THE ECOLOGY OF TRANSITION

by David Patriquin

From 1977 to 1986, I and a succession of Honors Biology students conducted experiments and observations at Tunwath farm, a laying-hen/grain farm in the Annapolis Valley, Nova Scotia. I went there originally to look' at fababeans. Basil Aldhouse was one of the few farmers in theEast growing this crop.

Basil and his wife Lilian were innovative and their farm unusual in other respects. He was one of the first farmers in the region to grow winter wheat. The oat yield in 1975 was the highest recorded in a provincial soils and crops competition. This was achieved using conventional methods, but Basil had also become convinced that this system of production was not sustainable. The next year he stopped all chemical inputs and began to experiment with organic techniques. When he did so, the cereal yields dropped by about 50%.

I became intrigued by this "farm scale experiment" and over the next two years attempted to determine why the cereal yields had dropped so sharply. They were suffering from a deficiency of nitrogen; we knew that, but why, when he had legumes on one-third of the land and was recycling manure? Our initial studies showed that the problem was not a matter of how much nitrogen was entering or leaving the farm (Figure 1). Even allowing for large losses of nitrogen as ammonia from the roost,the input of nitrogen via legumes should have been enough to support cereal yields of 4 to 5 tonnes per hectare.

Basil Aldhouse observing weeds and soil after harvesting wheat in the fall of 1981. His observations of deteriorating soil structure and loss of earthworms after 15 years of chemical farming prompted him to begin farming organically in 1976.

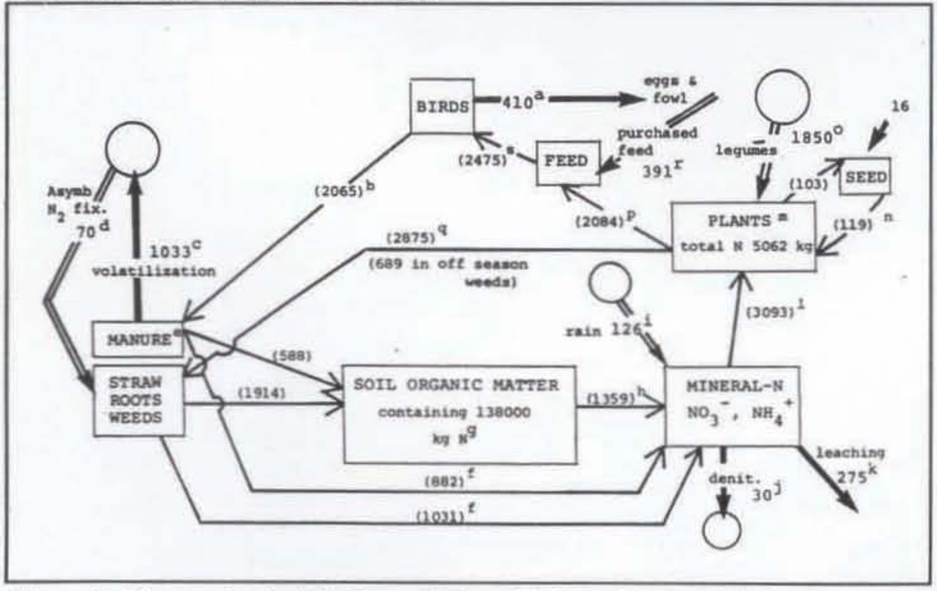

Figure 1. Nitrogen budget for Tunwath farm in 1979. *Numbers in brackets are flows of N within the farm. Big arrows and accompanying numbers not in brackets are flows of N into and out of the farm. Circles represent the atmosphere. Units are kilograms of N per farm per year (30 hectares of field crops).*

The problem lay in what happened to the nitrogen once it entered the farm. In essence, nitrogen was accumulating in the soil as SOM (soil organic matter) at the expense of increased crop production. SOM is nitrogen rich, containing about 5% N by weight. In time, as SOM increased, the supply of mineral nitrogen (ammonium and nitrate) which the crops could draw on would also increase. That was O.K., but our calculations indicated that it would take 100 years for the SOM to accumulate to the level that the annual supply of mineral nitrogen would be sufficient to support good yields. Waiting for SOM to build up was not a practical solution to the problem!

