Building healthy soil from air and organic matter

by David Patriquin

RECYCLING OF RESIDUES, SUCH AS ANIMAL MANURE, GREEN MANURE CROPS AND CROP RESIDUES, IS A KEY PRACTICE OF ORGANIC FARMING. The practice returns nutrients, builds up humus, and feeds the soil life. Recycling residues is essential for maintaining good soil structure, which in turn promotes aeration, infiltration and storage of water, and reduces the energy required for tillage.

Under some conditions, however, the decomposing residues create an environment that, for a period, is unfriendly to crops. This could be due to reduced oxygen in the soil pores, allelopathic effects of residues, the nutrient-robbing effects of low nitrogen residues, or some combination of those factors.

In this article, I will focus on the problems that occur when fresh (i.e. unweathered) residues are incorporated in soil and either decompose under poorly aerated conditions or create such conditions. The combination of decomposing residues and poor aeration can have mild to strongly adverse effects on crops, but may be difficult to diagnose. Such effects are most likely to occur in moist climates and in heavy soils.

> *"The single most important task of farmers is the management of soil air"*
> —Don Shriefer

Effects of poor aeration on crops

The adverse effects of poor aeration are most damaging to crops at the germination, seedling and early vegetative stages of growth. There are three major ill effects of poor aeration.

First, low oxygen and/or high carbon dioxide levels impair normal root development and functioning. This can result in reduced uptake of water and nutrients in both early and later stages of growth.

Second, both poor aeration and wetness stimulate root pathogens. The water provides a medium for movement of motile spores of *Pythium* and *Phytophthora* (root rot fungi). Low oxygen levels cause roots to become leaky and release substances which stimulate the growth of pathogens. They also stress plants, making them more susceptible to pathogens.

Third, when oxygen is depleted, decomposition is incomplete. Consequently, levels of certain products of microbial metabolism (e.g. acetic and butyric acids) accumulate to the point that they are phytotoxic. This means that they impair normal plant functioning in some way. At times the effects can be dramatic. For example, seed germination may be completely inhibited, or growth may be severely stunted. More often however, the effects of poor aeration are subtle. For example, germination rates may be reduced or germination slowed down a few days; root growth may be impaired but not drastically.

Aeration limitations may be difficult to diagnose

Recognition of aeration as a limiting factor is pretty straightforward when there are obvious drainage problems such as on a low-lying piece of land. However, it is not always obvious. Problems with poor aeration can occur when there is a juxtaposition of (i) wet weather, (ii) high rates of oxygen consumption following recent incorporation of fresh residues, and (iii) planting of a crop.

Aeration limitations are often attributed to other factors. For example, poor seed germination might be attributed to bad seed. Stunted growth might be attrib-

Glossary:

Aeration limitation: reduction in crop growth or yield due to occurrence of low levels of soil oxygen at some stage in the crop cycle.

Allelopathy: suppression of one plant species by another through the particular compounds secreted from roots or released from the plant residues.

Pathogen: an organism (e.g. virus, fungus or bacterium) capable of causing disease in other living organisms.

Phytotoxin: a substance that impairs normal plant development or functioning.

Ridge tillage: a reduced tillage system in which the crop is planted on top of ridges that are maintained from year to year.

