China-U.S. Exchange on Loess Landforms Meeting

Vertical variations of soil physical properties in the critical zone of the Loess Plateau, China

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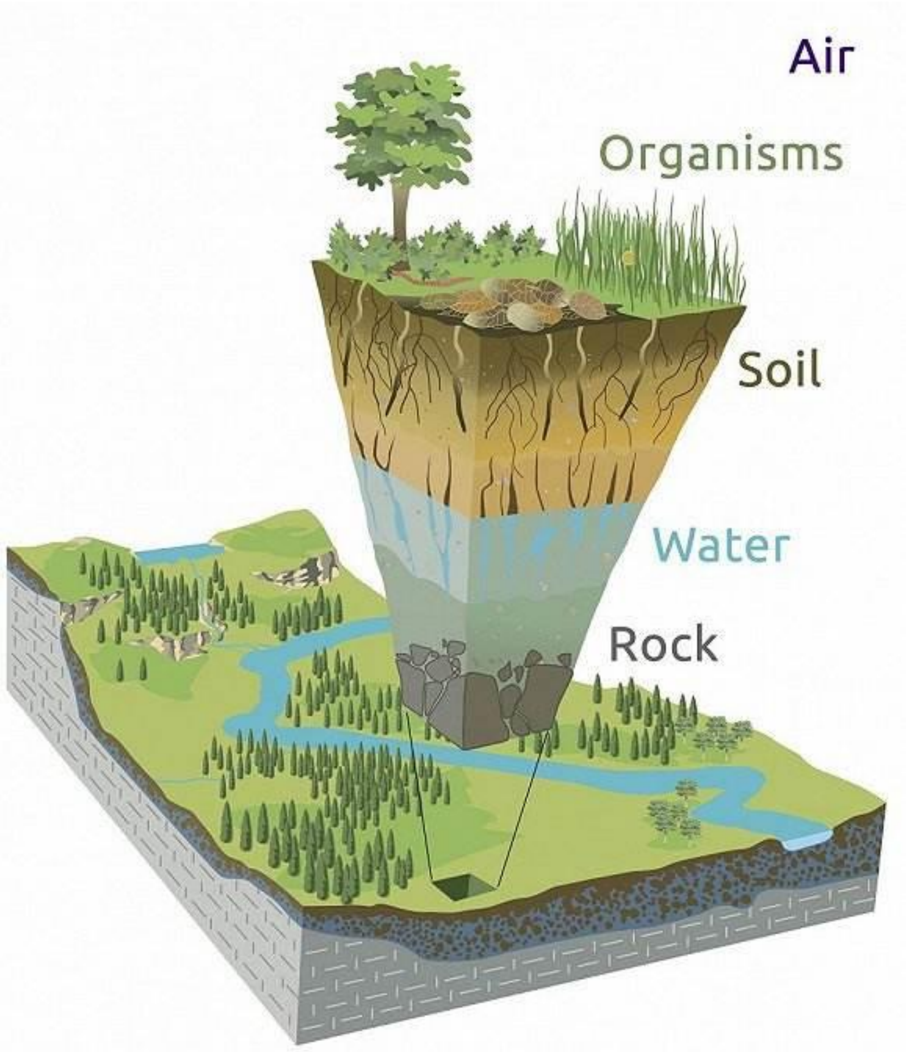
Contents