Instead we began to look at ways of managing the system so that less N went into SOM, but we also wished to maintain SOM. This we envisioned was a matter of (i) establishing a regular rotation of legumes and non-legumes; (ii) using more manure on certain crops and fields and less on others (i.e. apply it where you get the best response); (iii) correcting any mineral imbalances, and (iv) working out a system of weed management allowed weeds to function as "self seeding cover crops", while at the same time minimizing any detrimental effects on crops.

CROP ROTATION

Taking these considerations into account, in 1979/80, Basil initiated a four course, cereal-legume rotation: fababeans — oats underseeded with clover — clover (used as green manure for winter wheat) — winter wheat. Chicken manure was applied at a rate of 5.6 tonnes/ha to winter wheat in the fall, and none to oats — that was part of our strategy to apply manure where there would be the biggest response (oats are considered to be"non demanding"). Almost all straw was left in the fields; residues were incorporated by rotovating. The sequence of winter wheat to fababeans was set up to stimulate N2 fixation in fabas by incorporating a lot of low N wheat residues before hand.

We expected that this new sequence would result in more efficient cycling of N, and in improvement of yields. It didn't (Fig. 2). Yields declined even further. By 1982, this trend was clear for oats, but it wasn't until 1984/85 that we had a long enough sequence of data for fababeans and wheat to reveal that there had been (fabas) or was still (wheat) a chronic problem with these crops.

We were baffled by the low oat yields because oats usually do well in organic systems, and they had performed exceptionally well on this farm before the transition. In 1982, I conducted a large number of trials on oats including tests of 6 different cultivars, on different fields (Fig.3), and with 17 different combinations of minerals, lime, and manure.

To make a long story short, results from these experiments and other observations suggested that our problems were related to production of phytotoxins in decomposing residues.

Because the symptoms of phytotoxicity are multiple and not unique and because the conditions that result in production of phytotoxins (lots of residues; poor aeration) have other deleterious effects on crops, phytotoxicity can be difficult to diagnose. Symptoms may include one or more of: poor germination, stunting, chlorosis, injury to roots, damaged nutrient absorption, wilting, death of plants, or just generally poor growth.

Oats followed fababeans in the rotation. Fababeans were harvested in October, and large amounts of residues were incorporated by rotovation late in

