Soil functions, global diversity, and distribution

An introduction in the context of global cropping systems

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Outline

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What do we mean by "soils"?

- The Earth's **epidermis**
  - thickness not clearly defined, "soil" ($\approx$ 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

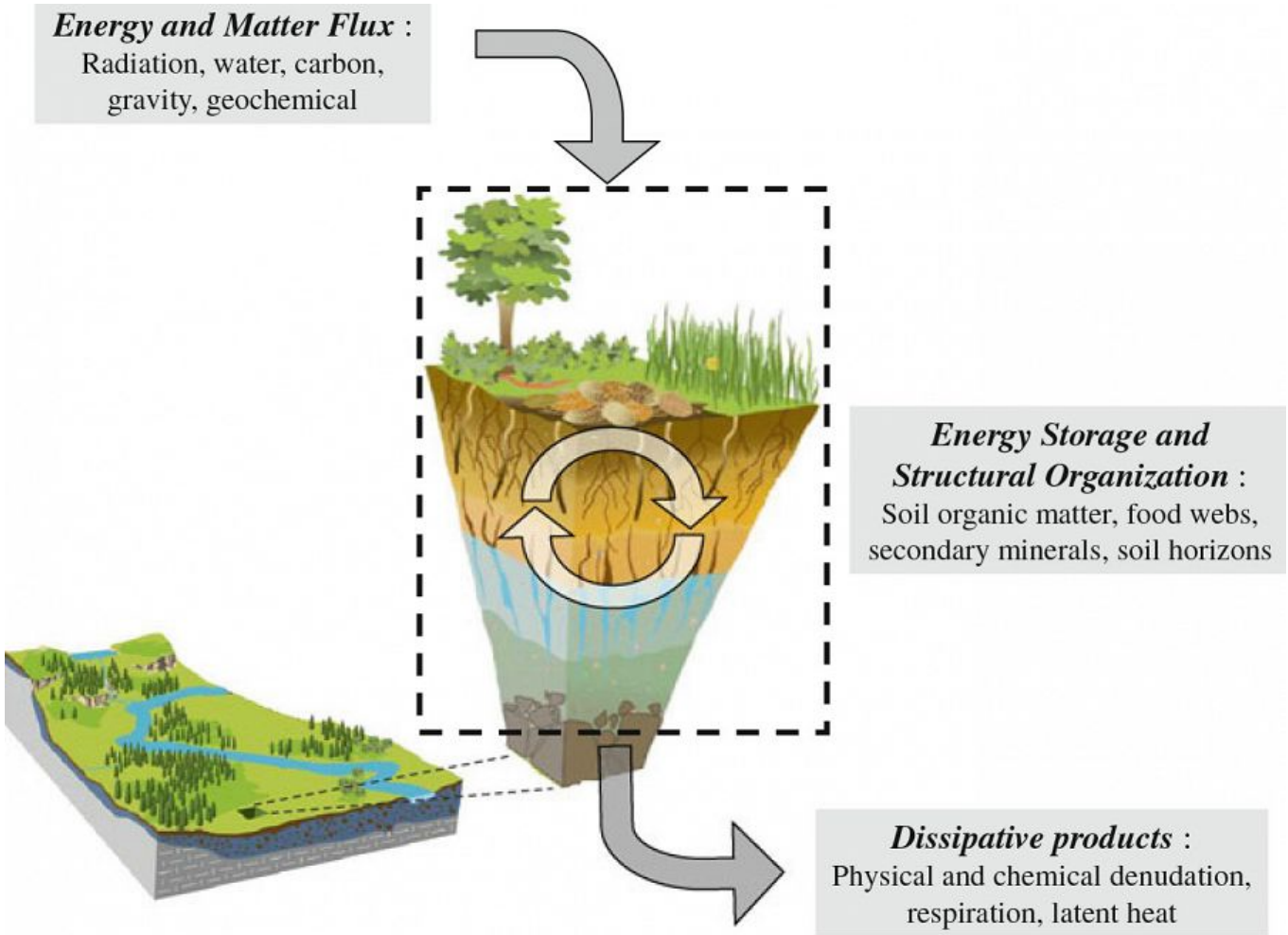
In prose . . .

