Agricultural systems research: An introduction

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Overview

• Why use a systems approach?
• Defining the system– some useful concepts
• Examples: Management and experimental design
• Concept mapping: A key tool for developing a research project
Systems approach to research

- System to be studied is defined
- Multiple components and their interactions are identified
- Scale—varies from large plots to whole farm, farmer network, community, watershed, food system
- Time frame—also varies, years to several decades, depending on processes to be studied
- Can involve multiple disciplines
Why use system based approaches?

• We need to understand mechanisms regulating ecological processes within farms/fields in order to optimize ecological management

• Assess agroecosystem-scale function (consequences of management systems beyond yield)

• Identify trade-offs and synergies among management options or enterprises

• New discoveries and novel solutions
Systems approaches are well-suited to support the transition to sustainable agriculture

- Allows for consideration of multiple goals
- Combine expertise from multiple disciplines and functions
- Can cope with interactions and harness reinforcing feedbacks
- Flexible—scale and time frame are determined by the research goal
Defining the system
Useful concepts from ecology for organizing research questions

• Ecosystems are composed of nested sub-systems
• Sub-systems can be defined to emphasize a variety of properties: biotic units, trophic levels, spatial-temporal scales
• Use of space and time to define processes
• Agricultural systems are open systems
• Structure determines function
Nested ecosystem scales provide a mechanism for integrating across scales

Global ecosystem
- What is the contribution of agriculture to greenhouse gas emissions?

Watershed
- How does farm management influence N loss and water quality of a watershed?

Agroecosystem
- How do crop rotation and tillage influence N cycling?

Rhizosphere
- What controls decomposition in the rhizosphere?

Modified after Chapin et al., 2002
The concept of nested hierarchies applied to weed management

Successful ecological weed control requires integrating knowledge across all these levels—i.e. “Many little hammers” (Liebmann and Gallandt 1997)
Ecosystem Services
The benefits people obtain from ecosystems

ECOSYSTEM SERVICES

Provisioning
- Food
- Freshwater
- Wood and fiber
- Fuel
- ...

Supporting
- Nutrient cycling
- Soil formation
- Primary production
- ...

Regulating
- Climate regulation
- Flood regulation
- Disease regulation
- Water purification
- ...

Cultural
- Aesthetic
- Spiritual
- Educational
- Recreational
- ...

Millennium Ecosystem Assessment- www.millenniumassessment.org
Environmental, biotic and management characteristics drive ecosystem processes

AGROECOSYSTEM STRUCTURE

Physical environment-
Climate, soil type and typology, time

Biotic components-
Biodiversity, community composition, population assemblages

Management-
Plant species in space and time, tillage, inputs, harvest regime, spatial scale of fields, enterprise diversity

ECOSYSTEM SERVICES

Provisioning
- FOOD
- FRESHWATER
- WOOD AND FIBER
- FUEL
- ...

Supporting
- NUTRIENT CYCLING
- SOIL FORMATION
- PRIMARY PRODUCTION
- ...

Regulating
- CLIMATE REGULATION
- FLOOD REGULATION
- DISEASE REGULATION
- WATER PURIFICATION
- ...

Cultural
- AESTHETIC
- SPIRITUAL
- EDUCATIONAL
- RECREATIONAL
- ...

Millennium Ecosystem Assessment- www.millenniumassessment.org
Systems thinking in agricultural management and research
Organic agriculture: Example of a systems-based management approach

- Agroecosystem components and management practices serve multiple functions.
  - Cover crops fix nitrogen, build SOM and soil structure, scavenge nutrients, suppress weeds, reduce erosion, provide habitat for beneficial arthropods.

- Management strategies rely on many distinct practices/processes—“many little hammers” (Liebman and Gallandt. 1997).
  - Weed management relies on rotation, strategic use of tillage, weed suppressive cover crops, seed bed depletion via management and food web based mechanisms).
Problem: Insect pest

Traditional Approach: How to manage soybean aphid?

• Factorial experimentation
• Test specific management practices in small plots
• Series of short-term experiments
Problem: Insect pest

Systems Approach: What interactions within the agroecosystem impact soybean aphid?

• Interdisciplinary team
• Define the system, i.e. concept mapping, knowledge gaps
• Design appropriate research plan
Sites for agroecosystems research

- Simulated on-station cropping systems experiments
- Commercial farms
- Agricultural landscape (i.e. watershed)
Strengths of replicated systems experiments on field stations:

• Minimize confounding sources of variability

• Innovative, promising cropping systems can be included in the experiment

• Usually less costly

• CONTROL!!
Experimental design: systems + reductionist experimentation

Scientific understanding

Farmer knowledge

Interdisciplinary team: farmers, researchers, & extension educators

Conceptual model

Goals

Agroecosystems experiment

1. Current farmer systems
2. Innovative farmer systems
3. New collaboratively-designed systems

Reductionist experiments (microplots, laboratory studies)

Satellite trial 1

Satellite trial 2

Factorial design
Rodale Farming Systems Trial: Organic and conventional corn after two weeks of dry weather
Strengths of on-farm studies

• Realistic in terms of scale, management practice and constraints

• Allows for robust characterization of agroecosystems

• Broad questions about the role of management, environment or market forces can be asked

• Sites that are closer to a steady-state can be studied
N fixation rates in soybeans, red clover and field pea were compared across a fertility gradient.

Soil texture had a significant impact on N fixation rates, sometimes more important than soil N fertility.

Schipanski et al. 2010
Concept mapping

- Pictorial depiction of a system
- Useful tool for defining a system
- Facilitate cross-disciplinary understanding
Concept mapping as a project development and communication tool
Figure 1
Socioeconomic Systems

Worlds of Practice

Dominant economic-technical regime, Professional practice

Farm Management

ΔN loading of
Farm Management

ΔN loading of surface and ground waters & greenhouse gases

Δ SON storage, N leaching, denitrification

Ecosystem Trajectory:
Change in fluxes & pools, Shift to non-steady state

Resource Management

Evolution of Public Policy & Development Trajectory:
Enterprise strategy, Paradigm Δ

Investment targets, Land-use, Research policy

Empirical Observation and Measurement

Local farm-scale biophysical attributes

Regional environment: soil type & climate→productive capacity, biochemochemistry

Biophysical Systems

Learning, Adaptation & Resource Reallocation

Development Trajectory:
Evolution of Public Policy & Knowledge

A

Environmental Change
Interactions across spatial scales: The case of rock P management

Background ecosystem characteristics

Climate and soil type

Field-scale

Addition of soil amendments

Selection of plant species

Solubilization of P

Soil microsites

Bacteria, fungi

Plant productivity, root exudates

Plant
A conceptual model should:

• Describe a system that encompasses the research questions but has clear boundaries

• Explicitly define the components of the system and how they interact with one another

• Provide a logical framework for the research questions to be addressed

• Be developed and agreed upon by all collaborators. Each person should be able to find their particular subsystem or area of expertise in the model

• Be simple enough to be understood by reviewers, stakeholders, potential funders

Heemskerk et al. 2003 Conservation Biology
Summary

• Systems thinking requires a paradigm shift, a re-assessment of the way we view agroecosystems

• There are many resources to draw from in the ecology literature, sustainability science, business world

• Need to apply a consistent framework to develop general principles and agroecosystem assessment methods

• Collaborative, systems projects benefit from structure: Follow a logical progression, set boundaries, use concept mapping

THANK-YOU!