An Introduction to Systems Thinking

Karl North

"W*e'll never be able to go back again to the way we used to think." – anonymous holist*

There is currently a growing revolution in the way people are examining, understanding and trying to manage our affairs in the world. We can find evidence far back in human history of attempts to comprehend how the world functions in wholes. Early glimmers of awareness of the ever-present feedback that ultimately drives what happens in the world come down to us from biblical maxims like "*as ye sow, so shall ye reap*", and reveal themselves in common sayings like "w*hat goes around, comes around*", "*chickens coming home to roost*."

Only lately have scientists, seeing the inadequacy of methods bounded by disciplinary traditions, seriously sought more holistic ways of doing science. These efforts, described variously as 'systems thinking' or 'complex systems science', are still small and have encountered plenty of resistance in the scientific community. In the words of one holistic scientist, "*…you can always tell the pioneers – they're the ones with all the arrows sticking in their backs!*" But they are creating powerful analytical tools that amount to a breakthrough in how science is done.

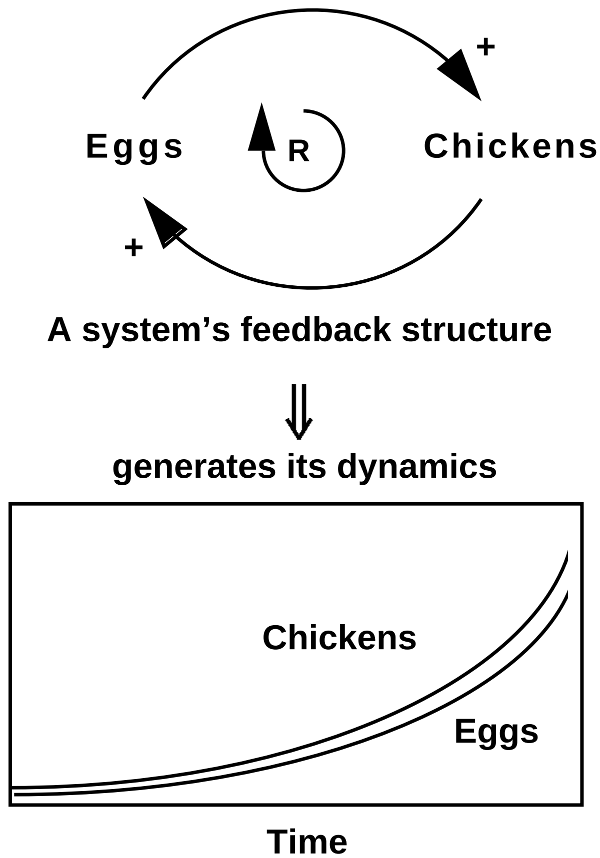
In the early seventies scientists used one of these tools, known as system dynamics (SD) to build a global model of what is causing the main threats to human civilization: unsustainable resource use, pollution, exponential population growth, and inequitable distribution of goods and services. Simulating various scenarios they found none but the most difficult to carry out would prevent global overshoot of planetary carrying capacity, leading to at least some degree of collapse of present human populations and quality of life during the 21^{st} century.

Published under the title *Limits to Growth,* which became an international best seller and put the science of system dynamics modeling on the map, the model came under heavy fire from those in the scientific community who have a vested interest in older ways of doing science. Even louder criticism came from groups who have a financial interest in maintaining an economic system structured for endless growth. Nevertheless, republished several times with only minor revisions, the model has vindicated itself as the disturbing outcomes it pointed to over thirty years ago have so far come to pass. Today a consensus has emerged among top scientists of many nations that we need to take seriously the possibility of a global future that resembles one of the scenarios in *Limits to Growth.*

In the last several years I have been studying system dynamics. Created originally at Massachusetts Institute of Technology, SD includes a very simple, but powerful way to draw DIAGRAMS which specifically help us study and talk to each other about how the parts of a system work together in terms of cause and effect, and even allow us to simulate the curious behavior patterns over time of complex wholes. Like flight simulators that teach how to pilot airliners without the risk of crashing planes and killing people, SD models allow us to test policies in the systems we manage and see likely outcomes before we do risky trials in the real "whole system", that is the planet.

