Organic soil management: holism and the nitrogen cycle

by David Patriquin

THE SINGLE MOST CRITICAL DIFFERENCE BETWEEN CONVENTIONAL AND ORGANIC SOIL MANAGEMENT CONCERNS THE WAY IN WHICH NITROGEN IS PROVIDED. Conventional management makes use of synthetic fertilizer or "artificials" as needed to saturate plant response systems, while under organic management, natural nitrogen sources are used.

Nitrogen fertilizer, in the form of urea, ammonia, salts of nitrate and ammonium, is the most consistently used soil amendment under conventional management. Indeed, scientific agriculture is generally considered to have begun in the mid-1800s with the discovery that the addition of purified nitrogen salts to soil could reverse the problem of "soil sickness" or rundown soil. It soon proved possible to grow plants with nutrients supplied entirely as inorganic salts. This led to the demise of the Humus Theory—the idea that humus is essential for plant growth—and to concepts of management of crop growth through diagnosing nutrient deficiencies and providing nutrients as inorganic salts.

The first commercial production of nitrogen fertilizers from atmospheric nitrogen (N_2)—a technological breakthrough which greatly reduced the cost of synthesizing nitrogen salts—occurred in 1913, primarily to manufacture nitrate-based explosives. Chemical-based agriculture took off after WWII, when there was a surfeit of chemical nitrogen, and both DDT and 2,4-D became widely available. In combination, these chemicals allowed farmers to produce crops without crop rotation and recycling of manure. The monoculture technologies that followed benefited from economies of scale and fields; farms and machinery got larger, and farm communities got smaller.

High levels of inorganic nitrogen in the soil suppress the nitrogen-fixing activity of legumes and increase demand for fertilizer nitrogen.

Addictive technologies

The new technologies generated demand for more chemical inputs per unit of product. There are many reasons for the addiction. When nitrogen fertilizer is substituted for nitrogen derived from soil organic matter and legumes, it does not substitute for the many other functions of soil organic matter and legumes (see Box 1). High levels of inorganic nitrogen in the soil suppress the nitrogen-fixing activity of legumes, and increase demand for fertilizer nitrogen. The high nitrogen levels acidify soil, increasing demand for lime; they also stimulate weeds, pests and diseases, increasing the demand for herbicides and pesticides. Monoculture, larger fields, and a lower return of organic residues each increase erosion and the demand for nutrients. The use of heavy machinery causes soil compaction, exacerbating pest and disease problems, reducing nutrient use efficiency and generating demand for more pesticides and fertilizers.

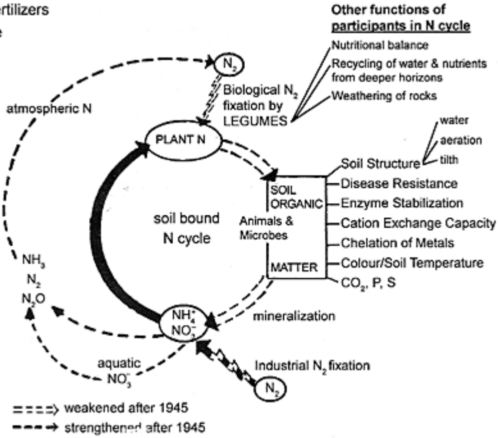
The separation of crops from livestock and the development of factory farming (today accounting for 37% of global meat production and still growing[1]) greatly increases the need to import fertilizer for field crops. Further, factory farms generate immense quantities of waste which cannot be readily assimilated in the vicinity of those operations. Altogether, modern methods of farming have altered global nitrogen cycling and made agriculture a major polluter of surface water, groundwater, coastal systems and the atmosphere.

Hindsight is 20/20. However, the problems were not unforeseen. In a detailed text published in 1897, Isaac Roberts[2] provides many pieces of caution about use of fertilizers and noted "...the effect of fertilizers was likened to the effect of alcohol on the confirmed toper; but to stop meant collapse and to go on implied constantly increased use."