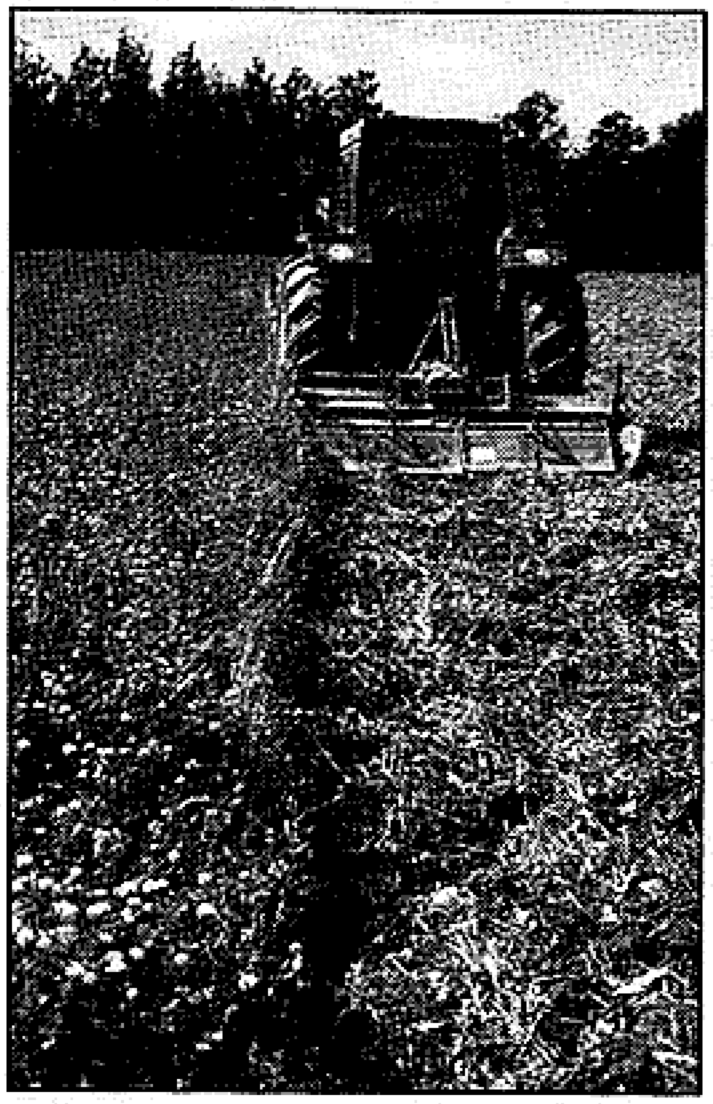
uted to severe nutrient deficiency or nutrient immobilization by residues. Delayed crop germination or slow early growth could result in severe weed pressure, which would be attributed to poor weed control. Root diseases might be attributed to infected seed. Low yields may be attributed to poor weather or insufficient nutrients, even though the cause is poorly developed roots limiting the uptake of water and nutrients.

The milder manifestations of poor aeration tend to be less severe under conventional management compared to organic management. In conventional farming, seed protectants can counteract root pathogens. Herbicides can counteract or mask increased weed pressure due to delayed germination of the crop. Applying soluble forms of nutrients at saturating levels may compensate to some extent for impaired root functioning. Farmers changing to organic production might be inclined to write off lower yields as simply a consequence of organic methods, rather than to poor aeration.

When to anticipate problems

A key to recognizing aeration limitations associated with decomposition is to be aware of the conditions conducive to their occurrence.

First, there must be decomposing residues. The greater the quantity and the fresher they are, the more oxygen they will consume and the higher the likelihood of oxygen deficiency and subsequent production of phytotoxins. Turning in a few weeds or cereal stubble is unlikely to cause problems, but turning in a full crop of stubble, straw and weeds, or a field of flowering clover could cause problems. Residues that have been left on the surface of the soil for a long time before being turned in will consume much less oxygen than will fresh residues.



Green manures and other fresh residues turned into soil consume a lot of oxygen as they decompose.

Second, consider the soil and weather conditions. Well-drained sandy soils are not very likely to develop aeration problems. Silt, loam and clayey soil are more prone to aeration limitations. Plow pans can cause poor surface drainage. Heavy machinery can compact soil, and intensive tillage can pulverize it. Both destroy the large pores, which aerate the soil, or make them smaller, thereby reducing oxygen flow into the soil.

