Soil Change and Soil Quality Indicators on Rangelands

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How soils change through time:

"Soils are formed by pedogenesis, affected by land-use history, and are currently changing in modern ecosystems that have increasing human influence."

Richter and Markowitz. 2001, Understanding Soil Change.

Outline

- Soil change
  - Time scales, resistance, resilience, rates of change, processes, and function
- Indicators for assessing and monitoring soil function
  - Plant-soil-management interactions, disturbances
- Organizing knowledge about soil change
  - State and transition models
- Soil Survey and soil change
  - Dynamic soil properties

Soil Change - Cause and Effect

Cause	Effect
Change in solar radiation	Patterns of change
Natural events (earthquakes, drought)	Natural perturbations
Use and management (disturbance regime)	Management-induced perturbations

Temporal Scales of Soil Change

Millennia

Entisol

Petroargid

Centuries

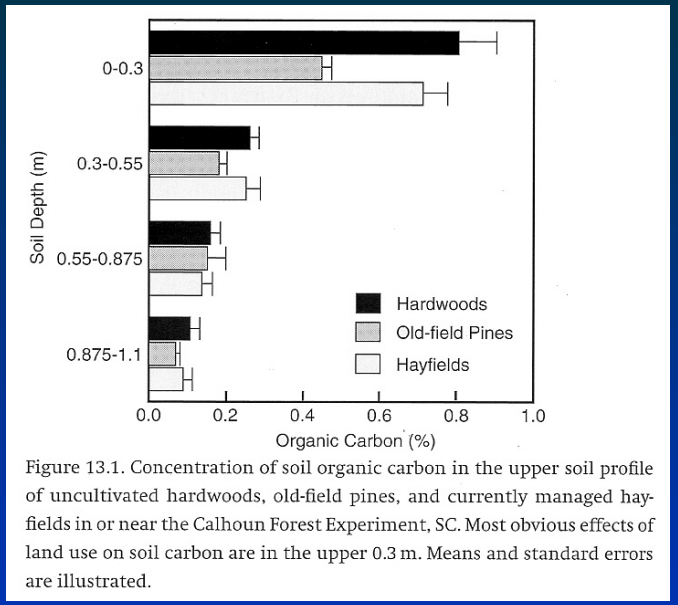
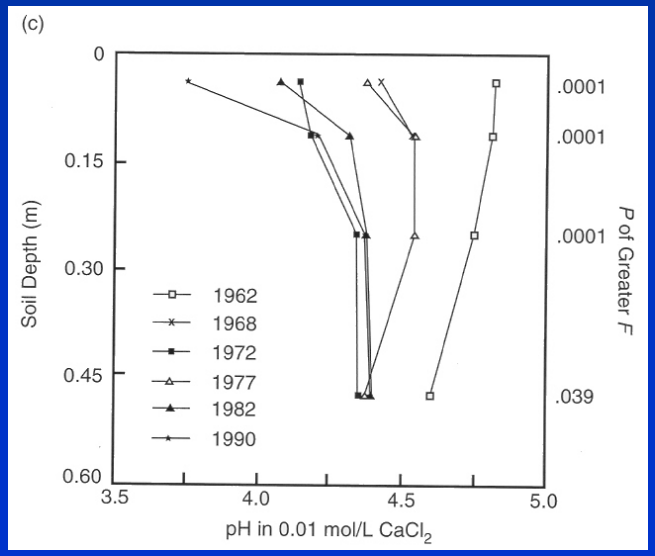


Figure 13.1. Concentration of soil organic carbon in the upper soil profile of uncultivated hardwoods, old-field pines, and currently managed hayfields in or near the Calhoun Forest Experiment, SC. Most obvious effects of land use on soil carbon are in the upper 0.3 m. Means and standard errors are illustrated.