In the early 1900s, Albert Howard observed that the new "artificials" caused increased disease in crops and livestock and began to define the alternative approaches of organic agriculture. Interestingly, writers in the 1940s expressed great optimism that the chemical era was about to end[3,4] but as we know today it was just getting geared up. Global fertilizer use increased tenfold between 1950 and 1990 (during which time the human population doubled).[5]

Box 1: The changing nitrogen cycle

The rapid increase in use of nitrogen (N) fertilizers after World War II was accompanied by the declining use of legumes and organic matter to provide N. Fertilizer N contributes directly to the inorganic N pool (NH_4^+ and NO_3^-) and, together with factory farming, dramatically increases the flow of N from the soil to water and to the atmosphere.



The level of nitrate (NO_3^-) in the soil acts as a regulator of the flow of N between the soil bound, on-farm N cycle, and the larger global cycles. Nitrate exists free in the soil solution and moves with water flowing through the soil into ground and surface waters. When oxygen becomes deficient in soil during heavy rains, nitrate is respired by soil bacteria, producing the gases N_2O and N_2 as byproducts.

In natural systems, nitrate rarely accumulates to more than a few kilograms per hectare because ecosystems evolve in a way that results in tight coupling of decomposition and plant growth.

When inputs of N to the inorganic pool exceed the capacity of plants (or microbes) to take up N, nitrate increases. It accumulates to very high levels (>100 kg NO_3–N/ha) when (i) fertilizer-N is applied in a large dose at the beginning of the growing season; (ii) there is excessive loading of soils with manure; or (iii) the soil remains bare for some time after crops are harvested or sod is broken. Release of ammonia from manure in feedlots is another major route of movement of N to the atmosphere. The weakest link in organic agriculture tends to be losses of nitrate occuring after crops are harvested or sod is broken.[10] Well-designed rotations including cover crops can greatly reduce N losses at these times.

The global nature and negative impacts of the changing N cycle became widely appreciated in the scientific community in 1997 when eight prominent ecologists published an article to highlight the issue.[11]

They concluded:

"Human activities during the past century have doubled the natural annual rate at which fixed nitrogen enters the land-based nitrogen cycle, and the pace is likely to accelerate. Serious environmental consequences are already apparent. In the atmosphere, concentrations of the greenhouse gas nitrous oxide and the nitrogen-precursors of smog and acid rain are increasing. Soils in many regions are being acidified and stripped of nutrients essential for continued fertility. The waters of streams and lakes in these regions are also being acidified, and excess nitrogen is being transported by rivers into estuaries and coastal waters. It is quite likely that this unprecedented nitrogen loading has already contributed to long-term declines in coastal fisheries and accelerated losses of plant and animal diversity in both aquatic and land-based ecosystems. It is urgent that national and international policies address the nitrogen issue, slow the pace of this global change, and moderate its impacts."

—David Patriquin

For many crops, strict monoculture has not proved sustainable even with a high level of chemical inputs, and since the mid-1980s there has been a move to some diversification of most cropping systems in North America. However there has not been a move to reintegrate crop and livestock farming on a scale that would substantially reduce the need for nitrogen fertilizer or resolve the massive waste problems.

It is somewhat ironic that the chemical revolution in agriculture began with synthetic forms of nitrogen, the one element that can be provided entirely by biological means, (i.e. by mineralization of organic matter and nitrogen fixation as illustrated in Box 2). Those processes were discovered in the latter part of the 19th century when the chemical revolution was already well underway. Had they been discovered earlier on, perhaps we would never have got on the chemical treadmill. On the other hand, we continue to put our faith in new technological fixes that are at variance with nature, even with a much more detailed understanding of the complexities of nature.

Box 2: Components of a strategy for achieving self-sufficiency in N**

- Intensify mineralization (by composting, mixed farming, maintaining high soil biological activity).
- Use legumes/ legume-based forages and pasture on 30–60% of the land area.
- Create conditions conducive to nitrogen fixation by legumes (by incorporating low N residues)
- Implement N conservation practices (cover cropping, conservation tillage).
- Improve soil aeration (by ridge tillage, feeding the soil, drainage).
- Synchronize seasonal rhythms in release of N by soil and its uptake by crops (by crop rotations, adjusting organic amendments according to field fertility).