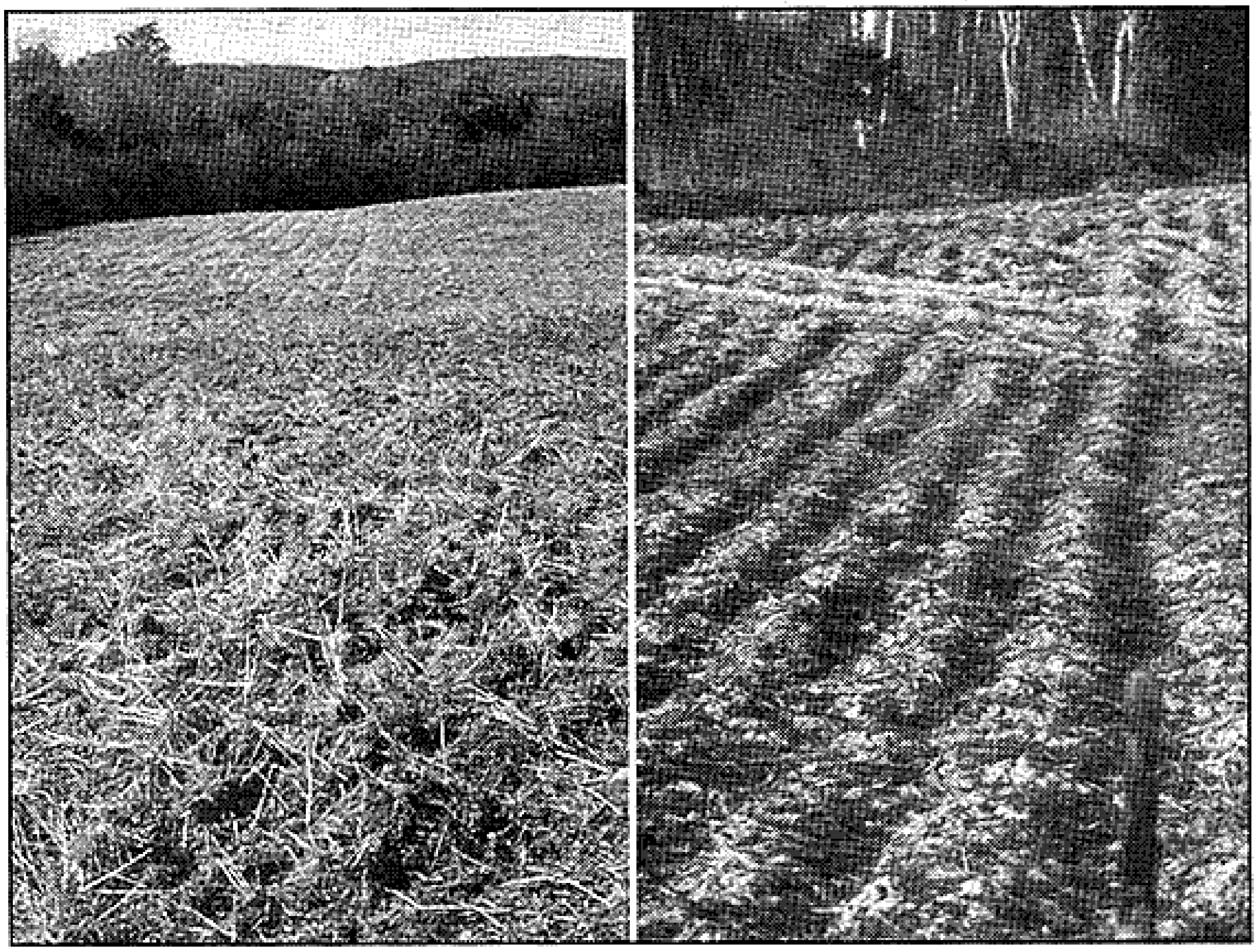
Cool wet weather slows down microbial activity and tends to preserve phytotoxins or delay their production. Thus, residues incorporated in the fall could create a problem with phytotoxins for a crop sown in April or May. A green manure crop incorporated in spring, followed by heavy rains could generate high levels of phytotoxins more quickly. These harmful substances will remain as long as the soil remains wet, and a bit longer.