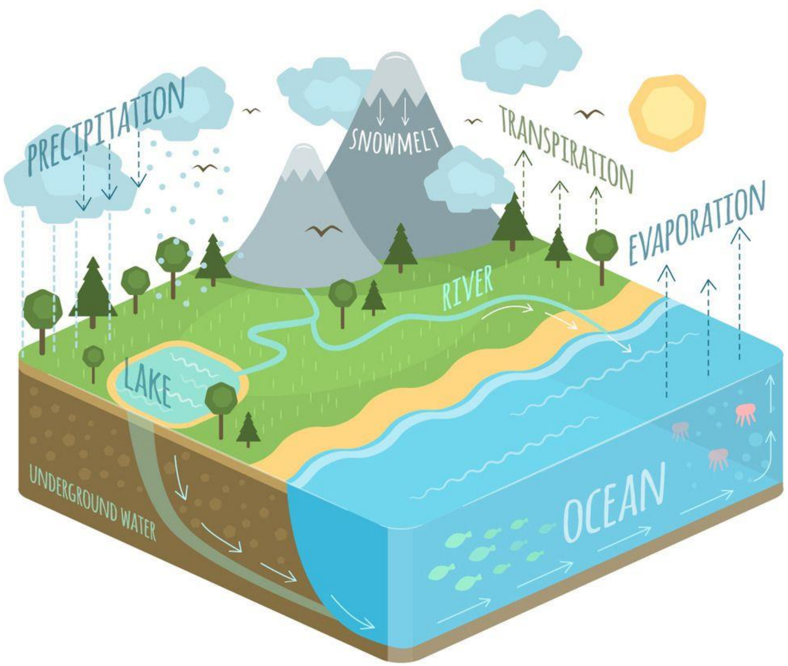
Background

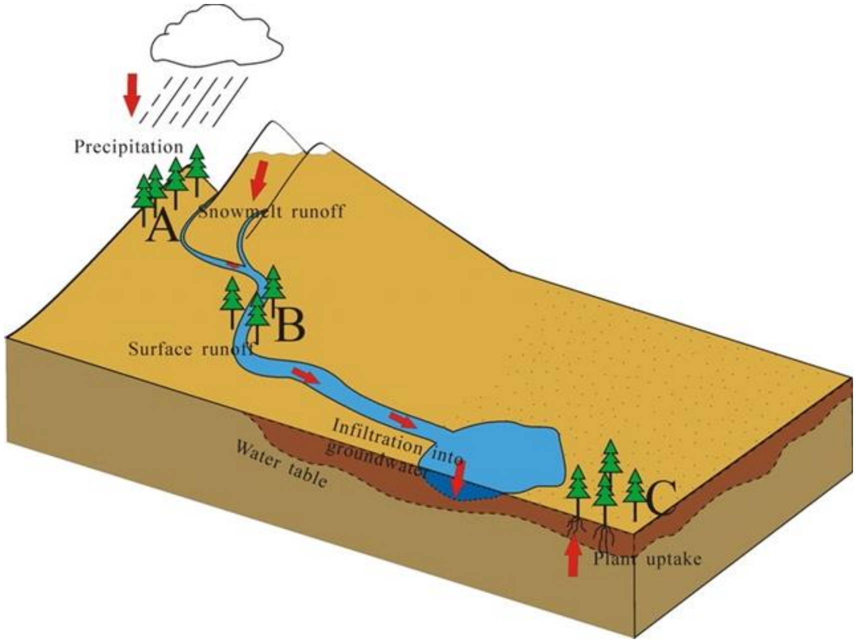
The **Earth's critical zone** (CZ) is the intersection area for matter migration and energy exchange in the pedosphere, atmosphere, hydrosphere, biosphere, and lithosphere in terrestrial ecosystems



Background

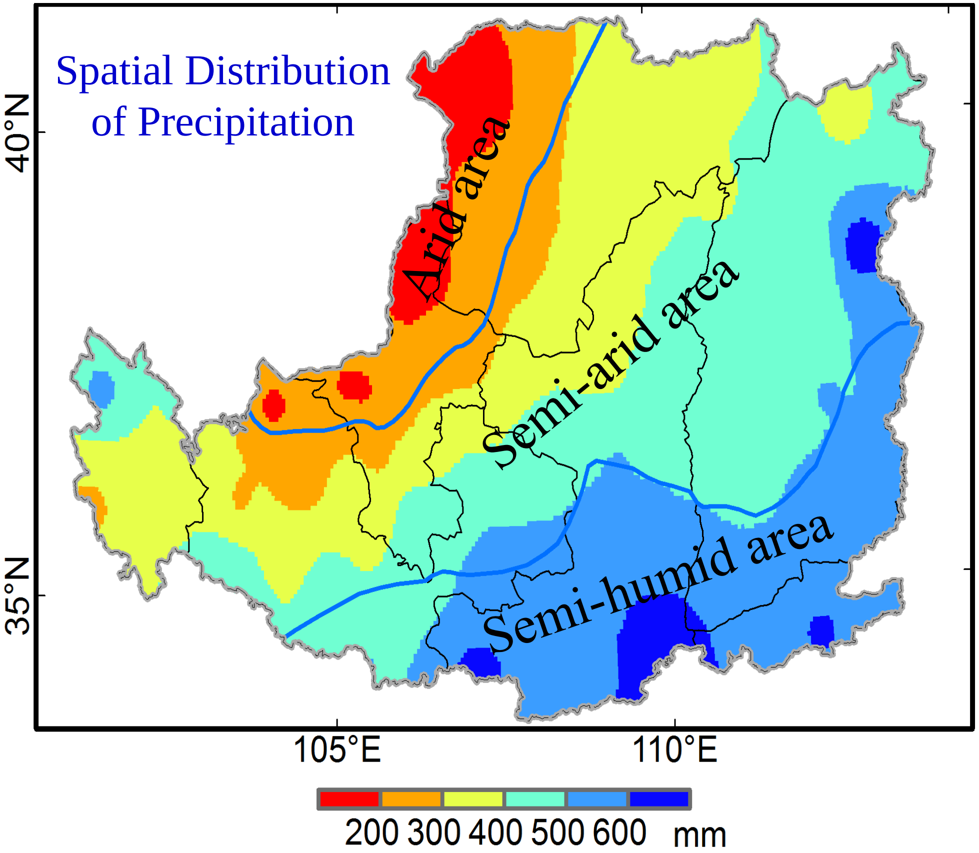
Water cycle processes are the core and link of matter cycle in the CZ, Investigating water cycle process in the CZ can contribute to the understanding of the interaction and effect between vegetation and water cycle processes





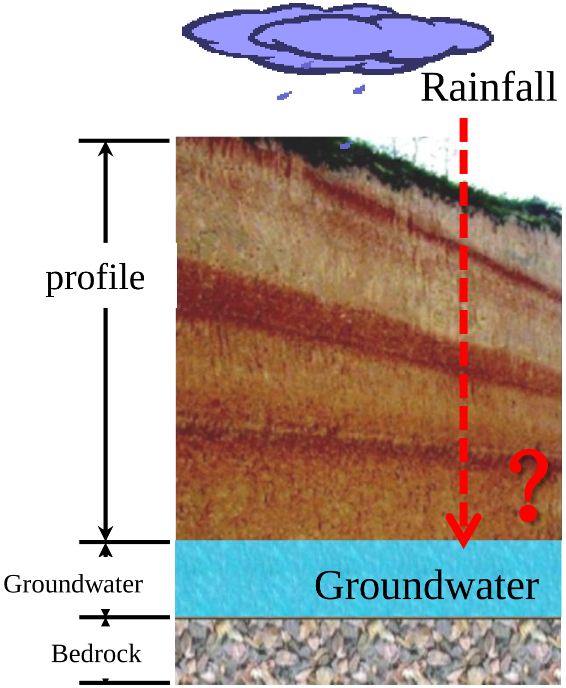
Background

The Loess Plateau is located in the continental monsoon region, and two-thirds of this region belongs to arid or semiarid areas. Investigaiting the water cycle processes could promote the reasonable use of limited water and soil resources in the Loess Plateau.



Background

The soil physical properties are important to understand and describe the water cycle processes in the CZ and were important input parameters for hydrological models.



