Evaluation of Water Vapor Sorption Hysteresis in Soils: The Role of Organic Matter and Clay

UID: 92016

Emmanuel Arthur[1](Emmanuel.Arthur@agro.au.dk), Markus Tuller[2], Per Moldrup[3], Lis W. de Jonge[1]

[1]Dept. of Agroecology, Aarhus University, Denmark. [2]Dept. of Soil, Water and Environ. Sci. The Univ. of Arizona, USA.

[3]Dept. of Civil Engineering, Aalborg University, Denmark.

Introduction

- Water sorption hystesis (H) is the difference exhibited in the relationship between the water content (w) of a soil and the corresponding water potential/relative humidity (RH) obtained by wetting or drying
- Extensive literature exist on causes and quantification of H for soil water potential range from 0 to −1.5 MPa but information on H is limited for water potentials < −10 MPa
- Consideration of H in the range from −10 to −480 MPa is crucial for modeling physical and biological soil processes

Objectives

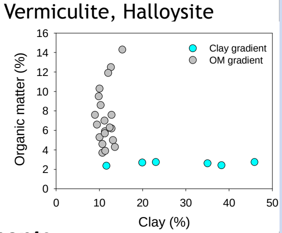
- Assess and compare recently developed methods for quantifying water vapor sorption hysteresis in soils and pure clays for the water potential range of −10 to −480 MPa
- Investigate the role of organic matter (OM) and clay content and type on water vapor hysteresis

Methods

- **Investigated Samples**

Five pure clays: Kaolinite, Illite, Vermiculite, Halloysite Montmorillonite

Two groups of soils
(i) Six soils with clay gradient (11-46%) and OM~2.6%,
(ii) 20 soils, OM gradient (3-15%) and clay content~11%.



- **Sorption Isotherm Measurements**

Wetting and drying isotherms measured with Vapor Sorption Analyzer
(−10 to −480 MPa; pF 5.0 to 6.6; RH 3 to 93%)

- **Hysteresis Quantification Methods**

(i) Based on number of molecular layers (n) from a modified BET ($MBET$) isotherm equation[1,2]

$$w = \frac{RH(1-RH^{n})}{[(k_1 + k_2 RH)(1-RH)]}$$

Model parameters: k_1, k_2, n
n = molecular layers in multilayer

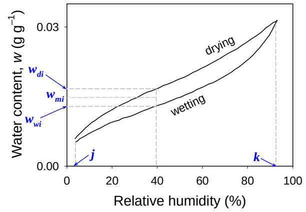
Model fitted separately to wetting and drying curves to obtain "n" and calculate H_1

$$H_1 = \frac{n_{wetting} - n_{drying}}{n_{wetting}}$$

(ii) Average Degree of Hysteresis[3], Dh

$$H_2 = \frac{\sum_{i=j}^{i=k} \frac{w_{di} - w_{wi}}{w_{mi}}}{k - j + 1}$$

10 data points between 3% and 93%RH selected for calculating H_2

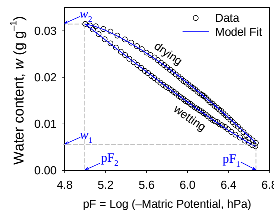


(iii) Single parameter non-singularity model[4], SPN

$$pF = pF_1 - (pF_1 - pF_2)\left(\frac{w_1 - w}{w_1 - w_2}\right)^N$$

Model fitted separately for wetting and drying curves to obtain 'N' and calculate H_3

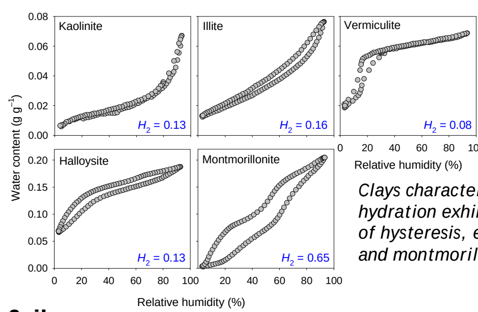
$$H_3 = \frac{N_{wetting}}{N_{drying}}$$



Results

Pure clays

MBET-n and *SPN* methods were unable to capture hysteresis
Dh method accurately described hysteresis (H_3)



Clays characterised by interlayer hydration exhibit larger degree of hysteresis, e.g. cf. kaolinite and montmorillonite

Soils

All 3 methods successfully quantified H for both groups of soils

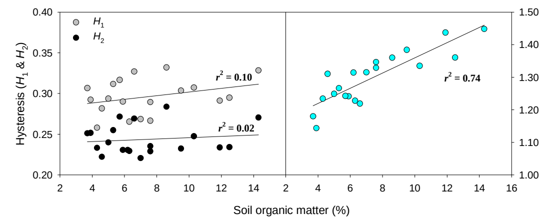
Clay gradient soils

Clay%	12	20	23	35	38	46
H_1	0.22	0.25	0.24	0.22	0.22	0.28
H_2	0.21	0.24	0.23	0.21	0.21	0.25
H_3	1.22	1.19	1.16	1.33	1.37	1.46

H_1 and H_2: no clear relationship with clay content
H_3: increases with increasing clay content

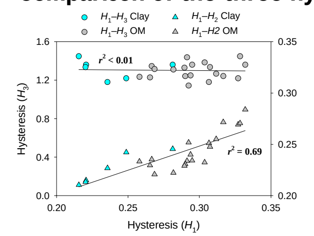
Organic matter gradient soils

Relationship between soil OM and the three hysteresis indexes (H_1, H_2, H_3)



- No clear effect of OM on H_1 or H_2
- For H_3, large contents of organic matter associated with greater degree of hysteresis

Comparison of the three hysteresis indexes



- Discrepancy between H_3 and other indexes due to scaling by magnitude of water content/molecular layers
- Similarities between H_1 and H_2 and their physical basis suggest they more accurately describe the hysteresis phenomenon

Trend of larger H_3 values with increasing clay or OM could be a reflection of increasing water content, not actual hysteresis

Conclusions

- All three methods accurately captured hysteresis for soils; but for pure clays, only the Dh method was appropriate
- For pure clays, extent of interlayer hydration determines the degree of hysteresis
- For soils, OM and clay contents showed no clear effect on H

Acknowledgments

The study was financed by the Danish Council for Independent Research | Technology and Production Sciences via the project *Water Vapor Sorption Isotherms as Proxy for Soil Surface Properties* (DFF -4184-00171)

References

1. Pickett, G. (1945), Modification of the Brunauer-Emmett-Teller Theory of Multimolecular Adsorption, J Am Chem Soc, 67(11), 1958-1962.
2. Arthur E., Tuller, M., Moldrup, P., & de Jonge., L.W. (2015). Evaluation of Theoretical and Empirical Water Vapor Sorption Isotherm Models for Soils. Water Resources Research. (Under review)
3. Lu, N., & M. Khorshidi (2015), Mechanisms for Soil-Water Retention and Hysteresis at High Suction Range, J Geotech Geoenviron, 0(0), 04015032.
4. Arthur E., Tuller, M., Moldrup, P., Resurreccion, A.C., Meding, M.S., Kawamoto, K., Komatsu, T., & de Jonge., L.W. (2013). Soil specific surface area and non-singularity of soil-water retention at low saturations. Soil Science Society of America Journal 77 (1); 43-53.