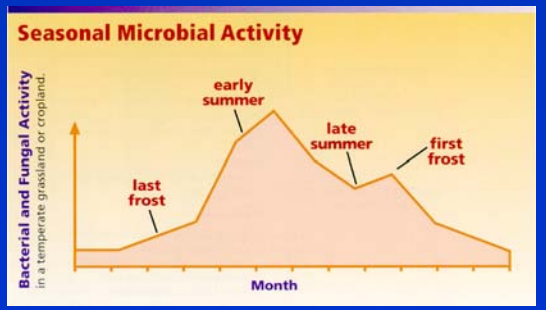
Richter and Markewitz, 2001

Decades

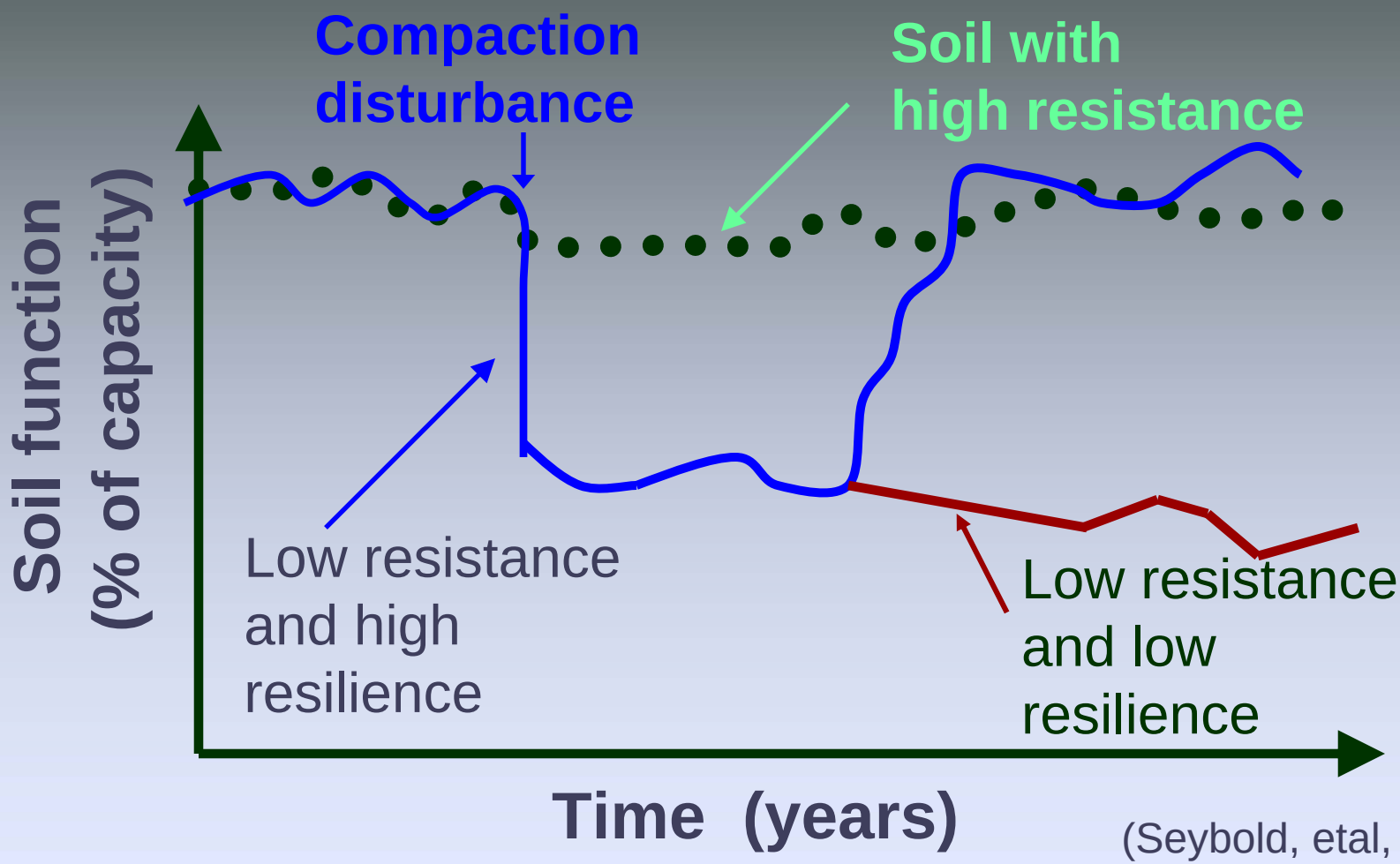
Richter and Markewitz, 2001



Yearly, Seasonally, Daily



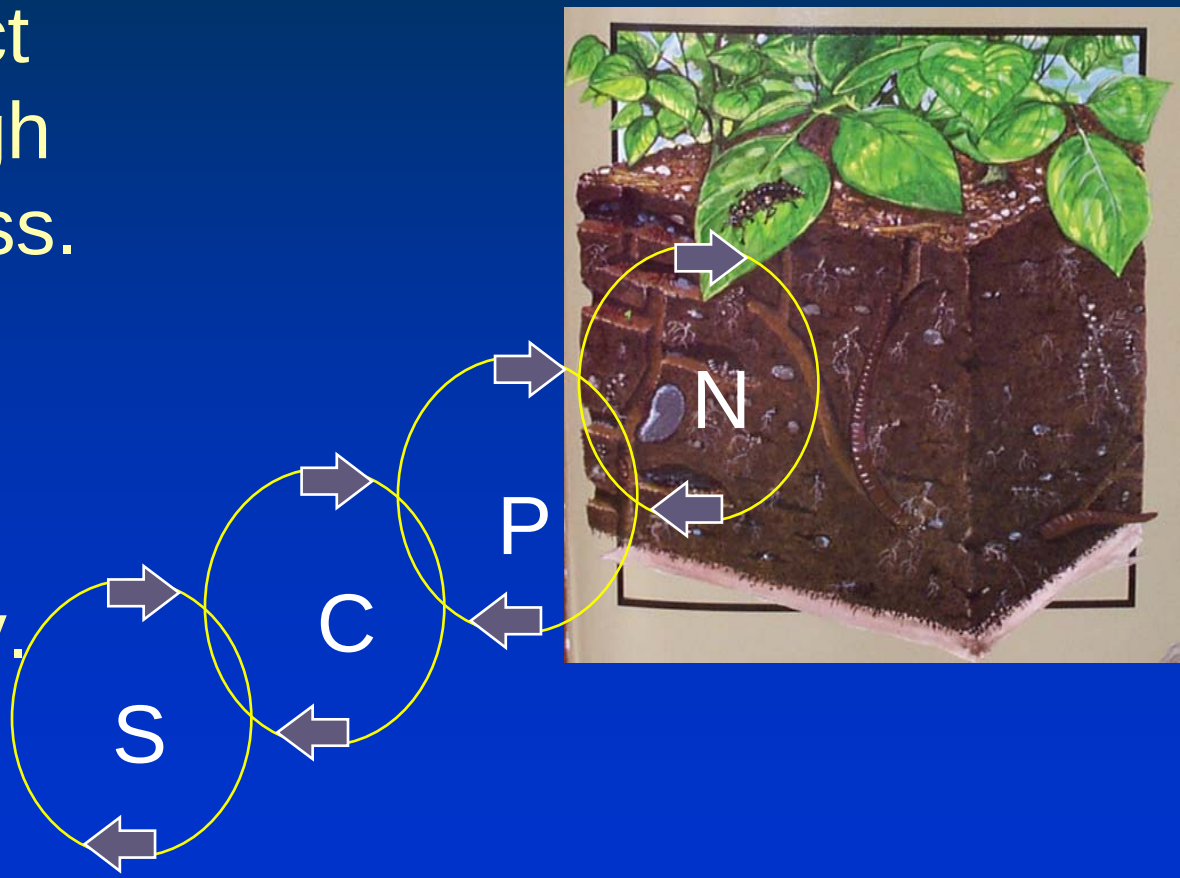
Resistance, Resilience, Thresholds and Rate of Change



(Seybold, etal, 1999)

Change in the context of process and function

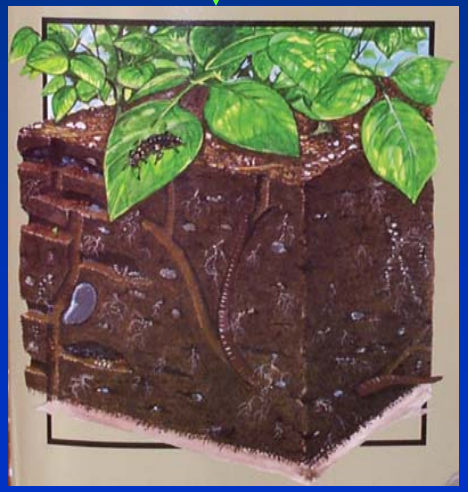
- The importance of change is its affect on function through changes in process.
- We need to understand, but cannot measure processes directly.



Linking pedology, ecology and soil function

- Pedogenic processes
  - **Inputs**
  - **Translocations**
  - **Transformations**
  - **Removal processes**

- Ecological processes
  - energy capture and flow
  - hydrologic cycle
  - nutrient cycling



Soil function

Capacity to Function

Rangeland health

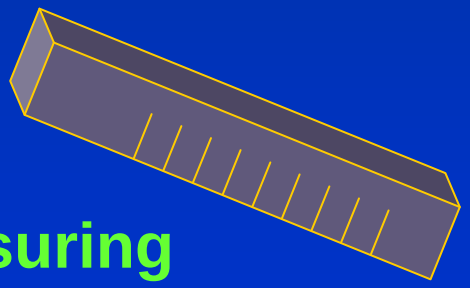
- Soil and site stability
- Hydrologic function
- Biotic integrity

Soil quality

- Maintaining biodiversity and productivity
- Partitioning water and solute flow
- Filtering and buffering
- Nutrient cycling
- Structural support

Indicators for assessing and monitoring soil function

How do we evaluate function?



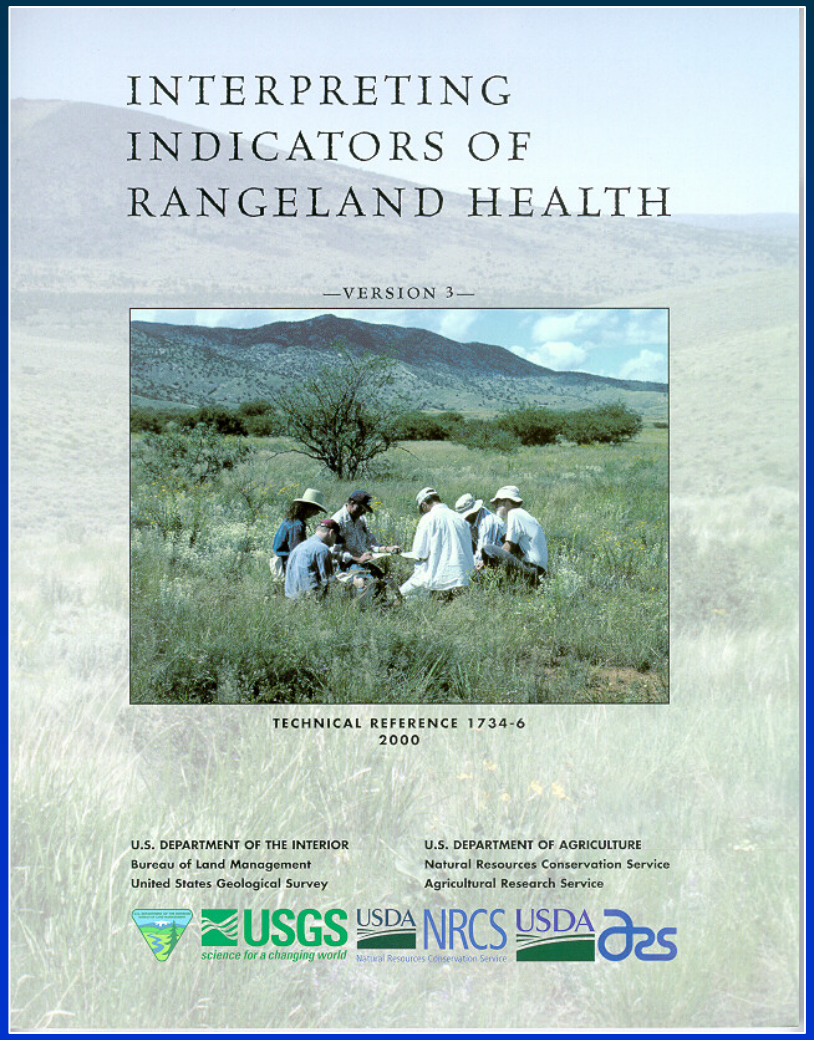
Measuring stick

What is an indicator?

