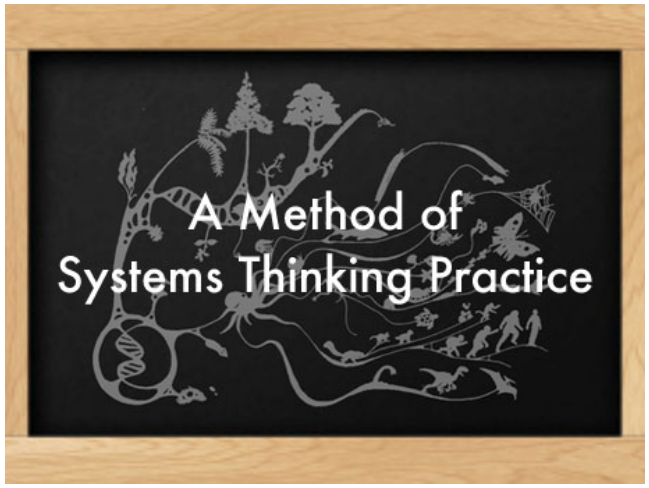
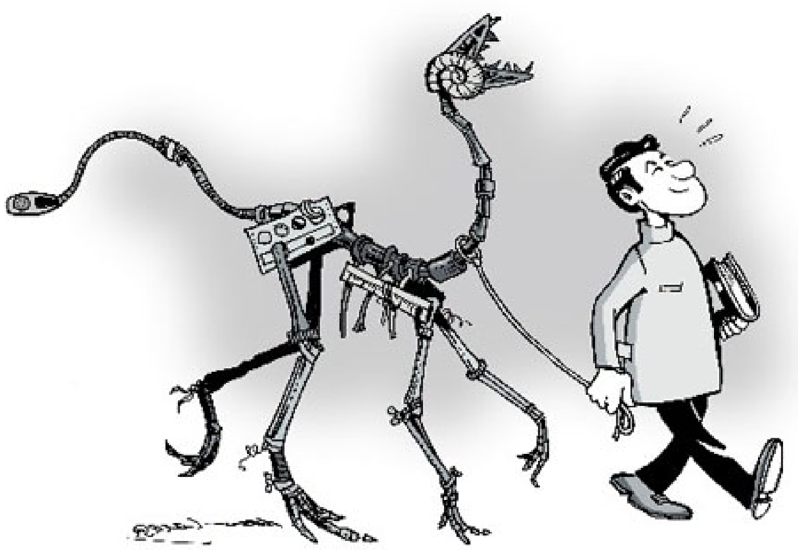
Lesson Week 9 – A Method of ST Practice



So far in this course you have learned principles, concepts and worldview that are distinctive of systems thinking. Gradually we presented some elements of how to approach problems by building models to reveal feedback structures that affect how a problem situation changes over time. This week we will introduce a more specific set of steps that systems thinkers have found help them to build insightful models of problems. We will provide an example of the use of this method. You can use it to tackle any problem of understanding or intervention that you encounter in your life.

This method is widely used to address complex problems by developing a quantified model in which behaviors of concern can be simulated. In this application, the method described here is called **system dynamics.** I will introduce simulation models in next week's lesson.

