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

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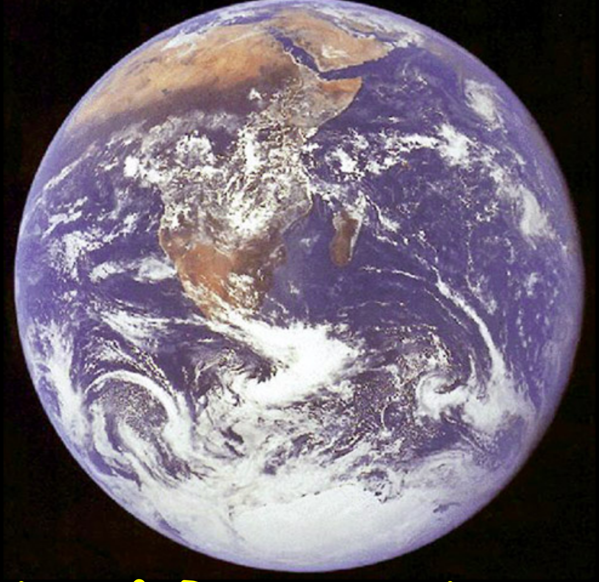
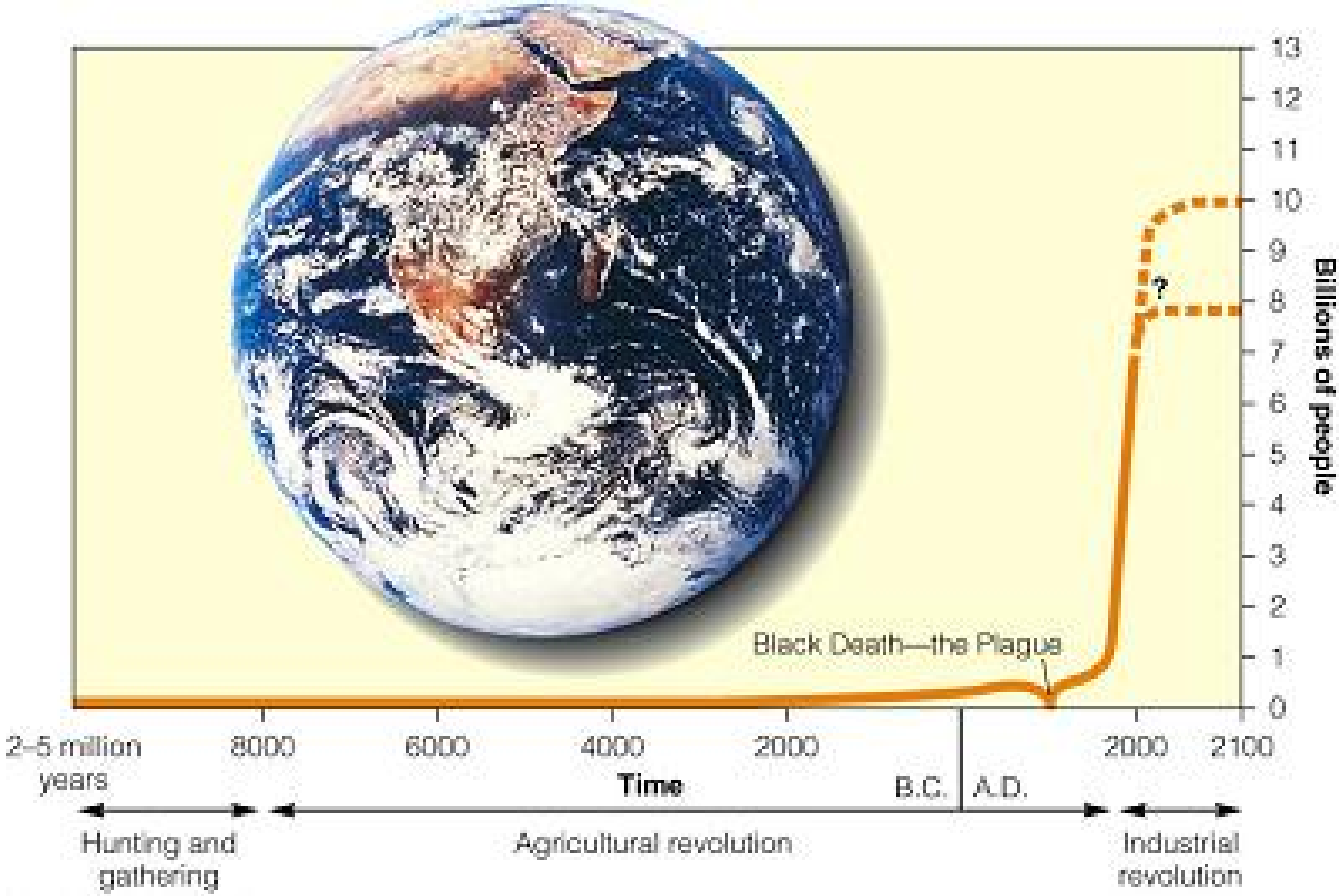
Colorado State University

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



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

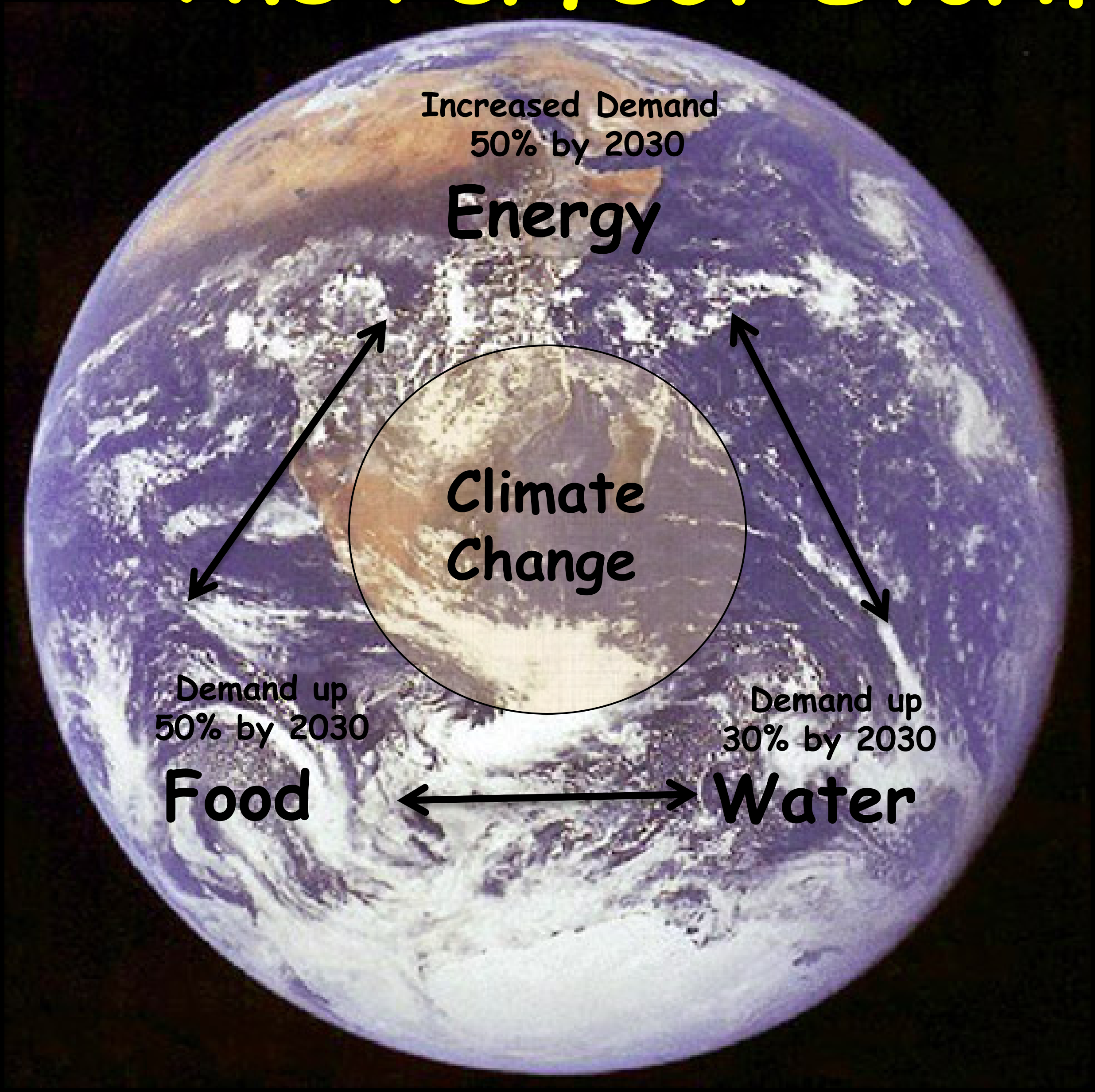
Change has been most rapid over the last 50 years !

- 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 <u>inflection point</u> in human history.
- Planetary scale resources going away

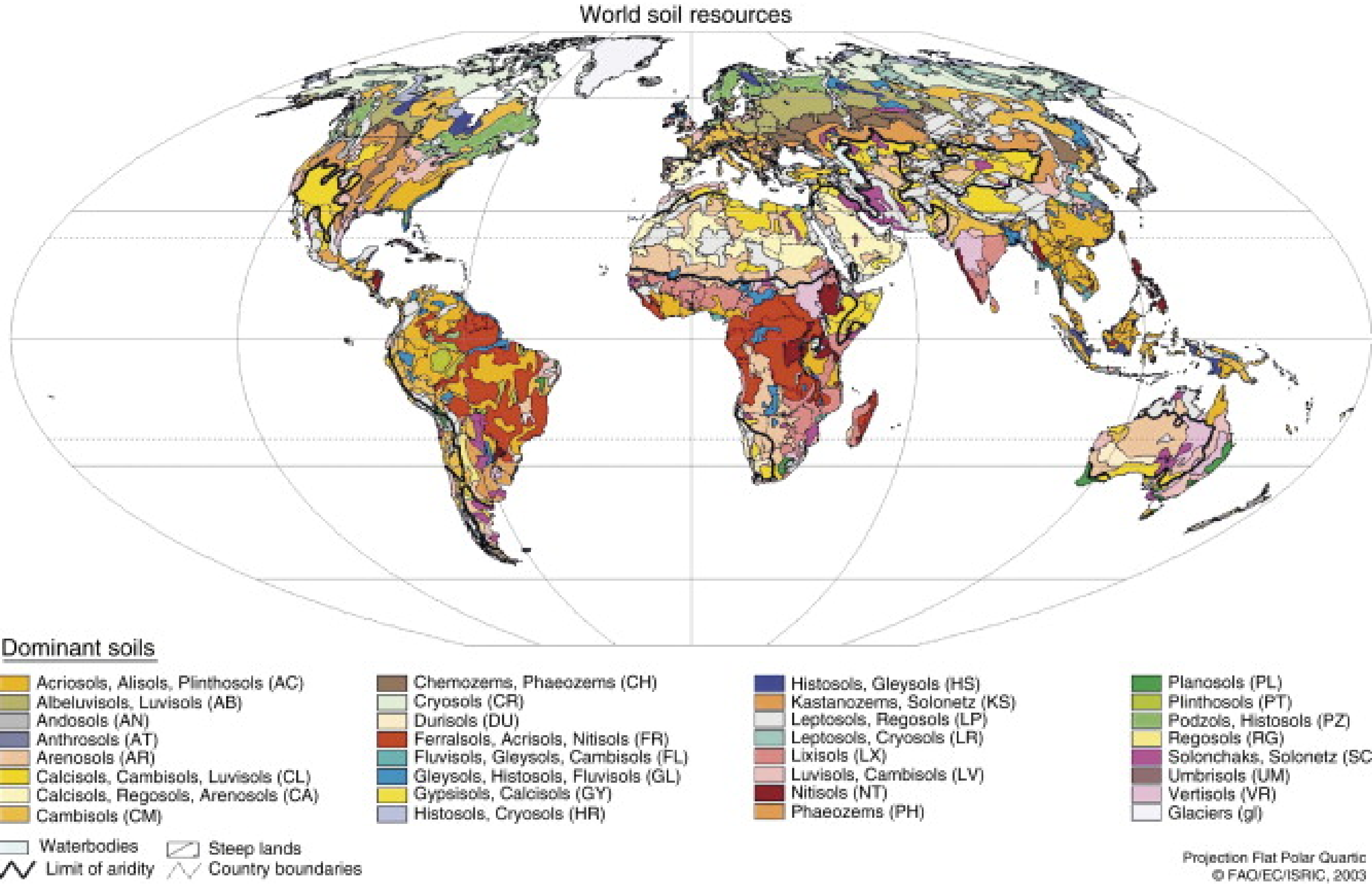
What are the major changes that we might be able to adjust ?

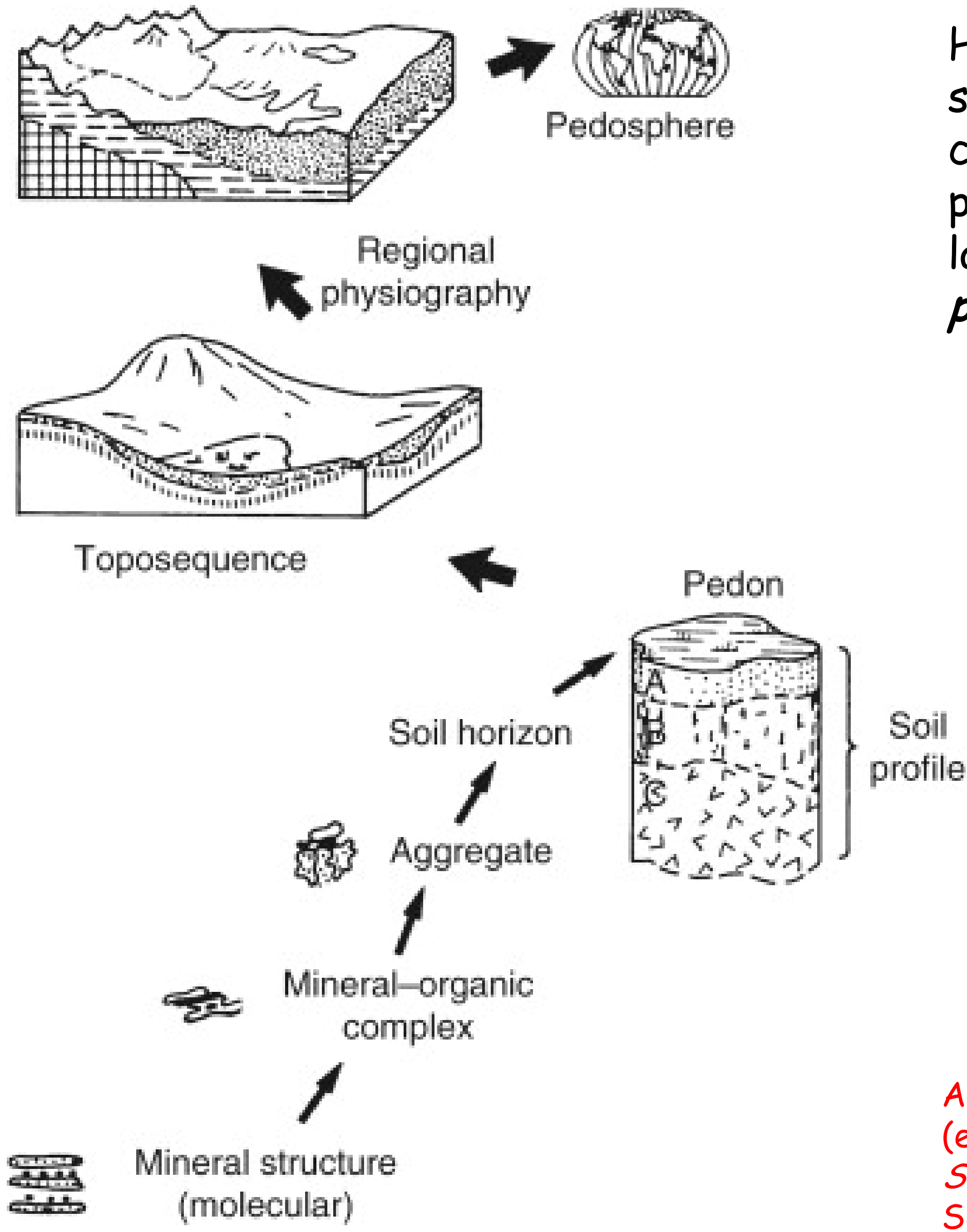
- Land Use Change - the world is smaller
- Food footprint is larger (40% of land used for Agriculture)
- Water Use – 70% for food
- Running out of atmosphere – used as as disposal for fossil fuels and other contaminants

The Perfect Storm



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.***

Adapted from Sposito G and Reginato RJ (eds.) (1992). *Opportunities in Basic Soil Science Research*, p. 11. Madison, WI: Soil Science Society of America.