- A key soil (or plant) property that is sensitive to change.
  - physical, biological or chemical properties
  - soil surface features
  - patterns and variability
- Reflects complex ecosystem process that are too difficult or costly to measure.
- Provides information about the current status of rangeland ecosystems.

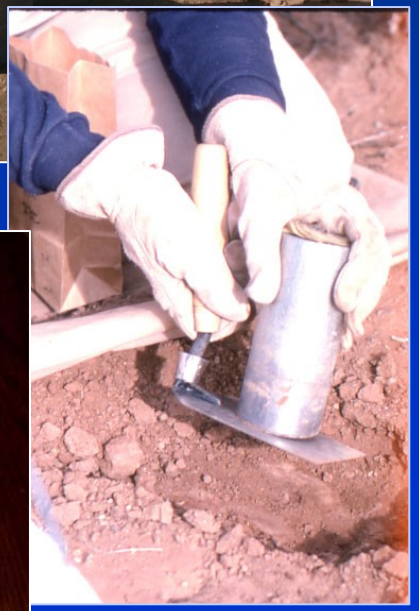
Qualitative

Assessment



Quantitative

Assessment and monitoring



Rangeland Health Indicators

17 Qualitative measures

- Rills
- Water Flow Patterns
- Pedestal/Terracette
- Bare Ground
- Gullies
- Wind Scour Areas
- Litter Movement
- Resistance to Erosion
- Loss of Soil Surface
- Plant/Infiltration Effects
- Compaction Layer
- Functional/Structural Groups
- Plant Mortality/Decadence
- Litter Amount
- Annual Production
- Invasive Plants
- Reproductive Capability

Soil Quality Indicators increase the value and accuracy of rangeland assessments and monitoring

- Quantitative measures are less subjective.
- Provide additional information below the surface.

Information sheets

USDA NRCS Natural Resources Conservation Service

Rangeland Sheet 1

Soil Quality Information Sheet

Rangeland Soil Quality—Introduction

USDA, Natural Resources Conservation Service May 2001

What is rangeland?

Rangeland is land on which the native vegetation is predominantly grasses, grasslike plants, forbs, or shrubs. This land includes natural grasslands, savannas, shrub lands, most deserts, tundras, areas of alpine communities, coastal marshes, and wet meadows.

What is rangeland health?

Rangeland health is the degree to which the integrity of the soil, the vegetation, the water, and the air as well as the ecological processes of the rangeland ecosystem are balanced and sustained.

What is soil?

Soil is a dynamic resource that supports plants. It consists of mineral particles of different sizes (sand, silt, and clay), organic matter, and numerous species of living organisms. Soil has biological, chemical, and physical properties, some of which change in response to how the soil is managed. The kind of soil is defined by the inherent soil properties that do not readily change in response to management.

What is soil quality?

Soil quality is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, sustain plant and animal productivity, maintain or enhance the quality of water and air, and support human health and habitation.

What does soil quality affect on rangeland?

- Plant production, reproduction, and mortality
- Erosion
- Water yields and water quality
- Wildlife habitat
- Carbon sequestration
- Vegetation changes
- Establishment and growth of invasive plants
- Rangeland health

How are soil quality and rangelan health related?

Rangeland health and soil quality are interdependent. Rangeland health is characterized by the functioning of both the soil and the plant communities. The capacity of the soil to function affects ecological processes, including the capture, storage, and redistribution of water; the growth of plants and the cycling of plant nutrients. For example, increased physical crusting decreases the infiltration capacity of the soil and thus the amount of water available to plants. As the availability of water decreases, plant production declines, some plant species may disappear, and the less desirable species may increase in abundance. Changes in vegetation may precede or follow changes in soil properties and processes. Significant shifts in vegetation generally are associated with changes in soil properties and processes and/or the redistribution of soil resources across the landscape. In some cases, such as accelerated erosion resulting in a change in the soil profile, this shift may be irreversible, while in others, recovery is possible.

Why is soil quality important?

Changes in soil quality that occur as a result of management affect:

- the amount of water from rainfall and snowmelt that is available for plant growth;
- runoff, water infiltration, and the potential for erosion;
- the availability of nutrients for plant growth;

Rangeland Sheet 2

Soil Quality Information Sheet

Rangeland Soil Quality— Indicators for Assessment and Monitoring

USDA, Natural Resources Conservation Service May 2001

What are indicators?

Indicators are key soil or plant community characteristics that are sensitive to change in the environment. They reflect complex ecosystem processes that are too difficult or expensive to be measured directly. They provide information about the current status of rangeland ecosystems. Trends from indicators measured regularly provide clues about the response of the system to management. Soil quality indicators complement vegetation indicators and may be qualitative or quantitative.

What soil quality indicators are used on rangeland?

Soil properties.—Physical, biological, and chemical soil properties are included. Some properties, such as bulk density, reflect limitations to root growth, seedling emergence, and water infiltration. Other properties, such as the diversity and activity of soil biota, reflect the availability of both water and nutrients to plants. Soil organic matter and soil aggregate stability reflect a combination of physical, biological, and chemical processes.

Soil surface features.—Pedestals, exposed plant roots, rills, gullies, wind scours, and soil deposition reflect such processes as runoff and erosion. These indicators are commonly assessed qualitatively.

Spatial patterns and variability.—The distribution and cycling of water and nutrients in rangeland soils are affected over both short and long distances by such processes as erosion and deposition. The kinds, amounts, and spatial distribution of living plants and decaying residue on the soil also affect nutrients and water. Accordingly, as the distribution of soil organic matter becomes less uniform, resource availability declines in some patches and increases in others.

The following qualitative assessment indicators and the attributes they reflect are from *Interpreting Indicators of Rangeland Health*, Version 3, 2000, TR 1734-6, BLM (http://www.truckee.usda.gov/sq/):

Rangeland health indicator	Soil/site stability	Hydrologic function	Biotic integrity
1. Rills	X	X	
2. Water flow patterns	X	X	
3. Pedestals and/or terracettes		X	
4. Bare ground	X	X	
5. Gullies	X	X	
6. Wind-scoured areas	X	X	
7. Litter movement		X	X
8. Soil surface resistance to erosion	X	X	X
9. Soil surface loss or degradation	X	X	
10. Plant community composition and distribution relative to infiltration and runoff	X	X	X
11. Compaction layer			X
12. Functional/structural groups			X
13. Plant mortality/decadence		X	X
14. Litter amount			X
15. Annual production			X
16. Invasive plants			X
17. Reproductive capability of perennial plants			X

SOM - What is it?

