Sustaining the Pedosphere: Establishing A Framework for Management, Utilzation and Restoration of Soils in Cultured Systems

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Outline

• Introduction
  - Its our Problems - Life in the Fastlane
  - Ecological Nexus of Food-Water-Energy
  - Defining the Pedosphere

• Framework for Management, Utilization & Restoration
  - Pedology and Critical Zone Science
  - Pedology Research Establishing the Range & Variability in Soils
  - Models for assessing human dimensions in ecosystems

• Studies of Regional Importance Systems Approach
  - System Models for Agricultural Research
  - Soil Water - The Master Variable
  - Water Quality, Soil Management and Conservation Strategies

• Concluding Remarks and Questions
Living in a Sustainable Age or Life in the Fast Lane

[Diagram showing population growth over time, with key events labeled: Hunting and gathering, Agricultural revolution, Black Death—the Plague, Industrial revolution.]
What do we know?

• There are key drivers across the planet that are forcing us to think and live differently.

• The drivers are influencing our supplies of food, energy and water.

• Science has helped us identify these drivers and our challenge is to come up with solutions.
Change has been most rapid over the last 50 years!

- In last 50 years we doubled population
- World economy saw 7x increase
- Food consumption increased 3x
- Water consumption increased 3x
- Fuel utilization increased 4x
- More change over this period then all human history combined - we are at the inflection point in human history.
- Planetary scale resources going away
What are the major changes that we might be able to adjust?

• Land Use Change - the world is smaller
• Food footprint is larger (40% of land used for Agriculture)
• Water Use - 70% for food
• Running out of atmosphere - used as disposal for fossil fuels and other contaminants
The Perfect Storm

Energy

Increased Demand 50% by 2030

Climate Change

Demand up 50% by 2030

Food

Demand up 30% by 2030

Water
2D View of Pedosphere
Hierarchal scales involving soil solid-phase components that combine to form horizons, profiles, local and regional landscapes, and the global pedosphere.

Pedology Research and the Critical Zone Exploration Network

Rational behind the Critical Zone Science stressed a lack of success in predicting many Earth surface processes due to:

- the complexity of coupled biological, chemical, and physical processes,
- the extreme heterogeneity of the Earth surface, and
- the cross-disciplinary nature of the problem.

**Overarching Question**: What controls the depth and chemistry of the Earth’s regolith?
State Factor Analyses

Contemporary Studies based on field observations, field experiments and modeling.

Soil = \( f(\text{cl, o, r, p, t, h}...) \)

- cl = Climate
- o = Biota or Organisms
- r = Topography/relief
- pm = Parent Material
- t = Time
- h = Humans

(Jenny, 1941, 1980)
Establish a Network of Sites

Some observatories also include sites along gradients in:
- elevation
- uplift rate
- biology
- exposure age

Climate Gradient

Lithology Gradient
Utilize Natural Gradients

Critical Zone Exploration Network

Other gradients:
- relief
- biology
- uplift rate
Central Plains CZEN Seed Site
Observations of Ecosystem Properties vs Climatic gradients

Tallgrass Prairie

Shortgrass Steppe

Shrubland

Increasing ANPP

mesic

arid
Increasing C Storage
Topographic Gradient

Parent Material Gradient
- nd sis
- nd ss
- nd shale

Moisture Gradient
- chey wells
- goodland
- oberlin

Summary:
- OC (g cm\(^{-2}\) m\(^{-1}\))
- Summit        Shoulder       Backslope     Footslope
Relationship of P fractions to depth and PPI

Huffmann et al., in Review
Cultivation and C Storage

- S.O.C. decreases as much as 61% due to cultivation
- S.O.C. loss is dependent on textural differences
Modeling C Sequestration in Grasslands

Improved management

Improved management with high inputs

Native/Nominal management

Degraded grassland (1st overgrazing)

C sequestration potential = \frac{3}{4} of some or all ??

Rate?

Duration?

Amount?

Characteristics?

Amount?

Influences?

Recovery?

Shape?

Slope?

K. Paustian
Hierarchical Dependency of Controls

<table>
<thead>
<tr>
<th>Hierarchical Level</th>
<th>Driving Variables</th>
<th>Processes</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Physiographic Section (10³ km²)</td>
<td>LT-Global Climate, Structural Geology, Tectonics</td>
<td>Glaciation, Denudation, Base Level Change</td>
<td>Geological Substrate</td>
</tr>
<tr>
<td>II. Landform Assemblage (ordering of watershed)</td>
<td>Geological Substrate, Regional Climate, Land Use</td>
<td>Hydrologic</td>
<td>Surficial Geology, Drainage Patterns</td>
</tr>
<tr>
<td>III. Landform (1 to 10³ ha)</td>
<td>Surficial Geology, Drainage Patterns, Local Climate, Land Use</td>
<td>Fluvial, Aeolian</td>
<td>Parent Material, Slope/Aspect, Configuration, % Cover</td>
</tr>
<tr>
<td>IV. Landform Element (10¹ to 10³ m²)</td>
<td>Parent Material, Slope/Aspect, Configuration, % Cover, Climate events, Mgt, Atm Deposition</td>
<td>Erosion/Deposition, Run-on/off</td>
<td>Soil Texture, Soil Moisture, Soil Temperature</td>
</tr>
<tr>
<td>V. Pedon (m²)</td>
<td>Soil Texture, Soil Moisture, Soil Temperature</td>
<td>Decomposition, Production</td>
<td>Soil Organic Carbon</td>
</tr>
</tbody>
</table>
Issues of Regional Importance