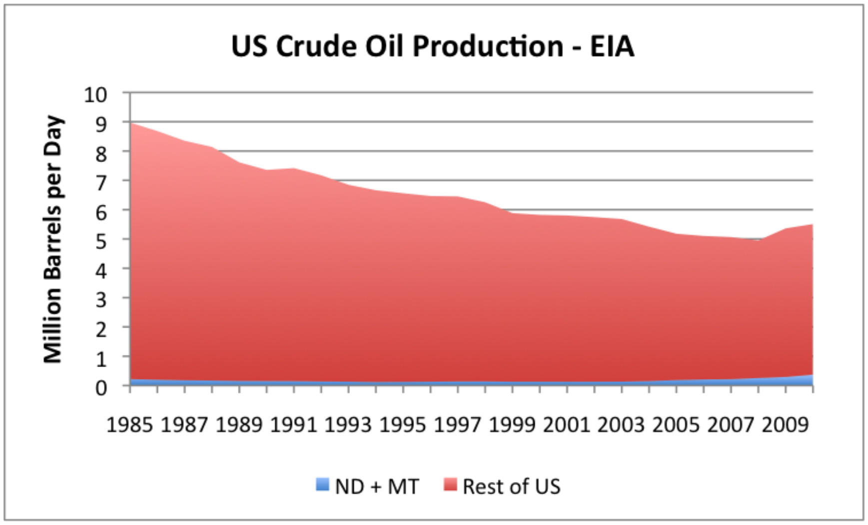


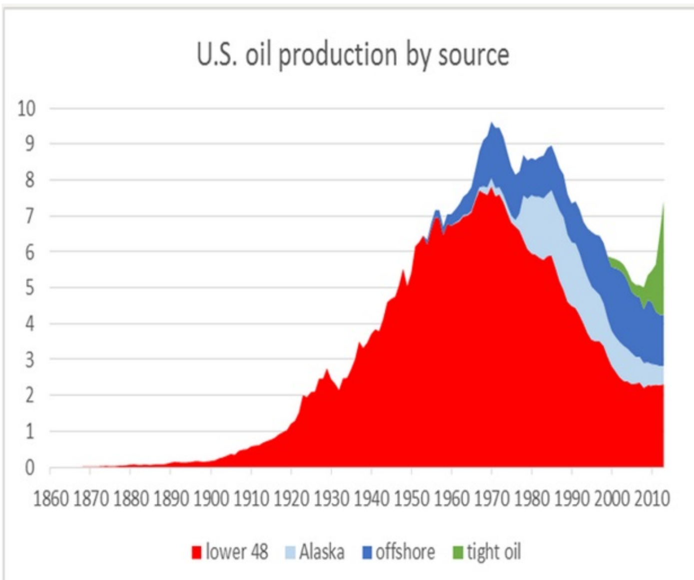
Here are the steps in the method:

1. **Define the problem**. Ask, what is the problem? Why is it a problem? Be specific – model a problem, not a whole system. Try to burrow past symptoms to focus on the real problem.

We need to be clear about what the word ‘problem’ means in this method of inquiry. It can have two different meanings. The conventional meaning refers to something wrong that needs a solution. Example: we need to get out of debt (that’s the problem). In the method of systems thinking presented here, the ‘problem’ is to describe the behavior(s) over time that concern us and to understand their causes by creating a model of the system of influence. It is important to distinguish understanding a situation from fixing it with a solution. All too often when we define a problem as something that needs a solution we have already assumed a mental model of the situation that may be mistaken, and need critical examination. A typical result is that thinking about a specific proposed solution can limit our exploration of the system of influence and blind us to important elements of it. Moreover, what we see as ‘the problem’ in the conventional sense, and how we address it, depends on our goals. One person’s goal might be ‘business as usual’ – to sustain the present situation; another person’s goal might require changes in the present situation. The method presented here attempts to avoid the tendency we all have to jump toward solutions before we understand the situation well.
In the above example, instead of a focus on the immediate or surface problem of debt, we probe deeper by asking: What in the system is causing the pattern of increasing debt? And we keep asking 'And why is that?', to penetrate as deeply into the situation as possible. That is, we frame the problem in terms of potential systemic causes.

2. **Describe the problem dynamically:** Create a time graph of past behavior of the problem to show its development over time, and different futures you think are likely under different policy scenarios. Most people see problems in too short a time frame. Because of delays, cause and effect often are not immediate. Your time horizon should be long enough to capture the full shape of change. Ask, How far in the future should we consider? How far back in the past lie the roots of the problem? In this graph of US oil production, for example, the period 1850-2009 shows only gradual decline. However, an expansion of the time frame reveals a dramatic rise and decline followed by a recent upturn. Because the full historical behavior shows a peak in production, it suggests a problem that the short time horizon did not: what caused the original peak, and what might cause the recent upturn in production to peak as well? And how does the fact that the recent increase is all in tight, costly-to-produce oil affect the problem? The answers to these questions might suggest the need to consider new key variables.