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.

<u>Overarching Question</u> : *What controls the depth and chemistry of the Earth's regolith?*

State Factor Analyses

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

$$Soil = f(cl, o, r, p, t, h\ldots)$$

cl = Climate

o = Biota or Organisms

r = Topography/relief

pm = Parent Material

t = Time

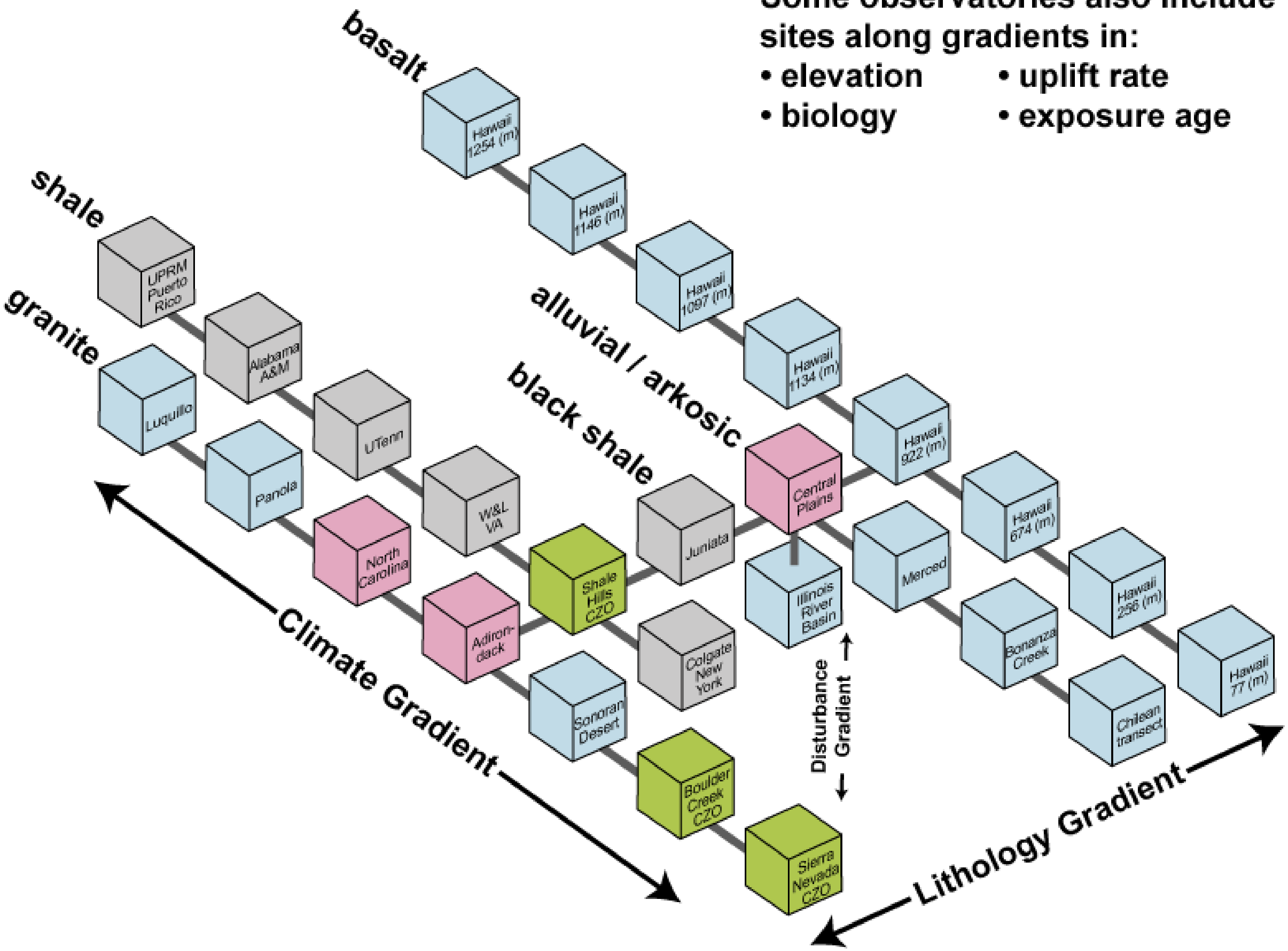
h = Humans

(Jenny, 1941, 1980)

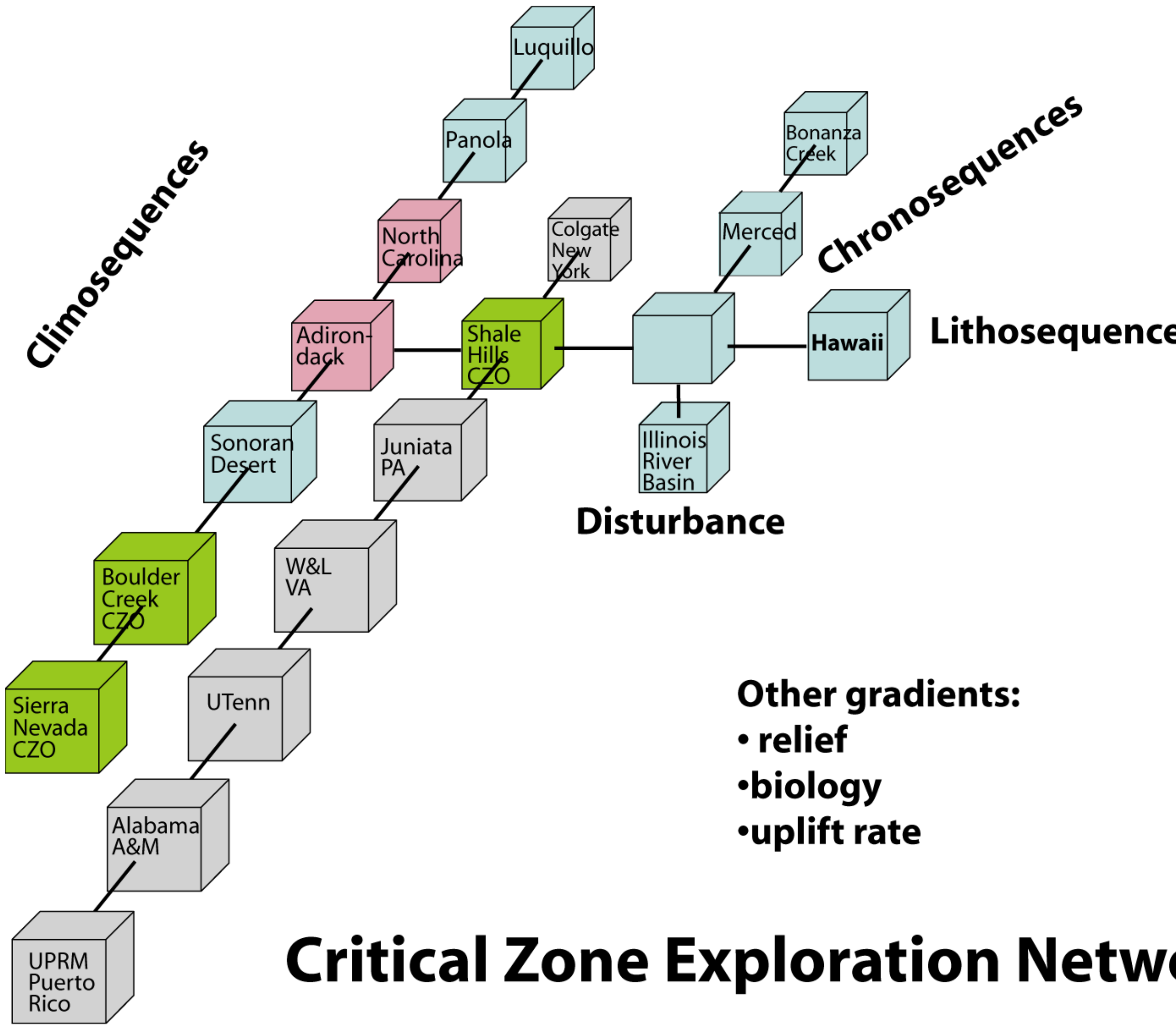
Establish a Network of Sites

Some observatories also include sites along gradients in:

- **elevation**
- **biology**
- **uplift rate**
- **exposure age**



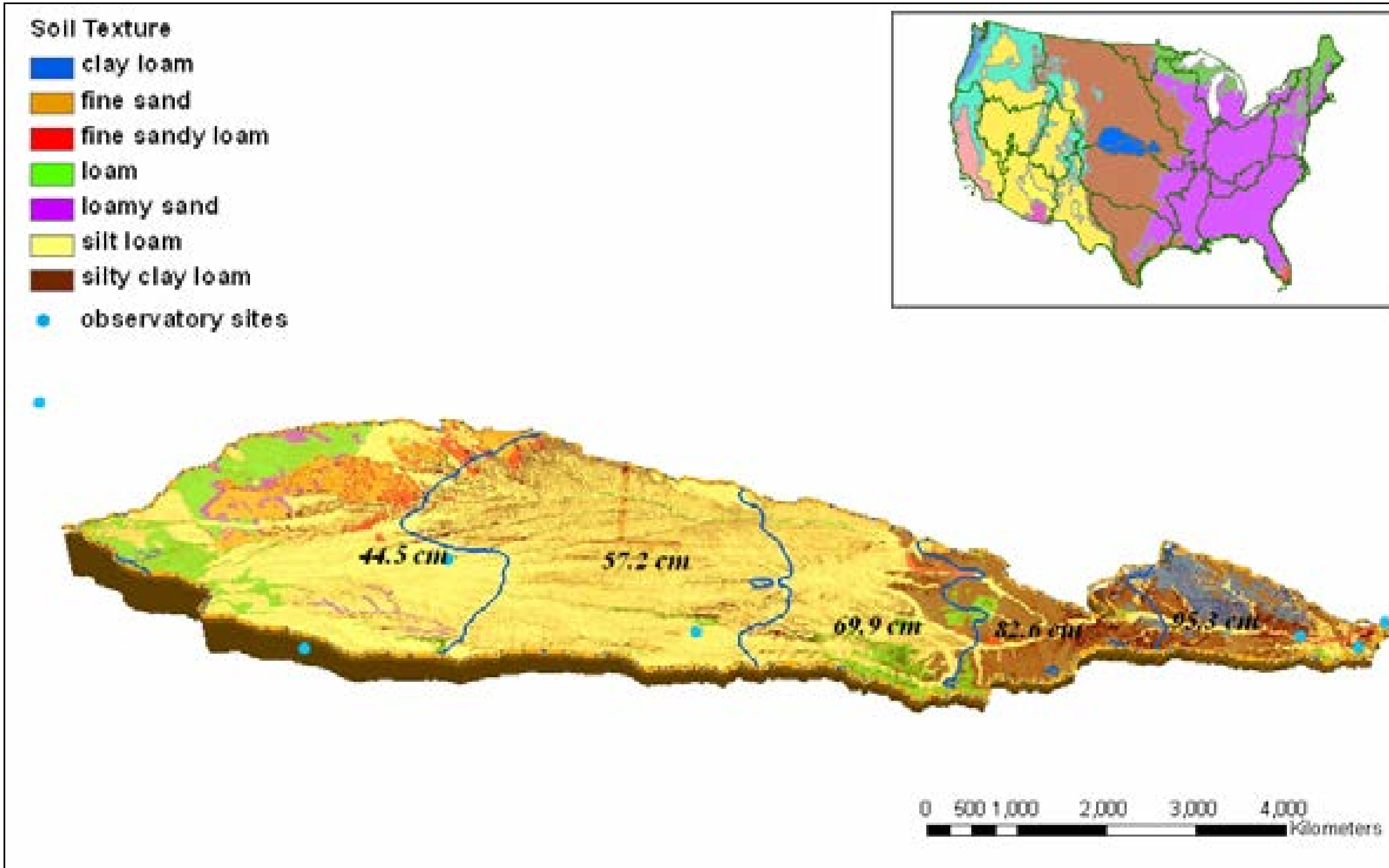
Utilize Natural Gradients



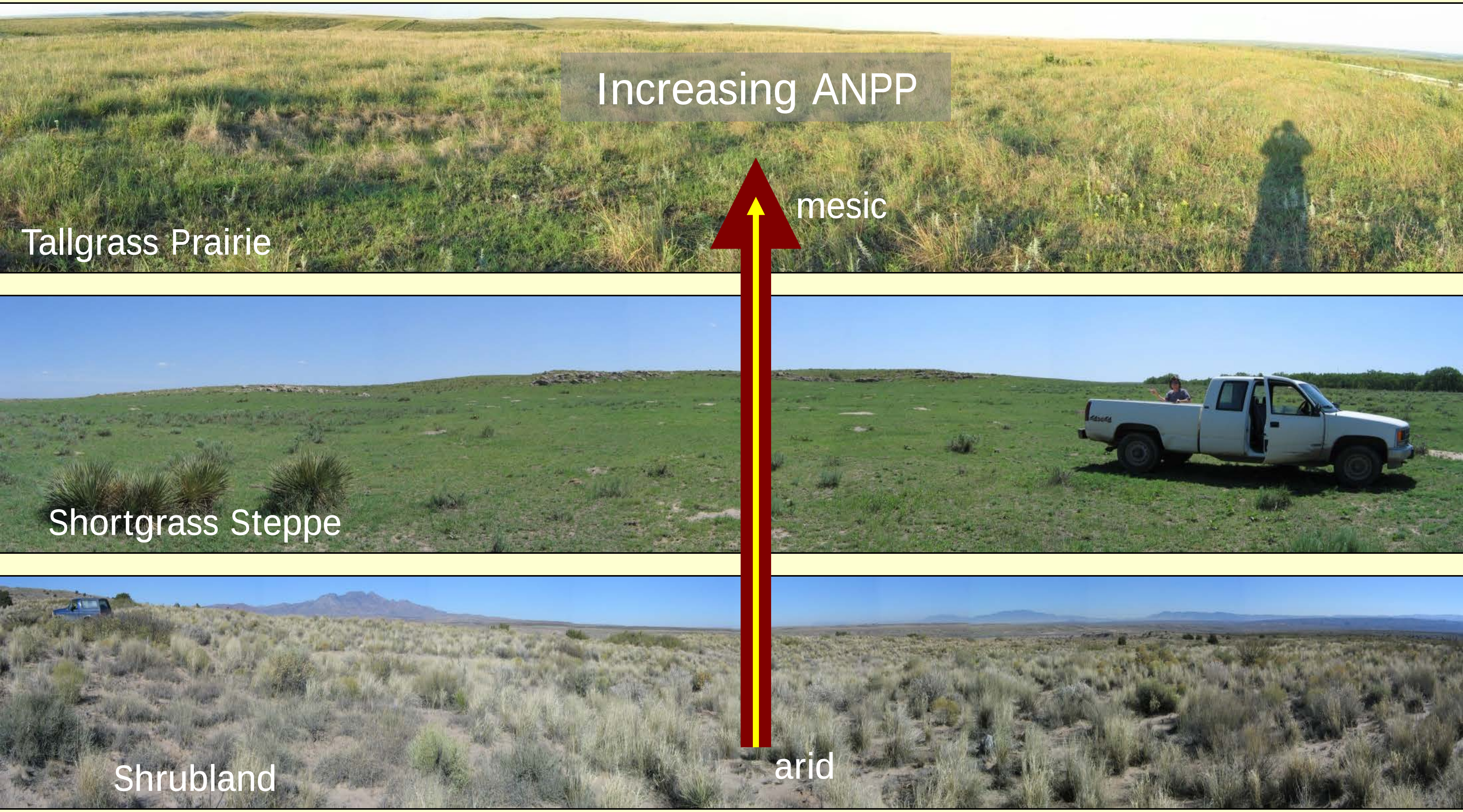
Other gradients:
- **relief**
- **biology**
- **uplift rate**