> *". . . 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

[1] *note: "man, his" in their inclusive sense*

The Critical Zone and its fluxes



Source: `https://criticalzone.org/national/models/conceptual-models-1national/`

Soils and humans

- **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 . . .)

Soils in the Sustainable Development Goals

Source: `https://www.un.org/sustainabledevelopment/sustainable-development-goals/`

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Textbook – simple introduction to soils for crop ecology

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?

- 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

- 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`

Soil functions - 1

Functions to **directly support cropping systems**:

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

Soil functions - 2

Other functions

- filtering, buffering, transforming
- biological habitat and gene reserve (e.g., antibiotics)
- physical medium for construction
- source of raw materials
- cultural heritage.

Soil bacterial functions related to plant growth

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

1. water availability (amount and timing); also for planting/harvest conditions
2. nutrient availability, nutrient retention (added fertilizers)
3. oxygen (non)availability (drainage)
4. soil physical conditions (tillage, rooting conditions)

These *and their response to management* all vary by soil type.

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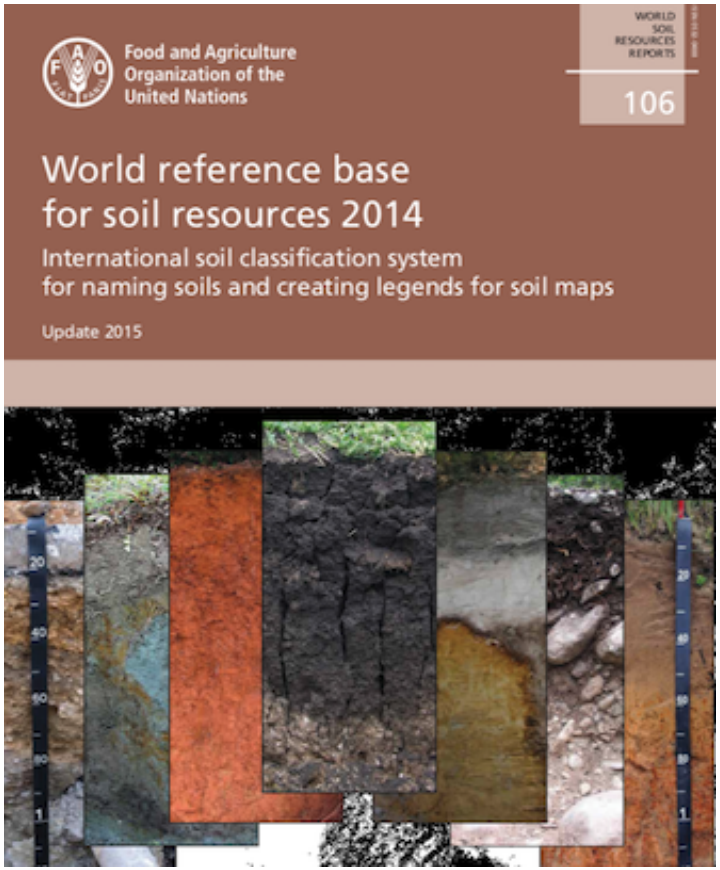
Soil diversity

- 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`
- These differ greatly in their properties and functions

Soils as natural bodies

- the whole is more than the sum of the parts
- a holistic concept
- 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
  - Other national systems, e.g., Australia, NZ, PRC, Brazil, F, NL, D, ex-USSR

Soil Classification



http://www.fao.org/soils-portal/soil-survey/soil-classification/world-reference-base/en/

Why these differences?

- 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.

The Jenny model of soil formation

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

Human influence

- 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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Waterloo (B), Ferme de la Haie Sainte

