Under the High Patronage of His Majesty King Mohammed VI

International Water Resources Association
IWRA

XIX WORLD WATER CONGRESS
International Water Resources Association (IWRA)
Marrakech, Morocco | 1 - 5 December 2025

Kingdom of Morocco
Ministry of Equipment and Water

Soil Water Holding Capacity: A Review

TEXAS A&M UNIVERSITY
Biological & Agricultural Engineering

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Regular Session, 2:30 - 4:00

WEF Nexus Research Group

Introduction

Current Challenges in Soil Science

- Heavy reliance on empirical models
- Limited integration of soil structure and thermodynamics
- Inadequate prediction of soil-water dynamics
  - Especially important under climate stress

Reasons to Change

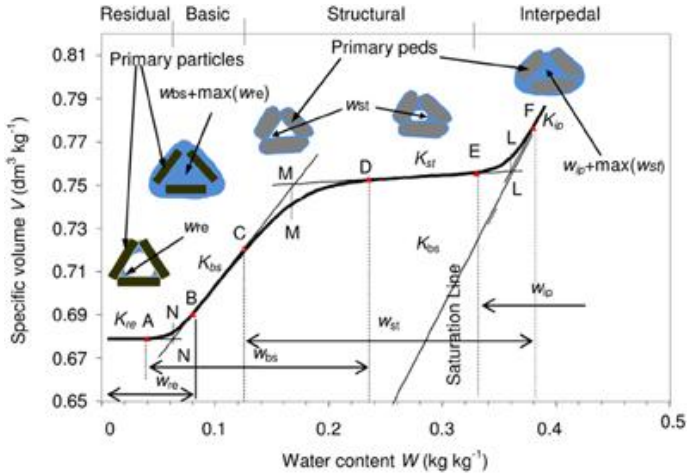
- Accurate water management
  - Rapidly changing climate
  - Increasing water gap
    - Water security
- Soil health and resilience
- Sustainable agriculture
  - Food security

Objectives

- Determine potential knowledge gaps in **soil hydrostructure**
  - Analyze our understanding of both **soil structure** and **water retention** capabilities
- Explore the concepts of **dynamic soil characterization**
  - Determine the need for this shift of thought
    - Improve our understanding of **soil structure**, **health**, and **water-holding capacity**
      - Support irrigation efficiency, food security, water security, and reduce water waste

Key Themes

- **Pedostructure Concept**
  - Aggregate arrangement => micro, macro, and interpedal pore spaces
- **Thermodynamic Framework**
  - Physical equations drive the water retention curve (WRC) and soil shrinkage curve (SSC), rather than empirical equations
- **Advanced Measurement Techniques**
  - Simultaneous measurement of the WRC and SSC
    - TypoSoil™ or HYPROP® with lasers
- **Structure-Based Modeling**
  - Switch from texture to hydrostructural parameters
- **Practical Applications**
  - Field capacity, permanent wilting point, and plant available water can be directly calculated



Key Article Highlights (Part 1)

- **Kutílek (2004) – Soil hydraulic properties as related to soil structure**
  - Kosugi's log-normal pore size distribution showed significant changes between matrix and structural domains, quantifying the impact of soil structure on hydraulic functions
  - Future Direction: The exponents α, β should be treated as changing values that differ in the structural and matrix domains
- **Dexter et al. (2008) - Water Retention Function, Texture + Structure**
  - Introduced a new double-exponential water retention equation with physically meaningful parameters; outperformed van Genuchten equations
  - Future Direction: Expand to include physical parameters of other scientists and incorporate other water retention functions
- **Solone et al. (2012) – Errors in Water Retention Curves, Pressure Plates**
  - Pressure plates were found to be erroneous for fine textured soils, affecting the parameterization of hydraulic properties
  - Future Direction: Results indicate that widespread data, including pedotransfer functions, may be incorrect and should be redone using different methods

Key Article Highlights (Part 2)