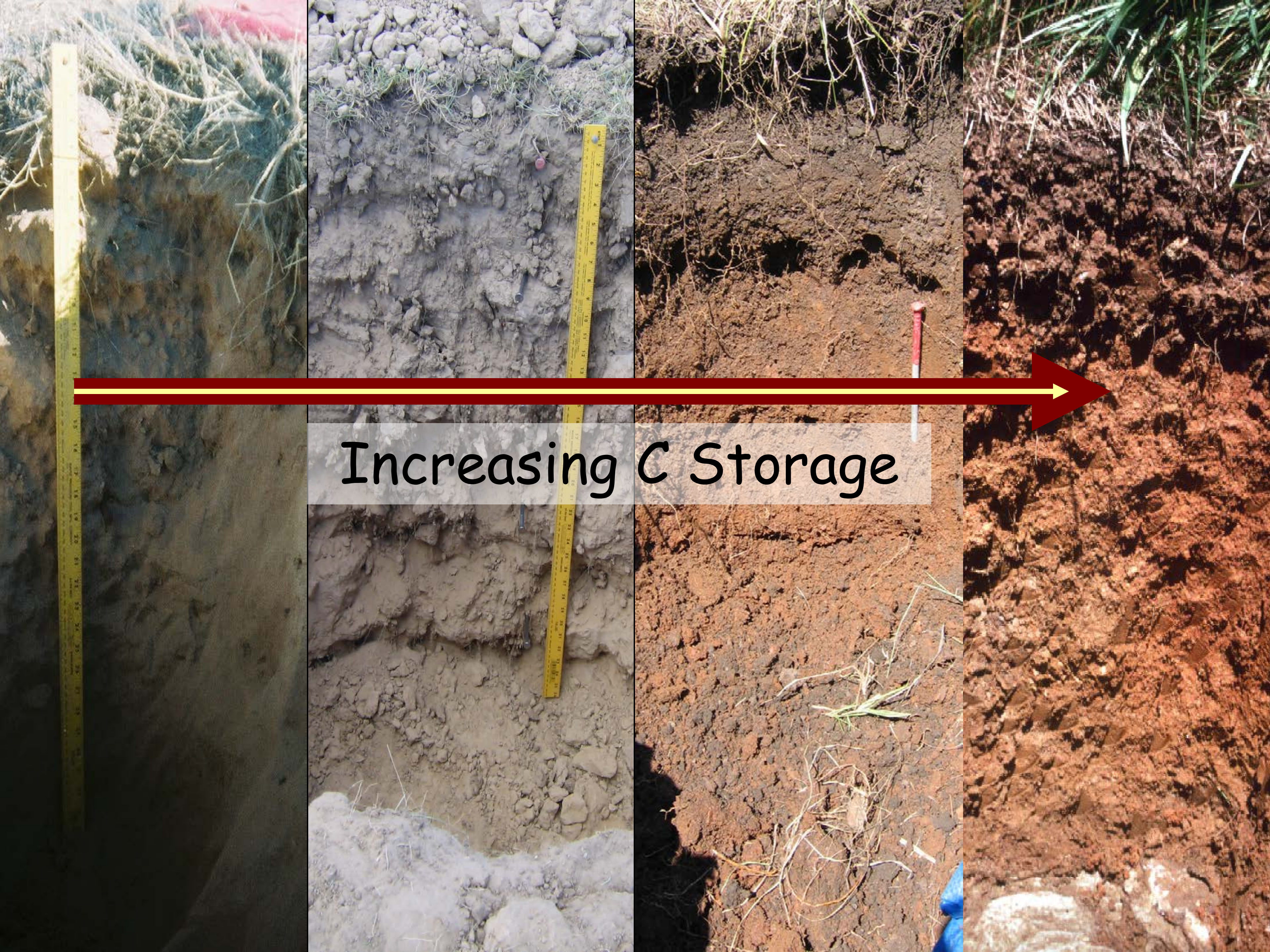
Critical Zone Exploration Network

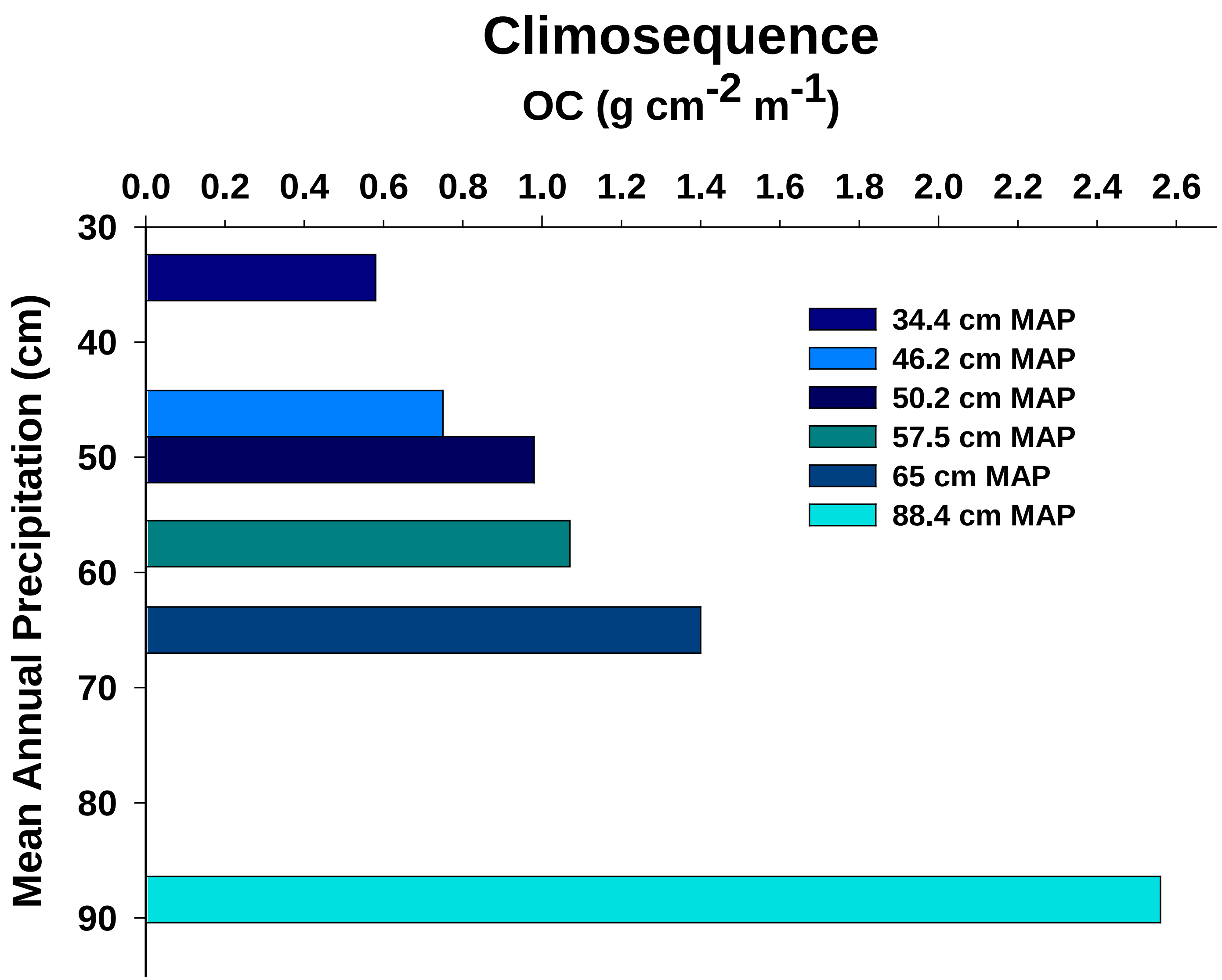
Central Plains CZEN Seed Site

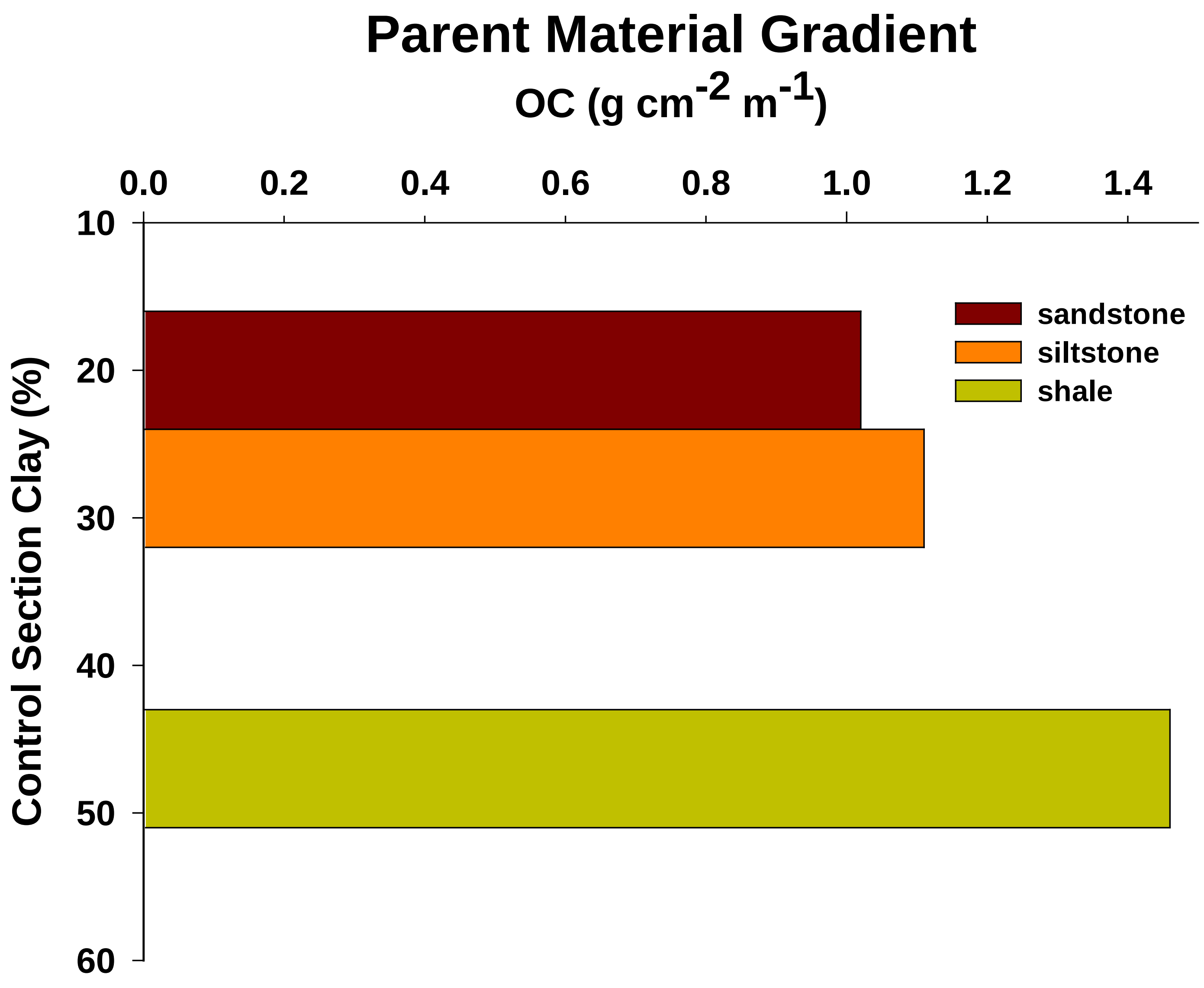


Observations of Ecosystem Properties vs Climatic gradients



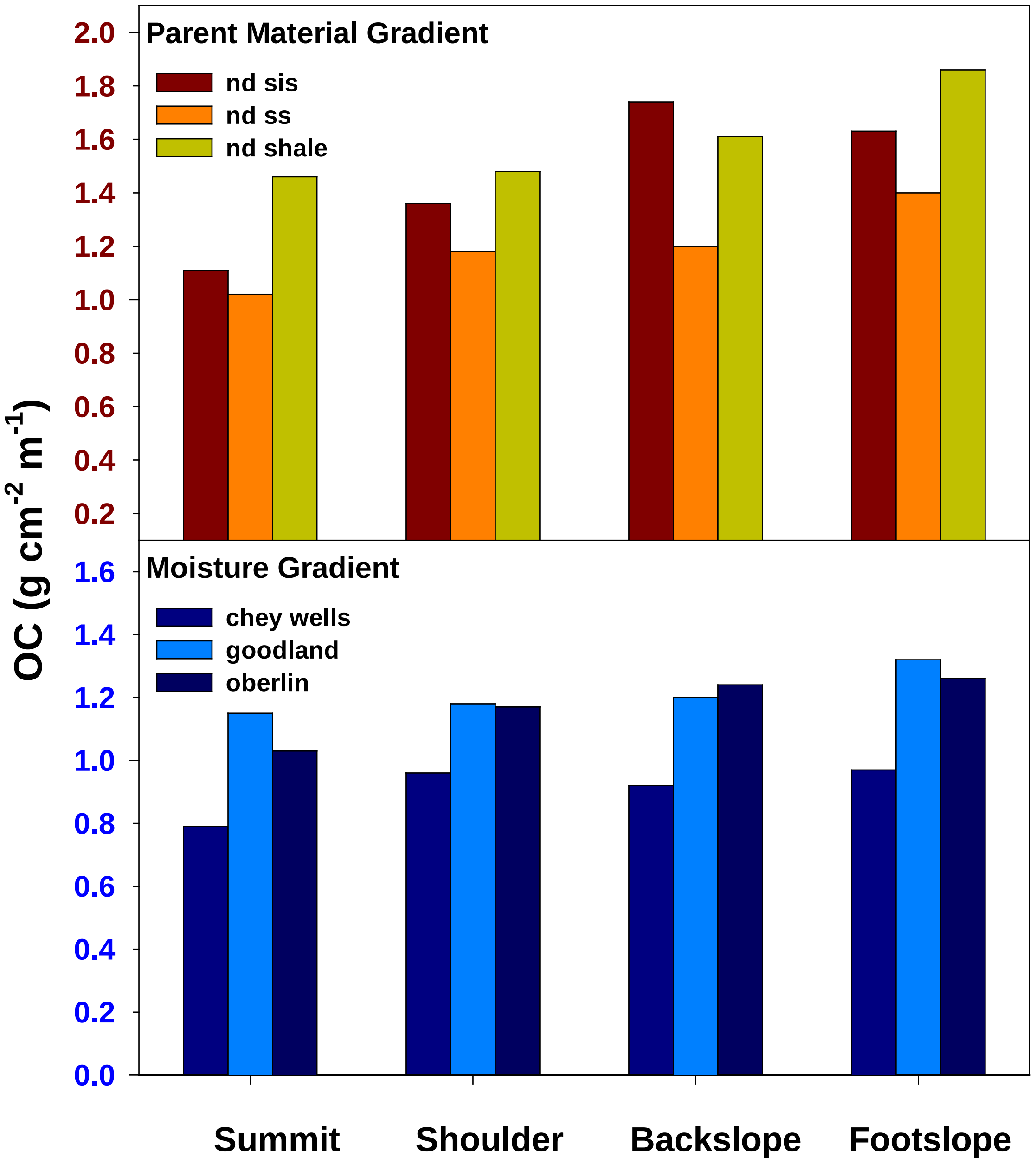

Increasing C Storage


Climosequence
OC (g cm-2 m-1)
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6
30 40 50 60 70 80 90
Mean Annual Precipitation (cm)
34.4 cm MAP
46.2 cm MAP
50.2 cm MAP
57.5 cm MAP
65 cm MAP
88.4 cm MAP

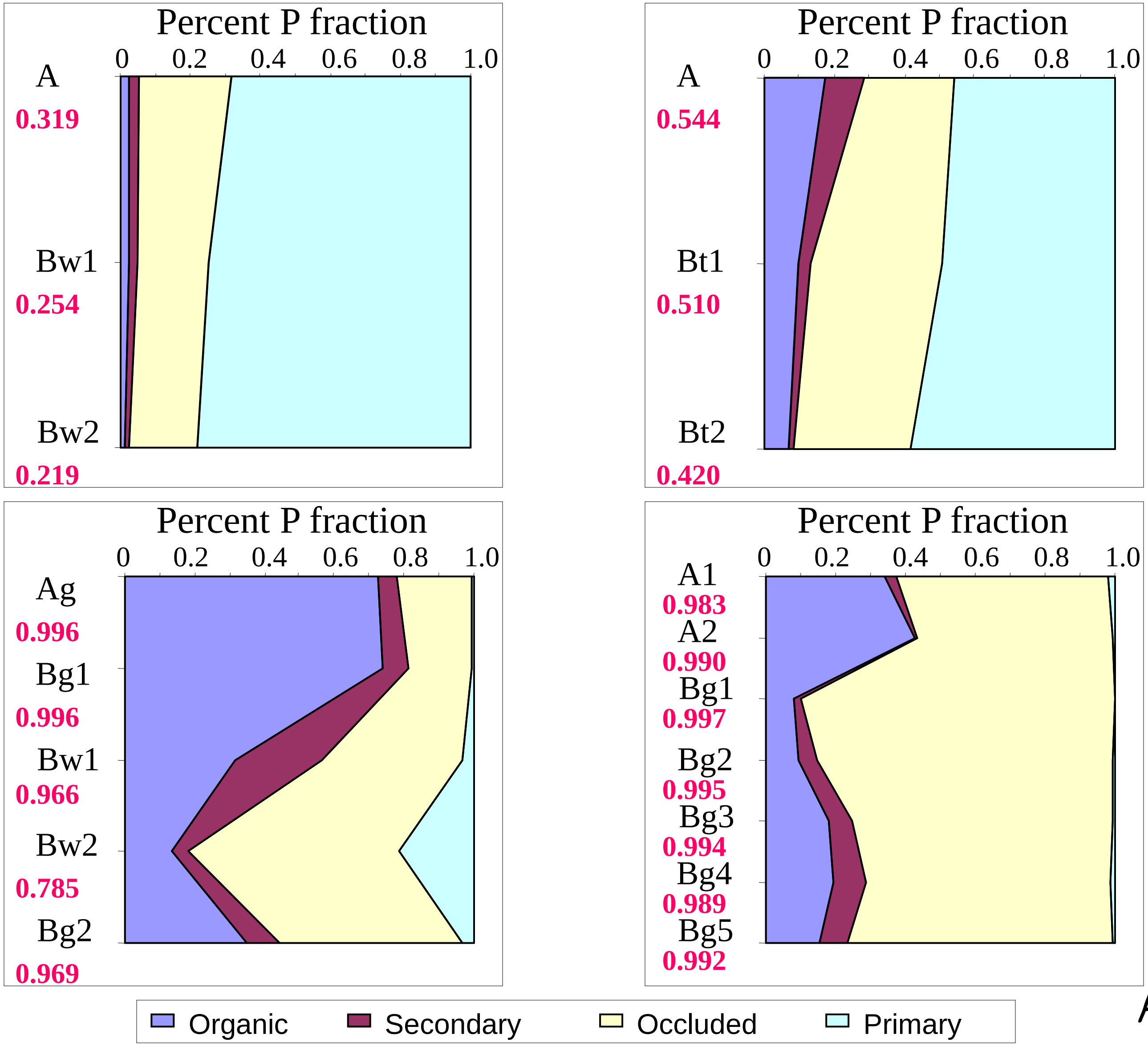


Parent Material Gradient
OC (g cm-2 m-1)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
10
20
30
40
50
60
Control Section Clay (%)
sandstone
siltstone
shale

