Soil functions, global diversity, and distribution An introduction in the context of global cropping systems PLSCS/IARD 4140

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31-August-2021

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Outline

Soil functions, global diversity, and distribution

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Soil distribution

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Drivers of change in soil properties

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Conclusion



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5 Soil geographic databases

6 Drivers of change in soil properties

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Soil? – CALS Arts Quad

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What do we mean by "soils"?

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• The Earth's epidermis

- thickness not clearly defined, "soil" (≈ 2 m in most studies) vs. "regolith" (all loose material above hard rock)
- typical zone of influence for crops 30 cm 1.5 m
- The **interface** between atmosphere, lithosphere, biosphere, hydrosphere, **anthrosphere**
- Almost all the transformations and energy fluxes on "solid" earth take place in soils
- **Pedogenesis** (soil formation) from these fluxes, hence **vertical differentiation** within soil profiles

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Yangzhou, Jiangsu province PRC

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In prose . . .

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"... the outer solid portions of the earth readily pass into a loose and disintegrated condition. This layer, although superficial and insignificant in comparison to the bulk of the earth, has performed and is still performing a marvelous function. "[containing] reactions of almost unbelievable complexity. "This debris of rock and plant residue, teeming with its microscopic life and ever restless in its endless efforts at equilibrium is the arable soil from which

man must obtain his bread"¹

– Lyon, T. L., & Buckman, H. O. (**1922**). The nature and properties of soils; a college text of edaphology., pp. 1–2

¹note: "man, his" in their inclusive sense < □ > < □ > < ⊇ > < ⊇ > < ⊇ > < ○ < ℃

The Critical Zone and its fluxes



Source: https:

//criticalzone.org/national/models/conceptual-models-inational/

Soils and humans

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- **Humans** have a large influence on soil functions and properties
- The soil is a **finite resource** and can be semi-permanently **lost** (erosion) or (often irreversibly) **degraded** (salinization, compaction ...)

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Kourites ($Kov\rho\eta\tau\varepsilon\varsigma$), Crete ($K\rho\eta\tau\eta$) (GR)

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Textbook - introduction to soils for crop ecology

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Connor, D. J. (2011). Crop ecology: Productivity and management in agricultural systems (2nd ed.). Cambridge University Press. ISBN 978-0-521-76127-7; Chapter 7 "Soil Resources" pp. 171-192 Relevance for cropping systems?

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- Soil chemistry
- Soil formation
- Soil types and uses
- Soil properties
- Water and air components
- Soil temperature relations

Discuss these in terms of **soil functions**.

Soil functions - concept

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• How the soil **affects** the atmosphere, lithosphere, biosphere, hydrosphere, anthrosphere

- on-, off-site
- An old idea, e.g. Blum, W. E. H., & Santelises, A. A. (1994). A concept of sustainability and resilience based on soil functions: The role of ISSS in promoting sustainable land use. In D. J. Greenland & I. Szabolics (Eds.), Soil resilience and sustainable land use (pp. 535"542). CAB International.
- Increasingly recognized outside of soil science, e.g. Bouma, J. (2014). Soil science contributions towards Sustainable
 Development Goals and their implementation: Linking soil functions with ecosystem services. Journal of Soil Fertility and Soil Science, 177, 111"120. https://doi.org/10.1002/jpln.201300646

Soils in the Sustainable Development Goals



Conclusion

Source: https:

//www.un.org/sustainabledevelopment/sustainable-development-goals/ $_{\mathcal{O} \land \bigcirc}$

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Soil functions and the Sustainable Development Goals



Keesstra et al. DOI: 10.5194/soil-2-111-2016

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Soil functions - 1



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Functions to directly support cropping systems:

- substrate for plants
- moisture supply
- nutrient supply and reserves
- habitat for soil organisms
 - symbiotic, pathogenic, transformative

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Soils supporting cropping systems

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Waterloo (B), Ferme de la Haie Sainte

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Other functions

- filtering, buffering, transforming
- biological habitat and gene reserve (e.g., antibiotics)

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- physical medium for construction
- source of raw materials
- cultural heritage.

Soils supporting hydrologic functions

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República Dominicana, Provincia Monte Plata, El Deán. Saiping Tso (MSc 1996)

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Soil bacterial functions related to plant growth

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An example of detailed soil functions:

- Associative N fixation;
- Lowering ethylene levels that are otherwise an impediment to plant growth;
- Sequestration of iron by siderophores;
- Production of photohormones (e.g., auxin);
- Introduction of pathogen resistance in the plant;
- Solubilization of nutrients such P;
- Promotion of mycorrhizal functioning;
- Modification of root morphology;
- Enhancement of legume "rhizobia symbioses;
- Decreasing (organic or heavy metal) pollutant toxicity.

Glick, B. R. *et al.* (1999). Mechanisms used by plant growth-promoting bacteria. London: Imperial College Press

Soil constraints to production

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- water availability (amount and timing); also for planting/harvest conditions
- Inutrient availability, nutrient retention (added fertilizers)
- oxygen (non)availability (drainage)
- soil physical conditions (tillage, rooting conditions)
- These and their response to management all vary by soil type.