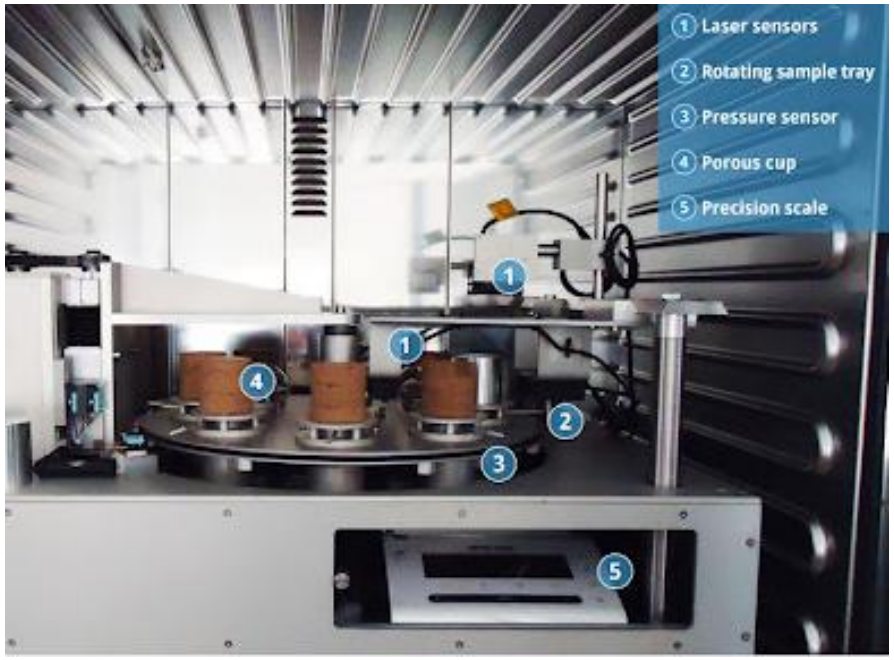
- **Braudeau & Mohtar (2014) - A framework for soil-water modeling**
  - Multi-scale soil-water modeling => Adopted SREV and Pedostructure
  - Future Direction: Build models to link micro-scale soil structure to macro-scale hydrology; couple with climate and crop models
- **Braudeau et al. (2014) - Physics of the soil medium organization part 1**
  - Link soil shrinkage and water retention to thermodynamics
  - Future Direction: Develop functional soil typologies from hydrostructural parameters to link different disciplines of soil science; support soil health monitoring and precision agriculture
- **Assi et al. (2014) - Physics of the soil medium organization part 2**
  - 9 hydrostructural parameters unique to each soil (Emi, Ema, WmiSat, WmaSat, Kbs, Kst, V_D, W_N, k_N) each with a physical meaning
    - Future Direction: Validate across soil types; integrate with soil mapping and implement at the field-scale

Key Article Highlights (Part 3)

- **Braudeau et al. (2014) - Unify Water Retention Curve**
  - Unify water retention measurements from pressure plates and tensiometers into one single thermodynamic framework; improve accuracy of soil hydraulic characterization
  - Future Direction: Replace empirical models with physics-based equations; classify soil according to hydrostructural parameters
- **Assi et al. (2018) – Soil pedostructure-based method**
  - Structure-based estimation of field capacity, permanent wilting point, and plant available water
  - Future Direction: Standardize pedostructure-based methods for global soil databases; improve irrigation scheduling and efficiency and drought prediction
- **Tahtouh et al. (2019) – Impact of brackish groundwater and treated wastewater**
  - Impact of non-traditional water sources on soil chemistry and mineralogy
  - Future Direction: Integrate water reuse with soil structural resilience; develop predictive models for long-term soil health under alternative irrigation

Emerging Tools & Techniques

- **TypoSoil™ Device**
  - Continuous measurement of WRC and SSC
- **Hydrostructural Parameters**
  - E_{mi}, E_{ma}, W_{miSat}, W_{maSat}, K_{bs}, K_{st}, V_D, W_N, k_N
- **Pedostructural Modeling**
  - Kamel® soil model

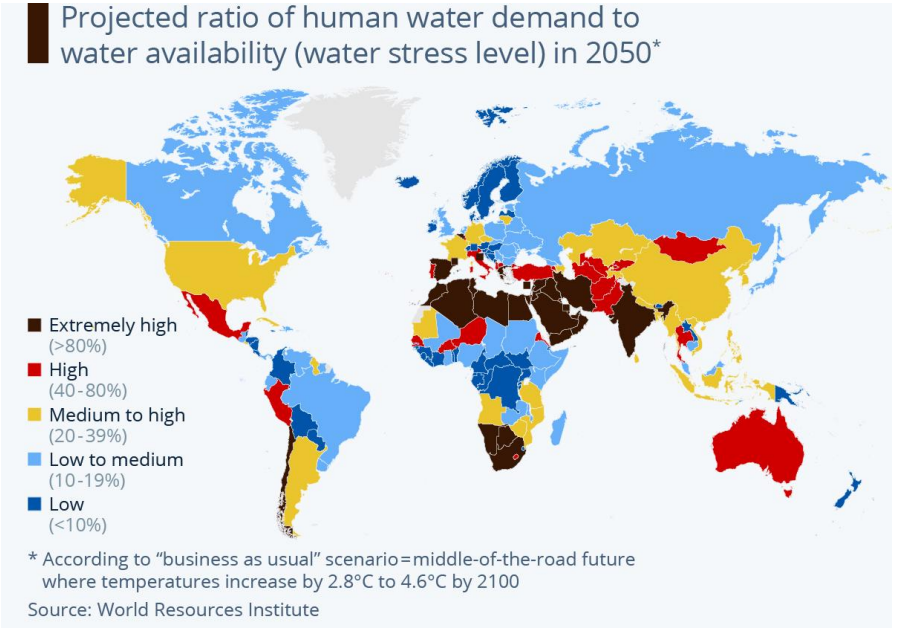


Future Research Priorities

- **Standardization**
  - Global protocols for hydrostructural characterizaion
- **Integration**
  - Link soil physics with remote sensing and AI for large scales
- **Education**
  - Incorporate thermodynamics and structural modeling into traditional soil science
- **Policy**
  - Adopt structure-based soil health metrics

Vision

- **Empirical → Physics**
- **Texture → Structure**
- **Static → Dynamic, multi-scale**
- **Predictive, sustainable soil management**
  - **Prepare for climate variability**
  - **Food & water security**



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Thank you!

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