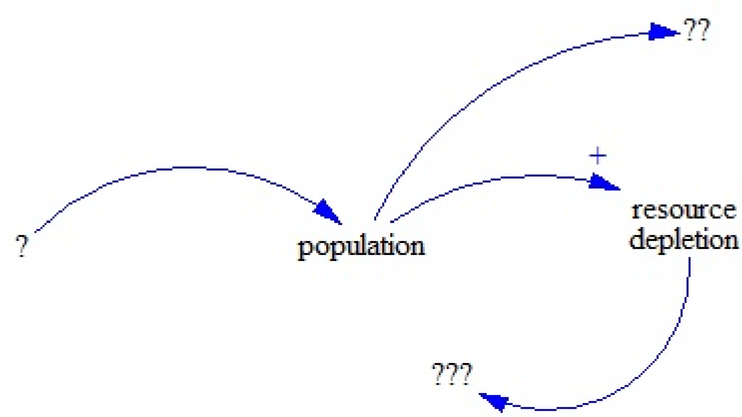
3. **List the key variables.** Make a preliminary list of the variables that you think most likely to affect or be affected by the problem behavior. Tangible variables that can be easily measured are not the only ones that might generate problem behavior. In situations that involve human behavior, intangible qualities such as perceptions, feelings, expectations, information and decision-making power may be important variables.

Divide your list tentatively into endogenous and exogenous variables, categories that you will repeatedly revise as you gain a better understanding of the system of influence that surrounds your problem. Because this process helps you discover what the model boundary should be (see explanation below), it is extremely important. It is a concrete method of tackling the boundary issue discussed at length in the lesson in week seven of the course.

The sort of thinking involved in identifying key variables is similar to that required to create the 'systems map' in assignment #1, which required categorizing issues or elements of a problem into related wholes within wholes. Here you sort key variables into a preliminary list as either endogenous or exogenous. Variables are called endogenous when we think they will be 'captured' within the structure of feedback loops and are thus subject to both cause and effect in our hypothetical model of the system of influence. Variables are considered exogenous when they act on the structure from outside and are not influenced by any variables in the feedback structure. This sorting process is an important step in the inquiry because in the consideration of each variable it imposes the question: And what other variable might influence that? Often that question reveals that variables first thought to be acting on the system from outside are really part of the systemic feedback structure. Hence this step in the method is essential to the process of challenging the boundary of the system of influence.

4. **Build a model.** Create a causal loop diagram as a hypothesis that explains the historical and future dynamics that you have described in the definition of the problem. Attempt to discover a feedback structure for your model that explains those dynamics.

Start putting key variables into a diagram and begin to build connections build by asking two questions for each variable: What causes that variable to change? and What other variable are affected by a change in that variable? In that process, look to build feedback loops that might explain the behavior over time that you described in the problem definition.



5. **Tell the story.** To build a model that is easily understood when shared, it should be unfolded in stages, each one with its accompanying narrative that explains the logic or thinking that underpins your creation of that part of the model.

This method is best used as an iterative back-and-forth process. This means that as you progress through the steps, increased understanding of the problem will likely send you back to revise previous steps. For example, construction of the model may suggest new elements for your list of key variables, or a new time frame in which to see the problem. Or your model building process reveals delays in causal relations in a feedback loop. This leads you to rethink the time horizon of your graphs of key variables. When you consider historical data over a longer period, the shape of the new time graph reveals nonlinearities that suggest the existence of other feedback loops that should be in your model.

Endogenous focus

The systems thinking approach is to look for endogenous causes of problems – dynamics that arise from variables interacting within a systemic structure, rather than external or exogenous causes. Sterman in his *Business Dynamics* explains why:

> … a theory relying on exogenous variables (those "arising from without", that is, from outside the boundary of the model) explains the dynamics of variables you care about in terms of other variables whose behavior you've assumed. Exogenous explanations are really no explanation at all; they simply beg the question, What caused the exogenous variables to change as they did? The focus in system dynamics on endogenous explanations does not mean you should never include any exogenous variables in your models. But the number of exogenous inputs should be small, and each candidate for an exogenous input must be carefully scrutinized to consider whether there are in fact any important feedbacks from the endogenous elements to the candidate. If so, the boundary of the model must be expanded and the variable must be modeled endogenously.

