Managing soils for effective pest control
by David Patriquin

SINCE THE MID 1990S, PRECIPITATION IN MANY PARTS OF CANADA HAS BECOME MUCH MORE
EARLY IN THE 20TH CENTURY, ALBERT HOWARD, WORKING IN INDIA, NOTED THE PROMINENCE OF PESTS ON CROPS WHERE "ARTIFICIALS" (CHEMICAL FERTILIZERS) WERE USED, AND THEIR VIRTUAL ABSENCE IN THE TRADITIONAL FARMING SYSTEMS. In this article, "pest" refers to insect pests, parasitic nematodes and pathogenic microbes. Howard's observations and trials indicated that good aeration and an ample supply of humus are the keys to "healthy soils," those being soils that support healthy, pest-free plants, livestock and humans. Howard promoted composting as a means of increasing the supply of humus.[1]

Howard worked with farmers and gardeners to test, develop and promote these concepts, setting in motion the organic farming movement. For the most part however, his concepts were received with skepticism and even derision by the mainstream scientific community.[1,2] That perspective began to change about thirty years ago as the scientific study of soils and pests, and the role of "pests" in natural systems became more sophisticated and extensive.

Today, a multitude of studies have confirmed the pest-suppressing qualities of compost and biodiverse soils. Biodiverse soils include soils from natural grasslands, forests and farmland managed to support high levels and diversity of soil biota. The many and subtle mechanisms of pest suppression are gradually being elucidated. They include, but not exclusively, the following.

Mechanisms of pest suppression

Competition: high levels and diversity of soil microbes diminish the populations or infectivity of soilborne pathogens; this occurs because the soil microbes compete with the pathogens for food and space. Soilborne pathogens include some of the more intractable diseases of crops such as take-all in wheat. Biodiverse soils also contain fungi and bacteria that consume, parasitize or are otherwise antagonistic to many soilborne crop pathogens.[3]

Induced resistance: exposure to compost, compost extracts or to certain microbes (both pathogenic and non-pathogenic) can induce plants to develop resistance to a broad range of soilborne and airborne pathogens. Induced resistance is described as a broad spectrum, long lasting resistance and appears to be most effective against fungi, less so against bacteria, and least against systemic viruses.[3,4]

Natural enemies: feeding the soil stimulates the proliferation of soil biota and production of alternate prey for natural enemies such as carabid beetles; high populations can then respond quickly to pest outbreaks.[5]

Buffering of nutrient supply: soils with a high level of humus have high nutrient holding capacity. Humus and microbial biomass provide a more gradual and balanced release of nutrients than is possible with synthetic fertilizers. More balanced mineral nutrition makes crops more resistant to pests and disease.[6]

The gradual release of N (nitrogen) from humus is particularly important. Many insect pests and fungal pathogens are stimulated by lush growth and/or high N in plants (although some are stimulated by low plant N).[6,7]

Reduced stress: soils with high humus and biodiversity have improved capacity to take up and store water. This can reduce water stress. As well, the avoidance of fertilizer salts on organic farms reduces added stress due to concentration of salts when soils lose moisture. These and other types of stress increase pest problems, possibly by restricting protein synthesis, which in turn increases soluble organic N and makes tissues more nutritious to many pests.[7,8]

Albert Howard attributed the pest-suppressing qualities of compost to the ability of compost to stimulate the development of mycorrhizal associations with plants. I am not aware of any modern studies on the stimulation of mycorrhizae by compost. However, there are many reports of mycorrhizal infections protecting plants from particular diseases and pests. A variety of mechanisms are involved.[3]

On-farm studies provide further evidence of the benefits of organic management for soil health. For example, a study of 31 tomato fields on 17 farms in California, half organic and half conventional, revealed that organic farms had higher microbial biomass, more efficient N cycling, reduced occurrence of cork root disease, a higher diversity of actinomycetes, and a higher abundance of natural enemies. Overall soil quality increased with time under organic management.[9]

The fact that organically managed systems are more resistant to pests hardly needs to be confirmed for its practitioners. The studies provide a basis for fine tuning organic management of soils and compost for control of pests. For example, we now understand that some disease-suppressing qualities are fairly universal and relate to overall soil or compost quality, while others are more sporadic and relate to the presence of specific organisms.[3] In the latter case, the specific organisms may be used as biological control agents. Such agents and also complex mixtures of microbes are likely to be most helpful during the transition to organic farming, and less needed on established organic farms.

Friend or foe?

Pests, in small doses, it appears, can be beneficial. This was recognized some time ago for insect pests; many experiments showed increased yields in response to mild pest infestations, or to simulated damage.[9] “Indeed, the attainment of maximum crop yield may sometime require a certain density of ‘pest’ insects.”[10] (See aphid story below).