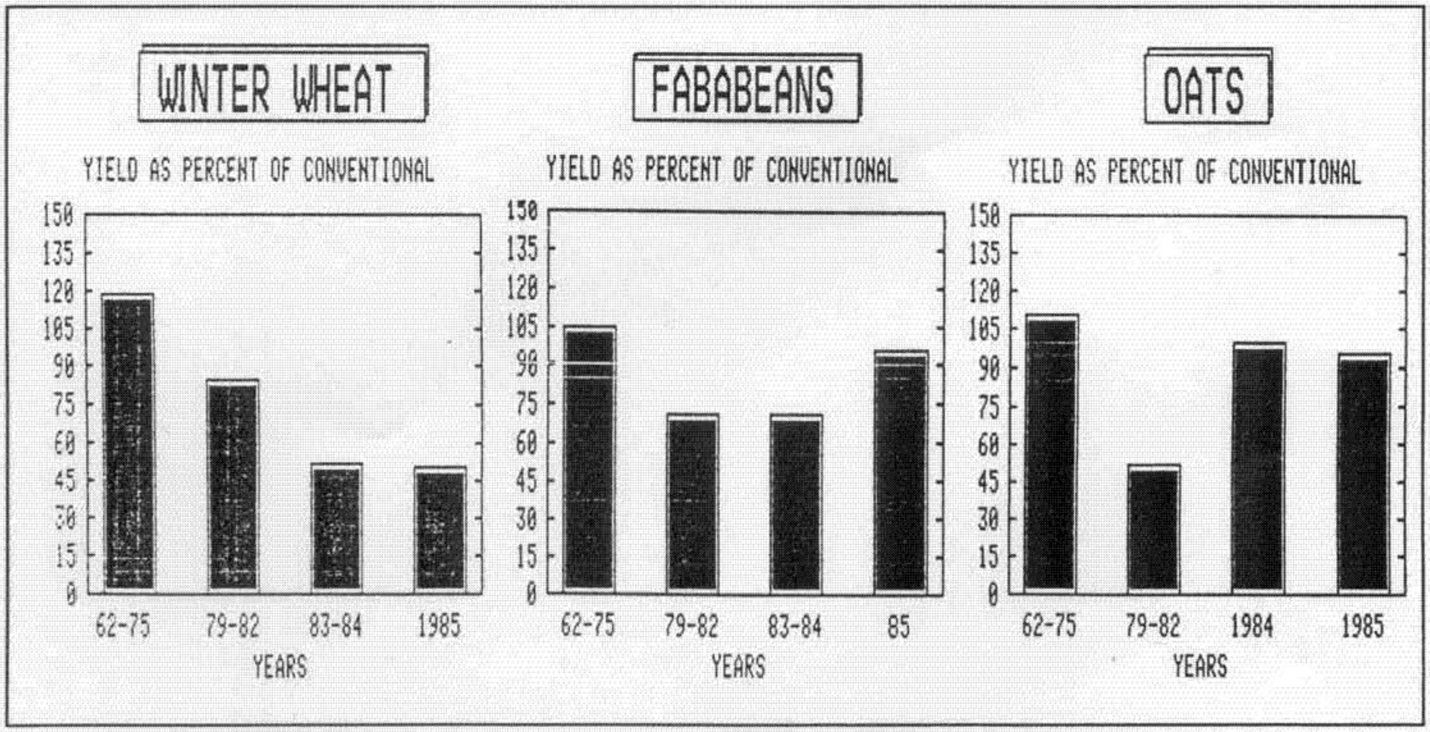

Figure 2. Combined yields for crops before and after the switch to organic methods (1976). Yields are expressed as percentages of recent provincial averages (cereals) or as percentages of cited attainable yields (fababeans).

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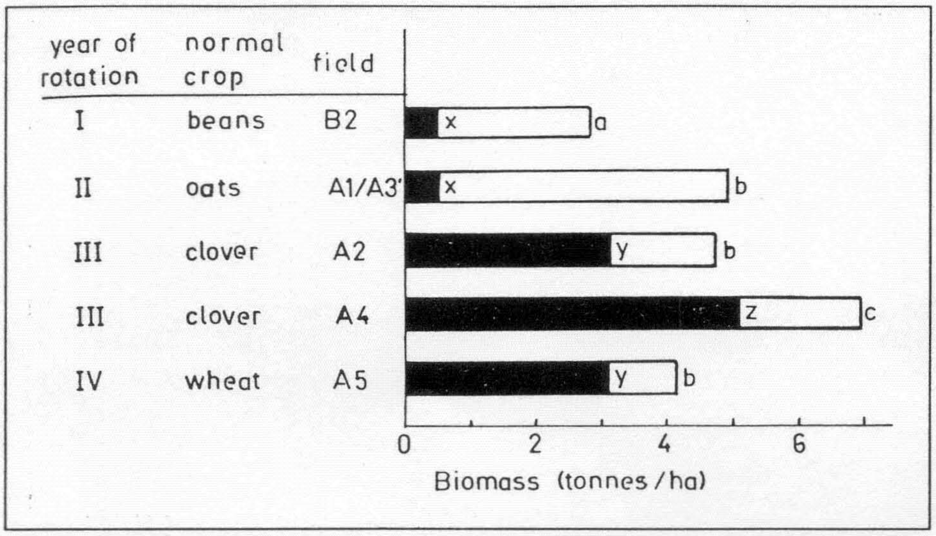


Figure 3. Oats (black bars) and weeds (open bars) in oat plots established in different phases of the rotation in 1982. *Oats were severely inhibited in fields in which large amounts of residues had been incorporated the fall before.*

the year when it was wet and cold. Under these conditions, anaerobic processes predominated and organic acids accumulated and remained until spring, when they retarded initial growth of oats. Then the weeds took over and crop yields suffered (Figure 3).