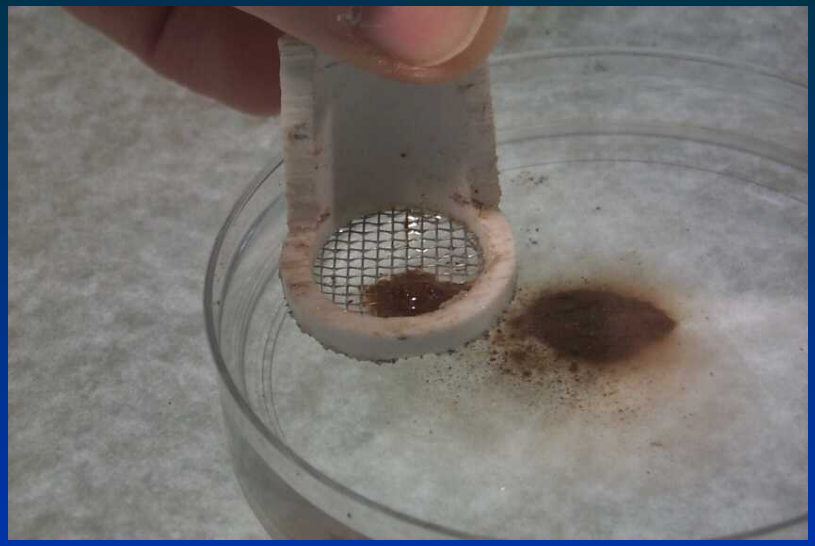
Carbon-rich material from plants, animals and soil microbes in various stages of decomposition

Short term

Long term

Soil Organic Matter		
TYPE	**RATE OF DECAY**	**FUNCTION**
Light fraction	Weeks to months	• Serves as food for soil organisms • Stores and provides plant nutrients
Physically protected	Decades	• Enhances soil structure and porosity and water holding capacity
Chemically stable	Hundreds to thousands of years	• Hold nutrients • Stabilizes micro-aggregates • Gives soil its dark color

Why is it important?



- Stable aggregates
  - resist erosion
  - reduce crusting
  - increase infiltration
  - hold more water
  - provide pores for growth
  - physically protect organic matter
- Changes may serve as early indicators of recovery or degradation.

What effects it?

- Environmental factors
- Soil properties
- Vegetation, roots
- Soil organisms
- Disturbances
  - Wind and water erosion
  - Grazing and traffic
  - Fire, absence of fire
  - Invasive weeds, shrub encroachment
  - Shrub removal

Disturbance effects on infiltration (min/in)