Likewise, certain pathogens may have beneficial effects that outweigh or at least compensate for their detrimental effects on a particular host (e.g. by inducing resistance to other pests). In natural communities, pathogens are part of the coevolutionary history that determines the botanical composition of those communities today. We are just beginning to unravel these types of interactions, but enough is known that there is concern about loss of pathogen biodiversity.[11]

Raoul Robinson argues persuasively that the high intensity of pest problems in agriculture is an aberration generated in large part by a fundamental misunderstanding and misuse of the genetics of plant resistance to pests.[12] I like to think that in a hundred years, pests will be no more—not vanquished but bearing a different name that reflects their real value as members of a biodiverse society.

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Aphids on faba beans: soil management makes the difference[13, 14]

In the 1980s during my research at Tunwath Farm, N.S., operated by Basil and Lilian Aldhouse, I became interested in why bean aphids (*Aphis fabae*) did NOT pose a problem for the Aldhouse's faba beans (also known as fava beans). Other farmers in the region had tried the crop and given it up, citing aphids as a major problem. Faba beans are highly attractive to bean aphids, in fact so much so that they are recommended as a trap crop for aphids. At Tunwath, I had witnessed a large outbreak of aphids that looked like it was going to destroy the crop. However, within ten days there was a noticeable buildup of ladybird beetles and other natural enemies, and by three weeks the aphids had been entirely consumed or parasitized. Such infestations elsewhere are described as lasting 6–8 weeks, and causing 80+% losses in grain yield, (unless controlled by using a pesticide). What, I asked, was so different about Tunwath that allowed the natural control to be so effective?

I suspected that weeds were involved. The faba bean fields at Tunwath were very weedy, in contrast to the largely clean fields on other farms. Basil's philosophy was to use the minimum control needed to prevent weeds from causing significant losses, but otherwise to tolerate them. He saw that the weeds provided food for wildlife and considered them to be important as "self-seeding cover crops." We discovered that weeds also augmented the regulation of aphids by both "bottom-up" processes (limitation of aphid proliferation by food quality) and "top-down" processes (destruction of aphids by natural enemies).

Aphids stick their stylet (piercing mouthpart) through several layers of leaf tissue to penetrate the phloem and can only do so on young tissue, hence they regularly move to new food sources as existing ones become unpalatable. Winged forms are produced when they migrate; otherwise they are wingless and multiply quickly by non-sexual means. A cascade-like movement of the aphids between forest, pasture and crop fields has been described (see diagram on next page). The diversity of vegetation at Tunwath provided year round habitat and supply of food for the aphids. That might seem undesirable and a reason to try to break the on-farm aphid cycle, but the cycle also sustained the aphid's natural enemies.

Aphids moved onto weeds in the faba bean field during the early vegetative growth of the crop. Natural enemies appeared in aphid colonies within 10–14 days. As well as providing food for aphids, early flowering weeds such as Canada thistle and wild radish provided food for the nectar- and pollen-feeding adult stages of natural enemies such as syrphids and parasitic wasps whose larval stages feed on aphids. Thus, the weeds allowed a reservoir of natural enemies to be established in the crop field well before the aphids moved onto the crop. This greatly reduces the time required for natural enemies to catch up with the aphids once they begin to proliferate on the crop.

We discovered a role of weeds in aphid control almost by accident. We had placed weeded plots throughout a faba bean field to examine the effect of the weeds on crop yield. At flowering, there were three times as many faba bean plants with aphids in weeded plots than in the adjacent unweeded areas. In another experiment, intercropping cereals with faba beans reduced the number of aphid-infested faba bean plants by 10-fold.

Various evidence suggests the following explanation. The reproductive rate of aphids is proportional to the supply of amino acids in the phloem. Legumes nodulate and fix gaseous N from air when the supply of mineral N in the soil is deficient; when it is not, they preferentially take up soil N. Weeds (or cereals) among the faba beans take up and thereby reduce soil mineral N to a level below that which suppresses nodulation (about 5 ppm nitrate-N for faba beans at Tunwath). This causes the faba beans to nodulate more and to obtain more N from nitrogen fixation. Under those conditions, there is closer coupling of N uptake and assimilation than when mineral N predominates, and consequently accumulation of amino acids in the phloem is reduced. The reproductive rate of the aphids is restricted accordingly. When the weeds are removed, the soil N supply increases, phloem N increases, and the plants are more attractive and more nutritious to the aphids. Other legumes have also been found to more resistant to pests when they are well nodulated.