Topographic Gradient

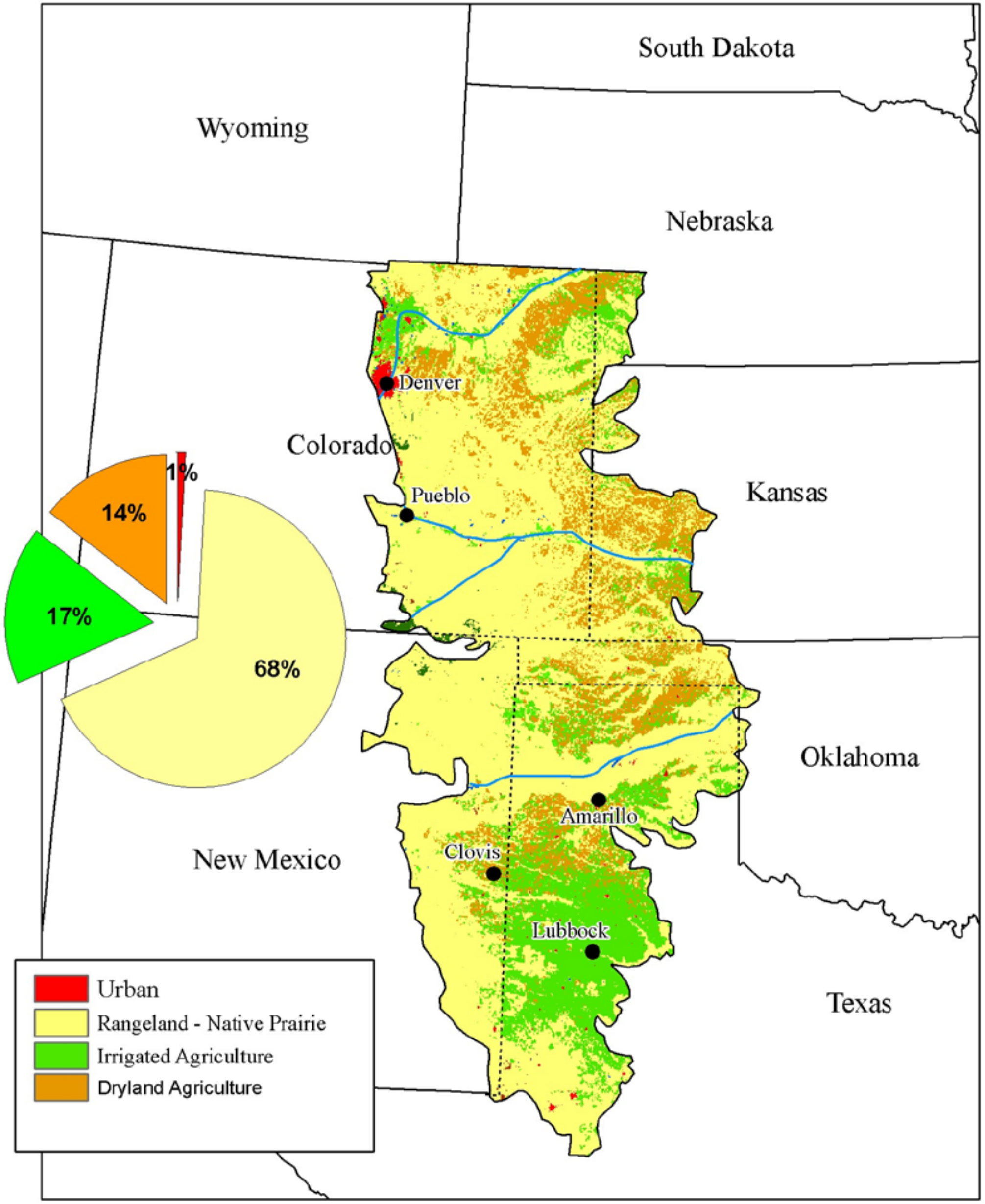


Relationship of P fractions to depth and PPI



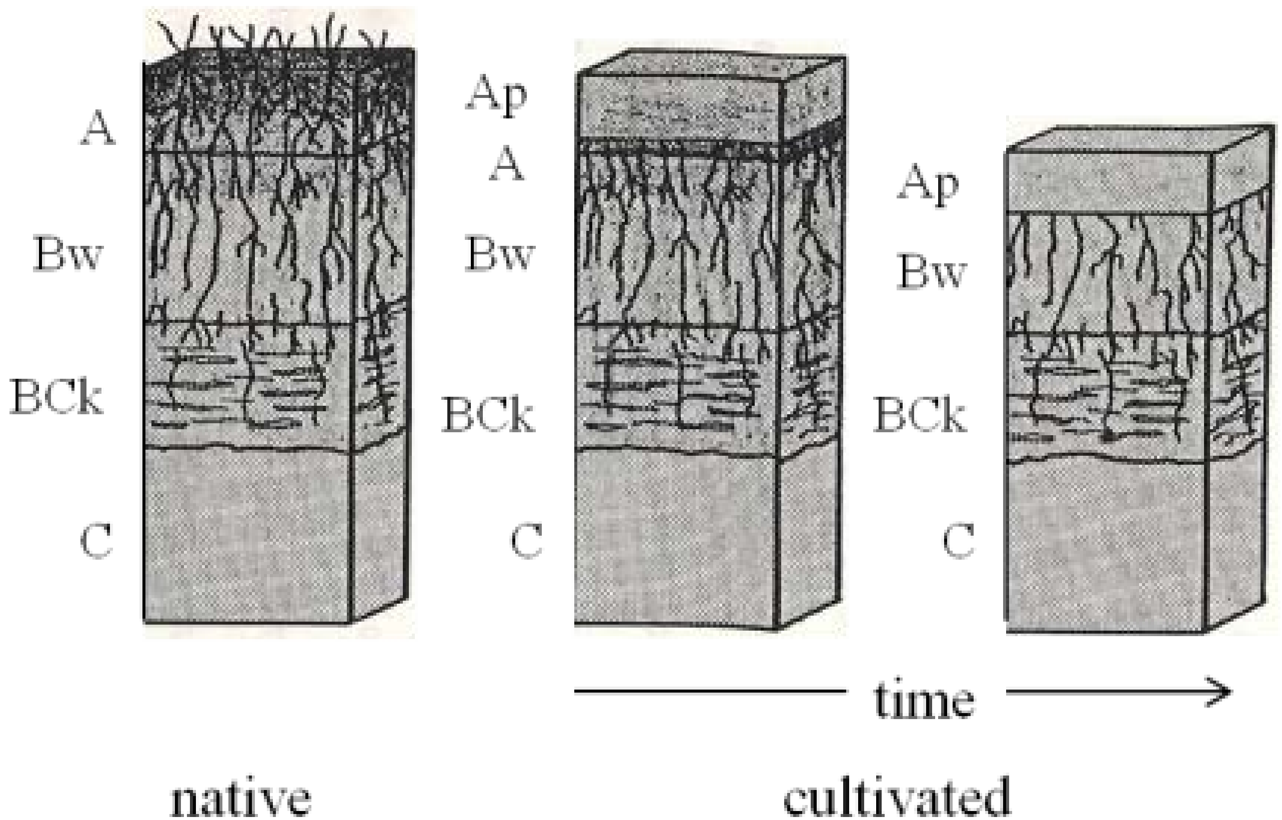
Huffmann et al., in Review

Land Use Gradients

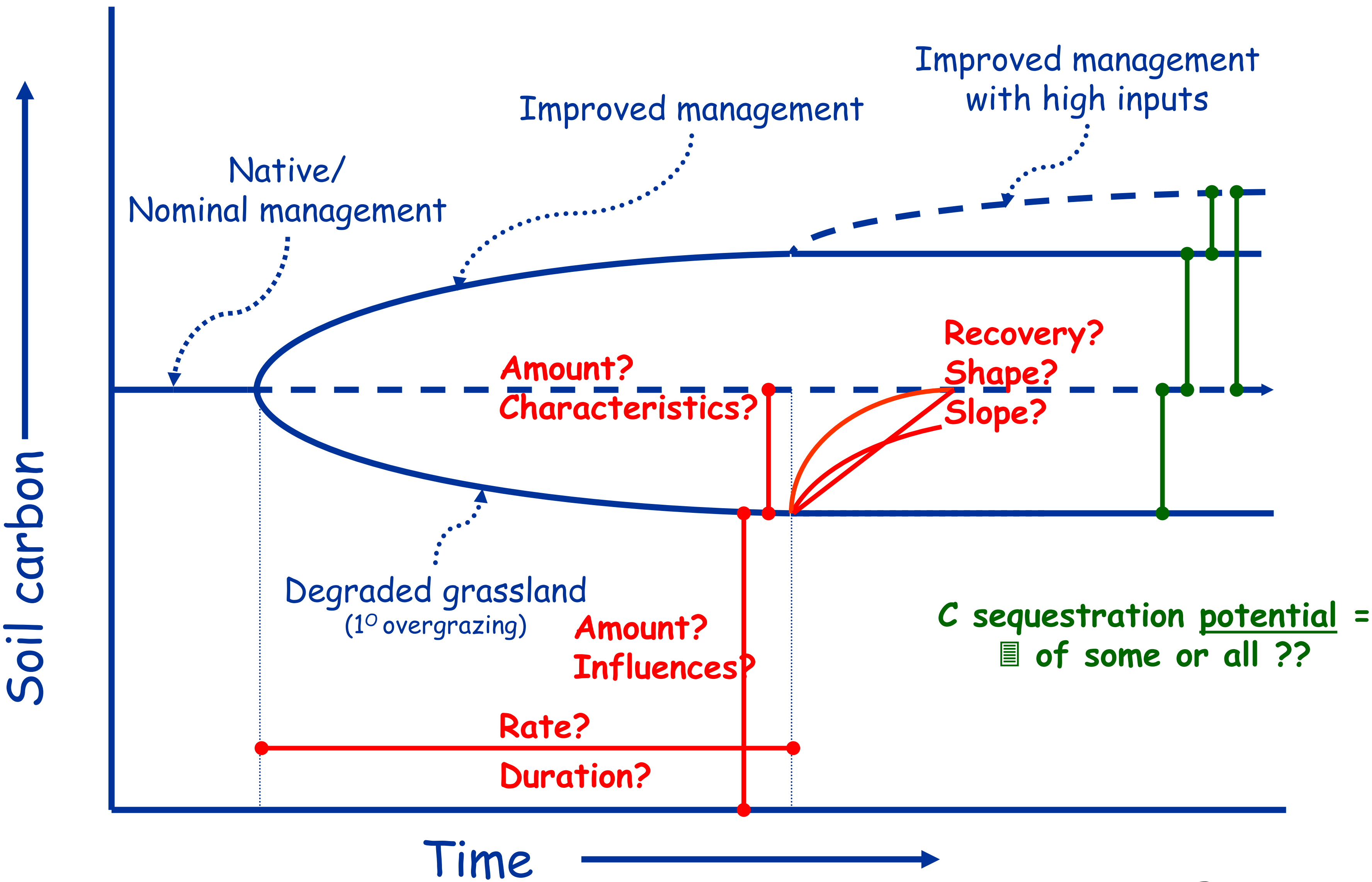


Cultivation and C Storage

- 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



K. Paustian

Hierarchical Dependency of Controls

Hierarchical Level	Driving Variables	Processes	Properties
I. Physiographic Section (10^3 km^2)	LT-Global Climate Structural Geology Tectonics	Glaciation Denudation Base Level Change	Geological Substrate
II. Landform Assemblage (ordering of watershed)	Geological Substrate + Regional Climate + Land Use	Hydrologic	Surficial Geology Drainage Patterns
III. Landform (1 to 10^3 ha)	Surficial Geology Drainage Patterns + Local Climate + Land Use	Fluvial Aeolian	Parent Material Slope/Aspect Configuration % Cover
IV. Landform Element (10^1 to 10^3 m^2)	Parent Material Slope/Aspect Configuration % Cover + Climate events +Mgt, + Atm Deposition	Erosion/Deposition Run-on/off	Soil Texture Soil Moisture Soil Temperature
V. Pedon (m^2)	Soil Texture Soil Moisture Soil Temperature	Decompositon Production	Soil Organic Carbon

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.

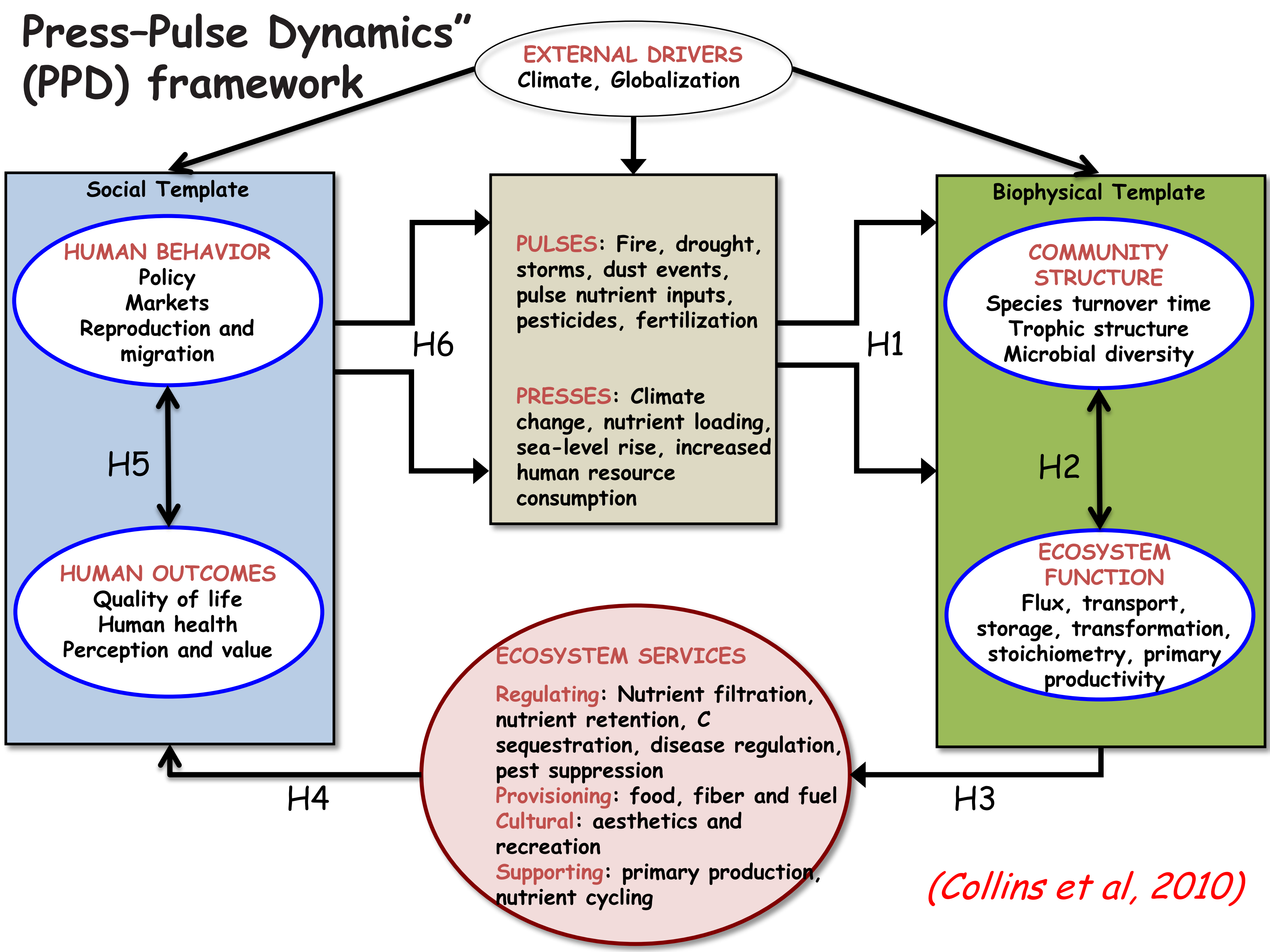
Various conceptual models have been proposed to characterize social–ecological systems, but new thinking is needed to guide long-term research that links humans with role in changing their environment

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

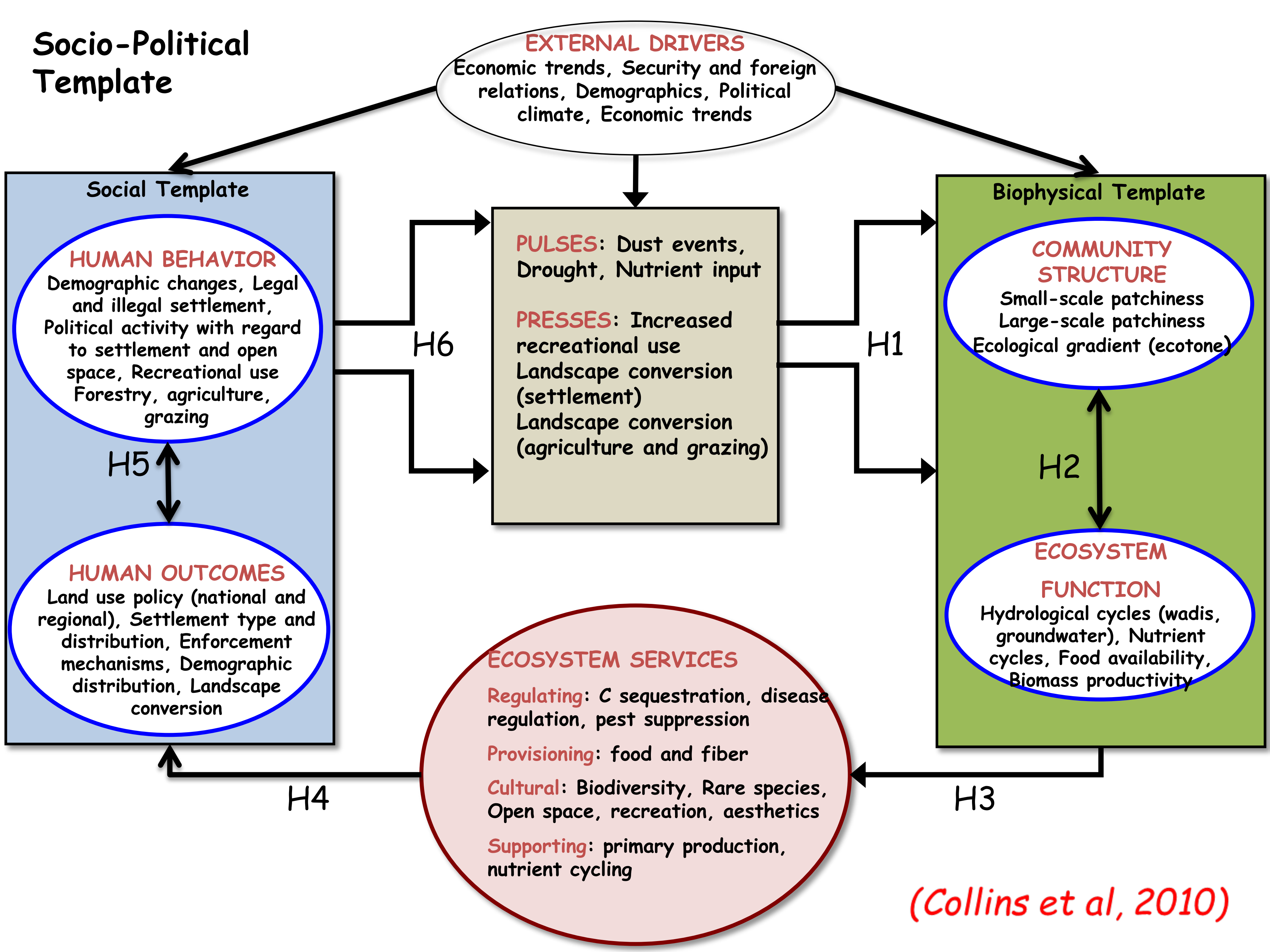
Application of this approach will bridge the social and natural sciences and build a knowledge base that can be used to help solve current and future environmental challenges

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
Social Template
HUMAN BEHAVIOR
Policy