"The correct relation between the processes of growth and the process of decay is the first principle of successful farming. Agriculture must always be balanced. If we speed up growth we must accelerate decay."
—Albert Howard, 1940

Could natural N cycles provide sufficient N to support all of us?
The Netherlands supports a very high population density (466 persons/ km^2) and the most intensive agriculture in the world. A study of the potential for food self-sufficiency based on natural sources of N in the Netherlands concluded that self-sufficiency could be achieved if a change was made to consuming more grains and beans, and less meat.[9] There would likely be less or no tradeoff required in North America (population density 30 and 3.4 persons/km^2 for U.S. and Canada respectively) where livestock could be supported by more extensive systems.

** Based on practical experience discussed in "Biological husbandry and the nitrogen problem." Patriquin, D.G. *Biological Agriculture and Horticulture* 3: 16–189. 1985.

* Humus is a complex, nitrogen-rich material with no visible structure, which confers qualities we associate with naturally fertile soil (such as its dark colour, good tilth and high nutrient supplying capacity). It makes up 60–80% of soil organic matter and is the largest reservoir of nitrogen in most terrestrial ecosystems. The terms "humus" and "soil organic matter" are often used interchangeably.

Holism as a pointer

In 1809, Daniel Thayer provided this simple rationale for the Humus Theory[6]: "As humus is a product of life it is also a condition of life."

Early agricultural science proved that we can grow plants without humus,* and in this sense the Humus Theory was wrong. However, Thayer's statement also expresses a notion that is now widely accepted: recycling of the products of life is essential for maintenance of the life ecosystem. This was a remarkable insight, made before any details were known about the nature of humus or about ecosystem functions. Thayer's statement expresses a holistic perspective that is shared by today's organic agriculturalists.

The concept of holism was first formally enunciated by Jan Smuts in the 1920s.[7] Smuts advanced the notion that "the whole is greater than the sum of the parts" which is the usual definition for holism, but it was not the key concept.[8] Rather, that was closely connected with the concept of co-evolution, the idea that evolutionary change in one entity can effect evolutionary change in coexisting entities.

Two ways of adding nitrogen (N): as chemical salts and in a leguminous cover crop. Red clover, shown here in corn stubble in late spring, was seeded into standing corn after the last cultivation, just before canopy closure. Besides fixing atmospheric N, the clover conserves N released from soil organic matter after harvest of corn, feeds soil organisms that improve soil structure, and protects the soil from erosion.

Smuts considered that entities in nature co-evolve within systems that also evolve and are in a sense "creative;" that there is an innate tendency for natural systems to evolve from simple to complex and towards a state of greater perfection or harmony.

The fundamental concepts of organic agriculture—the farm as an organism, increasing productivity by enhancing natural processes and cycles, using nature as the model—are likewise holistic concepts. They recognize (implicitly) that entities within nature have co-evolved and that to maintain the earth ecosystem and its innate regulatory systems, we must maintain and enhance the integral systems rather than circumvent them.

Holism was considered a "pointer" or a guide that in itself is not highly predictive except in a general way. A holistic perspective would have predicted that circumventing natural nitrogen cycles would generate significant disharmonies within nature. Experience and scientific analysis have proved this to be correct—in retrospect. Only a holistic perspective could have predicted it in the mid-1800s. Today, certification standards prohibit use of GMOs on the same basis, while the scientific arguments pro and con are still largely hypothetical and contradictory.

If we want to realize the full ecological efficiency of farm or garden systems, by which I mean to operate them with sustained high yields, avoid waste, achieve a high efficiency in the use of inputs, and maintain the sorts of "ecosystem services" offered by natural systems, then we can make good use of the techniques and the knowledge that science offers us. Inevitably, these are incomplete and changing; the holistic perspective provides the framework in which we can make use of them nonetheless and not go too far off the track.

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