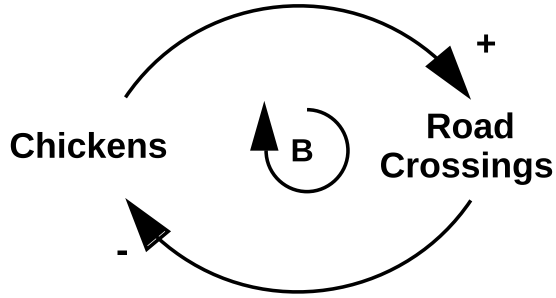
This article was written originally for those studying and practicing Holistic Management, as developed by Allen Savory and the Center for Holistic Management. The study of holism has been eye-opening for me, and has expanded my understanding of concepts that are implicit in the design of the Holistic Management framework. I would like to share here a few of the most important insights I have gained, to show that emerging schools of holism have much to learn from each other. A second goal of this article is to persuade Holistic Managers and educators to learn a simple way of drawing pictures that show in a glance the structures in our wholes that explain problem behaviors. Known as causal loop diagrams in systems science, this tool is one product of the systems thinking movement that most anyone can learn.

Where is the Root Cause?



In our HM learning groups, how many times have we gotten stuck on the very first Testing Question: Cause and Effect? Burrowing beyond symptoms we often find not a root cause but a bewildering range of causes. System science reveals that we are not in error; in complex wholes cause does not come from one place, it comes from variables linked in a circle. Since a change anywhere in the circle feeds back to impact the point of origin, these circles are called *feedback loops*. Thus in a simple system consisting of chickens and fertile eggs, it is neither component, but rather the feedback loop, chickens-and-eggs, that is causing the system behavior - that stocks of both components grow exponentially over time. The one loop in our system example is called a reinforcing loop (**R** in the diagrams), because more chickens makes more eggs makes more chickens in escalating fashion. The feedback loops of the system (in this case only one) are its 'structure' and are what generates its 'dynamics': what it does to the chicken and egg populations over time.

Structure:



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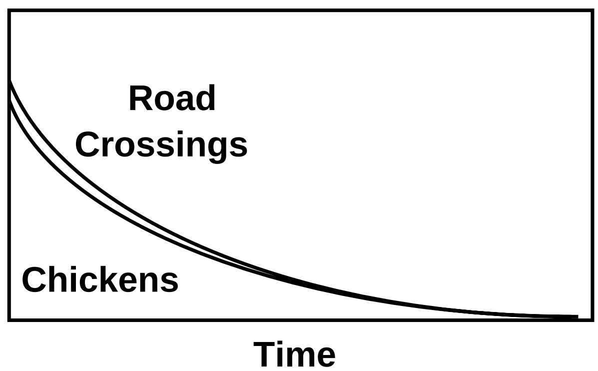
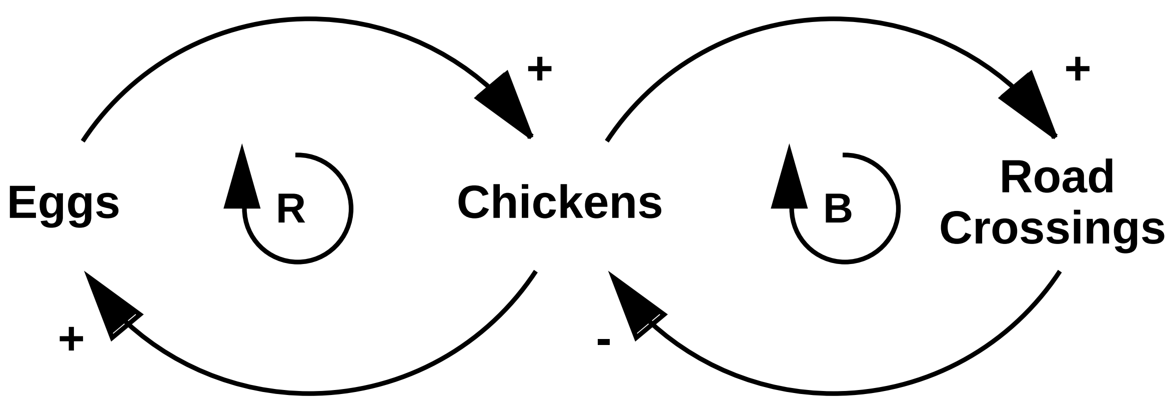
Behavior:



As any farmer knows, this simple system, structured as it is for exponential growth, would eventually overshoot the carrying capacity of its resource base and collapse. But systems science reveals the existence of one other kind of feedback loop in most wholes, one that works to limit growth and stabilize the system. Chickens-and-roadcrossings is an example that might work in our simple demonstration system. Called a balancing loop (**B** in the diagrams), the way it works in this case is: more chickens tends to cause more road crossings, which in turn causes fewer chickens. By itself, this loop eventually leads to the end of the chicken population. But joined to the reinforcing loop, the system could generate the behavior the manager desires, depending on how the two loops are managed: which loop is allowed to become dominant.



Looking for Feedback

How do these revelations help us better understand the wholes we must manage? SD scientists have shown that the structure of all complex systems of every type and scale – the rumen food web of a cow, the soil ecosystem, the social network of an enterprise, a market system, a system of international relations, consist of sets of just these two types of feedback loops fitted together in many combinations. Furthermore, it is this feedback structure that generates the long-term behavior trends in our wholes that we need to understand, and that humans have the most trouble grasping. So if we can begin to recognize and identify these two types of feedback in our wholes under management, some pulling, some pushing, we can do a better job of deciding where and when in this structure to apply leverage that will move the system in the direction of our holistic goal.

How to Read Causal Loop Diagrams (CLDs)

CLDs are ways to visualize relationships of important variables in your system where a change in one causes either a decrease or increase in another. The arrows show the direction of causality. So a change in the chicken population causes a change in the egg population. The signs (+, -) on the arrows have a special meaning, different from the usual one. A plus (+) means that a change in one variable has an effect *in the same direction* on the other. Thus an increase in the chicken population causes an increase in the egg population. And a decrease in one causes a decrease in the other. A minus (-) means that a change in one causes a change *in the opposite direction* in the other. So more road crossings tends to reduce the chicken population. And fewer road crossings implies a higher chicken population than there would have been if the number of road crossings had stayed the same.

To identify which kind of loop it is we must trace its causality around the circle. Starting with any variable, imagine either an increase or decrease, and trace the effect through all the elements of the loop. If a change in the original variable in the end causes an additional change of that same variable *in the same direction*, we call it a reinforcing loop (**R**) because it reinforces the original dynamic. More chickens means more eggs, which increases the chicken population even more. A reinforcing loop tends to cause exponential growth in all variables in the loop. If a change in the variable we start with leads to a change *in the opposite direction*, we call it a balancing loop (**B**) because it tends to counteract the original change. More chickens means more road crossings, which tends to reduce the chick population.

Learning to see feedback structure and its consequences is not as complicated as it sounds. Like using the HM framework, it gets better with practice. An expanding branch of the SD network has taught elementary school children to diagram the feedback they experience in the wholes in their lives, and even to create computer models where they can simulate changes in feedback structure to learn their long-term consequences for system behavior.

Once we see that cause and effect runs in circles, we can appreciate what a hash verbal communication makes of our understanding of system behavior, because it runs in straight lines (subject-verb-predicate), and rather too short ones at that. Then we see the advantages of a diagrammatic language of circles and arrows that can communicate the dynamic, causal interconnections of all system components at a glance.

How to Anticipate System Surprises
Folktales like The Turtle and the Hare reveal insights about the holistic way the world works. This folktale demonstrates the *counterintuitive behavior* that systems dynamicists say is an abiding characteristic of complex systems. We expect the hare to win the race, but it is the turtle that wins. Many of our management and design failures happen because we fail to recognize system feedback structures that generate these surprising, unexpected results. Common examples of “fixes that fail” from unperceived feedback:

1 Information technology has not enabled the “paperless office” – paper consumption per capita is up

2 Road building programs designed to reduce congestion have increased traffic, delays, and pollution

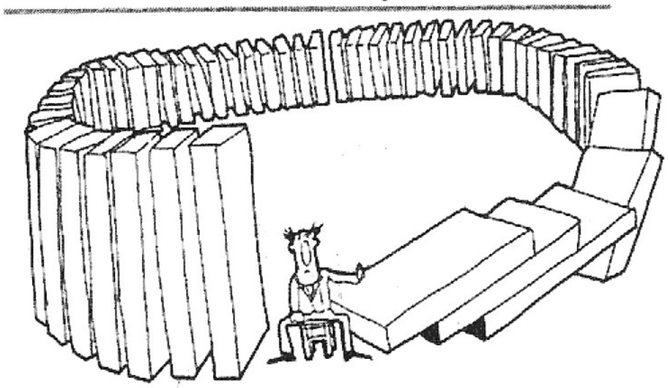
3 Despite widespread use of laborsaving appliances, Americans have less leisure today than 50 years ago.

4 Antibiotics have stimulated the evolution of drug-resistant pathogens, including virulent strains of TB, strep, staph and sexually transmitted diseases

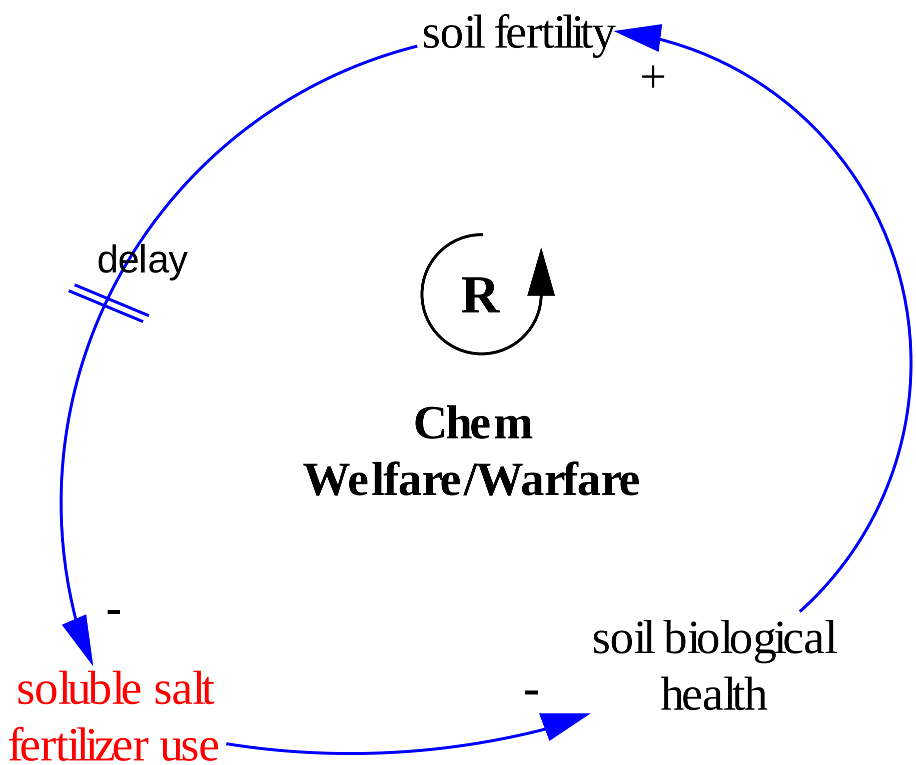
5 Pesticides and herbicides have stimulated the evolution of resistant pests and weeds, killed off natural predators, and accumulated up the food chain to poison fish, birds, and possibly humans.