Water movement for the deep profile

Rainfall recharges groundwater

Background

The Loess Plateau is famous for its deep loess deposits (average 50–200 m). The calculated mean loess thickness is 105.7 m (Zhu et al. 2018).

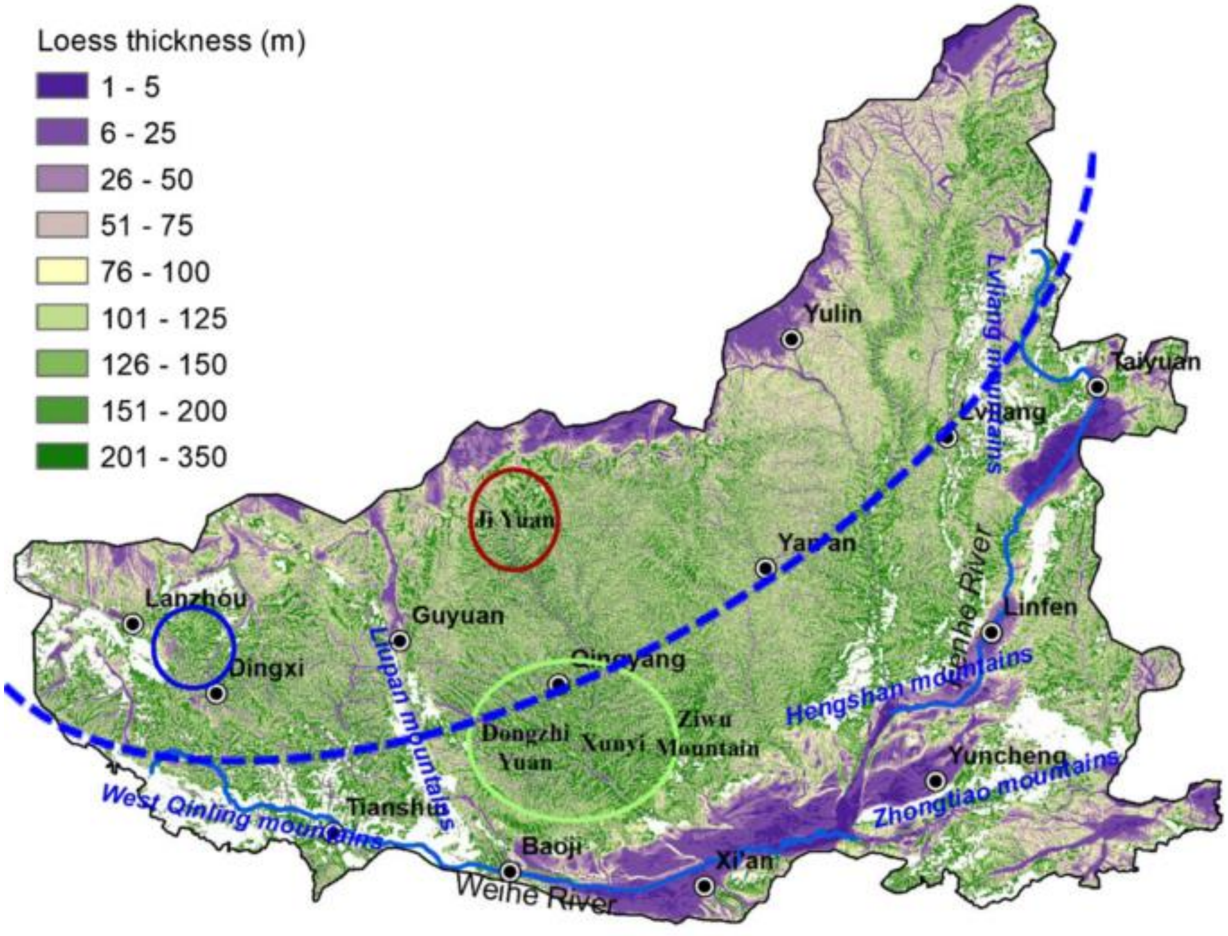
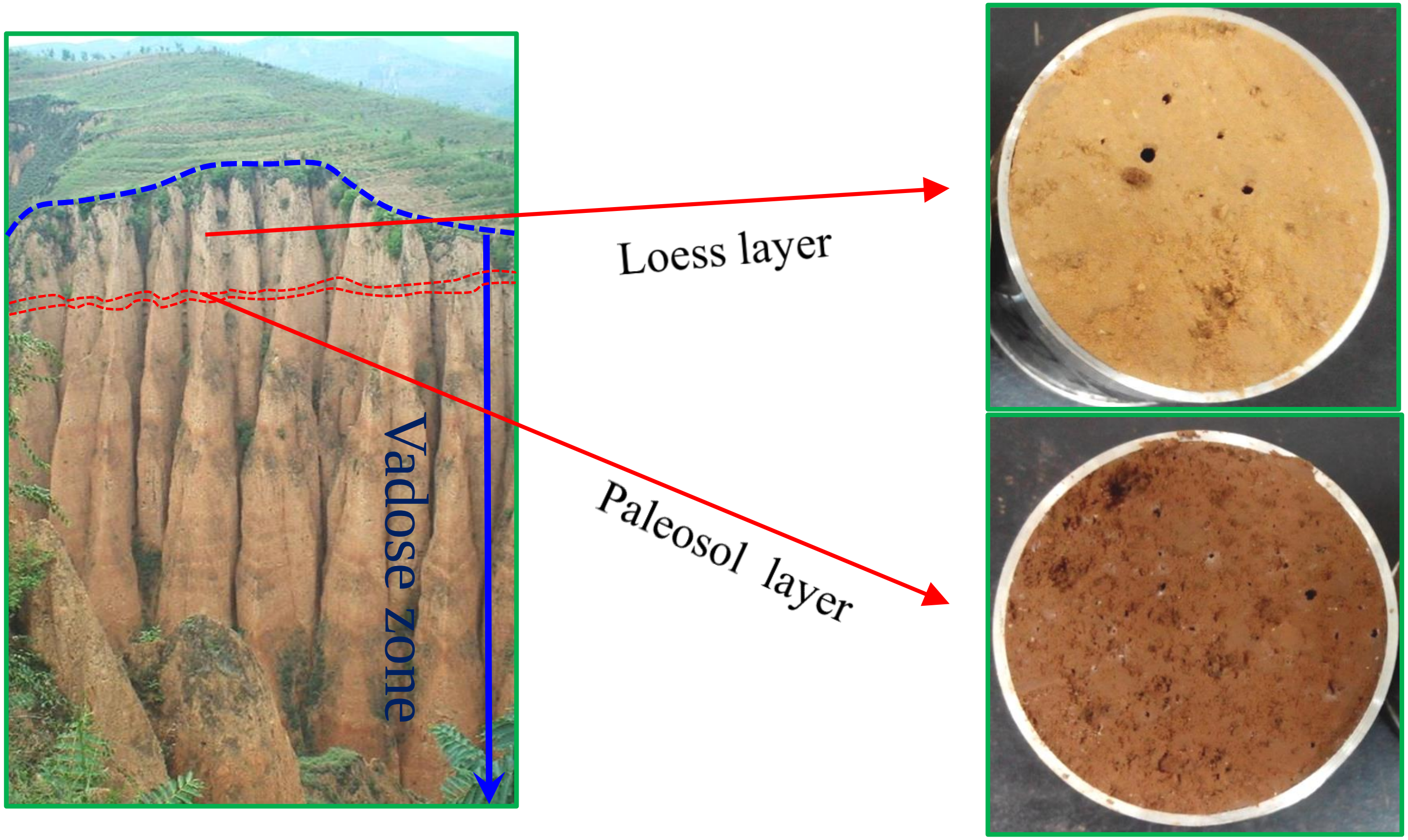