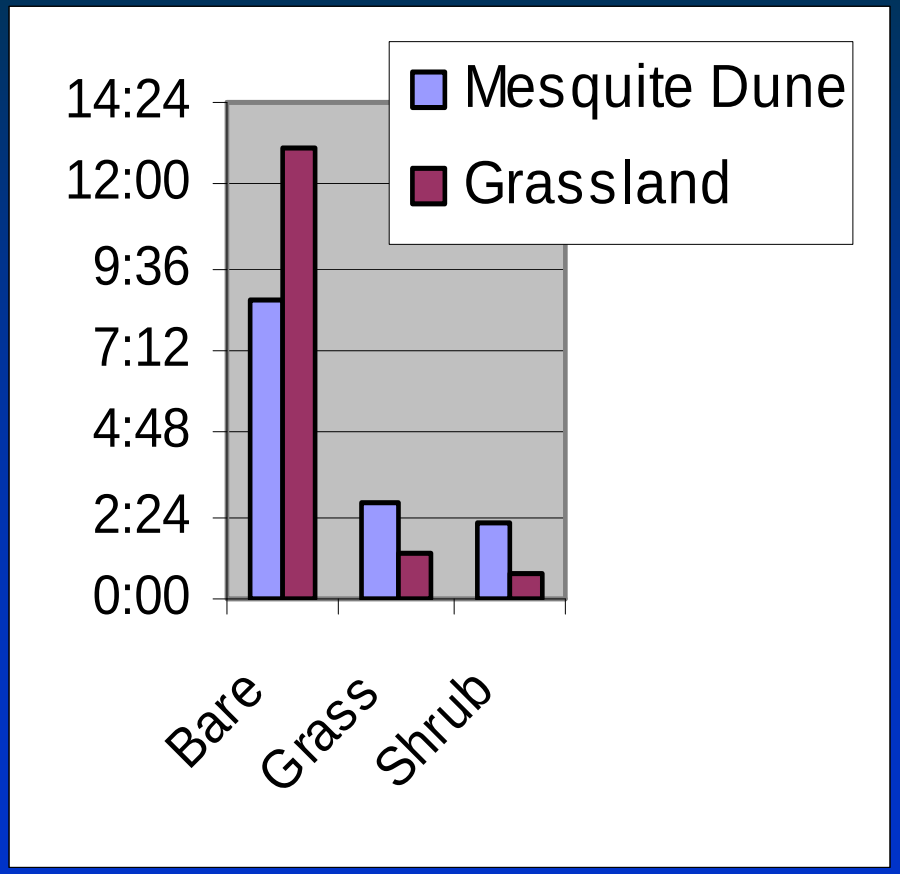
Heavy grazing + drought

↓

Mesquite establishment and increase

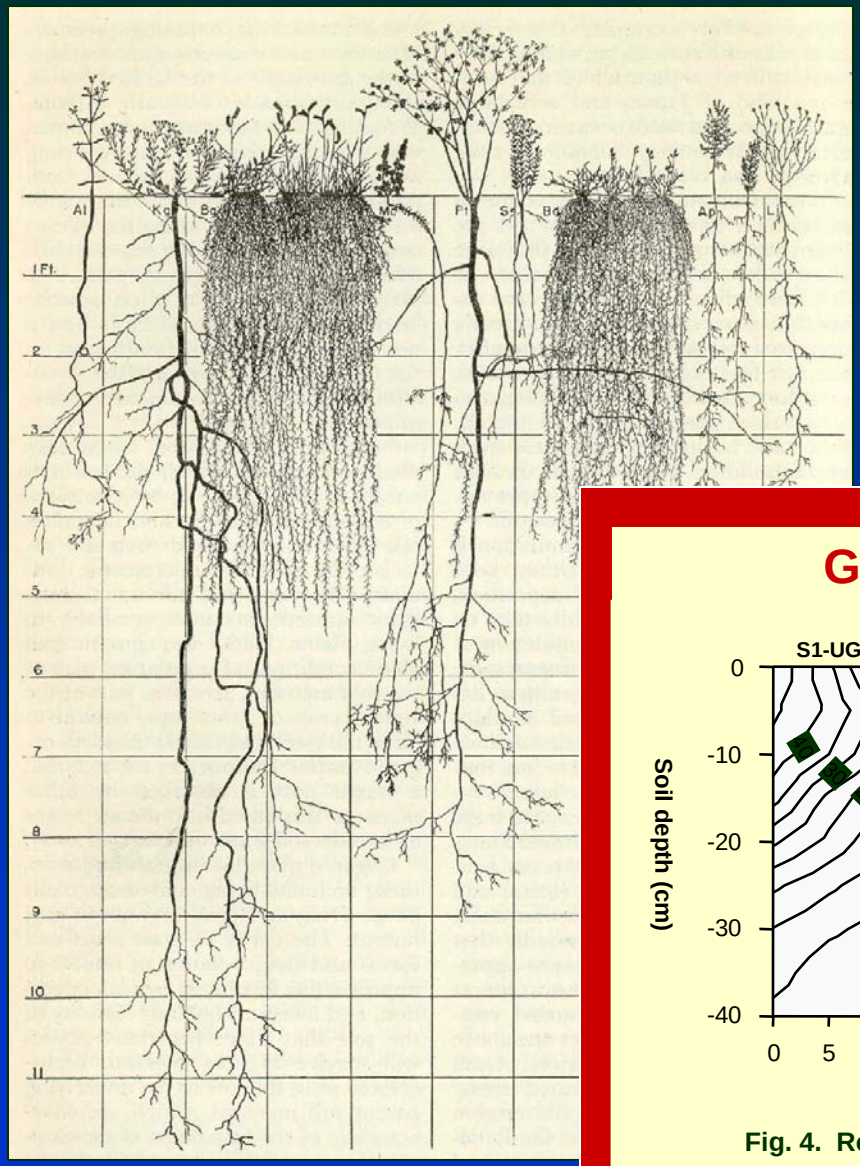
↓

Redistribution of resources, decrease in grass and increase in erosion



Herrick, etal, 1999

Soil-plant-management interactions



- Roots are primary source of SOM in grassland soils

Norfolk, et. al. 2001

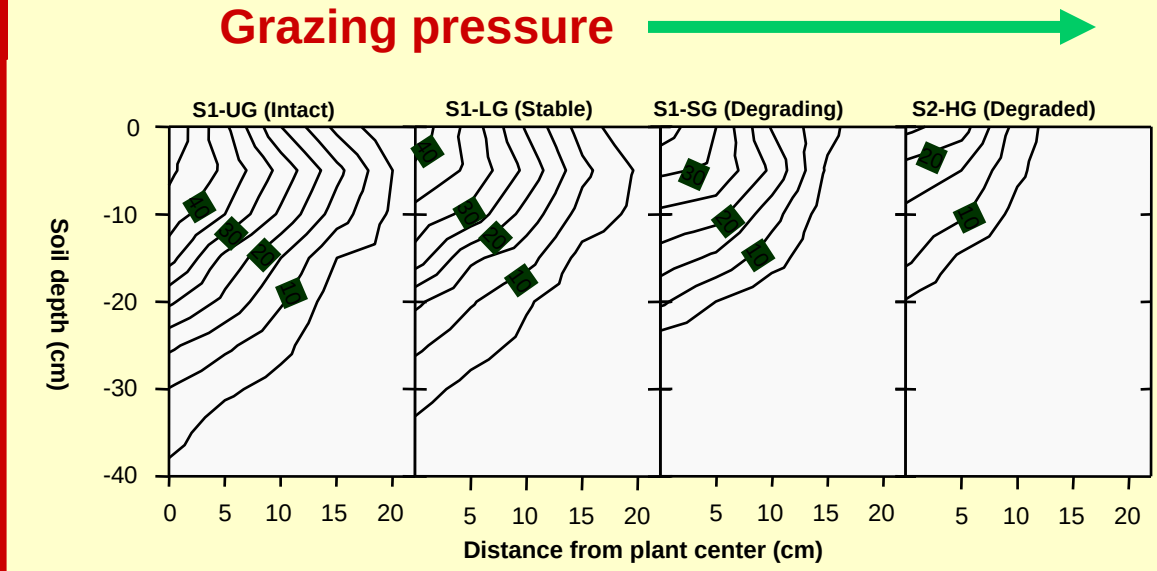


Fig. 4. Root distributions (mm^2/cm^3 soil) within soils of tropical tallgrass sites in response to accumulated grazing pressure.

Information sheets

- **Aggregate stability**
- **Compaction**
- **Infiltration**
- **Organic matter**
- **Physical and biological crusts**
- **Soil biota**
- **Water erosion**
- **Wind erosion**

Rangeland Sheet 6

Soil Quality Information Sheet

Rangeland Soil Quality—**Organic Matter**

USDA, Natural Resources Conservation Service **May 2001**

What is soil organic matter?

Soil organic matter is carbon-rich material that includes plant, animal, and microbial residue in various stages of decomposition. Live soil organisms and plant roots are part of the carbon pool in soil but are not considered soil organic matter until they die and begin to decay.

The quantity and composition of soil organic matter vary significantly among major ecosystems. Soil in arid, semiarid, and hot, humid regions commonly has less organic matter than soil in other environments. The total content of organic matter ranges from less than 0.5 to more than 8 percent in the surface layer of rangeland soils.

Soil organic matter includes three main components (table 1). The **light fraction** is more biologically active than the other two and includes relatively fresh plant fragments. **Physically protected** organic matter is locked within aggregates of mineral particles, where it is protected from microbial decomposition. **Chemically stable** organic matter gives soil its dark color and is generally the largest pool of organic matter in soil. Physically protected organic matter may also be chemically stable.

Table 1.—Soil organic matter

Component	Rate of	Primary function

Organic mattter darkens and stabilizes the surface layer in soils.

- enhances soil fertility and plant productivity by improving the ability of the soil to store and supply nutrients, water, and air;
- provides habitat and food for soil organisms;
- sequesters carbon from the atmosphere;

- What is it?
- Why is it important?
- How is it measured?
- What affects it?
- Management strategies

Management strategies to improve the indicator (function)

- Maintain or increase vegetation and litter cover.
- Decrease the number and size of bare patches.
- Promote the growth of species with high root biomass.
- Include a mix of species with different rooting depths and patterns.

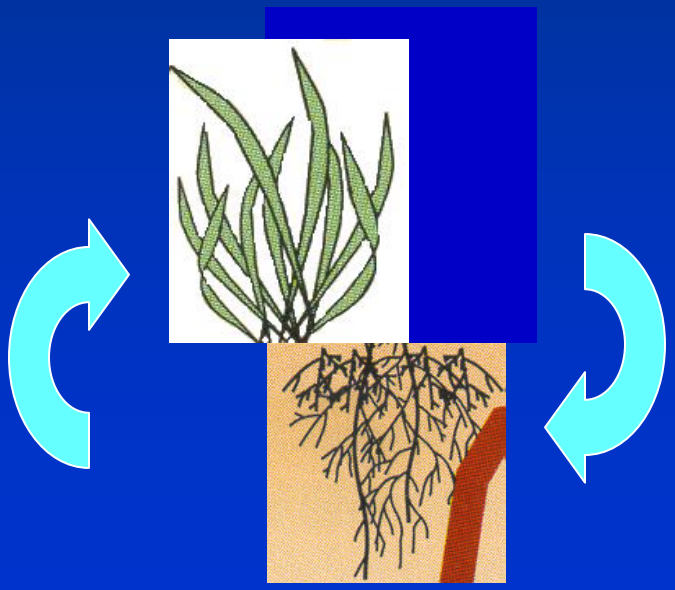
Management strategies

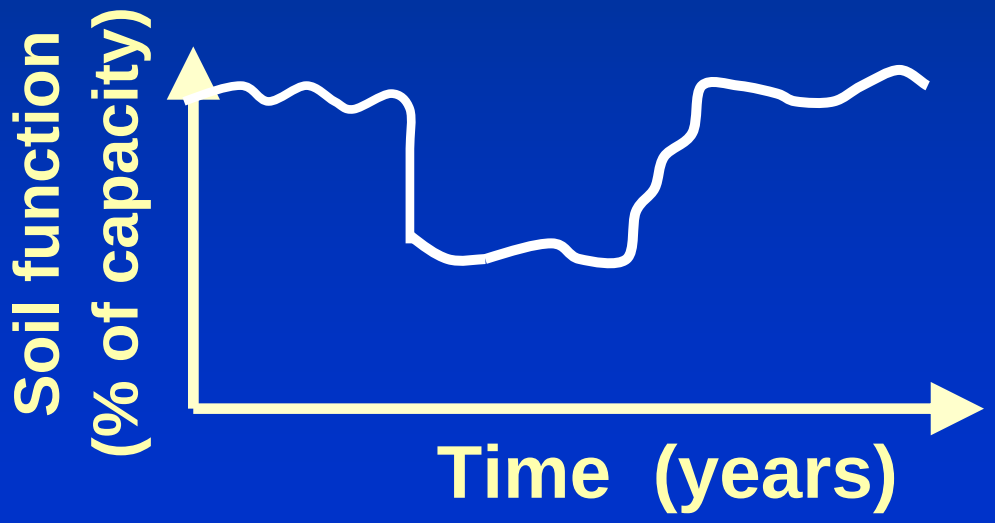
- Reduce soil surface disturbance, especially in arid and sandy areas.
- Use prescribed burning appropriately to prevent fuel build-up.