6 A system of unrestrained free trade generates monopolies that control trade.

In complex systems, cause and effect are distant in time and space

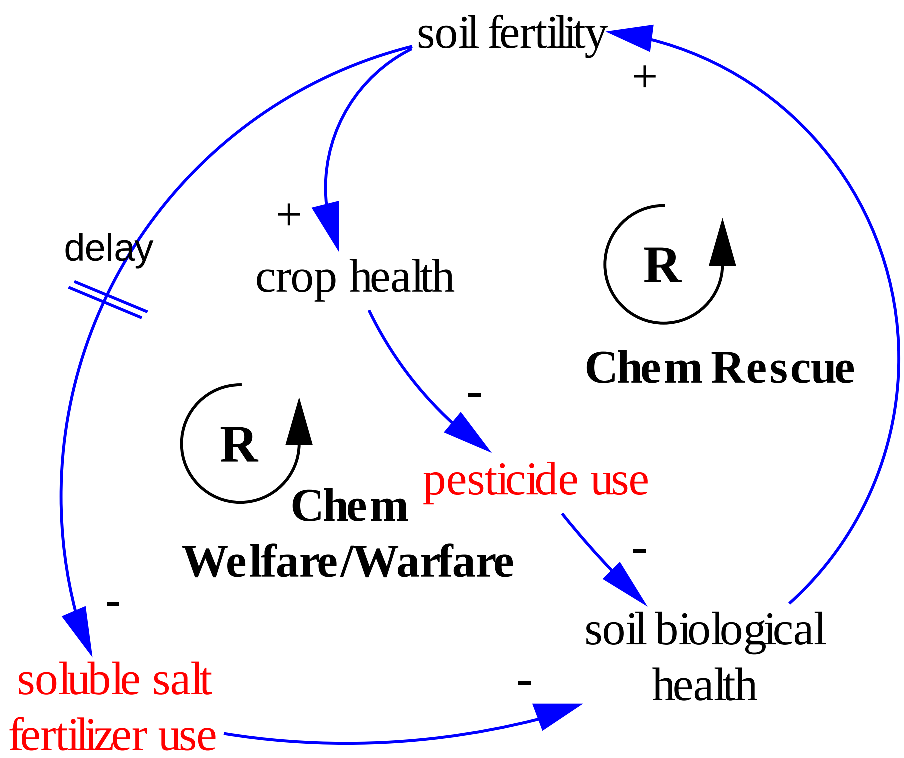


In every case failure stems from inability to identify feedback structures and anticipate how they would play out. And in every case, because of *delays* characteristic of feedback in complex systems, short-term success preceded long-term failure. This contrast between short- and long-term consequences of decisions has been one of the hardest things to learn about managing wholes. But systems science has identified a small number of classic feedback structures that generate the counterintuitive behavior that keeps taking us by surprise. It can teach us to spot these and thus reinforce and complement the practice of Holistic Management.