Figure. 1 Map of loess thickness distribution across the region (Zhu et al. 2018).

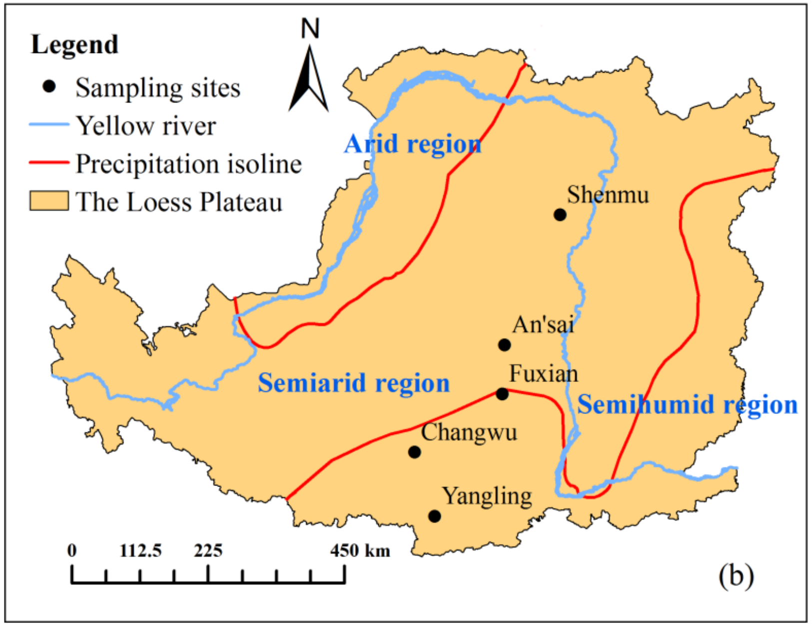
Background

Previous studies have determined the spatial distributions of soil physical properties and the relationships between them and related factors mainly in shallow layers (0–5m). However, details are lacking about the soil physical properties for the deep profile on the Loess Plateau.



Materials and methods

- Instruments: Drilling machine
- Borehole: 15 cm
- Sampling sites: Yangling, Changwu, Fuxian, Ansai, Shenmu



Materials and methods

Table 1 General information on five sampling sites

Sites	latitude	longitude	altitude	Depth	groungwater	Soil type	Rainfall
Yangling	34°17'	108°04′	525	104.5	73.6	Lou soil	660
Changwu	35°14'	107°41′	1226	204.5	84.5	Heilu soil	580
Fuxian	36°7'	109°16′	1277	189.5	93.9	Huangmian soil	550
An’sai	36°51'	109°18′	1281	161.5	147.2	Huangmian soil	505
Shenmu	38°47'	110°21′	1246	56.5	54.3	Fengsha soil	440

Materials and methods

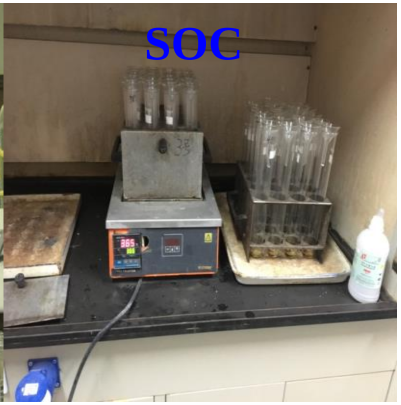
- Time: 3 years
- Soil indexes: 17
- Data: 11968

Sampling sites	Depth (m)	Number
Yangling	104	96
Changwu	205	205
Fuxian	190	190
Ansai	161	159
Shenmu	56	54


