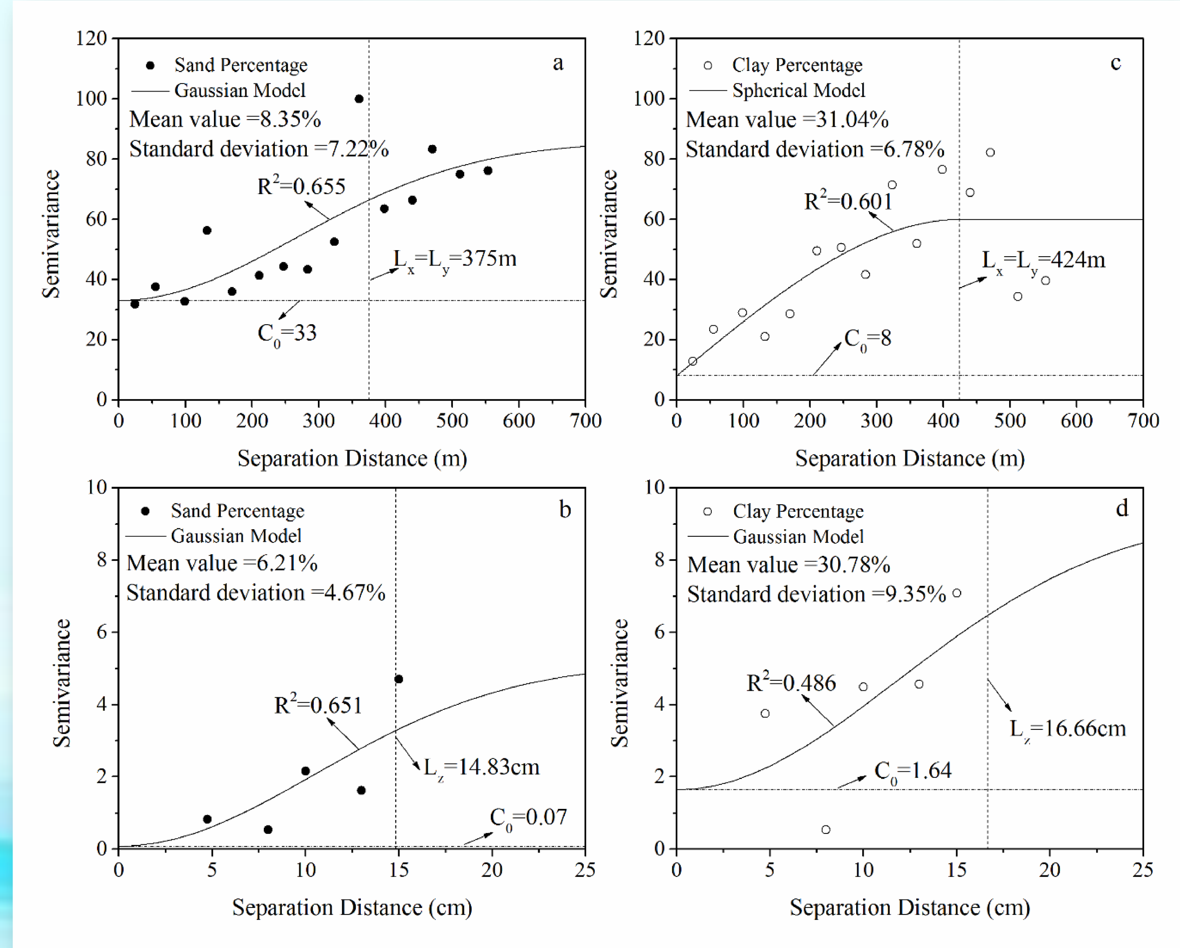

Fig 4: Semivariograms of the spatial distributions of sand and clay percentages

- A Gaussian model was used to fit the sand percentage, and vertical section of clay percentage; a spherical model was used to fit the horizontal section of clay percentage.