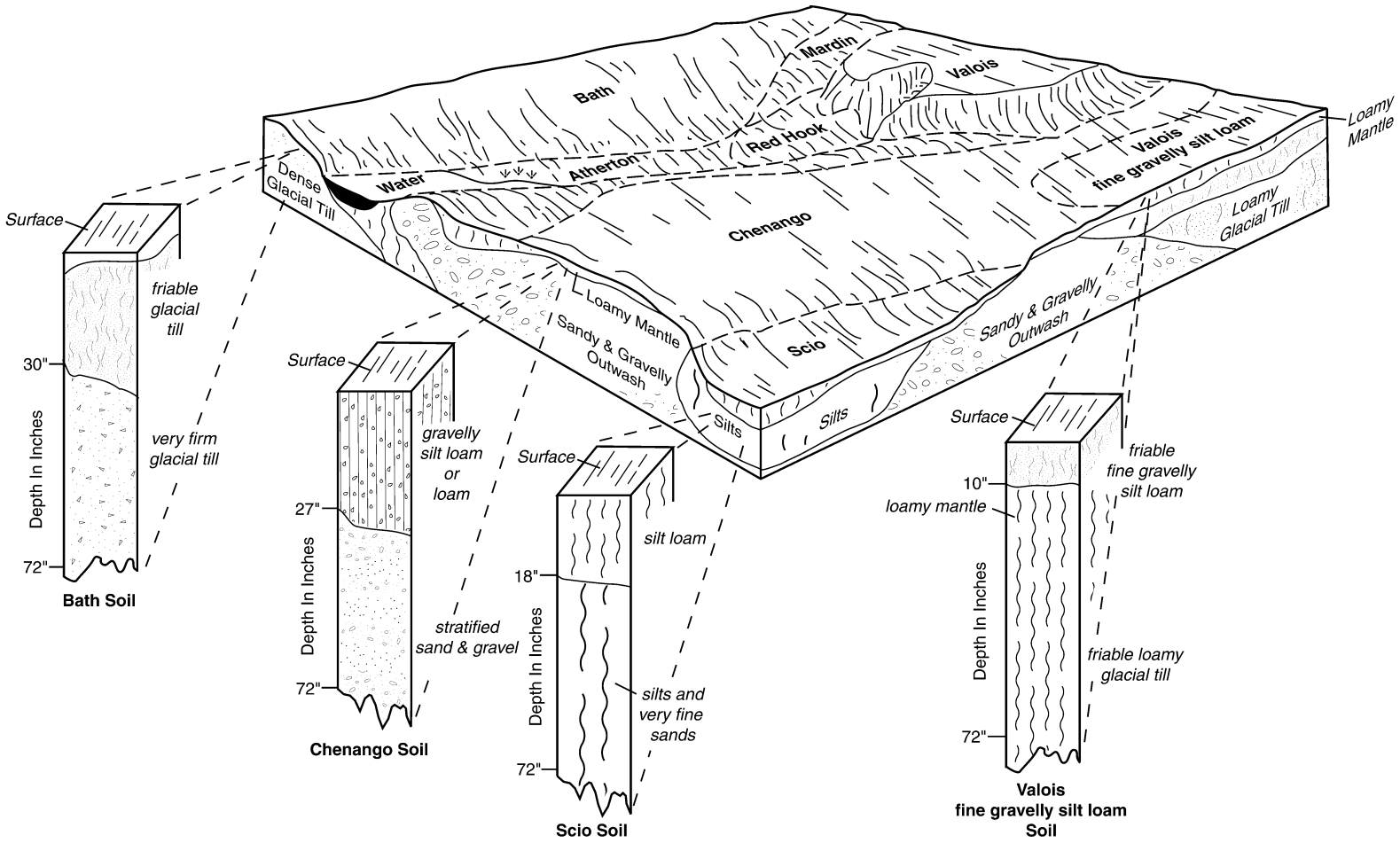
"Zonal" concept

- Climate is a determining factor for upland soils
- So, climate zones map onto major soil zones
- Not true in detail!

The catena concept

- 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
- 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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Where to find information on soil classes and properties?

- World: ISRIC[2]
  - World Soil Information Service (WoSIS) soil profile databases [3]
  - Links to non-ISRIC Soil Geographic Databases [4]
  - 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]