SWRC


Soil particle composition

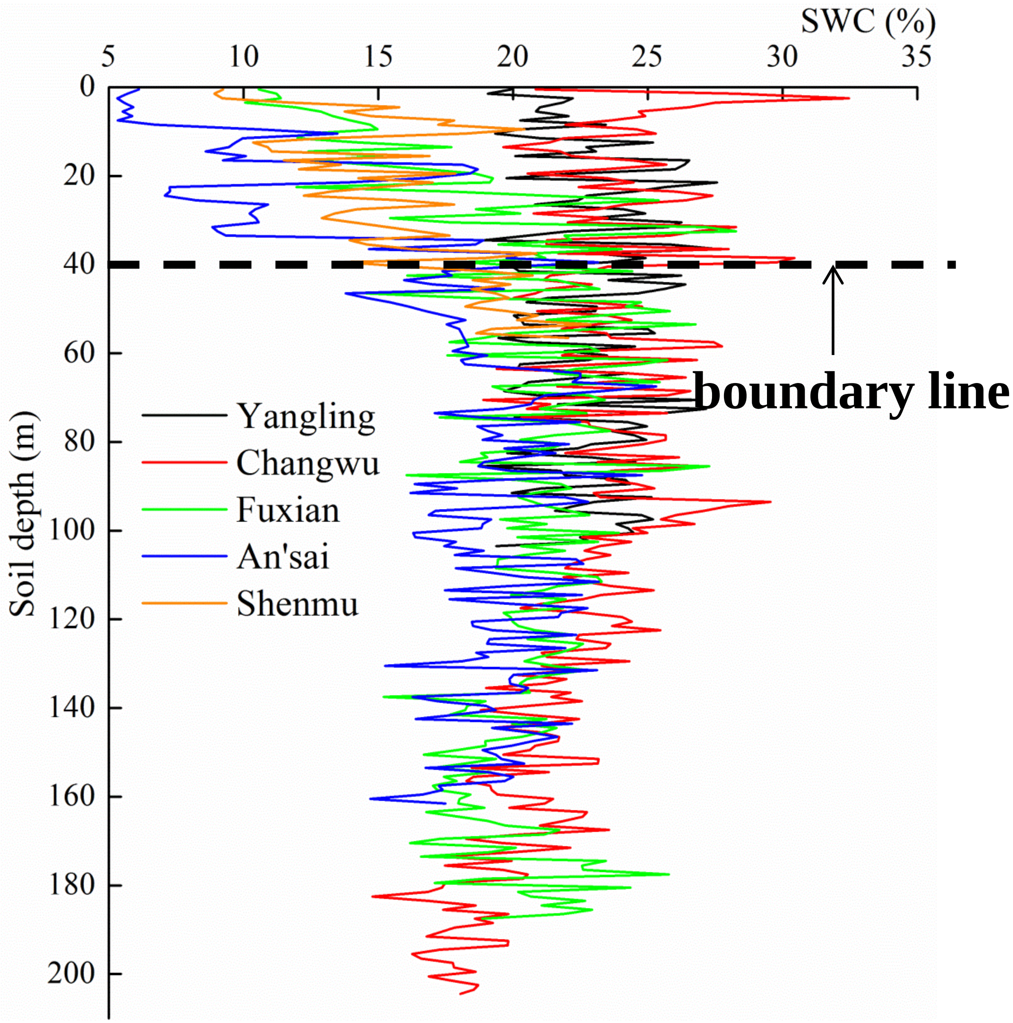

Ks


SOC

Photos

Results

Vertical Variations of soil water content for the deep profile



- Mean soil water content in the entire profile decreased at south-north direction
- Soil water variation in each site became weak gradually
- Difference in soil water content between the sites decreased as soil depth increased from 40 m to 200 m

Qiao et al., 2018, Vadose zone journal

Results

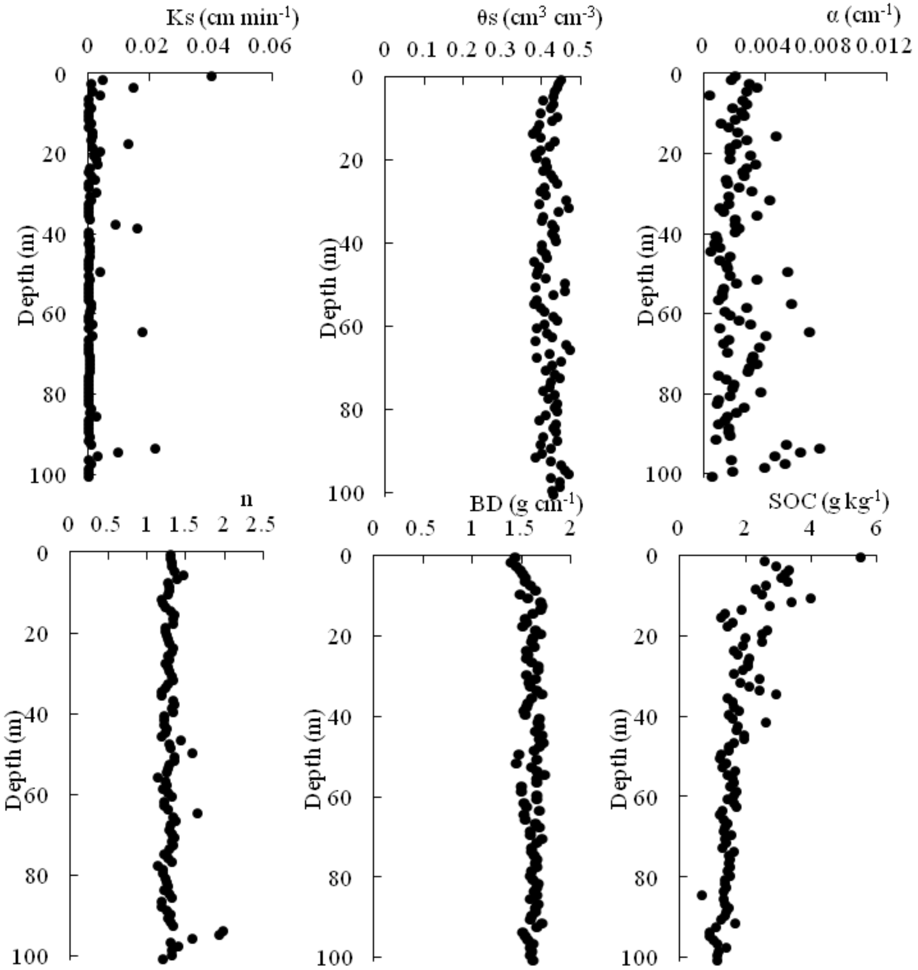
- Soil hydraulic properties : the soil water retention curve (SWRC) and the soil saturated hydraulic conductivity (Ks)
- Important variables to describe the migration of water in the soil