To summarize, when you are considering where to place a variable in a model, always ask the question, And what might be causing that variable to change? Thus the endogenous focus is really a specific application to the modeling process of the boundary problem discussed at length in the lesson in week seven.

An example of the boundary problem is conventional economic thinking that typically fails to consider the impact on economies of the long term changes in access to energy revealed in the long time horizon oil graph above. Moreover, the influence of a long term decline in energy on economies may affect in turn their ability to access energy, creating a feedback loop that is likely to alter economic projections.

An Example of the Method

Define the Problem. Conventional agriculture that relies on external inputs of synthetic fertilizers tends to ignore soil organic matter, which historically has declined on most farms. Soil organic matter (SOM) tends to decline to 1% or below in the Northeast US due to neglect to replace it and to regular tillage that occurs in the cropping systems common in the region. Chemical fertilizer substitution is unsustainable. Rebuilding SOM can partially solve the problem because of the essential ecosystem services it provides: nutrient transfer to plants, tilth, aeration and water storage.

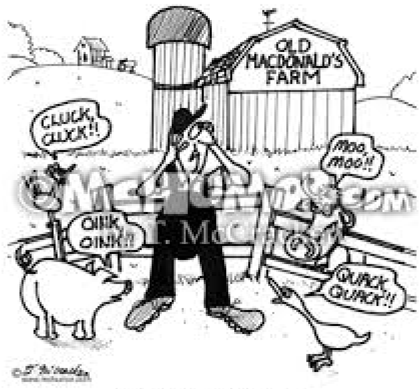
> **The target solution.** In temperate, well watered climates like the Northeastern US where soil organic matter can accumulate, building organic matter levels has proven to increase overall agroecosystem health and resilience and long term farm productivity, and the positive response continues to levels of at least 15% organic matter.
> **A model to test management policy alternatives.** In this situation a useful goal would be to model an agroecosystem that can simulate soil organic matter trends under conventional nutrient management, but includes elements and variables that would allow simulation of alternative farm system design and management policies that have proven themselves in regard to building soil organic matter. Given the importance to sustainability of self-sufficiency in farm fertility systems and the debate over livestock-based versus non-livestock strategies in regard to soil-building efficiency, model building should ultimately aim for comparison of animal-integrated with other low-input fertility systems.

The problem is, What farming system rebuilds SOM more quickly? The hypothesis: an animal-integrated system in which animals are used as part of the nutrient cycle and as tools to manage biomass productivity builds SOM faster than a system where SOM is managed mainly by incorporation of crop residues, cover crops and other green manures. Specifically,

An animal-integrated approach out-performs all others in its rate of soil organic matter accumulation, using:

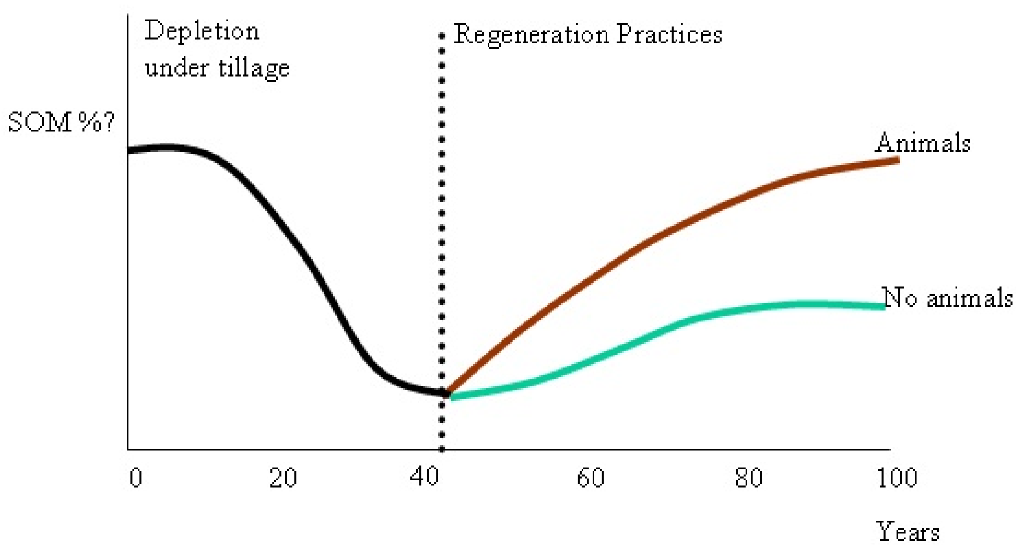
- Intensive, grass-based livestock management
- Winter manure nutrient capture and storage with deep litter bedding under cover
- High carbon composting of the bedding pack during the warm season
- Spreading back on grassland timed for fast incorporation by the soil community