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[2] www.isric.org

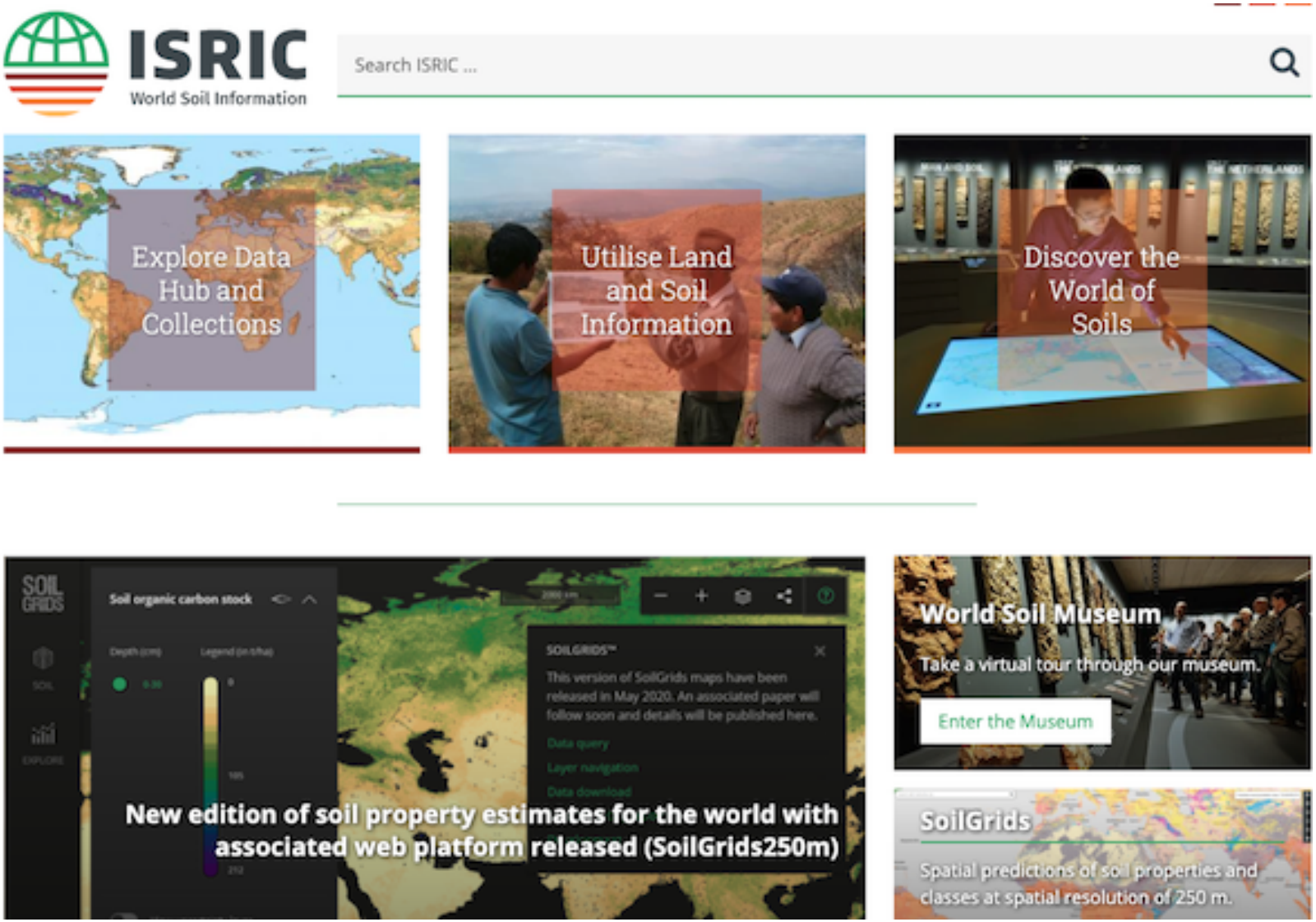
[3] https://www.isric.org/explore/wosis

[4] https://www.isric.org/explore/soil-geographic-databases

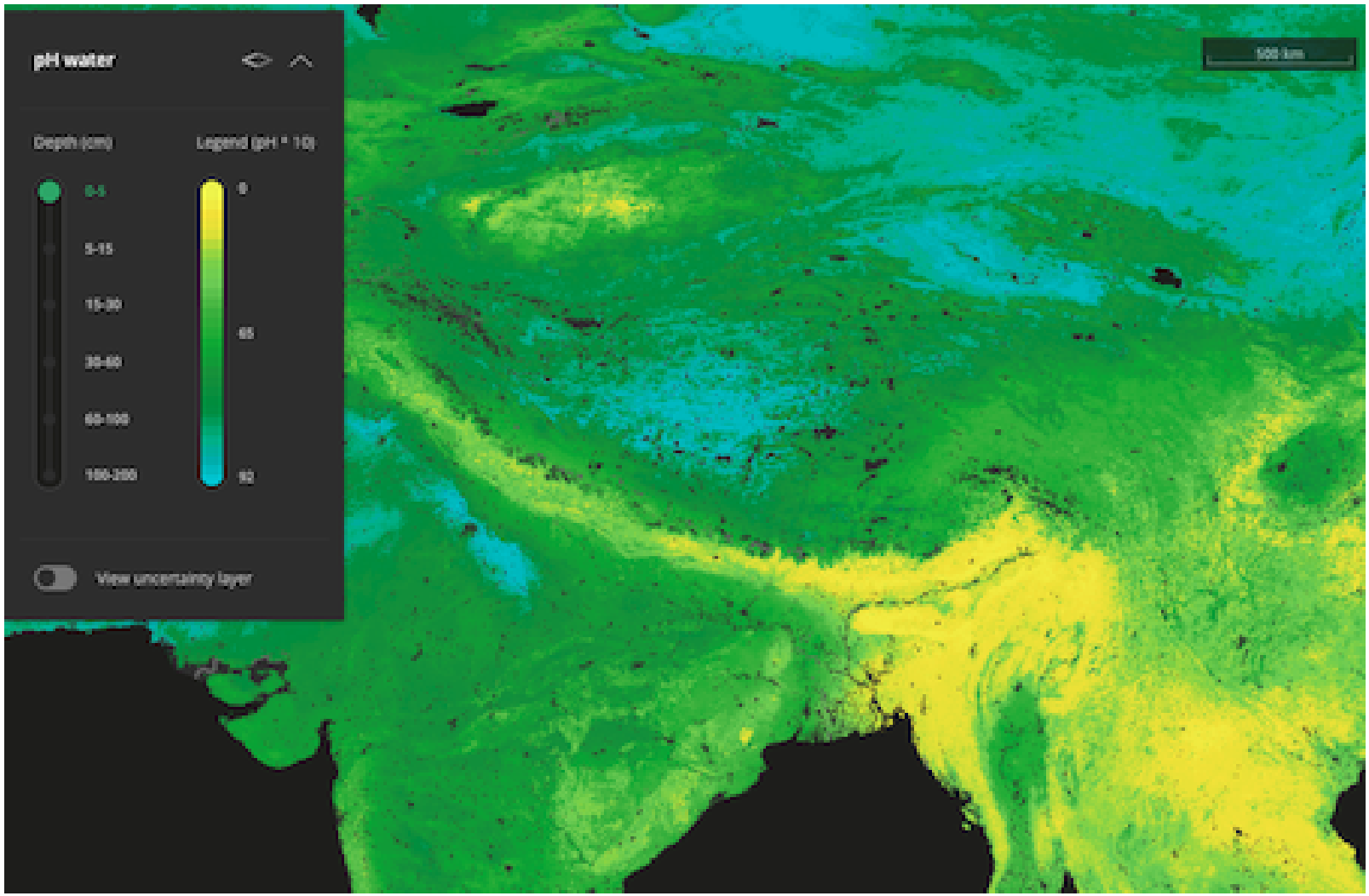
[5] https://soilgrids.org/

[6] https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/geo/

ISRIC-World Soil Information



SoilGrids™


pH water
Depth (cm)
Legend (pH * 10)
0-5
5-15
15-30
30-60
60-100
100-200
9
65
92
View uncertainty layer

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Soil genoforms and phenoforms

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)
- **reversible** over the medium term with appropriate management
- 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

- 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? $\rightarrow$ watershed hydrology)
- major change in cropping systems
  - nutrient stocks and cycling
  - soil structure (e.g., rice-wheat vs. rice-rice systems)
  - soil biota

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Sustainability challenges

- land degradation: reversible or not?
  - 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 → destroyed soil structure
    - in northern humid temperate climates → **restored** by freeze-thaw cycles and root action
    - in arid climates **negative feedback loop** of "pavement" surface soil → very low infiltration capacity → increasingly hardened