$$\theta(h) = \theta r + \frac{(\theta s - \theta r)}{(1 + |\alpha h|^{n})^{1-\left(\frac{1}{n}\right)}}$$

(**Van Genuchten, 1980**)

Results

Vertical Variations and influencing factors of soil hydraulic properties



- θs and n remained almost stable along the profile, with **weak variation**
- The Ks values showed a fluctuating trend, with **strong variation**
- Bulk density belong to weak variation, and SOC belong to moderate variation

Qiao et al., 2018, Catena

Results

Table 1 State-space analysis of soil hydraulic properties using soil basic properties

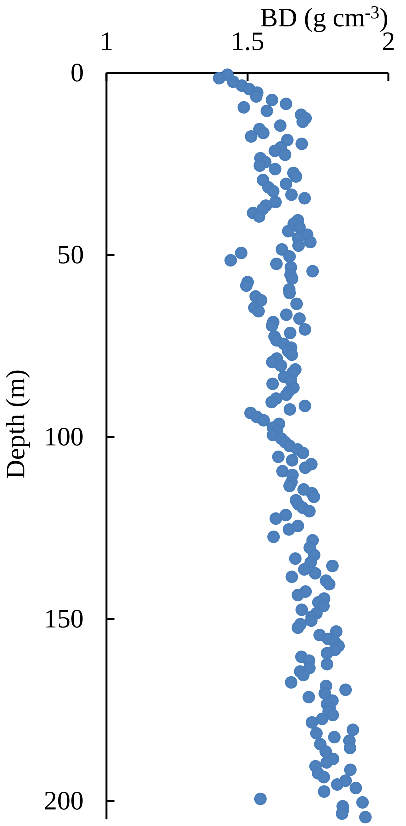
State-space Model	**R^2**
$(Ks)_i = 0.760^* (Ks)_{i-1} + 0.229^* (Clay)i_{-1} + w_i$	0.875
$(\theta s)_i = 0.697^* (\theta s)_{i-1} + 0.321^* (BD)_{i-1} + w_i$	0.897
$(\alpha)i = 0.736^* (\alpha)i - 1 + 0.135^* (BD)i - 1 + 2.099^* (Sand)_{i-1} + wi$	0.965
$(n)_i = 0.711^* (n)_{i-1} + 0.289^* (Sand)_{i-1} + 0.008^* (Clay)_{i-1} + w_i$	0.987
Stepwise Multiple Linear Regression	
$Ks = 8.296 - 6.53^*BD - 0.055^*Clay$	0.318
$\theta s = 0.753 - 0.214^*BD + 0.002^*Sand$	0.560
$\alpha = -0.165 - 1.648^*BD + 0.021^*Sand$	0.375
$n = 7.158 - 4.808^*BD + 0.098^*Sand$	0.292

- The **soil physical properties** (bulk density, sand content, and clay content) could account for most of the total variation in SHP
- **State-space modeling** described the spatial relationship between SHP and soil physical properties much better

Qiao et al., 2018a, Catena

Results

Vertical Variations and influencing factors of bulk density



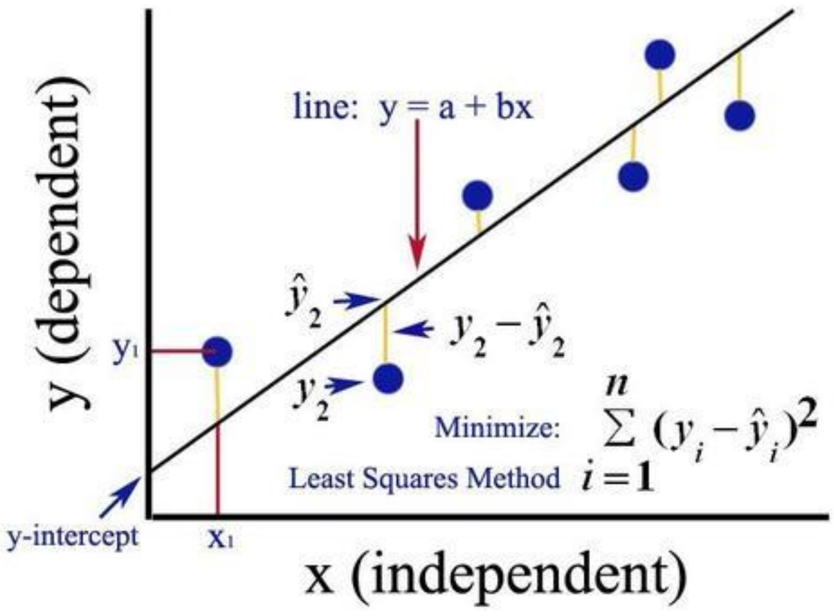
State-space model	**R^2**
$BD_i = 0.928*BD_{i-1} + 0.087*Sand_{i-1} + w_i$	0.82
$BD_i = 0.245*BD_{i-1} + 0.510*Dep_{i-1} + 0.251*Clay_{i-1} + w_i$	0.98
$BD_i = 0.387*BD_{i-1} + 0.413*Dep_{i-1} + 0.061*Sand_{i-1} + 0.150*Clay_{i-1} + w_i$	0.94
$BD_i = 0.545*BD_{i-1} + 0.373*Dep_{i-1} – 0.006*Silt_{i-1} + 0.022*Clay_{i-1} + 0.067*SOC_{i-1} + w_i$	0.89