A first model will attempt to explain SOM behavior over time in the animal-integrated system.



"I CAN'T STAND THE NOISE.
WHY DID I GIVE UP VEGETABLE FARMING?"

Describe the problem dynamically. SOM can be lost quickly in annual tillage systems but may take a generation or more of farmer activity to be lost in the best soils. Regeneration is also a process that can take decades if the farm is to be commercially productive at the same time. A tentative time horizon should be at least 40 years, and perhaps hundreds of years to demonstrate sustainability.



List the key variables. The main variable to be tracked over time is SOM. Contributing variables include

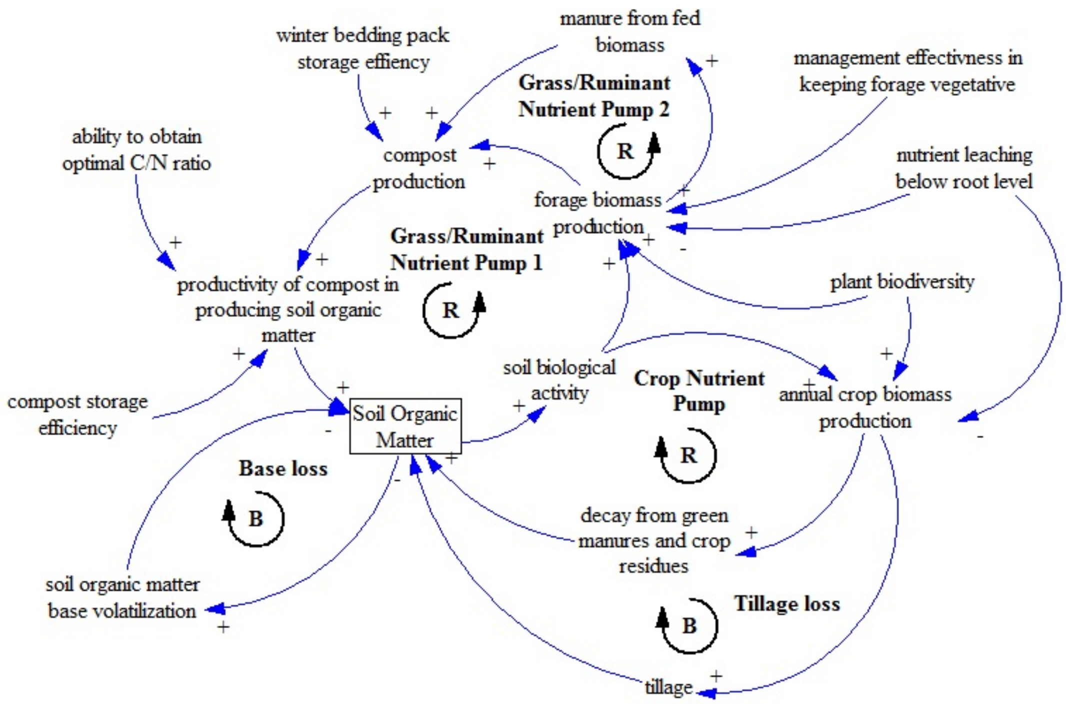
1. biomass productivity of the farm above and beyond the fraction harvested for food or fiber
    a. biomass production, both above ground and root growth
        i. forage and grazing management
        ii. N fixing capacity – legume content
        iii. Other forage biodiversity
        iv. soil biological activity

2. variables that affect the efficiency of the nutrient cycle – its nutrient losses.
    a. C/N ratio
    b. other variables in the biomass storage and composting parts of the cycle.
3. variables that affect SOM loss rate

In addition to potential endogenous and exogenous variables, it is helpful to list variables that might be related to the problem but will be deliberately excluded as external and irrelevant in this case.