Markets
Reproduction and migration
H5
HUMAN OUTCOMES
Quality of life
Human health
Perception and value
H6
PULSES: Fire, drought, storms, dust events, pulse nutrient inputs, pesticides, fertilization
PRESSES: Climate change, nutrient loading, sea-level rise, increased human resource consumption
H1
Biophysical Template
COMMUNITY STRUCTURE
Species turnover time
Trophic structure
Microbial diversity
H2
ECOSYSTEM FUNCTION
Flux, transport, storage, transformation, stoichiometry, primary productivity
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
H4
H3
(Collins et al, 2010)


Socio-Political Template
EXTERNAL DRIVERS
Economic trends, Security and foreign relations, Demographics, Political climate, Economic trends
Social Template
HUMAN BEHAVIOR
Demographic changes, Legal and illegal settlement, Political activity with regard to settlement and open space, Recreational use Forestry, agriculture, grazing
H5
HUMAN OUTCOMES
Land use policy (national and regional), Settlement type and distribution, Enforcement mechanisms, Demographic distribution, Landscape conversion
H6
PULSES: Dust events, Drought, Nutrient input
PRESSES: Increased recreational use
Landscape conversion (settlement)
Landscape conversion (agriculture and grazing)
H1
Biophysical Template
COMMUNITY STRUCTURE
Small-scale patchiness
Large-scale patchiness
Ecological gradient (ecotone)
H2
ECOSYSTEM FUNCTION
Hydrological cycles (wadis, groundwater), Nutrient cycles, Food availability, Biomass productivity
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
H4
H3
(Collins et al, 2010)

A) Presses and Assessing Drought

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

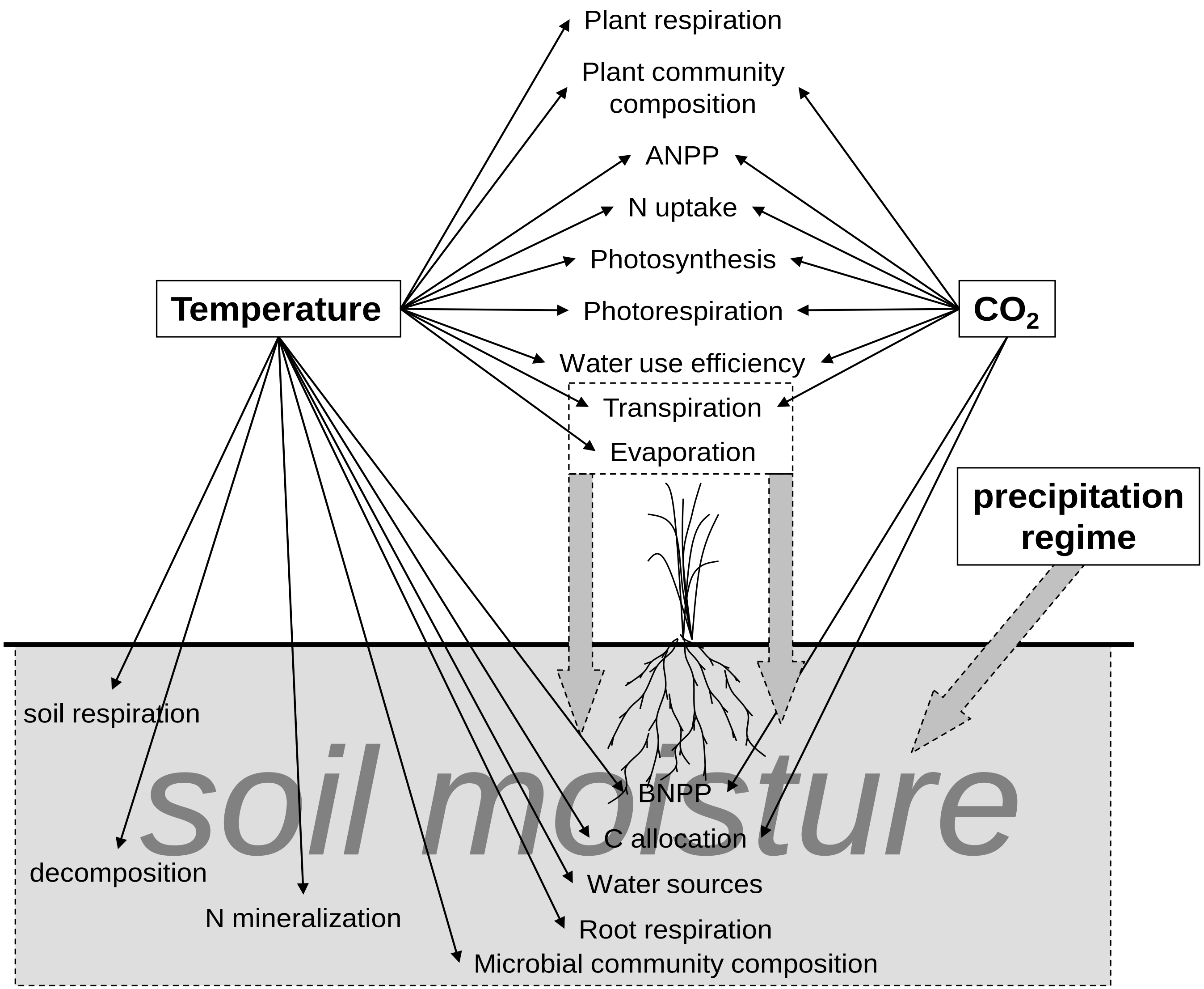
The extent of drought in July, August and September 2012 is on par with the worst months of the multi-year droughts of the 1930s Dust Bowl and the mid-1950s.