Surface Moisture

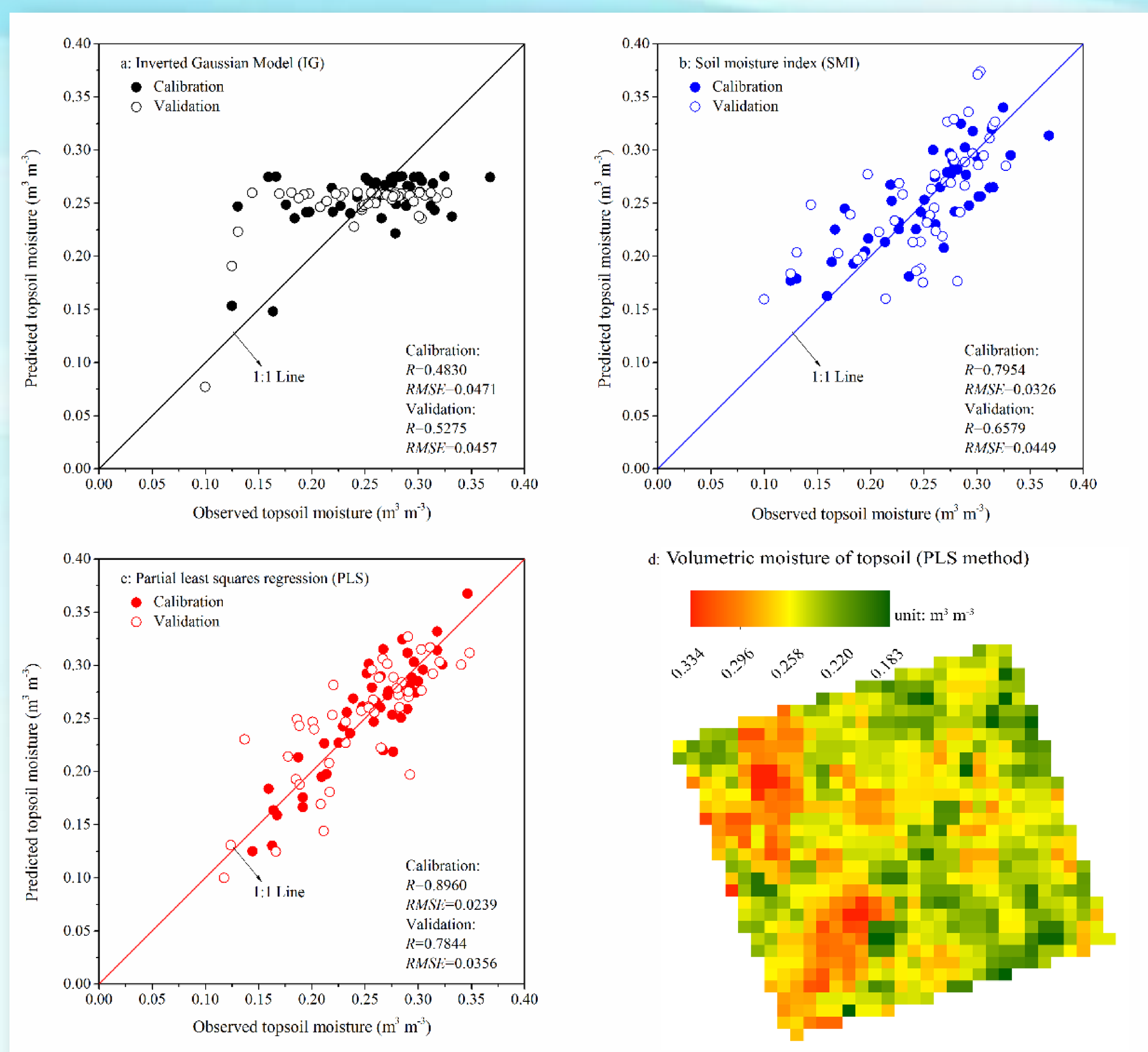

Fig 5: Volumetric moisture content of topsoil (d) obtained from inverted Gaussian model (a), soil moisture index (b), and partial least squares regression (c).

- The optimal wavelengths in Eq. 1 were 1034 nm and 1064 nm; the IG model failed to accurately predict topsoil moisture; the PLS method exhibited highest *R* of all investigated models.
- The PLS method was used to estimate topsoil moisture from EO-1 Hyperion imagery.