Water has two effects. 1) Some moisture is required for microbial activity to get going. Residues turned into a very dry soil won't do much of anything until there is some moisture; then there will be a surge of microbial activity and oxygen consumption. 2) A lot of rain combined with imperfect surface drainage will plug up larger soil pores and restrict aeration. Temperature is another consideration; microbial activity doubles for every 10°C rise in temperature.

Symptoms of aeration problems

One symptom is simply poorer growth or lower yields than expected, or less of a boost from green manures than you might expect. In such cases, ask the question, "Were conditions conducive to poor aeration when the crop was planted?" Ask the same question for a crop that is excessively weedy from early in the season, or if you notice erratic germination or poor early growth. Look at the roots to see if they are diseased, small or abnormally developed.

There may be other visual clues, such as highly variable growth of the crop within a field. I have noted this particularly in winter cereals planted after incorporating green manures. There may be patches that are light green, or shorter, sometimes they are regularly distributed and related to the distribution of tile drains or of residues before incorporation. A second clue is the prominence of chickweed in areas of poor crop growth. Walters and Fenzau[1] maintain that chickweed is symptomatic of overfeeding soils with organic matter, or of a soil not being able to "digest" the organic matter. My observations, formal



Improved surface drainage doubled the yield of oats. Photo at left shows a field in the fall after incorporating residues from a fava bean crop by rotovation. At right, the same field has been ridged using a tool bar with shanks and 8 cm (3") shovels. Ridges were spaced at 70 cm (28") and were 15–20 cm (6–8") high. Protuding pieces of residue act as wicks to increase water uptake. Ridges were broken down just before seeding in the spring.

and informal, tend to support that contention. However, absence or low prominence of chickweed should not be taken as evidence for absence of phytotoxins, as other factors also affect their occurrence (e.g. numbers in the seedbank).

Solutions

Following are some possible means of dealing with, or avoiding, aeration limitations associated with decomposition.

1. Allow more time for decomposition. Plant crops after the low oxygen and phytotoxic phases have passed. Turn residues under earlier than usual or delay seeding. This could be appropriate when green manures or other fresh residues are incorporated in the spring prior to summer-sown crops, or in summer prior to fall-sown crops. The minimum interval between turning residues in and seeding will vary according to the particular site, residue types, crops, weather and other factors. Various reports suggest that at least three weeks and up to eight or more weeks may be required for dissipation of toxins.

2. Improve surface drainage. This particularly applies to crops sown in the spring after incorporating residues in the fall. Most microbial activity takes place near the surface of the soil, and residues should normally be incorporated within a few inches of the surface. That is where we need to ensure good aeration. Raised beds (for gardens) and land forming (for whole fields) are possible approaches. Don Schriefer, who I regard as the guru on managing decomposition processes, is a strong advocate of ridge tillage for many reasons, a major one being to ensure good aeration.[2] Ridge tillage can be effective on poorly drained land.[3]

The ridges do not have to be permanent to provide desirable conditions for decomposition. In a "Modified Ridge System," ridges are prepared at the primary tillage stage and leveled prior to planting.[2] This is an effective replacement for mouldboard plowing because the ridges retain the benefits for surface drainage achieved by mouldboard ploughing, but keep residues near the surface for better soil conservation,

The Tunwath Farm story

Yields of oats at Tunwath Farm were chronically low and excessively weedy after adopting organic methods. The transition included implementing a regular four-year rotation of crops consisting of fava beans ➢ oats underseeded with red clover ➢ clover grown for another year and incorporated followed by the planting of winter wheat ➢ winter wheat. There was also a switch from a mouldboard plow to a rotovator to incorporate residues. A clue to the cause of the low yields came from trial planting of oats in the different stages of the rotation. Yields were low in the stages that followed incorporation of large amounts of residues in the previous fall. That and other observations (e.g. no response to fertilizers) suggested that there were aeration/phytotoxicity problems. These were resolved by ridging the soil after rotovation to improve surface drainage. The results of this small change in practice were dramatic; yields approximately doubled, going up to the levels achieved before conversion. The increased yields were attributed to improved aeration and reduced formation or faster breakdown of phytotoxins, and to faster warming up of soil in the spring. (See photo above.)

water intake and decomposition.