- BD exhibited an **increasing trend** along the profile with low variation
- **Clay and depth** were important factors for the total variation in the BD

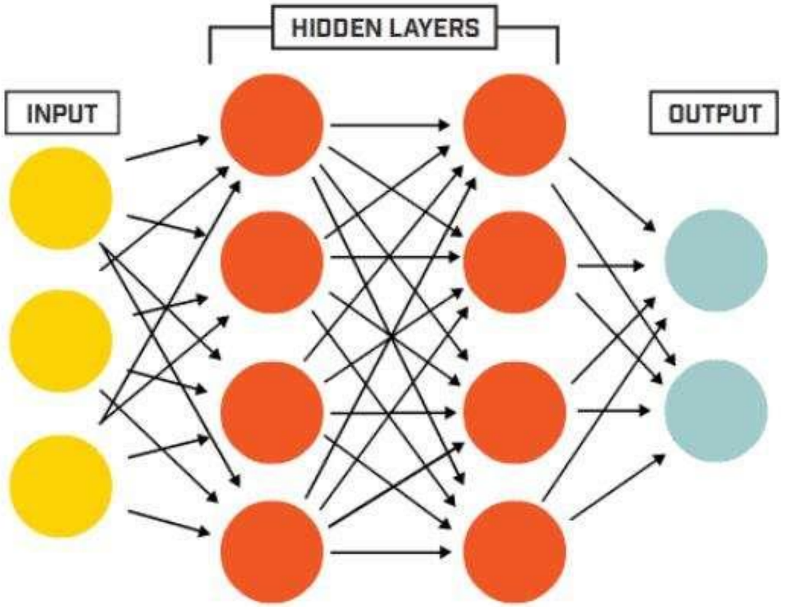
Qiao et al., 2018b, Catena

Results

- Soil hydraulic properties: Obtaining direct measurements is time consuming and expensive
- Pedotransfer functions: Estimating soil parameters based on readily measured soil properties



Multiple linear regression (MLR)



Artifical neural network(ANN)

Results

Development of pedotransfer functions for soil hydraulic properties

Table 1 New pedotransfer fuctions for SHP

parameters	Regression equations	R^2
Ks	$-1.523 + 1.685*BD^{-1} + 0.0004*Sand + 0.996*\ln BD$	0.561
α	$0.012 + 0.0002*Sand - 0.007*BD$	0.474
n	$5.507 + 6.966*Clay^{-1} - 7.272*BD^2 + 0.186*SOC^{-1} - 4.399*BD^{-1}$	0.526
θs	$-0.779 - 0.608*BD^2 + 0.016*\ln Sand + 1.712*BD - 0.000027*Sand^2$	0.519

- The bulk density and sand content were important input variables for predicting Ks, α, and θs
- The bulk density, clay content, and soil organic carbon were important input variables for n

Qiao et al., 2018, Hydrological Processes

Results

Development of pedotransfer functions for soil bulk density

Table 1 R^2, RMSE, and ME for the models developed using MLR and ANN models

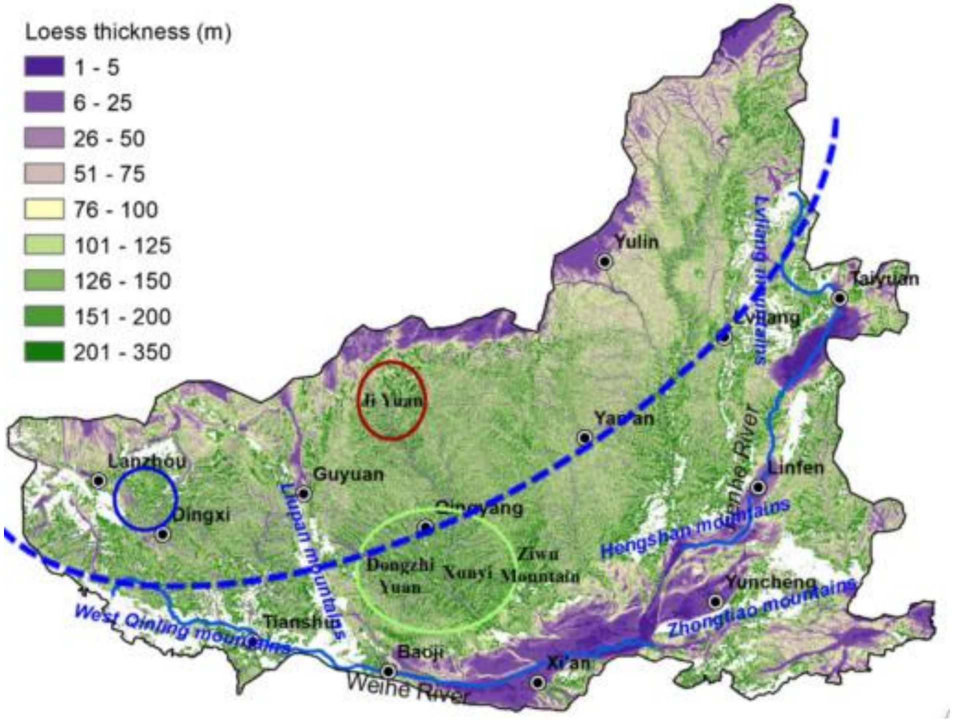
Model	Input variables	R^2	RMSE	ME
M1	Depth + Clay	0.347	0.080	–0.018
M2	Depth + Sand + Clay	0.350	0.080	–0.010
M3	Depth + Silt + Clay	0.347	0.082	–0.021
M4	Depth + Sand + Silt + Clay	0.344	0.082	–0.018
M5	Depth + Sand + Silt + Clay + SOC	0.345	0.081	–0.014
A1	Depth + Clay	0.345	0.081	–0.023
A2	Depth + Sand + Clay	0.347	0.079	–0.021
A3	Depth + Silt + Clay	0.352	0.082	–0.020
A4	Depth + Sand + Silt + Clay	0.349	0.082	–0.020
A5	Depth + Sand + Silt + Clay + SOC	0.346	0.081	–0.019