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



Why Soil Moisture ?

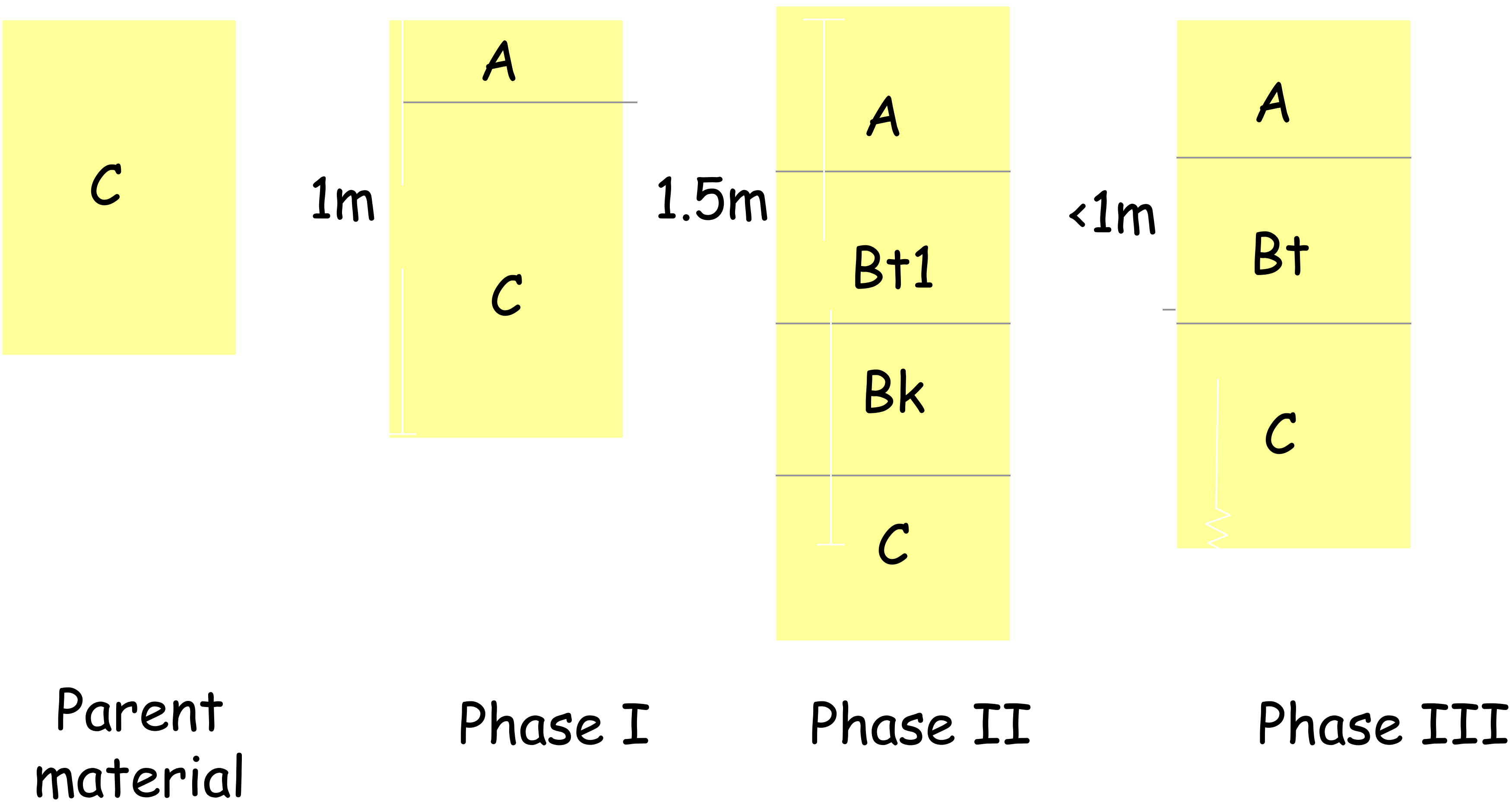
1) Soil moisture is a key driver of almost all ecological processes in water-limited grass dominated ecosystems
2) Soil moisture shapes vegetation structure and community composition.
3) Drives community dynamics across all trophic levels.
4) Regulates carbon allocation patterns, biogeochemical cycling,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



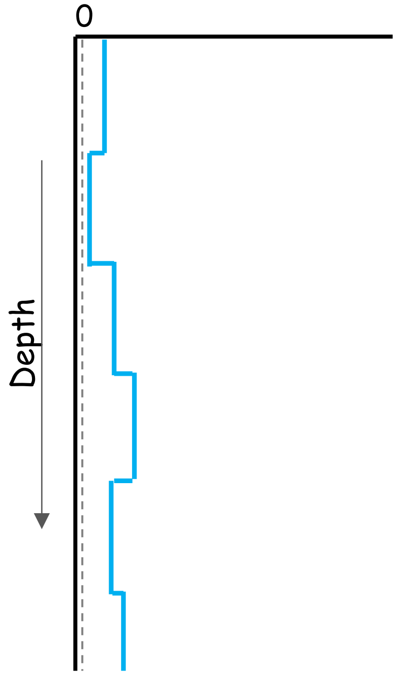
Kelly et al 2008

Soil Development Phases

Available Water Capacity

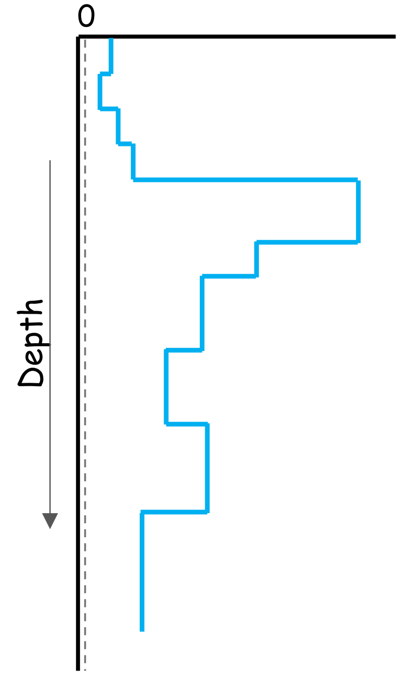
[cm water / cm soil]