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Physical constraint: crusting, cracking, poor structure

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Pusa, Bihar, India

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- Tremendous diversity: 32 internationally-recognized Reference Soil Groups
 - IUSS Working Group WRB. (2015). World Reference Base for Soil Resources 2014; Update 2015. International soil classification system for naming soils and creating legends for soil maps. FAO. http://www.fao.org/3/i3794en/I3794en.pdf

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• These differ greatly in their properties and functions

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Soils as natural bodies

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- the whole is more than the sum of the parts
- a holistic concept
- \bullet ensembles of properties and vertical distributions \rightarrow "personality"
- lowest-level: soil series
- can be grouped into a monothetic hierarchical system
 - international standard: World Reference Base for Soil Resources (WRB)
 - USDA Soil Taxonomy also used in many other countries, e.g. India, Thailand, Venezuela

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 Other national systems, e.g., Australia, NZ, PRC, Brazil, F, NL, D, ex-USSR

Soil Classification

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Why these differences?

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- Main insight: soils are in their place for a reason
- Soils are the product of **soil forming factors** operating over time
- These factors differ in space and time, and therefore so do soils
- First insights by Dokuchaev (1883) "Russian Chernozem" [= black earth]: soils are **natural bodies** to be studied as such.

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The Jenny model of soil formation

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- Systematization of soil genesis concepts by Jenny (1941)
- Soil forming factors: s = f(cl, o, r, p, t)

cl climate

- o organisms: plants, animals (of all sizes), microbes
- r relief, terrain position
- p parent material (pre-soil, e.g., weathered rock, sediments)

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- t time of soil formation
- Note that cl, o, r, p may have changed over t (e.g., paleosols)

Different soil-forming factors \rightarrow different soils

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Human influence

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• Humans can and do modify soils

- minor: light tillage, agroforestry
- major: deep tillage, heavy fertilization/liming, irrigation
- extreme: land levelling (terracing), excavation, deep plowing
- "improvement" (for immediate human needs) vs. "degradation"
- Two classes recognized in the WRB: Anthrosols, Technosols, but human influence is recognized in most RSG

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Soils on the landscape

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"Zonal" concept

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- Climate is a determining factor for upland soils
- So, climate zones map onto major soil zones

Not true in detail!

The catena concept

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- Catena = "chain": a sequence of soils on a hillslope, connected by fluxes
 - water (surface, sub-surface), nutrients, minerals, clays
 - soils in different slope positions have different properties and functions

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• Very well developed in some settings, e.g., Kampala area (Uganda) where first developed

Soil-landscape relations



Otsego County NY https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ soils/survey/geo/?cid=nrcs142p2_054317

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Traditional soil maps



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Konyango, Homabay County, Kenya

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Digitized soil maps



Pony Hollow, Newfield NY; source

Where to find information on soil classes and properties?

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- World: ISRIC²
 - World Soil Information Service (WoSIS) soil profile databases³
 - Links to non-ISRIC Soil Geographic Databases⁴
 - SoilGrids^{™5}
 - **consistent** global predictions at 250 m resolution & 7 depth slices
 - organic C density & stock; bulk density, coarse fragements/clay/sand/silt concentration; cation exchange capacity; total N; pH
- USA: NRCS Soil Geography ⁶

- ³https://www.isric.org/explore/wosis
- ⁴https://www.isric.org/explore/soil-geographic-databases
 ⁵https://soilgrids.org/
 ⁶https:

//www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/geof 🖉 ର୍ବ

²www.isric.org

ISRIC-World Soil Information



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https://soilgrids.org/

SoilGrids[™] – caution

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- not field checked, only cross-validated at training points
- global product, not optimized for any area
- calibrated with observations available to ISRIC (WoSIS database), many countries have more observations they won't share
- observations over 50+ years, especially for soil organic C may be outdated
- \bullet old observations with poor georeference \rightarrow poor correlation in models
- classes (holistic information carriers for technology transfer) only at most general (RSG) level

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Soil genoforms and phenoforms

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Soil genoforms **reference state** that encompasses inherent soil capability under specific **long-term** circumstances; **soil series as mapped**

Soil phenoforms the **condition** of soils with similar inherent properties but **dynamic properties** modified by specific land-use or management history.

> more than temporary or cyclical changes (e.g., annual tillage, crop rotation effects)

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- reversible over the medium term with appropriate management
- $\bullet~$ If not reversible \rightarrow new genoform

Rossiter, D. G., & Bouma, J. (2018). A new look at soil phenoforms – Definition, identification, mapping. Geoderma, 314, 113–121.

doi:10.1016/j.geoderma.2017.11.002

Drivers of change

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intensification

 nutrient depletion, loss of soil biodiversity, acidification or salinization (depending on genoform and type of intensification)

land clearing/conversion

 major losses of soil organic carbon (SOC), increased aeration, rainwater reaching the soil surface (infiltrates? runs off? → watershed hydrology)

• major change in cropping systems

- nutrient stocks and cycling
- soil structure (e.g., rice-wheat vs. rice-rice systems)

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soil biota

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- land degradation: reversible or not?
 - \bullet WOCAT (World Overview of Conservation Approaches and Technologies)^7
- resilience
 - after a disturbance, ability to return to a stable state with (all, most, some) of the functionality of the original states
 - example: excessive tillage \rightarrow destroyed soil structure
 - $\bullet\,$ in northern humid temperate climates \rightarrow restored by freeze-thaw cycles and root action
 - in arid climates **negative feedback loop** of "pavement" surface soil \rightarrow very low infiltration capacity \rightarrow increasingly hardened

⁷https://www.wocat.net/en/

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- Without soils, no large-scale cropping systems (only hydroponics/greenhouses)
- Soils can be used but also abused
- Soils differ greatly in how they must be managed for sustainable cropping systems

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End

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