Land Use
- Conservation
- Cultivation
- Urbanization
- Restoration

Climate Change
- Drought
- Rainfall timing and amount
- Temperature
- Duration

Disease
- Livestock
- Plant
- Human

Biological Invasions
- Species introductions

Central U.S.

Regional Climate/Hydrology

Communities/Land Cover Change

Changes in Biogeochemistry
New Models and Research Approaches Are Necessary

There is growing recognition that the environment must be viewed and studied as a social-ecological system to evaluate global change.

Various conceptual models have been proposed to characterize social-ecological systems, but new thinking is needed to guide long-term research that links humans with role in changing their environment.

We describe a new model for integrated social-ecological research, the key components of which include environmental and social sciences, press and pulse interactions, and ecosystem services.

Application of this approach will bridge the social and natural sciences and build a knowledge base that can be used to help solve current and future environmental challenges.
Example: Press-Pulse Dynamics (PPD)

- A conceptual model for research that integrates the biophysical and social sciences through an understanding of how human behaviors affect “press” and “pulse” dynamics and ecosystem processes.
- Such dynamics and processes, in turn, influence ecosystem services – thereby altering human behaviors and initiating feedbacks that impact the original dynamics and processes.
Press–Pulse Dynamics (PPD) framework

**EXTERNAL DRIVERS**
- Climate, Globalization

**Biophysical Template**
- **COMMUNITY STRUCTURE**
  - Species turnover time
  - Trophic structure
  - Microbial diversity
- **ECOSYSTEM FUNCTION**
  - Flux, transport, storage, transformation, stoichiometry, primary productivity

**Social Template**
- **HUMAN BEHAVIOR**
  - Policy
  - Markets
  - Reproduction and migration
- **HUMAN OUTCOMES**
  - Quality of life
  - Human health
  - Perception and value

**ECOSYSTEM SERVICES**
- **Regulating**
  - Nutrient filtration
  - Nutrient retention
  - C sequestration
  - Disease regulation
  - Pest suppression
- **Provisioning**
  - Food, fiber and fuel
- **Cultural**
  - Aesthetics and recreation
- **Supporting**
  - Primary production
  - Nutrient cycling

**PULSES**
- Fire, drought, storms, dust events, pulse nutrient inputs, pesticides, fertilization

**PRESSES**
- Climate change, nutrient loading, sea-level rise, increased human resource consumption

(Collins et al, 2010)
ECOSYSTEM SERVICES
Regulating: C sequestration, disease regulation, pest suppression
Provisioning: food and fiber
Cultural: Biodiversity, Rare species, Open space, recreation, aesthetics
Supporting: primary production, nutrient cycling

ECOSYSTEM FUNCTION
Hydrological cycles (wadis, groundwater), Nutrient cycles, Food availability, Biomass productivity
COMMUNITY STRUCTURE
Small-scale patchiness, Large-scale patchiness, Ecological gradient (ecotone)

EXTERNAL DRIVERS
Economic trends, Security and foreign relations, Demographics, Political climate, Economic trends

HUMAN BEHAVIOR
Demographic changes, Legal and illegal settlement, Political activity with regard to settlement and open space, Recreational use, Forestry, agriculture, grazing
HUMAN OUTCOMES
Land use policy (national and regional), Settlement type and distribution, Enforcement mechanisms, Demographic distribution, Landscape conversion

PULSES: Dust events, Drought, Nutrient input
PRESSES: Increased recreational use, Landscape conversion (settlement), Landscape conversion (agriculture and grazing)

Biophysical Template
Socio-Political Template

(Collins et al, 2010)
A) Presses and Assessing Drought

Last September, 64% of the continental United States was experiencing drought.

The extent of drought in July, August and September 2012 is on par with the worst months of the multi-year droughts of the 1930s Dust Bowl and the mid-1950s.

September, July and August 2012 had the second, third and fourth greatest monthly percentage of area in the continental United States in moderate or greater drought.

Only July 1934—when 80% of the lower 48 states were experiencing drought—had a higher percentage of the United States impacted in a single month.
Soil Moisture

**Integrative Master Variable**

- Plant respiration
- Plant community composition
- ANPP
- N uptake
- Photosynthesis
- Photorespiration
- Water use efficiency
- Transpiration
- Evaporation
- Root respiration
- BNPP
- C allocation
- Water sources
- Soil Moisture
- Microbial community composition
- Temperature
- CO₂
- Soil respiration
- Decomposition
- N mineralization
- C allocation
- Water sources
- Precipitation regime
Why Soil Moisture?