Organizing knowledge about soil change

How do we present information on processes, soil properties and function?

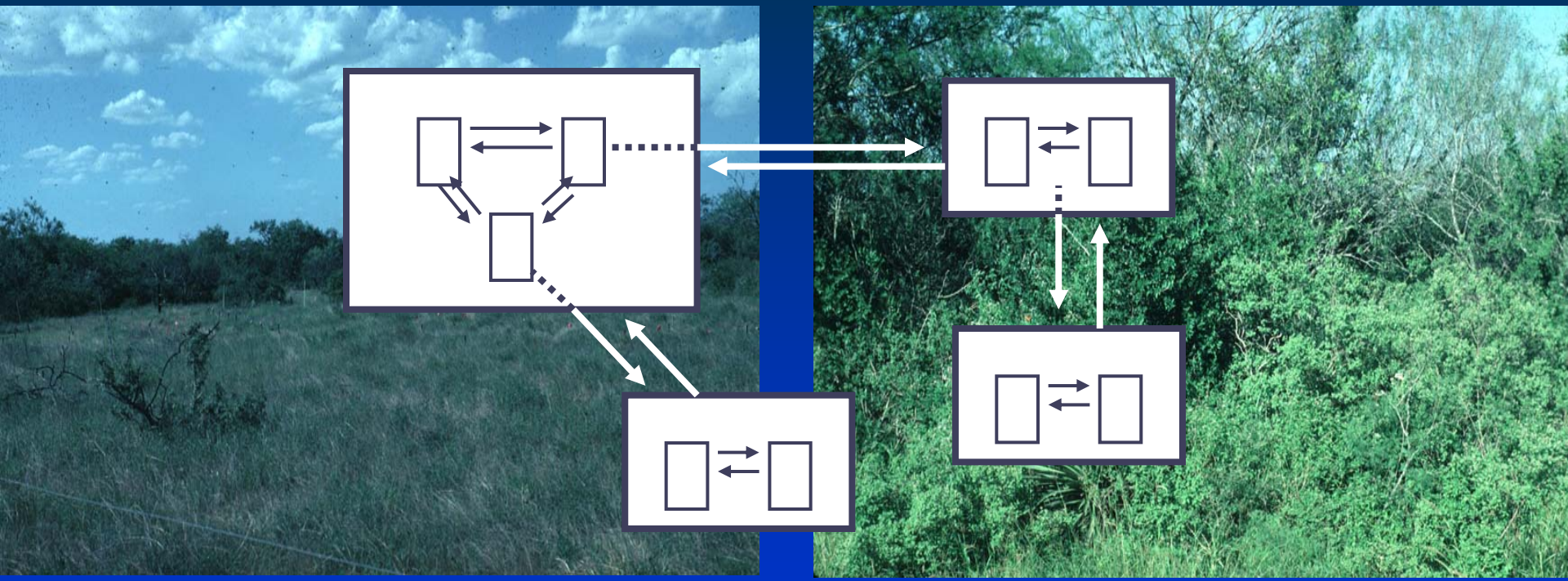
Disturbances and uncoupling of the soil-plant relationship are important keys to predicting plant and soil dynamics and change in function.





State and Transition Ecological Model

Westoby, et. al., 1989
Stringham et.al., 2001



Concept model for predicting vegetation dynamics

What the **S&T Model** provides.

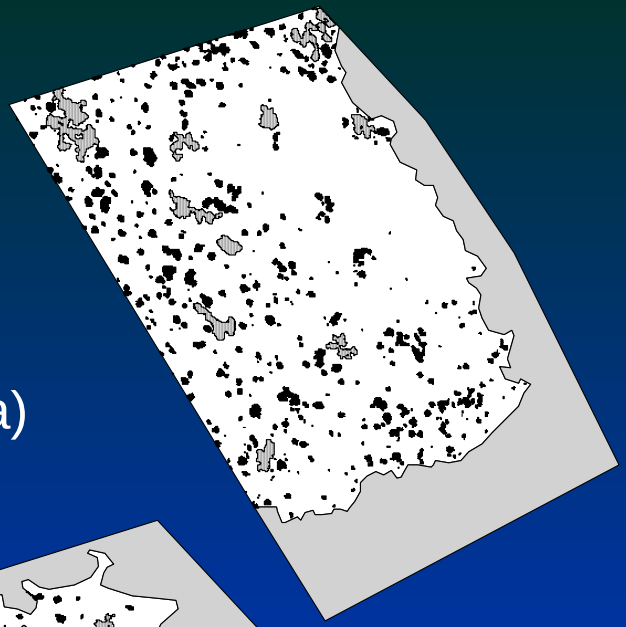
Integrates soil-plant-management interactions

1. Potential: historic climax community, **states** and plant communities
2. Drivers of change: **transitions**, community pathways (disturbances, stresses, practices and natural events)
3. Boundary of change in process: **thresholds for resistance and resilience, early warning indicators**

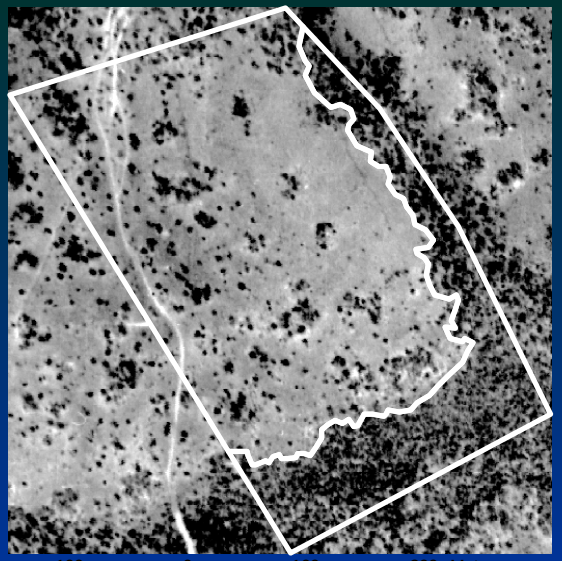
What the **S&T model** provides

4. Temporal scale: management time-scale
5. Spatial scale: ecological site (a grouping of soil map units – functional edaphic unit)