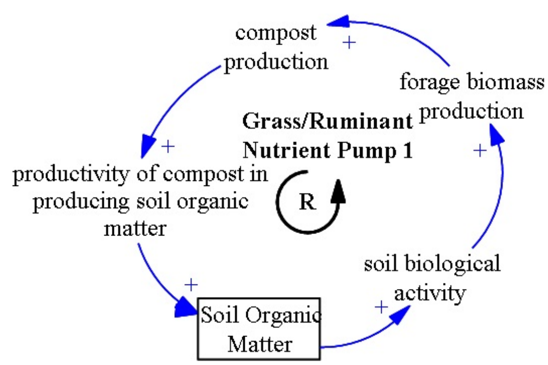
Endogenous	Exogenous	External
Soil organic matter	Forage and grazing management	Climate
Soil biological activity incl. N fixing capacity via azotobacter	Plant biodiversity	Exported organic matter from erosion
Manure to compost production	Other forage biodiversity	Exported biomass in farm products?
Forage biomass production	Manure to compost fraction	
Compost production	Compost management – C/N ratio, etc.	
Soil organic matter base volatilization	Winter bedding pack storage efficiency	
Tillage	Nutrient leaching below root level	
Annual crop biomass production		
Decay from crop residues and green manures		
Manure from fed biomass		

Build a model. In this model, The **Grass/Ruminant Pumps 1 and 2** are the feedbacks that represent what happens to SOM in the **animal integrated system**. The **Crop Nutrient Pump** and the **Tillage Loss** are the feedbacks that represent what happens to SOM in the **non-animal** system. The **Base Loss** feedback applies to both systems.

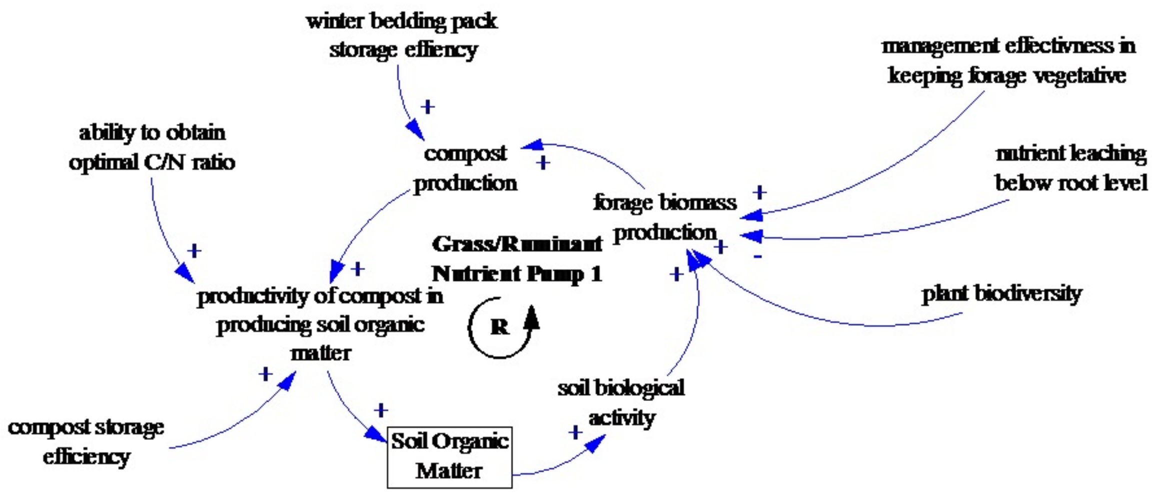


Tell the Story. Tell it in a way that unfolds the model and explains it piece by piece.