Building Causal Loop Diagrams

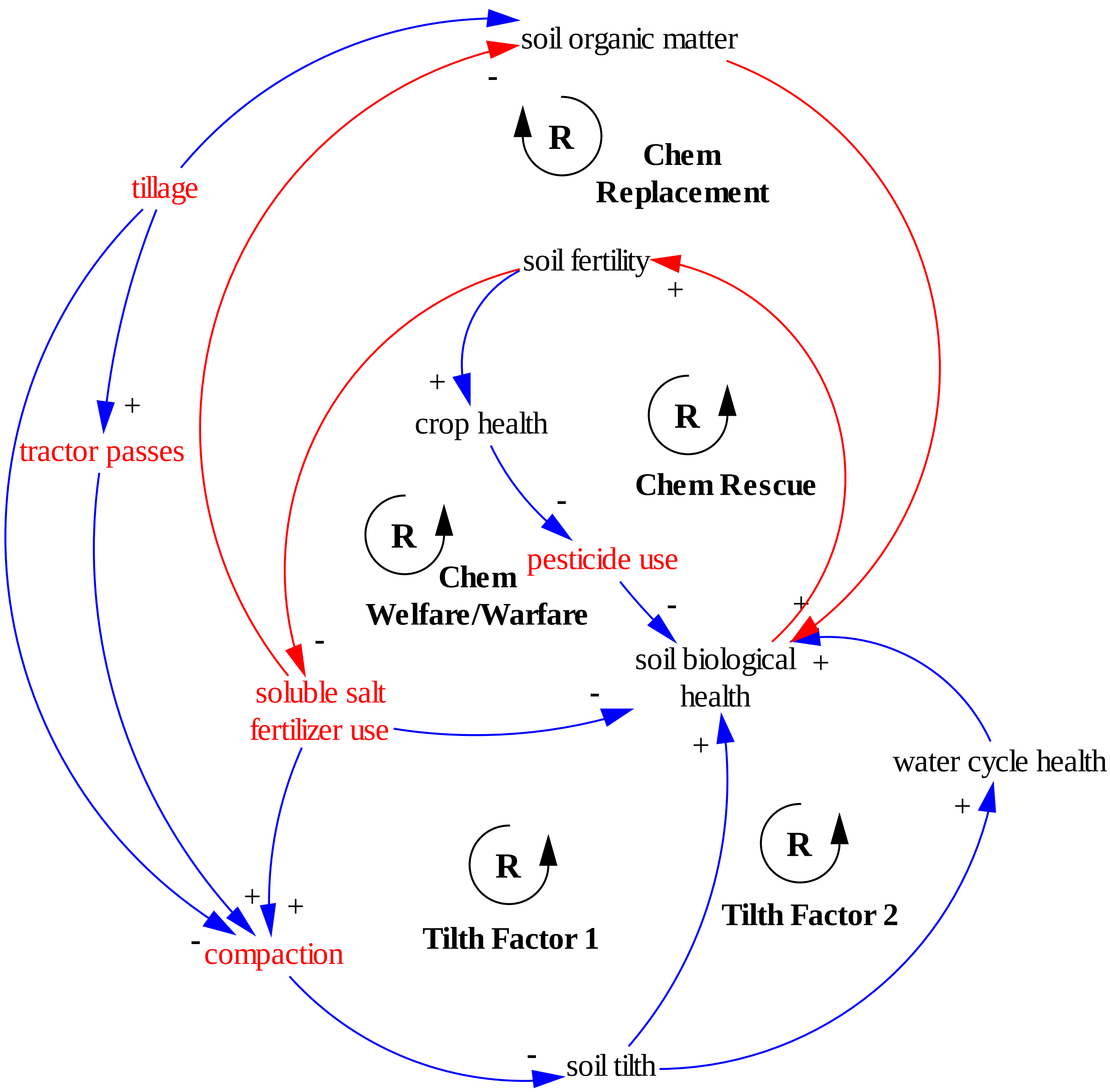
Learning to build the causal loop diagrams that SD scientists have created as a study tool can help us identify and understand the interdependencies in the wholes we manage. Sometimes they reveal things we want to avoid. Let's build a diagram of industrial agriculture to show how this works.