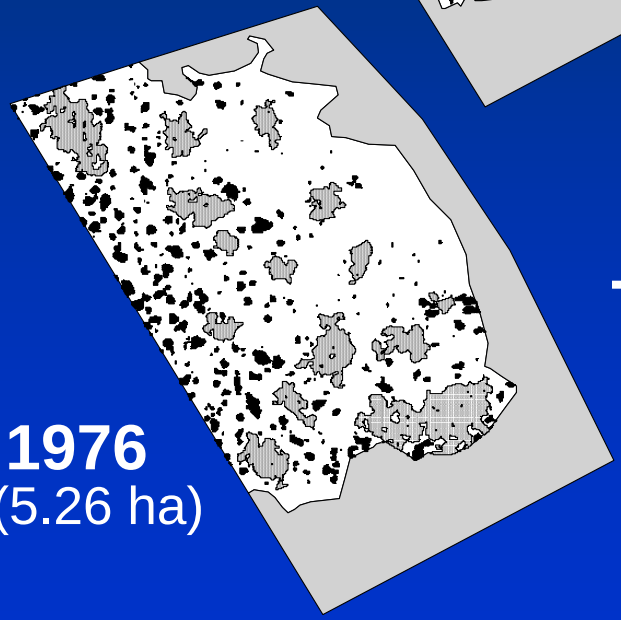
La Copita, TX example



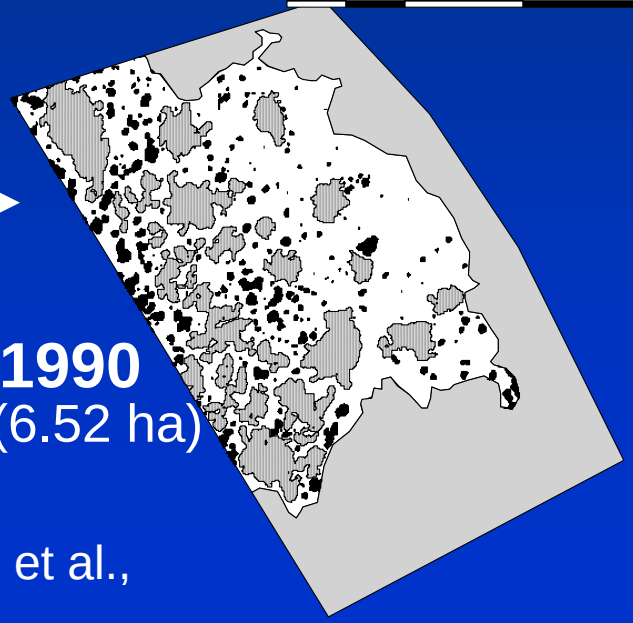
1950
(3.59 ha)



1950



1976
(5.26 ha)



1990
(6.52 ha)

Woodland

Groves

Clusters

Herbaceous

Archer, et al., 2001

La Copita, TX

Soil properties for Runge fine sandy loam

ESD: Sandy loam 83c

	C % (0-10 cm)	Bulk Density (gm/cm3)
NASIS	1.0-2.0	1.30-1.55
State 1; A – Tall and mid-grass	1.2 *	Assume 1.1
State 1; C – Short grasses and annuals	0.84	1.4
State 2; D – Clusters and mesquite groves	2.2	1.1

Threshold

* Derived from Century model simulation. (Hibbard 1995; Archer et al. 2001)

Soil survey and soil change on rangelands

- Soil data needs for interpretation
- Integrating dynamic and inherent soil properties
- What's next?

Interpret and Predict

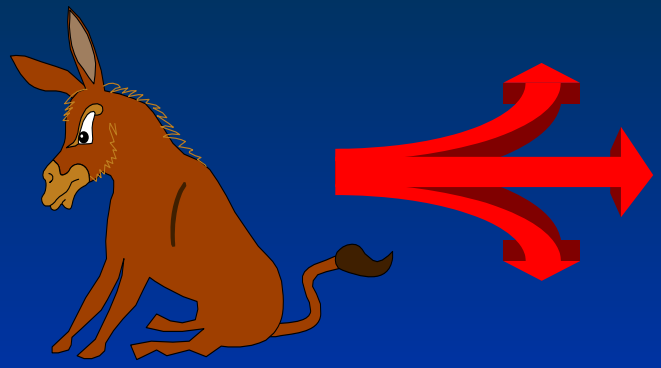
A rancher makes a rangeland health assessment and finds a compaction problem.

Soil data needs for S&T Model

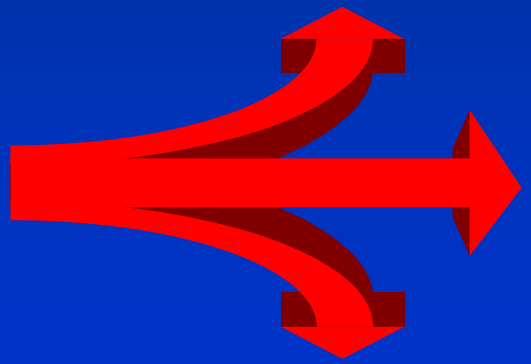
Quality criteria or reference value for plant community	➔ What should it be? Is 1.4; should be 1.1, NASIS: 1.30-1.55
Transitions for STM (drivers of change, management regime)	➔ What will it take to get it there?
Thresholds, resilience and rate of change	➔ Will it return and how long will it take to get it there?

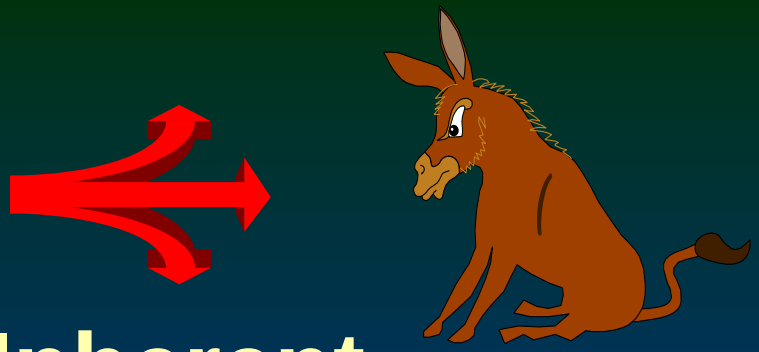
Need to integrate inherent and dynamic soil properties with state and transition models

- **Inherent soil features:**
  "Static" and dynamic



- **Dynamic soil properties: Susceptible to change on the management time scale**



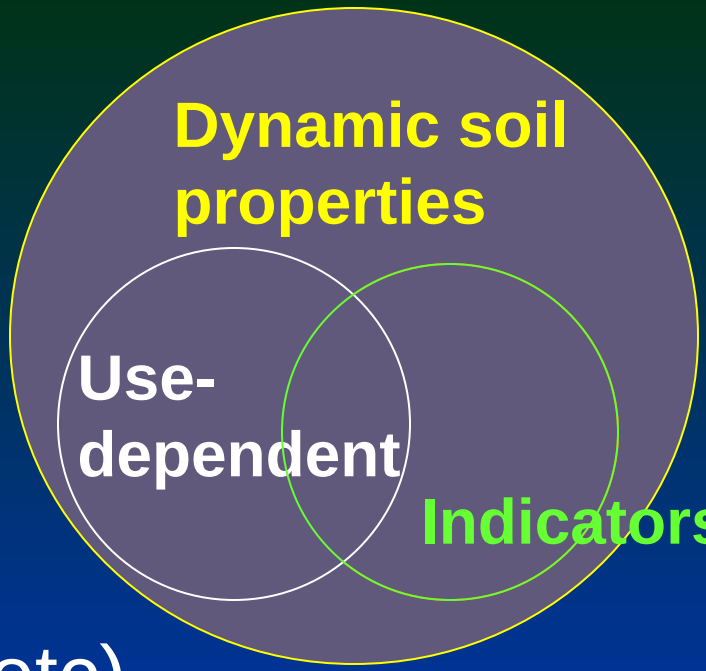


Inherent -

Result of soil formation; used to make a soil survey.