It also turned out that the weedy plants had higher yields than the plants in the weed-free plots. That's because the benefits of increased nodulation outweigh any losses due to weeds. This beneficial interaction between weeds and the crop works only if levels of soil nitrate are relatively low (e.g. 10 ppm) to begin with. When we fertilized plots with urea, weeds overgrew the crop and greatly reduced yields. On another organic farm where soil nitrate levels were 5 to 10 fold higher than at Tunwath, weeds overgrew the faba bean crop. In spite of an abundance of natural enemies, large aphid infestations caused massive yield loss.

Managing the soil N to keep it low under faba beans was thus critical for favourable crop-weed and crop-aphid interactions. At Tunwath, faba beans followed winter wheat in the rotation. The highly "immobilizing" (nitrogen robbing) wheat residues were worked into the soil following harvest. This was a deliberate strategy to lower soil nitrate levels under the faba beans and thereby stimulate nodulation and nitrogen fixation.

There is a final interesting twist in this aphid story. Our data indicated that seed yield of aphid-infested plants at Tunwath Farm was not reduced and was even slightly higher than those of non-infested plants. A British study found that when aphid infestations were allowed to run their normal course, about 6–8 weeks, there were large yield losses. However, when the infestations were allowed to get started but then artificially terminated at 3 weeks, there was a large increase in yield.[15] They attributed the benefits to aphids pruning the youngest flowers, which would not produce mature seed in any case. Gardeners commonly lop off uppermost flowers of Windsor beans to achieve the same effect. It is interesting that aphid infestations normally occurred at 3–4 weeks at Tunwath, not at 6–8 weeks as in Britain.

Faba beans are an ancient crop, still widely used in the developing world without use of agro-chemicals. Until the mid-1900s when cheap imported soybeans became available, faba beans were the major grain legume in Europe. Aphid infestations are blamed for the decline. However, it seems unlikely that faba beans could have become a major crop had it routinely suffered massive yield losses due to aphids. It is more likely that short infestations, rather than devastating long ones, were the norm under the conditions in which this crop was domesticated and underwent most of its subsequent evolution (i.e.

that low soil N and the presence of weeds and pests are part of its coevolutionary environment).

BOX 1

Guidelines for enhancing the pest-suppressing qualities of compost and soil

Compost production

- Consider special measures to facilitate recolonization of compost after the heating phase. Many beneficial microbes are eliminated during the heating of compost. Thus composting on top of soil (versus a concrete pad) and regular turning of compost after the heating phase may help to establish a beneficial biota. It may be helpful to introduce some good soil to the compost once temperatures start to decline or to incorporate compost in field soil several months before planting. Moisture content following peak heating should be at least 40 to 50% moisture to facilitate recolonization and compost should be cured for 4+ months.[3,16]

Feeding the soil

- Employ residue management systems that break residues up and incorporate them near the soil surface to stimulate colonization and aerobic decomposition by soil microbes. On the other hand, strict no-till systems increase a number of soilborne pathogens that affect foliage (e.g. glume blotch) and roots (e.g. take-all). This is because large, infested plant fragments can act as refuges from competing microbes.[17]
- Always use a well matured compost in seedling flats (where it is particularly effective against damping off and root rot), seedbeds and on growing crops.[3]
- When fresh residues or immature compost are applied to soil, allow a digestion period of 2–3 weeks before planting a crop; fresh residues stimulate root pathogens.[16]

Providing good drainage

- Ensure good surface drainage and aeration of soils; break up hardpans to allow better root penetration. When root growth is restricted by poor aeration, hardpans or other factors, the roots tend to get leaky and infection by soilborne pathogens is more likely.[18]

Mineral balance

- Potassium supplements can improve pest resistance if soil levels are low enough to restrict crop growth (e.g. as indicated by leaf tissue tests); above minimal levels, there seems to be little benefit.[6]
- Provide adequate, but not excessive, amounts of phosphorous.
- Calcium supplements (e.g. lime) can help to control many soilborne diseases (e.g. damping off). However liming increases a few diseases (e.g. potato scab and take-all), so find out what is known about lime/pH effects before liming to control a particular pest.[3, 6]
- Match crop demand for N (nitrogen) and soil supply as closely as possible.
  - Elevated plant N stimulates many parasitic fungal pathogens, notably rusts and mildews and many insect pests, including sap-feeders, chewers and mites.[6, 7]
  - A deficiency of N stimulates some leaf eating pests, many facultative fungal parasites (e.g. leaf spot diseases caused by *Alternaria* spp) and most bacterial diseases.[6, 7]

• Reduce soil nitrogen under legumes to stimulate nodulation and nitrogen fixation. Incorporate low N residues in soil, intercrop and rotate legumes with N-demanding crops. Ensure that appropriate rhizobia are present in the soil to nodulate the legume. Well nodulated plants are more pest resistant.[14]

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