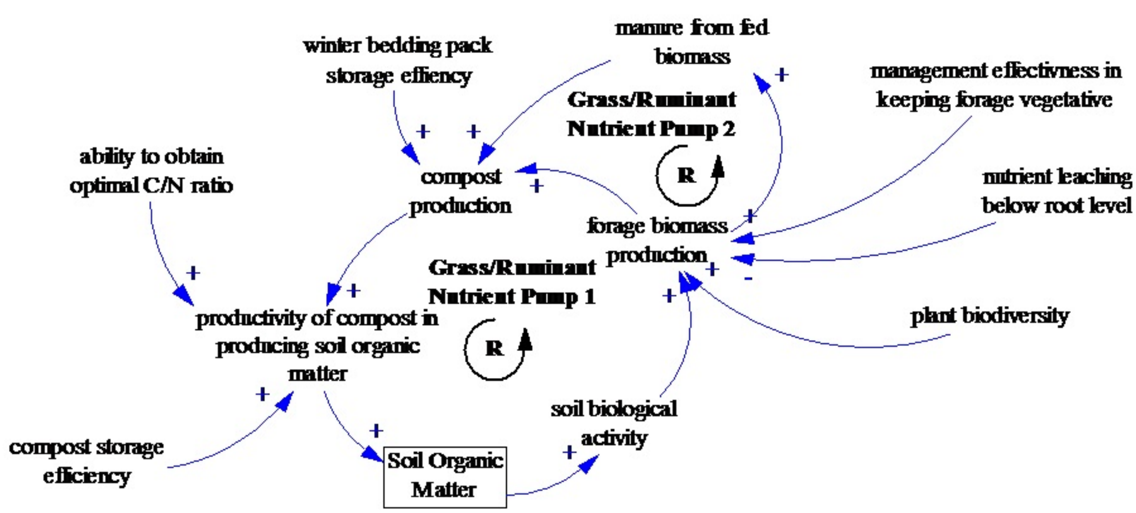
In the main feedbacks driving the animal-integrated system, an increase in SOM raises soil biological activity and leads to more production, in this case perennial forage fields with no tillage. Composting accelerates the process, again increasing SOM.



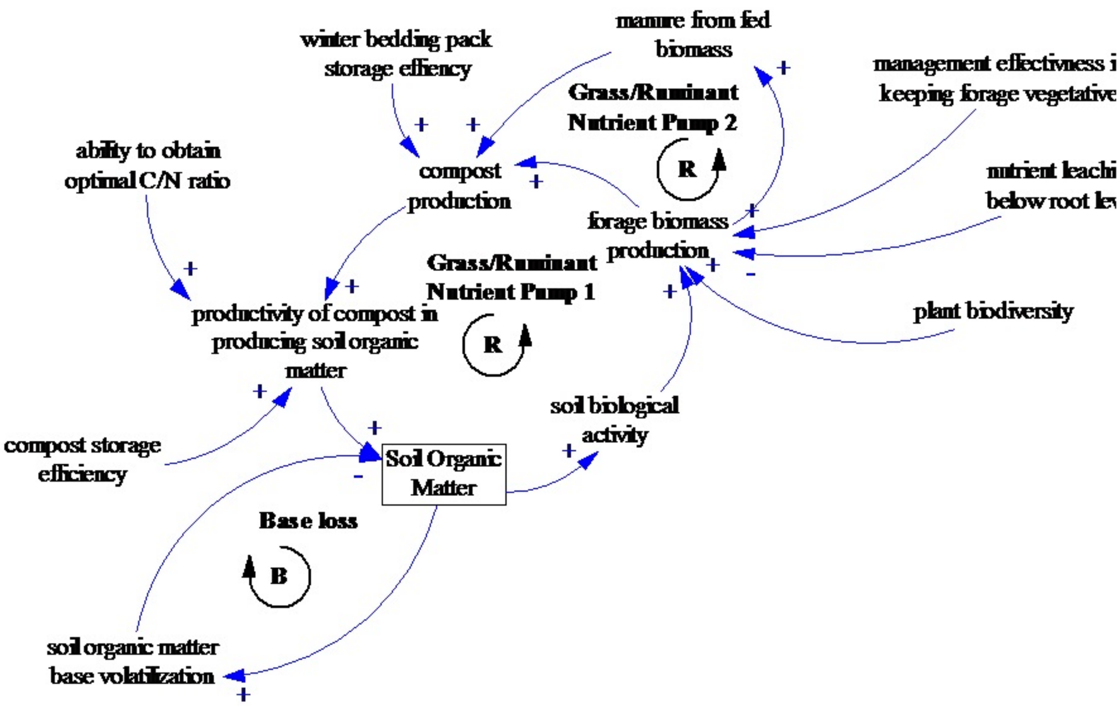
The exogenous variables, those not captured in the model feedbacks, are ones that the farmer may be able alter to increase SOM accumulation via this feedback loop. Examples are storing the compost better before returning it to the soil, or adding to plant diversity, which in turn can increase forage production.