- texture
- mineralogy
- horizon sequence
- soil depth
- slope
- hourly soil temperature
- seasonal pH cycle

Dynamic soil properties



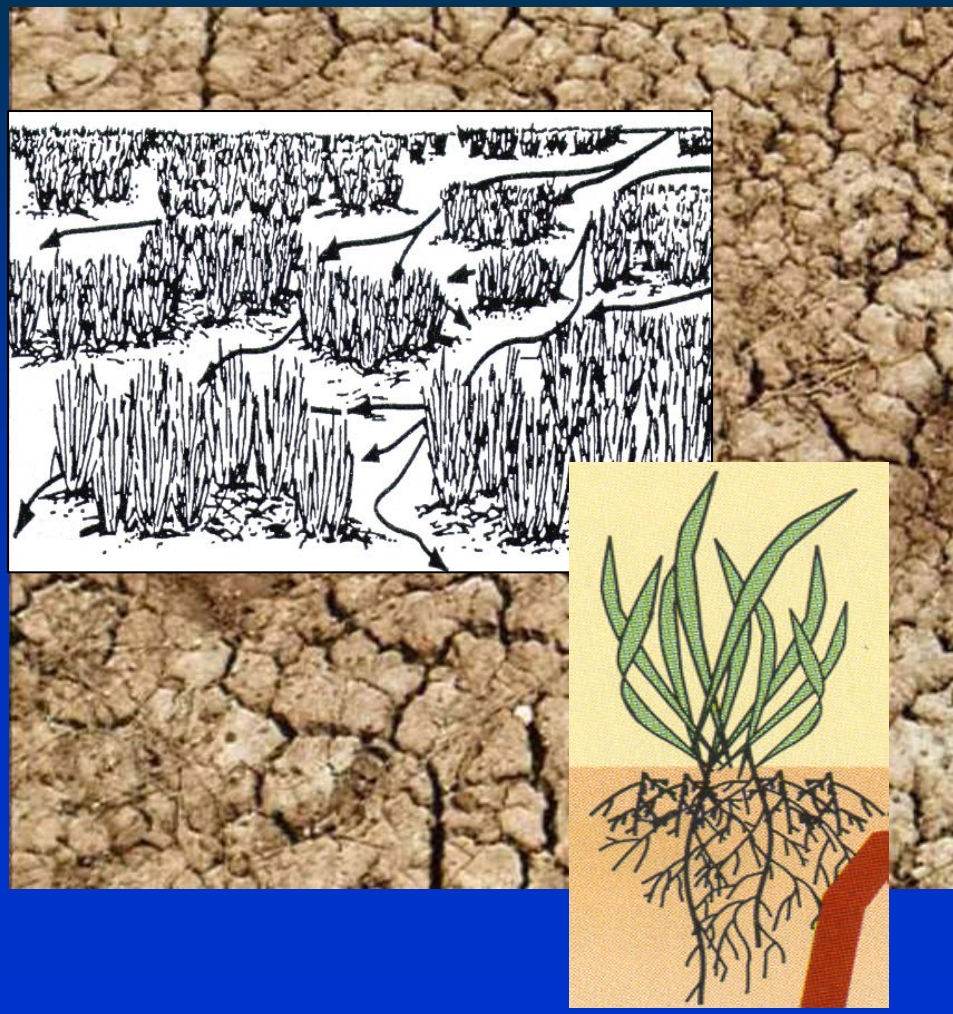
All temporal soil properties; includes changes due to management, natural disturbances (drought, flood, etc), and natural cycles (seasonal, daily, etc); includes use-dependent soil properties.

(Relevant to human time scales)

Indicators: properties that change in response to management, climate or both and reflect current functional status.

What's next?

- Test soil dynamics in State and Transition Models.
- Learn to interpret soil response.
- Develop measurement methods for dynamic properties.
  - **What, where, how many, how deep?**
- Think "soil behavior."



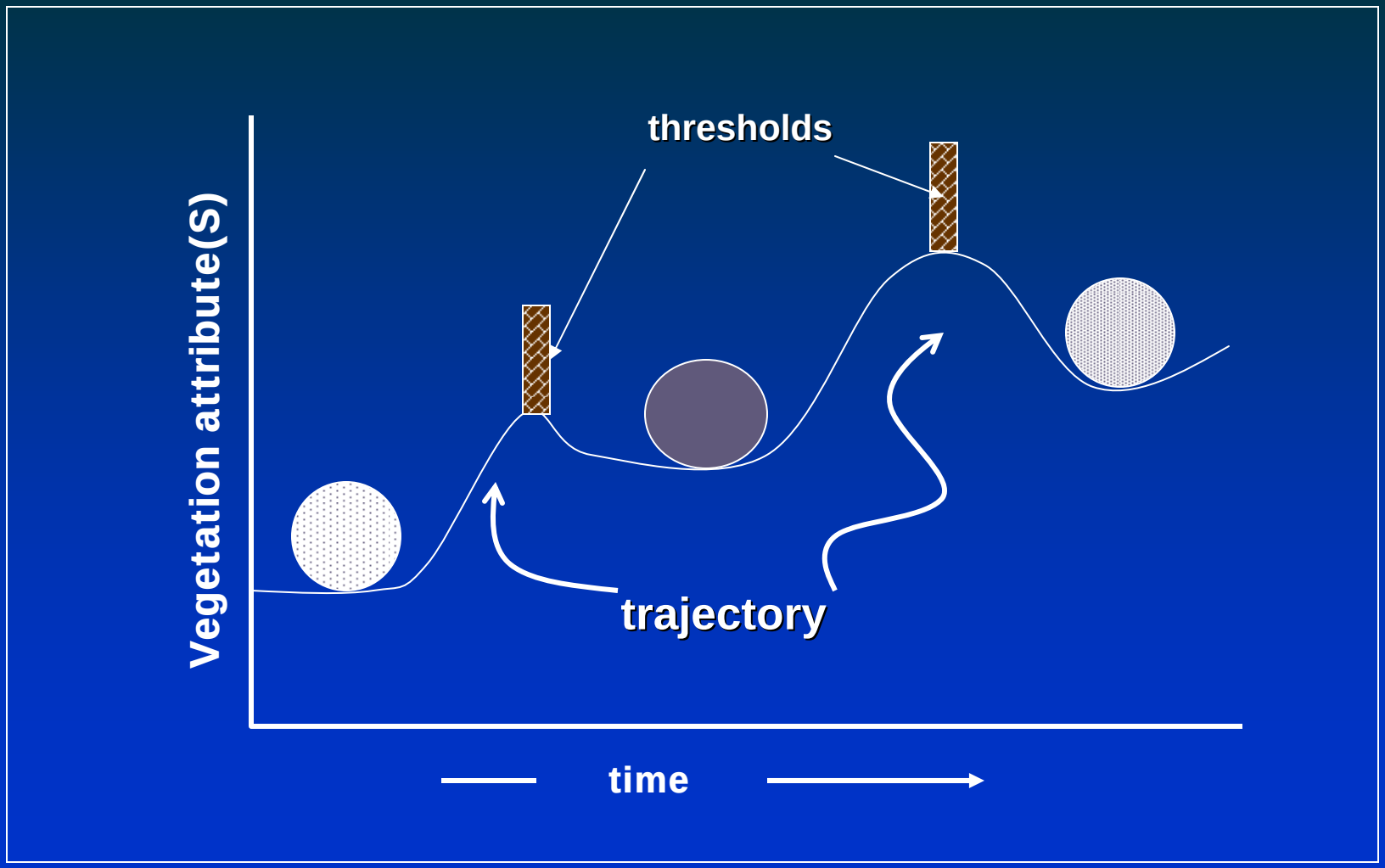
- Rangeland soil quality information sheets
  - SQ Institute website http://www.statlab.iastate.edu/survey/SQI/
- Interpreting Indicators of Rangeland Health, ver 3. Pellant, M. et.al., 2000. Tech. Ref. 1734-6.
  - http://www.blm.gov/nstc/library/techref.htm
- Understanding Soil Change. 2001. Richter and Markowitz.
- States, transitions, and thresholds: Further refinement for rangeland applications. Stringham et al, 2001.
  - http://www.ftw.nrcs.usda.gov/glti/pubs.html
- Dynamic Soil Properties Symposium, SSSA, Nov. 11, 2002, Indianapolis.

Soil dynamics

- Dynamics: “The pattern of change or growth of an object; variation and contrast in force or energy.”

- Soil Dynamics: The pattern of change in soil resulting from changes in energy or forces applied to soil.

THRESHOLDS



Questions to be covered

- How are rangeland health and SQ related?
- What makes a good indicator?
- What is the most important soil-plant interaction?
- What affects the capacity of soil to function on rangelands?
- How do we document soil dynamics on rangelands?