Phase I
Entisol



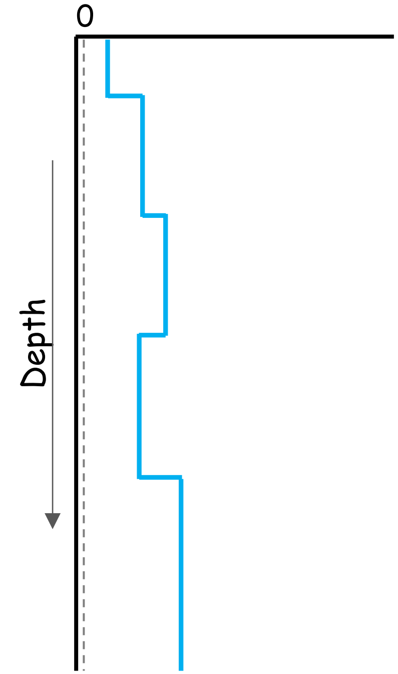
2 k

Phase II
Haplargid



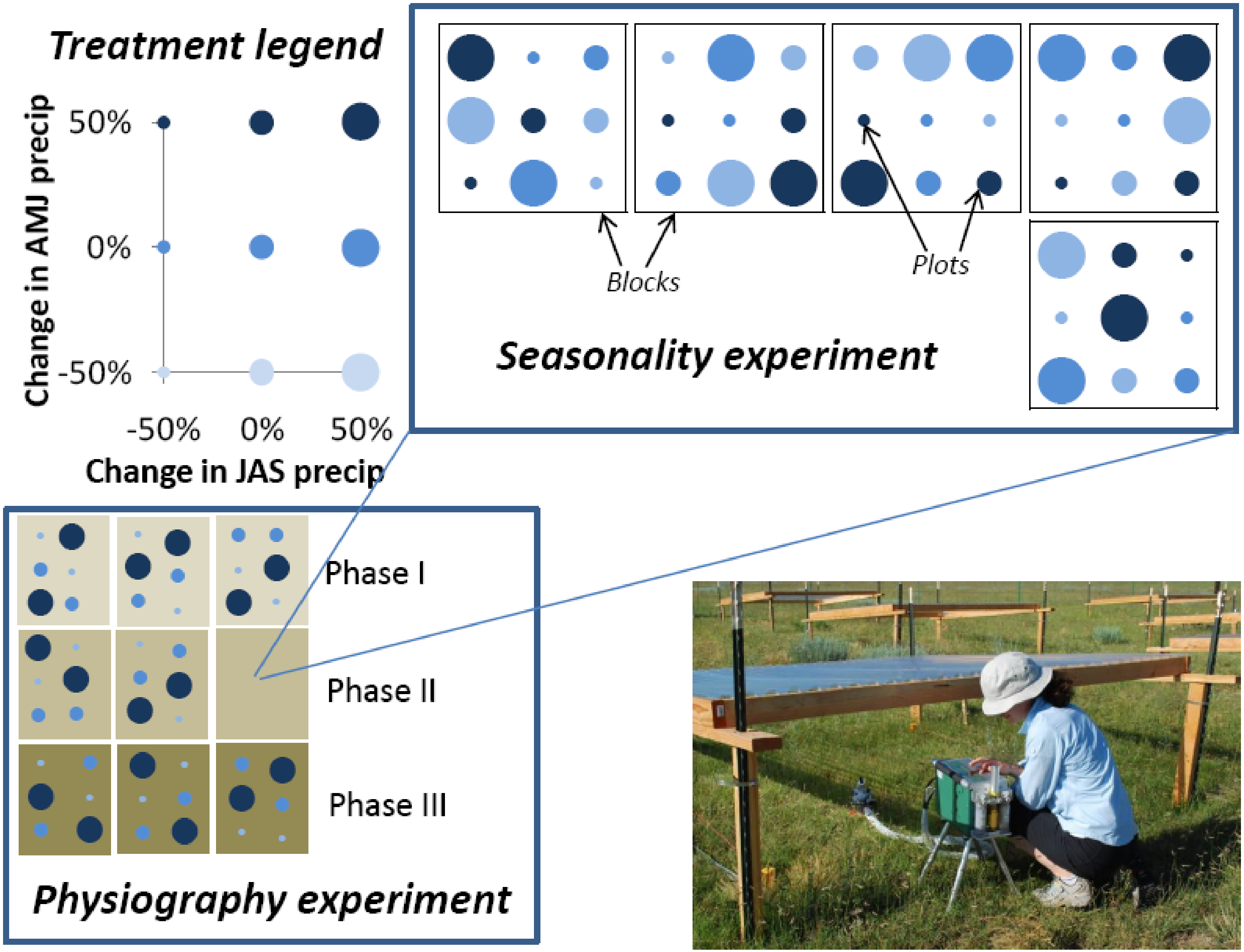
125 k

Phase III
Haplocambid

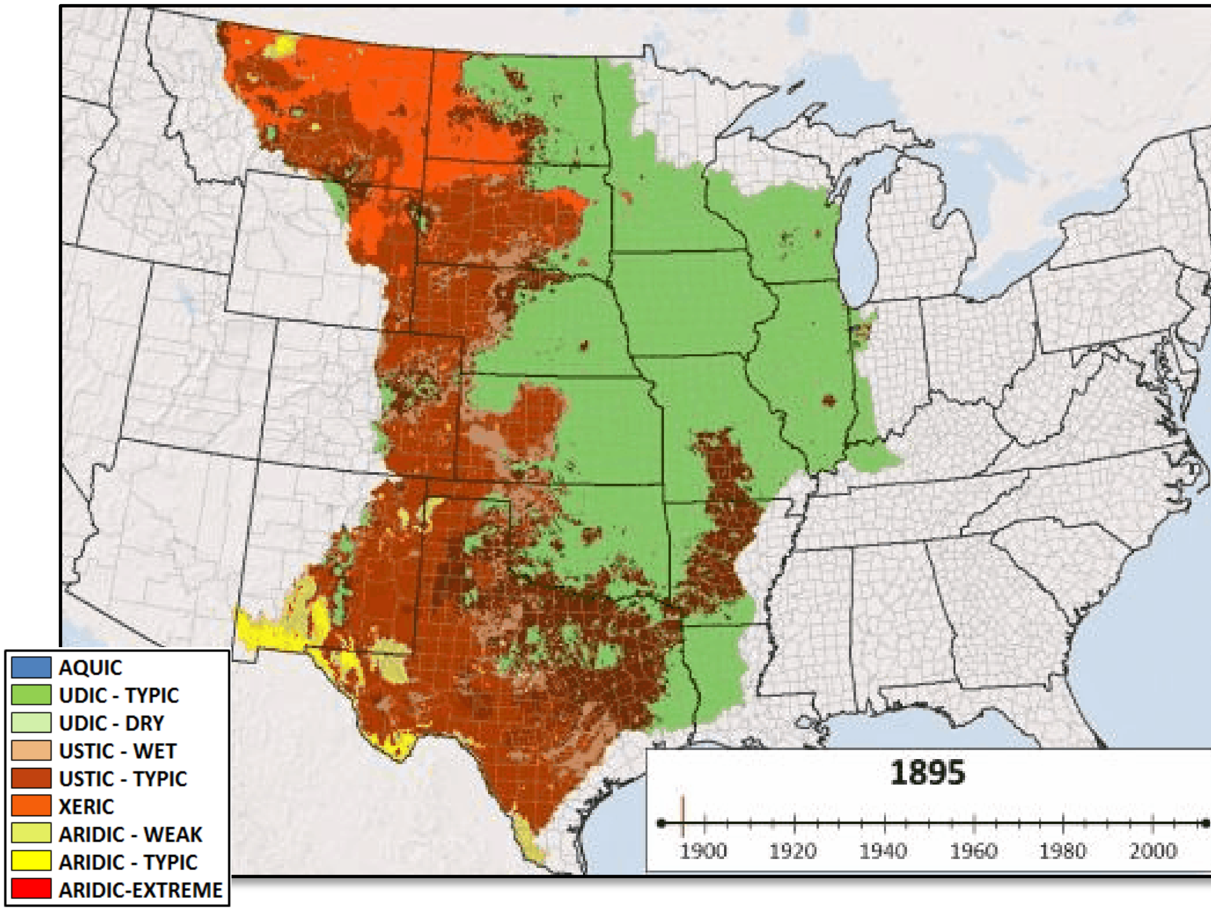


660 k

SW Salley, in prep

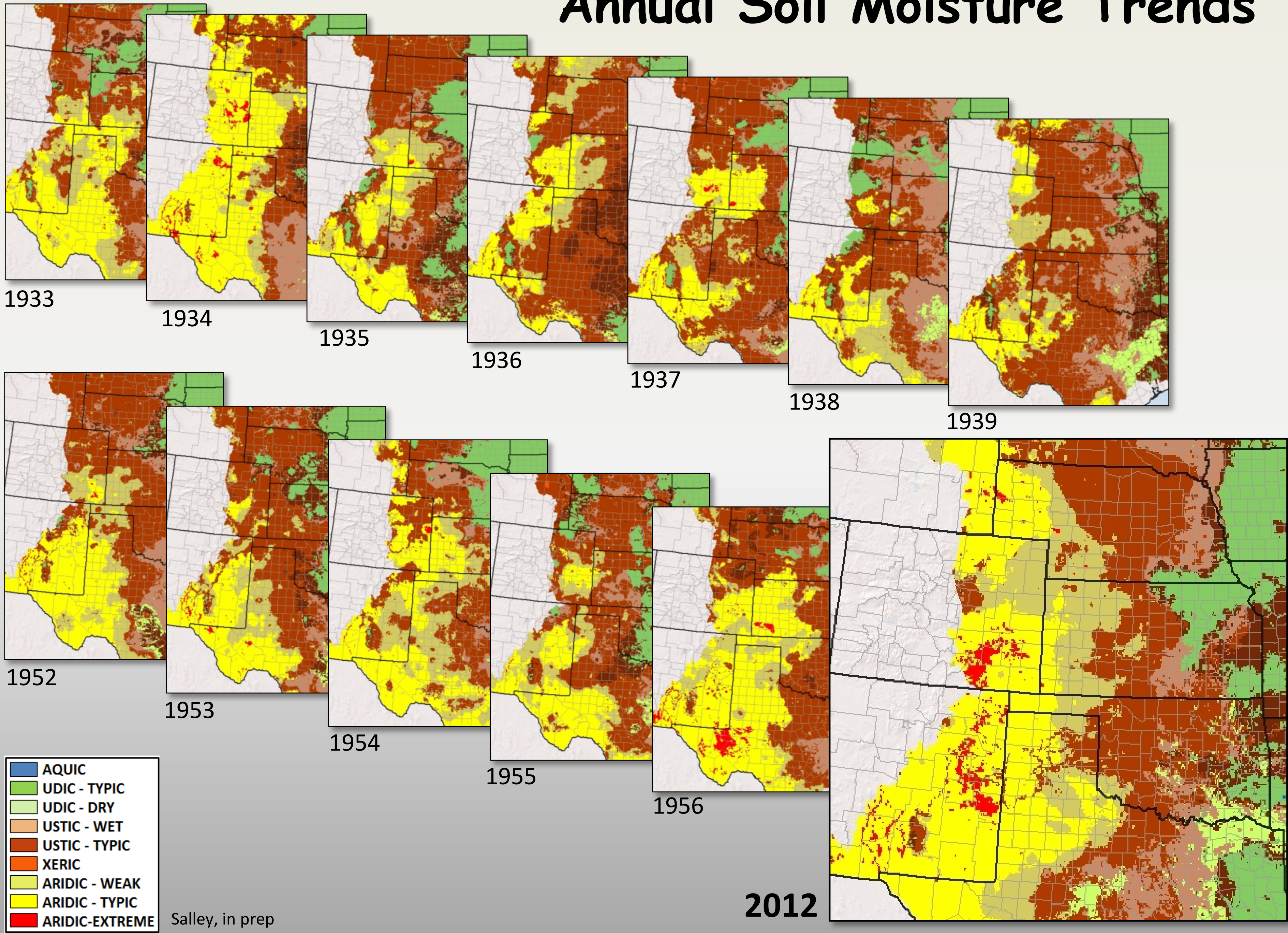

Treatment legend
50%
0%
-50%
Change in AMJ precip
-50%
0%
50%
Change in JAS precip
Blocks
Plots
Seasonality experiment
Phase I
Phase II
Phase III
Physiography experiment

Forecasting Annual Soil Moisture



SW Salley, in prep

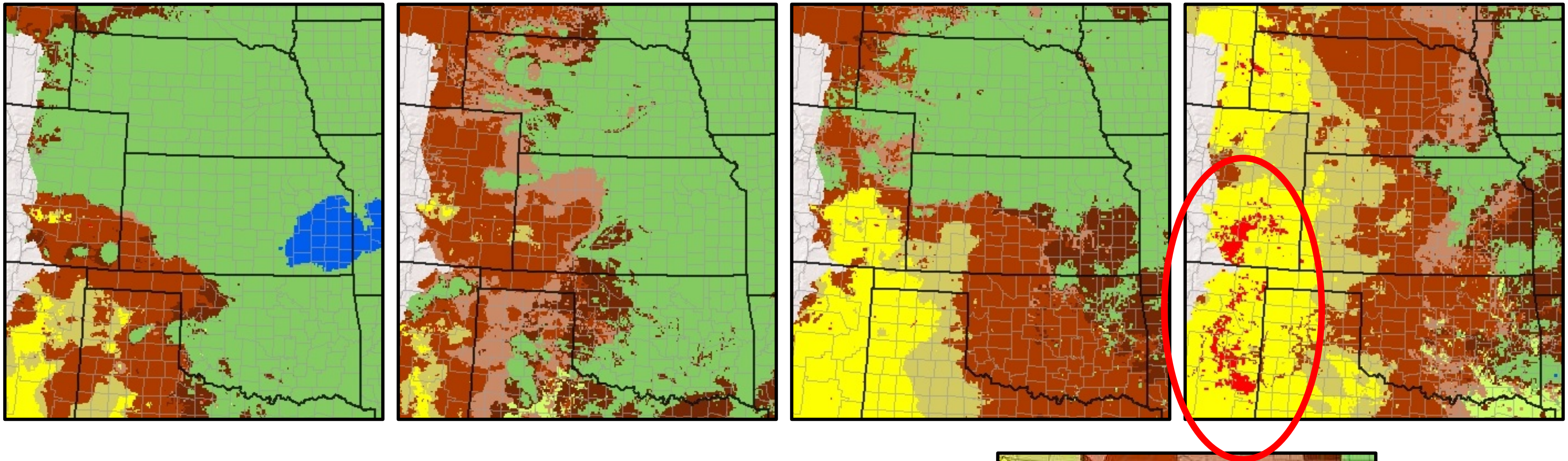
Annual Soil Moisture Trends

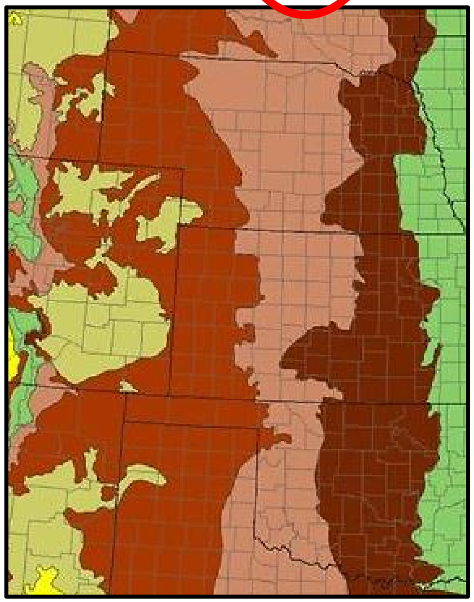


Salley, in prep

Current Drought

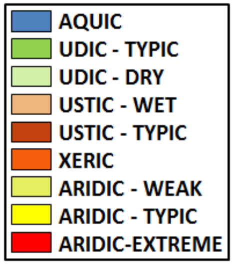
2009 2010 2011 2012





"Normal"

We identified the areas of greatest soil degradation that will continue to be vulnerable to chronic drought and perhaps never recover !



Salley, in prep

Vulnerability of Soils to Chronic Drought

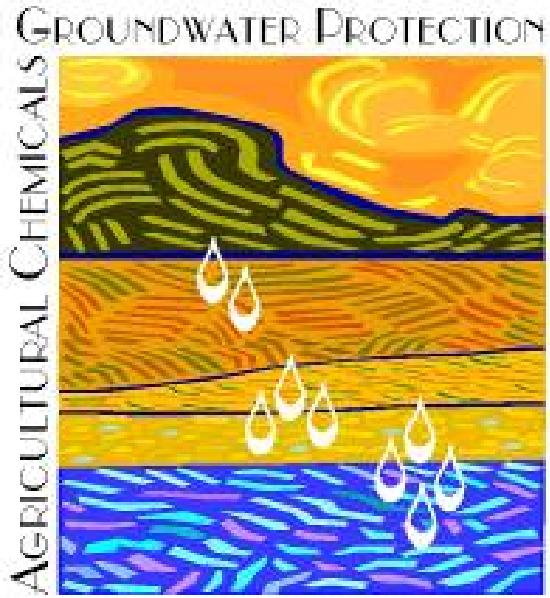
- Hydrological properties provide insights into assessing the vulnerability of agricultural soils to long term chronic drought conditions.
- Establishing broader nutrient thresholds and biogeochemical feedbacks in cultured systems should be considered in the determinations.
- There is a necessity to 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.

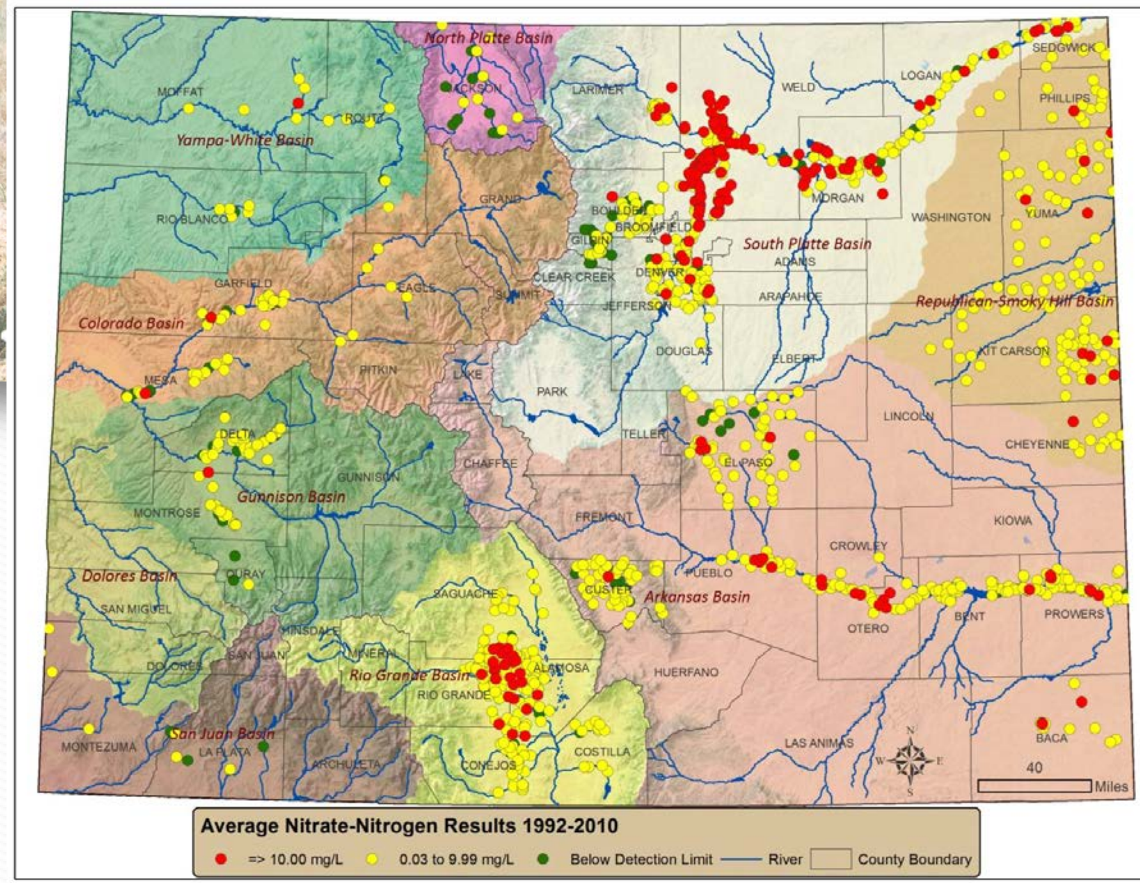
Agricultural Chemicals and Groundwater Protection Program