GOOD AERATION WAS THE KEY

The solution to this problem came from Basil's reading about Don Schrieffer's theories in ACRES USA; he stresses the importance of aeration of soil (which in this case would stop the organic acid production), and is a strong advocate of ridging the soil to promote good surface drainage. Basil was not happy with rotovation of residues because it leaves a fair amount of residue on the surface, and leaves the surface flat which tends to keep it cold.

So in the fall of 1983, he equipped a tool bar with six right hand throw shanks and 3 inch shovels which he pulled through a field after rotovating fababean residues. This left the soil in a nicely ridged condition and effected good mixing of residues within the soil (see photo) without turning the soil over or without residues occasionally clumping together as they can do with chisel ploughs.

RIDGING IS THE CRITICAL STEP.

The next spring, there was the nicest crop of oats since 1975! Not only did the yields improve but the supply of soil nitrogen doubled, and so did oat protein content. We were able to repeat this the following year, and subsequent studies confirmed that ridging was the critical step. Likewise, we found that ridging or mouldboard plowing (which also ridges the soil) benefited fababeans, compared to incorporation of wheat residues without ridging.

That left winter wheat to improve. A variety of observations suggested that winter wheat had also been inhibited by phytotoxins, in this case originating from clover residues which were incorporated in late July. Microbial activity is restricted in August by low moisture. Winter wheat begins to grow at a time of decling temperature and onset of fall rains — all of this (lots of residues, low temperatures, and wet soil) are conducive to accumulation of phytotoxins. A solution, we surmised, was to incorporate the clover residues earlier, in this case early June, when the clover was near peak biomass anyway.

This would also allow us to insert a "cleaning phase" in the rotation for control of Canada thistle. Rotovation of clover residues in early June would be followed by shallow cultivation at 3-week intervals. Early vegetative growth of Canada thistle consumes sugars stored in the rhizomes. Research in the 1950's showed that after four or five cycles of allowing it to grow and then cultivating or mowing, sugars are lowered to the point that the plant is critically weakened. In our system, any surviving plants would be supressed by the winter wheat, as the wheat would be well established in the ensuing spring before temperatures were favourable for thistle.

We were never able to properly test our ideas on wheat. Basil died suddenly in the spring of 1985. Today, Lilian operates the farm on a reduced scale, and the precise tillage practices and rotation vary from year to year according to the help she is able to get. But the health of the land is maintained — no chemicals are used — and hopefully, through our documentation of his farm scale experiments, Basil's efforts can still benefit other farmers.

There are so many other things that we learned or learned to inquire about from our time at Tunwath that I can only outline some of the main points. A lot of them will already be familiar to organic farmers.

OATS

Oats differ in a fundamental way

from other cereals. When they are not inhibited by poor aeration or phytotoxins, oats can take up 100+ kg of N on soil from which other cereals can take up only 50 kg N. We think that under favourable conditions, oats form associations with beneficial microbes which help break down certain fractions of the humus. This process is inhibited by high levels of soluble N resulting in "feedback control". N is released according to the requirements of the crop and there is no excess to stimulate weeds or be leached. Marcos Alvarez, a microbiologist from Brazil, is studying this phenomenon for his PhD research at Dalhousie University.

WINTER WHEAT

This crop, (or modern varieties of it) is on the other end of the scale from oats; it seems unable to prime the breakdown of humus in the way oats do, and usually needs added fertilizer (manure, compost), to give maximum yield. It is very sensitive to poor aeration especially under organic conditions. I use the patchiness of leaf coloration and of height in winter wheat as an indicatotor of variation in soil structural quality. (You can't do this on a conventional farm because the high levels of added N will compensate to a large extent for poor structure.)