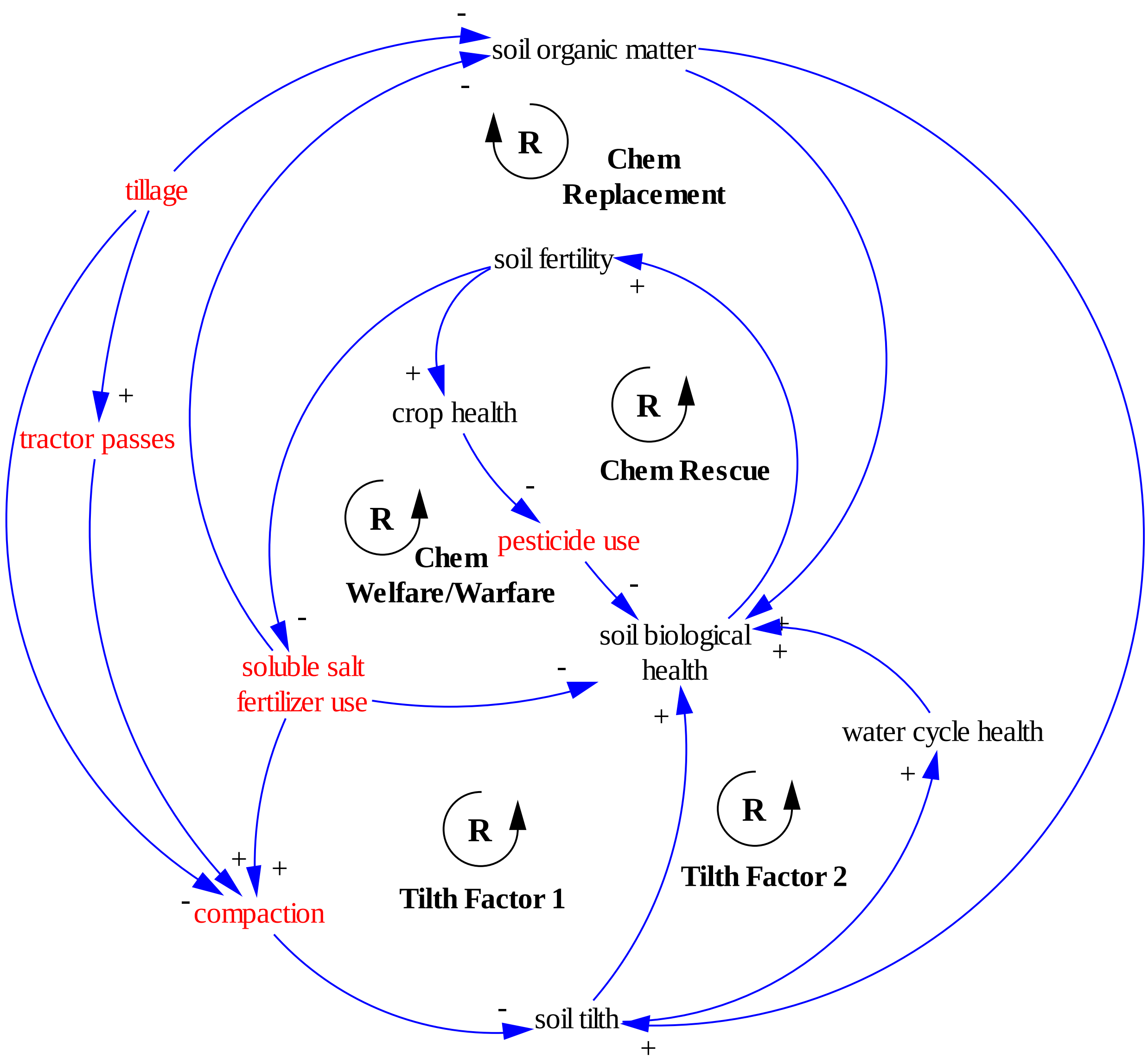


Suppose our problem is soil biological health, which we see deteriorating over time. This diminishes soil fertility, which induces increasing soluble salt fertilizer use, causing soil biological health to deteriorate even more. Here we have a classic reinforcing loop. It facilitates good communication to give feedback loops labels that evoke the behavior they generate. I call this one Chemical Welfare/Warfare because these fertilizers have both an initial positive effect and a long-run negative one. I show one of the delays that generate this classic long-run/short-run effect. Can you add others?

To compensate for the declining crop health that accompanies salt fertilizer use, farmers increase pesticide use, with negative toxic effects on soil biological health. We depict this by adding another reinforcing loop called Chemical Rescue. Compaction and the practices that produce it bring two tilth loops into the picture. Finally, increasing dependence on chemical fertilizer leads farmers to neglect soil organic matter, so we add the Chem Replacement loop shown in red.

The complete CLD shows how all the reinforcing loops containing the red variables have a negative impact on soil biological health, possibly with a multiplier effect more easily recognizable in a diagram than in a prosaic description. But it also shows how, by adding soil organic matter, these vicious circles can be reversed to become virtuous circles. Can you trace the causality to see how this works?





Feedback Structure Generates Behavior – Pogo's Law

Characteristic of holism aka systems thinking is its endogenous focus – that patterned system behavior generally arises out of the structure of the system itself, rather than from external inputs or shocks. But our world consists of nested wholes, so where do we set the boundaries? A basic tenet of SD science is that the nature of the problem that interests us must tell us the boundaries. If we want to know why big agriculture consumes family farms, it helps little to focus on farm or even watershed ecosystems and their processes. The system structure that is generating the problem behavior – a shrinking farm population – lies beyond even the agricultural economy. The historical pattern of big fish swallowing little fish occurs in every sector of our economy. So the boundaries of the system we need to look at to understand this pattern encompass the whole economy, the political rules that govern it, and the knowledge and information institutions that shape people's behavior in the whole society.