[7] https://www.wocat.net/en/

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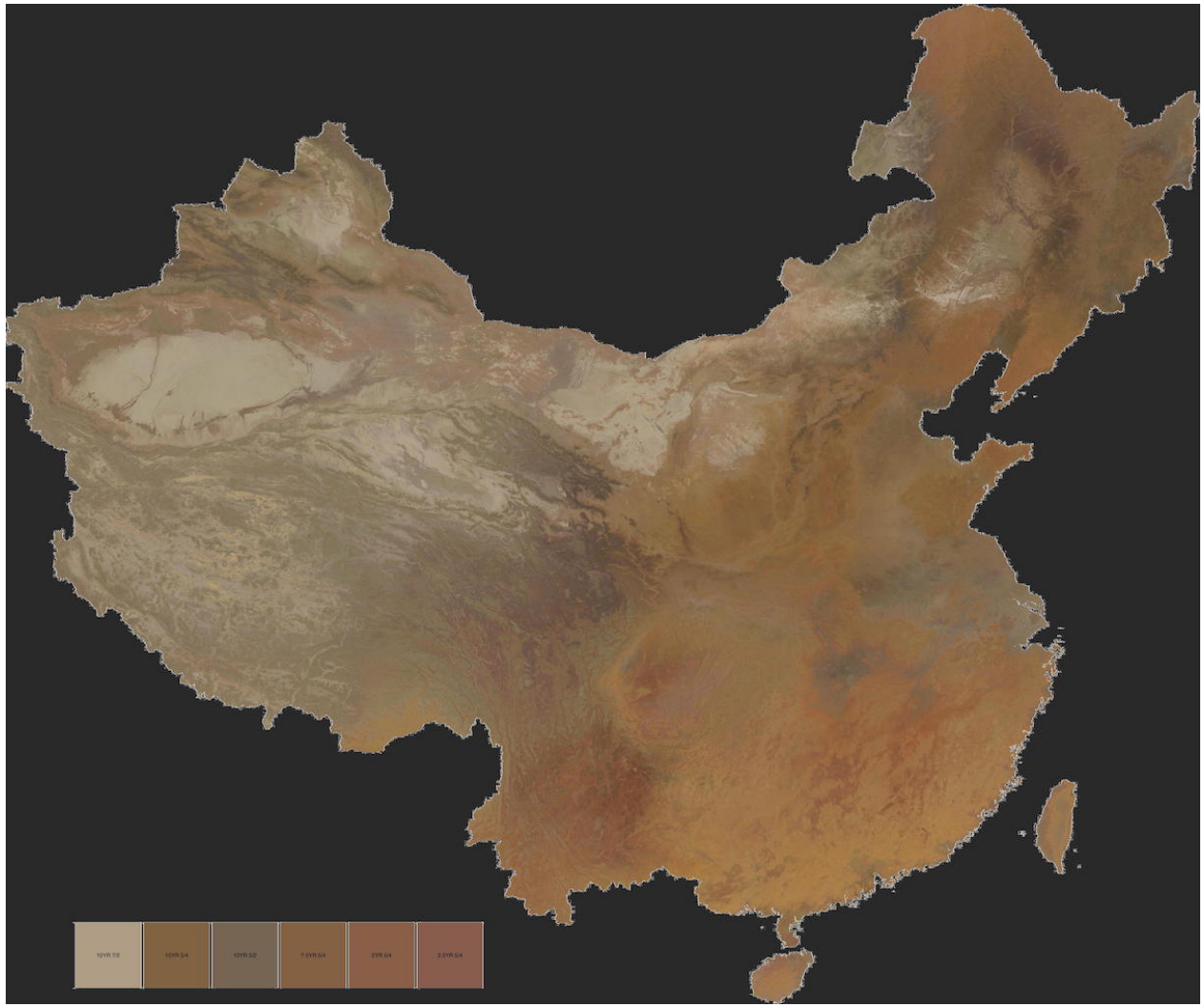
- Without soils, no large-scale cropping systems (only hydroponics/greenhouses)
- Soils can be used but also abused
- Soils differ greatly in how they must be managed for sustainable cropping systems

End



Source: doi:10.1016/j.geoderma.2020.114556