At Tunwath Farm in Nova Scotia, Basil Aldhouse resolved limitations associated with decomposing residues by adopting a Modified Ridge approach.[4] In that case, he ridged the soil after turning in residues by rotovation (see box). Other types of equipment can be used to incorporate residues and ridge soil in one step, also with greater energy efficiency.[2,5] Shriefer describes a twisted shank tool (disc chisel) equipped with a gang of cutting coulters up front. The coulters are spaced at 19 cm (7.5") and run directly in front and between each shank. They cut residues into specific lengths to prevent plugging and so that they can function as wicks for the penetration of water.

3. Spread residues evenly before incorporating them. Oxygen depletion and the production of phytotoxins associated with residues are usually quite localized. Seeds or roots must be close to pieces of residue to be affected. Increased residue-soil contact helps to reduce the size of affected zones and the likelihood of plant contact with those zones. Some advocate fine chopping of stalks, however Schriefer[2] contends that is not desirable because it destroys the wick action of larger residue pieces and covers the surface with small pieces of light coloured stalks that slow warming in the spring.

4. Get the mouldboard out and turn the residues under the seedbed. It's not a good idea to do this regularly because of the problems associated with mouldboard plowing, but it will work in a pinch. For example, use the mouldboard if there are a lot of weeds and old residues to be

Ridge planting of vegetables ensures good aeration in the root zone. Furrows were mulched with residues from a grain crop.

incorporated when it's planting time because it was not possible to incorporate residues in the fall.

5. Remove residues. In general, phytotoxins associated with decomposition will not exist on a farm where residues are removed for livestock bedding and returned as mature compost, which has a low rate of oxygen consumption. Note however, that fresh manure or immature compost, applied in quantity, could both contain and produce phytotoxins. For stockless farms, removing residues is a less sensible option, but removing some or all of the residues, rather than working them in, might make the difference if it is urgent to get in a crop.

6. Maintain and improve soil structure by regular feeding of soil with plant and animal residues or compost, conservative use of tillage, cover cropping and minimizing compaction by machinery.

A wrinkle: allelopathic residues

In some cases, the ill effects associated with freshly incorporated residues could be due to allelopathic effects. These are associated with phytotoxic chemicals, commonly phenolic compounds, contained in the living plant and secreted by roots and/or released from fresh residues. Alfalfa, rye, some clovers and brassicas are considered to be allelopathic. Distinguishing true allelopathy from other effects of the living plants or their residues is difficult.[6] Regardless, the guidelines offered above to avoid problems associated with with poor aeration are generally applicable to avoiding allelopathic inhibition of crops by incorporated residues. For example, the "clover-maize" syndrome (poor growth of corn planted immediately after ploughing down clover) is usually attributed to allelopathy; it is avoided by allowing three weeks between incorporation of residues and sowing.[7]

Ill effects of mulches on crops due to allelopathy or stimulation of pathogens are known to occur in some no-till or minimum-till systems, in which most residues remain on the surface and a crop is planted shortly after killing the previous crop (e.g. in fall planting of cereals).[8] Solutions include moving residues away from a strip where the seeds will be planted, or tilling the residues into the soil in that strip ("strip tillage"). Normal residue cover is maintained on at least 2/3 the total area.

Experiment!

Each farm has its own unique features and experiments or trials may be necessary to identify aeration/decomposition limitations and the most effective ways of dealing with them. Removing residues or reducing their quantity, planting at different intervals after incorporation, different systems of spreading and incorporating residues, and ridging soil are some of the variables that might be tried out in strips within a field or on part of a field.

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