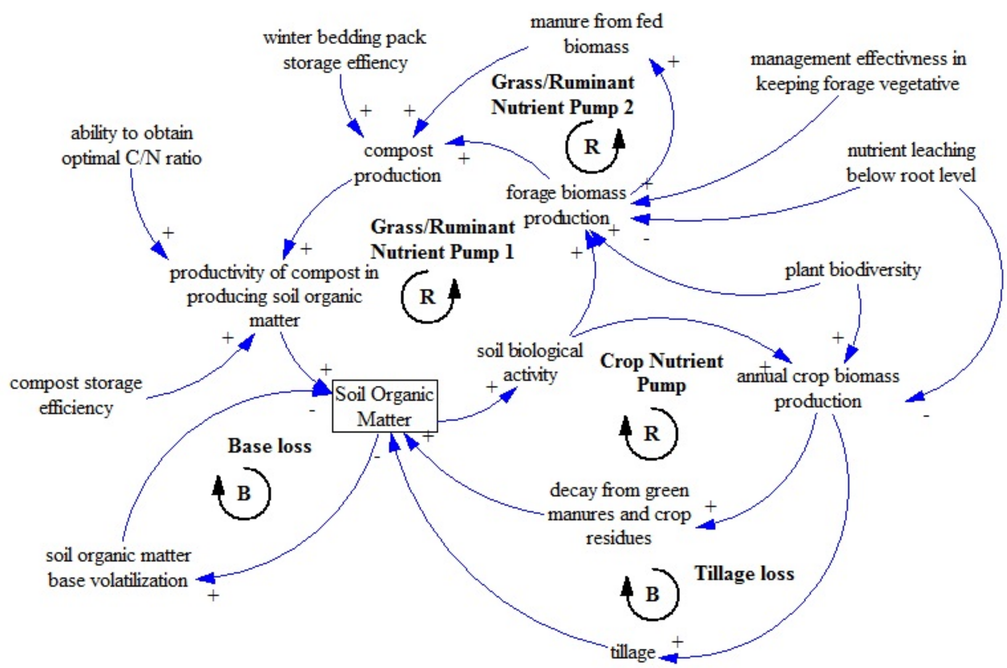
The biomass becomes either bedding (**Pump 1**) or goes through the animals to become manure (**Pump 2**). Combining the bedding and manure to become compost is more productive of SOM than vegetation decay in the system without animals, because there is less loss from volatility.



The **Base Loss** is a balancing feedback where more SOM leads to more volatilization loss leading to less SOM. It applies equally to both animal-integrated and non-animal systems. The **Base Loss** feedback is what ultimately limits SOM increase and causes it to level off in both systems in the time graph.



The full model includes two feedback loops that represent what happens in the system without animals. The **Crop Nutrient Pump** increases SOM, in a reinforcing feedback loop, but the decay process from green manures and crop residues is less efficient than composting. Also more cropping increases tillage, which decreases SOM in the **Tillage Loss** balancing loop.



For several reasons, the animal integrated system builds soil faster than in the system without animals. Plant production is enhanced from grazing management. Because it is a perennial forage system there is no tillage to cause SOM losses from volatility. Also the composting is an efficient way of plant decomposition back to soil organic matter. The model thus explains the hypothesis proposed in the time graph of the two regeneration systems.

In this example, the story is kept brief for demonstration purposes. A story that explains the logic of the model in more detail will be more effective for sharing the model. Also, writing a more detailed narrative may help the builder discover weaknesses of his/her understanding of the situation or in the explanation of the builder's hypothesis about the problem.