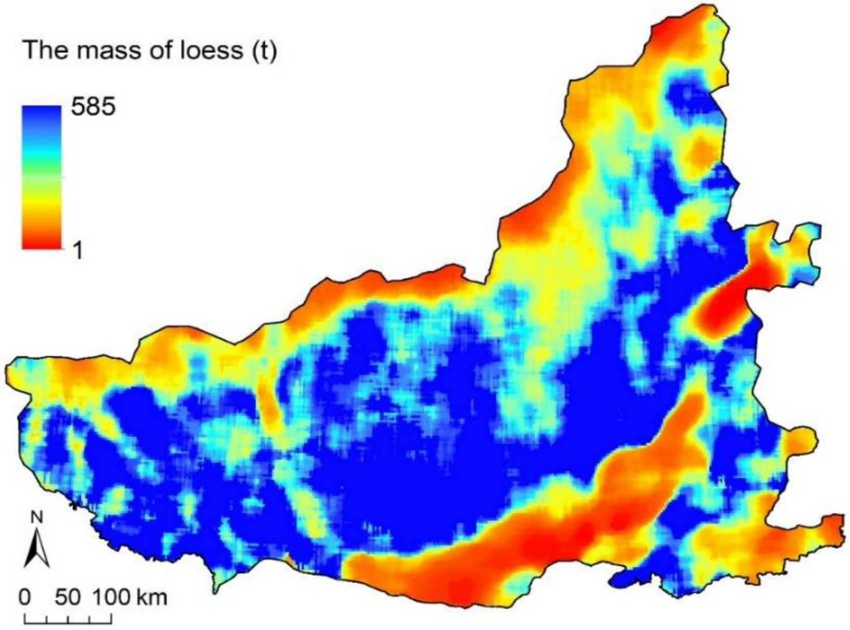
- ➢ The performance of MLR was similar to that of the ANN method
- ➢ The soil depth and clay were also important input variables for the BD prediction

Qiao et al., 2018, Journal of Soils and Sediments

Results

The mass of loess in the Loess Plateau of China





The total loess mass is approximately $5.45*10^{13}$ t

Zhu et al. 2019, Science Bulletin

Results

Five Long-time position stations to measure the variation of soil water content

Summarys

- Obtaining the important hydraulic parameters, which are important to study the water movement for the deep profile on the Loess Plateau
- Developing the pedotransfer functions of soil physical properties, which could improve the work efficiency for our study

Publications

1. Jiangbo Qiao, Yuanjun Zhu. Xiaoxu Jia, Laiming Huang, Ming'an Shao. 2018. Development of pedotransfer functions for soil hydraulic properties in the critical zone on the Loess Plateau, China. Hydrological Processes. doi: 10.1002/hyp.13216
2. Jiangbo Qiao, Yuanjun Zhu. Xiaoxu Jia, Laiming Huang, Ming'an Shao. 2018. Vertical distribution of soil total nitrogen and soil total phosphorus in the critical zone on the Loess Plateau, China. Catena .166: 310-316.
3. Jiangbo Qiao, Yuanjun Zhu. Xiaoxu Jia, Laiming Huang, Ming'an Shao. 2018. Spatial variation and simulation of the bulk density in a deep profile (0–204 m) on the Loess Plateau, China. Catena .164: 88-95.
4. Jiangbo Qiao, Yuanjun Zhu. Xiaoxu Jia, Laiming Huang, Ming'an Shao. 2018. Estimating the spatial relationships between soil hydraulic properties and soil physical properties in the critical zone (0–100 m) on the Loess Plateau, China: A state-space modeling approach. Catena. 160: 385-393.
5. Jiangbo Qiao, Yuanjun Zhu. Xiaoxu Jia, Laiming Huang, Ming'an Shao. 2018. Development of pedotransfer functions for predicting the bulk density in the critical zone on the Loess Plateau, China. Journal of Soils and Sediments. doi:10.1007/s11368-018-2040-1.
6. Jiangbo Qiao, Yuanjun Zhu. Xiaoxu Jia, Laiming Huang, Ming'an Shao. 2018. Factors that Influence the Vertical Distribution of Soil Water Content in the Critical Zone on the Loess Plateau, China. Vadose Zone Journal. 17: 1. doi:10.2136/vzj2017.11.0196.
7. Jiangbo Qiao, Yuanjun Zhu. Xiaoxu Jia, Laiming Huang, Ming'an Shao. 2018. Pedotransfer functions for estimating the field capacity and permanent wilting point in the critical zone of the Loess Plateau, China. Journal of Soils and Sediments. doi:10.1007/s11368-018-2036-x.
8. Jiangbo Qiao, Yuanjun Zhu. Xiaoxu Jia, Laiming Huang, Ming'an Shao. 2017. Spatial variability of soil water for the entire profile in the critical zone of the Loess Plateau. Advances in Water Science. 28: 515-522 (In Chinese).

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Thanks for your attention!