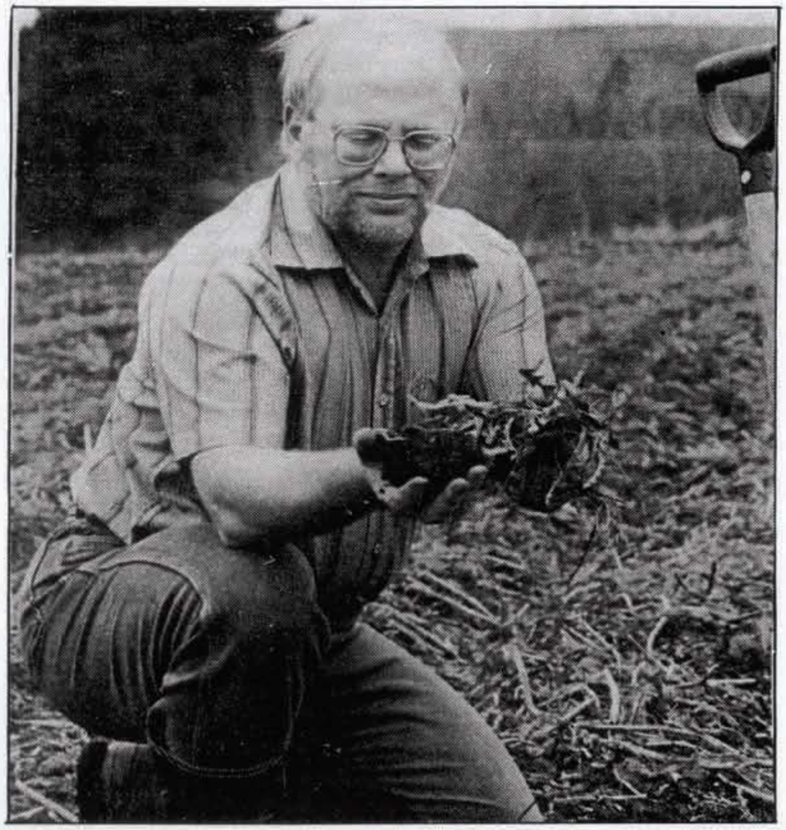
FABABEANS

A fantastic crop for organic farmers where it can be grown — more or less where corn can be grown — but it suffers when temperatures exceed 28-30°C. This crop does better under organic than under conventional management. It's good to incorporate low N residues in the fall before planting fabas and to ridge the soil. If planted in 7 inch rows at 200 lbs seed/acre, quick canopy closure will help in weed control.

pH AND LIME

Basil had Dept. of Agriculture soil analyses from the early 60's to 1978, and we took suites of soil samples in 1980, 1983, and 1985. The farm is in a region of "naturally" acid soils where under conventional management large applications of limestone are required to maintain pH. Remarkably, after the switch to organic methods, and cessation of use of fertilizer and lime, pH increased and stabilized at desireable values. Increase in pH after adoption of organic methods is a common observation of organic farmers, and is due in large part to recycling of nitrogen and use of legumes rather than fertilizers to provide net inputs of N. The hydrogen and nitrogen cycles are closely linked; close the nitrogen cycle and you also go a long way towards closing the hydrogen cycle, resulting in a better–buffered system.

Not only did pH stabilize, but between 1975 and 1980, Calcium and Magnesium in surface horizons INCREASED by 29 and 92% respectively. We think that during the period of intensive chemical use, large amounts of limestone were leached into the subsoil; under organic management, leaching decreased, and upward movement in-



Patriquin examining earthworm laden dandelion roots in spring of 1985. Earthworms are important in aeration of soil, and in vertical recycling of nutrients; Patriquin thinks they were responsible for movement of approximately 3 tonnes /ha of lime from the subsoil to the surface horizons in the first 3 years of the transition. Note soil that had been ridged following incorporation of fababean residues by rotovation in the fall; residue pieces protruding from the soil act as wicks which assist in penetration of water.