1) Soil moisture is a key driver of almost all ecological processes in water-limited grass dominated ecosystems.
2) Soil moisture shapes vegetation structure and community composition.
3) Drives community dynamics across all trophic levels.
4) Regulates carbon allocation patterns, biogeochemical cycling, population dynamics and organismal physiology.
Field Experiments

To what extent are ecological dynamics, resilience and sustainability of ecosystems explained and integrated by alterations in soil moisture dynamics – and in particular in response to global change factors?

Do soils differ in response to “projected” climate change scenarios?
Soil development influence water content

Parent material  Phase I  Phase II  Phase III

Kelly et al 2008
Soil Development Phases

Available Water Capacity

\[ \text{cm water / cm soil} \]

Phase I
Entisol

Phase II
Haplargid

Phase III
Haplocambid

Depth

0

2 k

125 k

660 k

SW Salley, in prep
Forecasting Annual Soil Moisture
We identified the areas of greatest soil degradation that will continue to be vulnerable to chronic drought and perhaps never recover!
Vulnerability of Soils to Chronic Drought

• Hydrological properties provide insights into assessing the vulnerability of agricultural soils to long term chronic drought conditions.

• Establishing broader nutrient thresholds and biogeochemical feedbacks in cultured systems should be considered in the determinations.

• There is a necessity to match cropping and soil management systems to vulnerability classes to help prevent further spiraling of soil functioning.
B) Pulses and Assessing Water Quality

• In recent years, intensification of land use has required an increased proficiency in measuring, quantifying water quality and quantity, and soil quality effects of BMP’s and conservation practices at the field, farm, and sub-watershed scale.

• Changes in precipitation observed over the past century suggests increases in soil erosion ranging from 4 percent to 95 percent and increases in runoff from 6 percent to 100 percent could already be evident on croplands.

• There is a need for nutrient-reduction efforts, in the form of agricultural best management practices (BMP) that focus on the sites within watersheds that release the nutrients into rivers.

• Importantly, while agricultural BMPs might be less effective under future climates, higher BMP implementation rates could still substantially offset anticipated increases in sediment and nutrient yields.
Agricultural Chemicals and Groundwater Protection Program

- Collaborative program between CSU, CDA and CDPHE
- Address nonpoint source pollution in agriculture
- Education and applied research to achieve voluntary adoption of BMPs (CSU Extension)
- Regulation of bulk chemical storage facilities (CDA)
- Monitoring of groundwater

Bauder et al, 2013
Monitoring Groundwater Nitrate
Soil Conservation and Water Quality

Integrated Research & Outreach Work:

- Adoption and Cost of Nutrient Management BMPs
- Nutrient, pesticide and irrigation management under conservation tillage
- Water management & advanced irrigation scheduling
- Ag practices and nitrate trends in S. Platte groundwater
Demonstrating Conservation Tillage Methods and Benefits Under Furrow Irrigation

A Collaborative Project with University, Conservation District, Producer, and Industry Participation

• Demonstrate conservation tillage as feasible and economically viable in furrow irrigated systems

• Manage residue to achieve conservation goals without reducing irrigation water uniformity

• Compare yields/economics among tillage systems

• Investigate the differences in runoff water quality between tillage systems
Tillage Treatments

Strip-till (ST)
9 operations

Min-till (MT)
6 operations

Conventional (CT)
14 operations
Spring Soil Moisture at Planting (top 6 in.)

<table>
<thead>
<tr>
<th>Year</th>
<th>CT</th>
<th>MT</th>
<th>ST</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>1.6</td>
<td>2.7</td>
<td>2.2</td>
</tr>
<tr>
<td>2012</td>
<td>0.6</td>
<td>1.9</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Bauder et al, 2013
Runoff - Herbicides

*Applied as product Lumax

Bauder et al, 2013
Nutrient Loads and Tillage

Total Phosphorus Load

- CT: 5 lbs/ac
- MT: 4 lbs/ac
- ST: 2 lbs/ac

Total Nitrogen Load

- CT: 4.5 lbs/ac
- MT: 3.5 lbs/ac
- ST: 2.5 lbs/ac

Bauder et al, 2013
Yield Comparisons

3 Year Average - Relative Yield (to Average CT Yields)

CT | MT | ST
---|----|----
1.000 | 0.865 | 0.996

Gross Revenue
- CT: $1,496
- MT: $859
- ST: $1,267

Net Return
- CT: $1,473
- MT: $926
- ST: $718

Bauder et al, 2013
Concluding Remarks

• Scientists now recognize the pervasive influence that human activities have in all ecosystems – even those not directly managed – and that these impacts, collective referred to as Global Change, will only become more pressing in the future.

• Conservationists should be seriously concerned about the implications of climate change—as expressed by changes in precipitation patterns—for the conservation of soil and water resources in the United States.

• The magnitude of observed trends in precipitation and the bias toward more extreme precipitation events are, in some cases, larger than simulated by global climate change models, particularly since 1970.
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