- 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

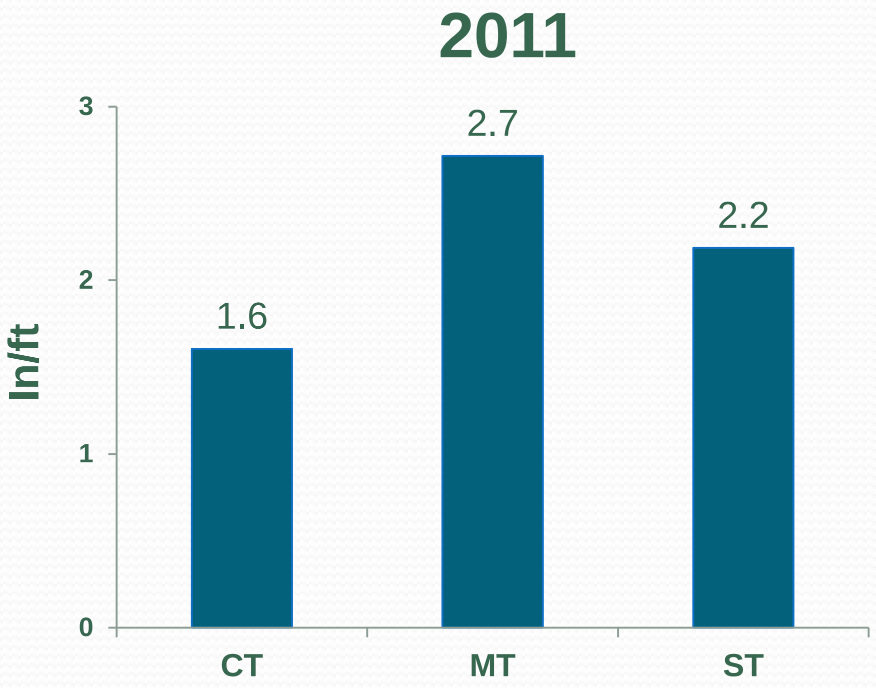
Tillage Treatments

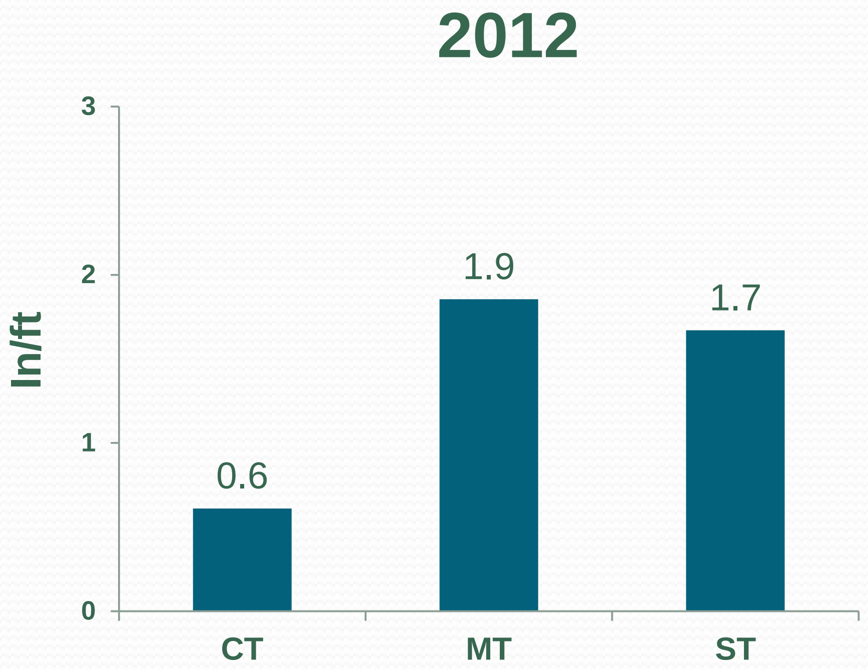
Min-till (MT)
6 operations

Conventional (CT)
14 operations

Strip-till (ST)
9 operations

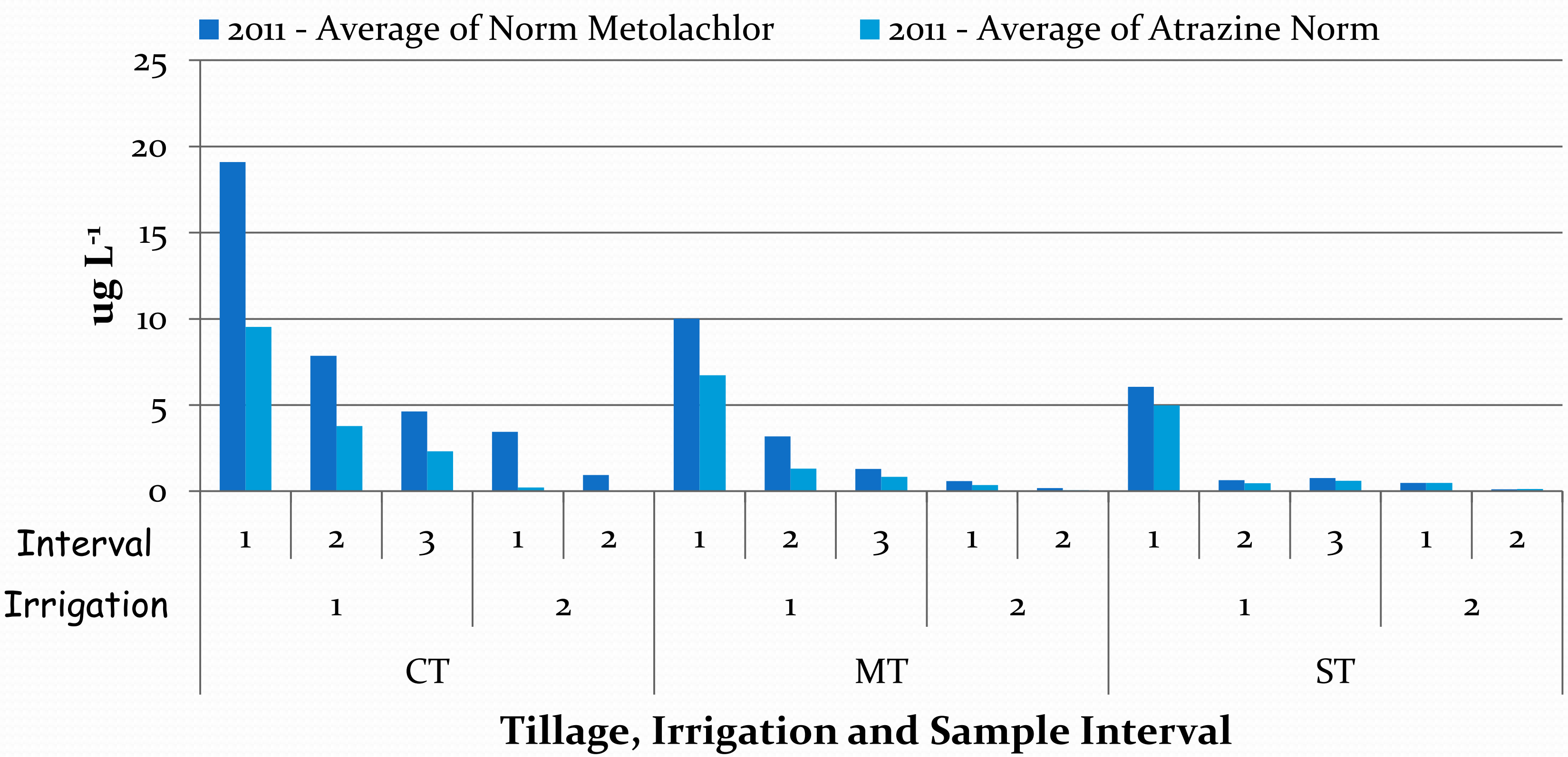
Spring Soil Moisture at Planting (top 6 in.)





Bauder et al, 2013

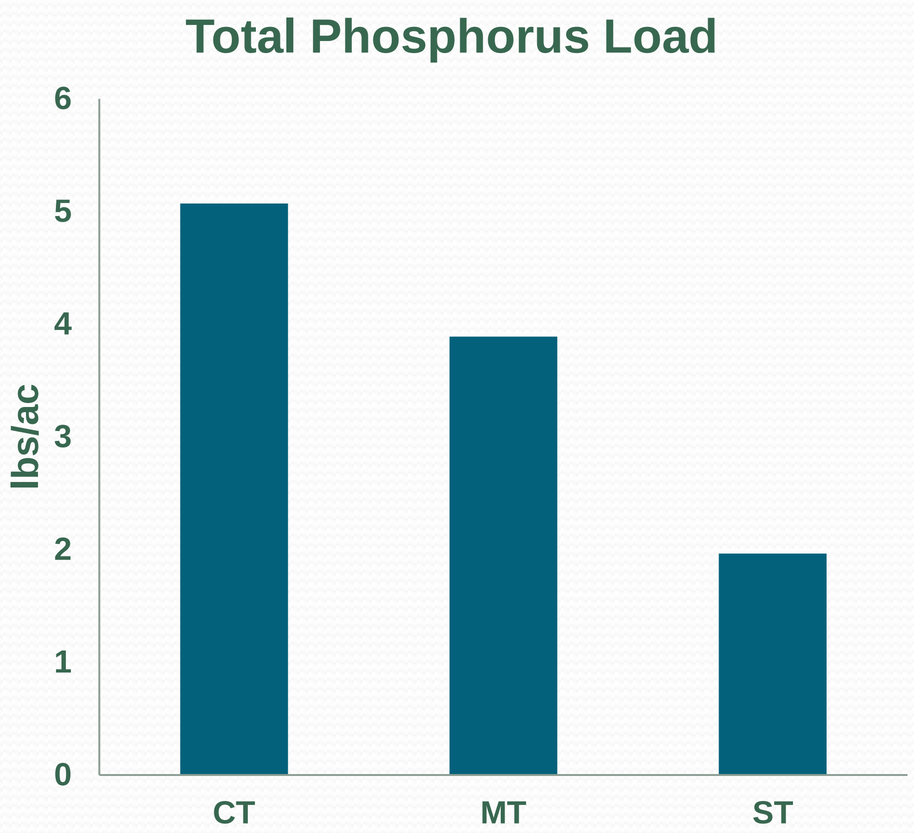
Runoff - Herbicides

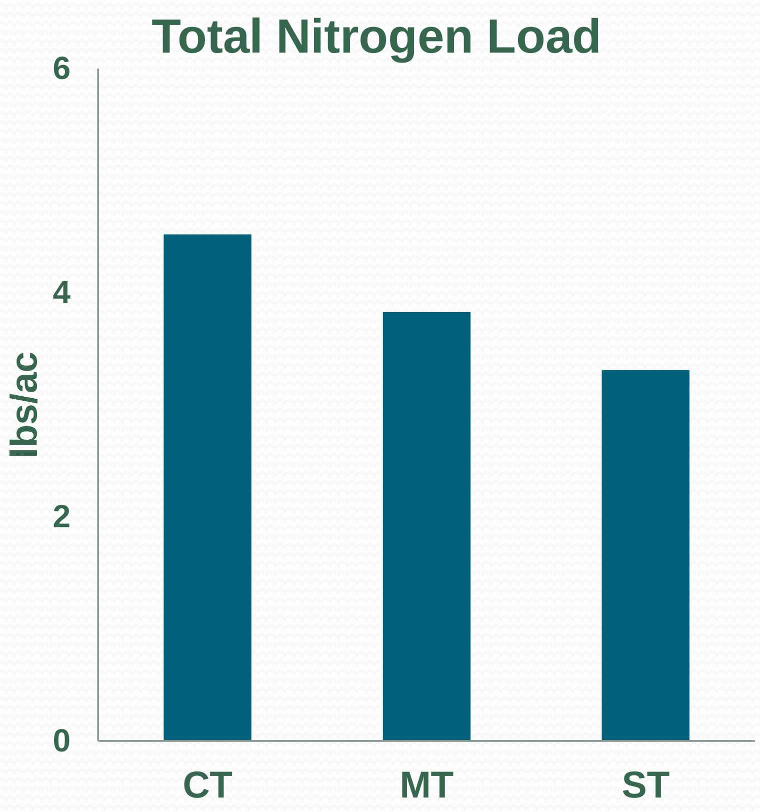


*Applied as product Lumax

Bauder et al, 2013

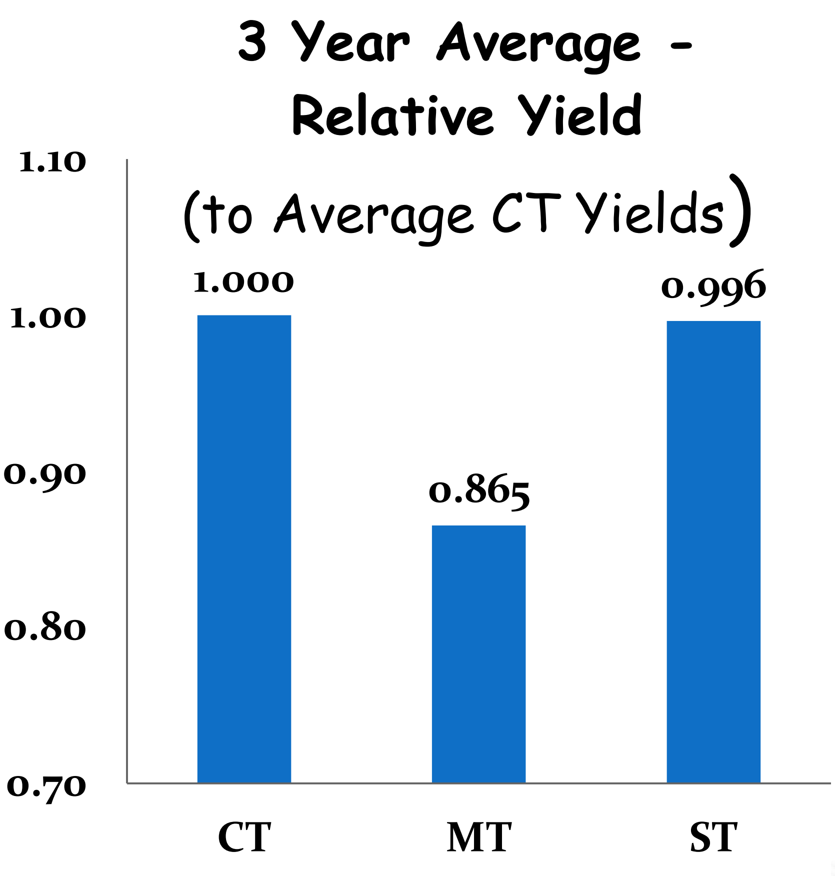
Nutrient Loads and Tillage

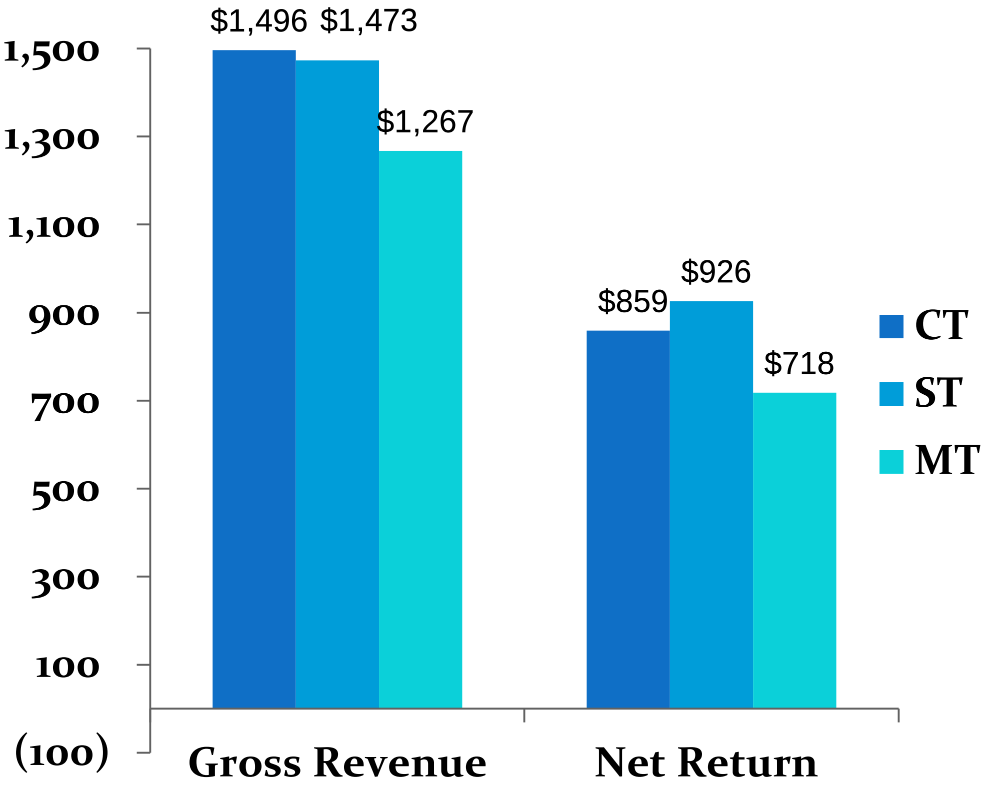




Bauder et al, 2013

Yield Comparisons





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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