Root Zone Soil Moisture

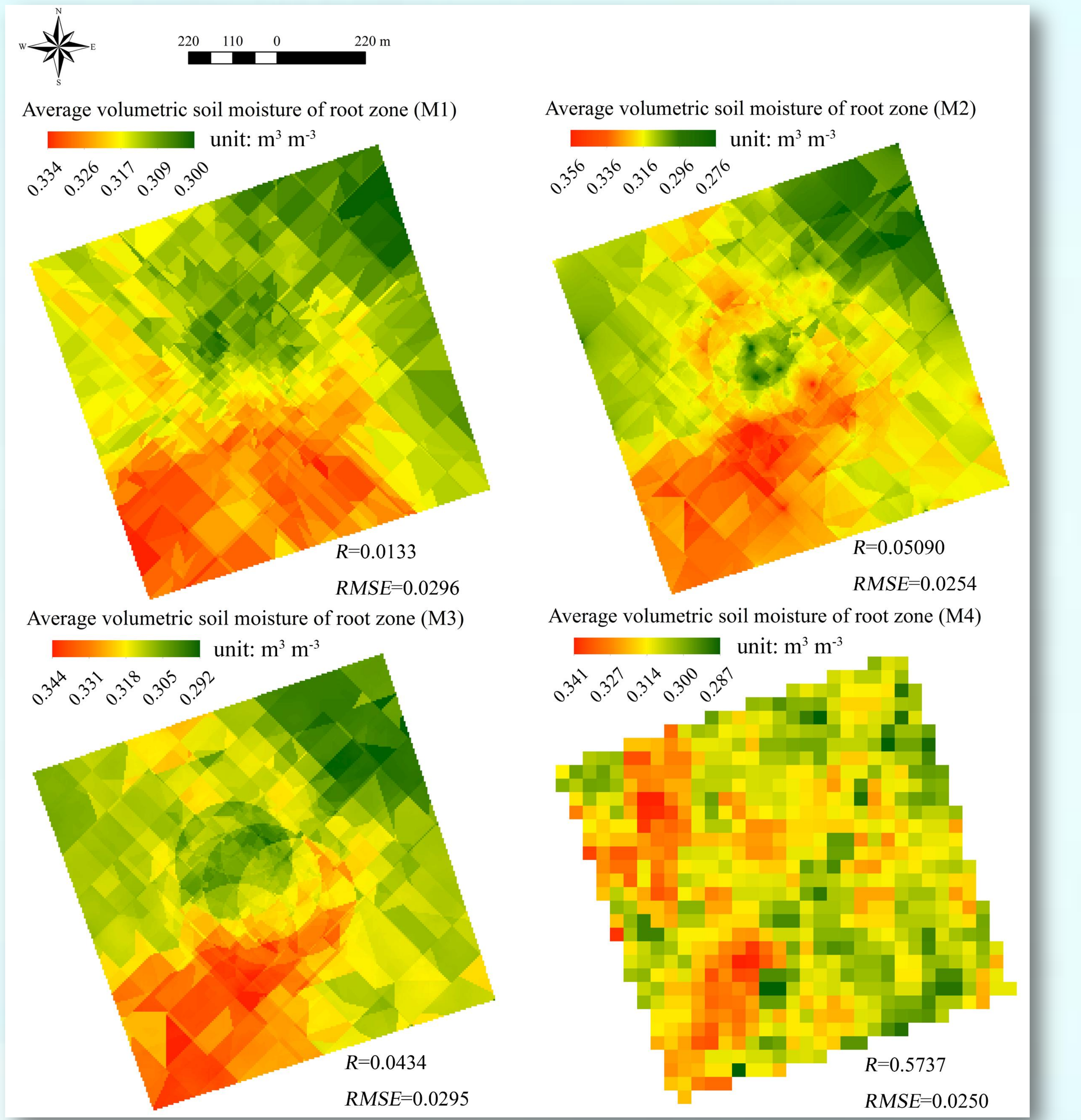

Fig 6: Average root zone soil moisture obtained with 4 different methods (see Fig.3)

- Cokriging *(M2)* with experimental topsoil data improved kriging predictions *(M1)*, but using imagery as collaborative variable *(M3)* failed to enhance prediction accuracy.
- The empirical relationship (Eq. 3) obtained from HYDRUS-1D simulations *(M4)* exhibited the highest *R* and lowest *RMSE* of the 4 investigated methods.

$$\theta_{root} = 0.3571\theta_{top} + 0.2216 \quad (3)$$

θ_{root} and θ_{top} are the root zone and topsoil volumetric moisture contents.

Conclusions

- The PLS method provides powerful means for prediction of surface soil moisture from hyperspectral data.
- Cokriging based on measured root zone and topsoil moisture predicts root zone moisture distributions more accurately than kriging.
- HYDRUS-1D simulations revealed that a linear function can be used to predict root zone moisture from surface moisture.
- Because the lack of temporal soil property data HYDRUS could not be applied in inverse mode. Hence, soil hydraulic parameters were generated randomly and Monte Carlo simulations were performed to determine empirical relationships.

References

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