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creased resulting in a net movement of lime to the surface horizons.

The increase in lime in surface horizons was too fast to be accounted for by purely physical phenomena, and we suspect that dandelions and earthworms were involved. Dandelions were much more abundant post-1975, and with them, earthworms (if you want to find earthworms, dig up some dandelions). Earthworms need a continuous supply of calcium, but will excrete excess Ca if they encounter calcium–rich material. So we postulate that the dandelions created channels to the subsoils for earthworms, and the earthworms in turn transported calcium from deeper horizons to the surface (photo). After 1980, levels of Ca and Mg began to decline, but at much lower rates than they had under conventional management. This meant that we could maintain levels by infrequent applications of very coarse limestone.

POTASSIUM

The potassium status gradually improved under organic management, we think because increased biological activity enhanced the weathering of soil minerals. This does not occur on all organic farms, and I am trying to find out why.

PHOSPHORUS

Phosphate fertilizers had been routinely recommended on the basis of soil analyses before the switch to organic methods. We found no evidence for phosphorus limitation of crops under organic management. Chicken manure solubilized phosphate, and the small amounts of P going in the farm as dicalcium phosphate feed supplement were sufficient to balance losses.

NITROGEN FIXATION

It is often assumed that in organic system, there will not be enough mineral nitrogen to supress N2 fixation by legumes. This is not so. We estimated N2 fixation by clover and fababeans in different fields and years to vary between 15 and 205 kg per hectare per year. N2 fixation is highest when low N residues are incorporated in the soil before legumes are planted; the low N residues consume soil N, forcing the legumes to fix more N from the air. Then more of the soil N is left for the subsequent non-legume crop.

CHICKEN MANURE

Chicken manure does not build up organic matter. The garden soil, which received the equivatlent of 10-15 tonnes/ha of chicken manure annually, had the lowest organic matter content on the farm (2.8%); pasture soil had the highest (7.3%).

Photos illustrate Basil's simultaneous use and control of weeds. Wild radish was the predominant weed in the summer crops. It was kept at manageable levels by a rotation that included winter wheat. At left, wild radish has germinated between rows of winter wheat, about the 3rd week in September. The radish protects the soil where the wheat cannot, and conserves nutrients that might otherwise be lost by leaching. Mid photo illustrates frost-killed radish in December, forming a protective mulch for wheat. Right, in spring the succulent residues decompose quickly turning over the contained nutrients, and leaving an almost pure stand of wheat.

WEEDS

I didn't expect to study weeds when I went to the farm to look at fababeans, but it is the aspect that I became most fascinated with. Our nitrogen budget (Fig.1) showed that off-season growth of weeds was important in the conservation of N. Basil did not get upset about such weeds, and deliberately allowed them to grow as "self-seeding cover crops". So instead of asking "how do you control weeds without chemicals?", we begin to ask "how much control is necessary?" That is, what levels of weeds could we allow in crops without incurring an unnaceptable decline in yields?

It turns out that the answer varies according to the crop and to how nutrients, especially nitrogen, are being managed. In legume crops, high levels of soluble N tip the competitive balance in favor of weeds; then a lot of cultivation is necessary to keep them from causing large reductions in yield. In contrast, at modest or low levels of soil N, some legume crops may benefit from the presence of weeds. We think this is because the weeds consume soil N, stimulating the crop to fix atmospheric N. For non-legumes, modest levels of soluble N favor the crop providing there is good weed control in early stages; allowing some weed growth in later stages seems to benefit the crop.

Many observations we made of weeds at Tunwath concur with reports in the informal literature on use of weeds as indicators. Some examples: Fenzau, writing in ACRES USA, maintains that chickweeds are indicative of incomplete decomposition of organic matter. At Tunwath, chickweeds predominated in soils when we had phytotoxicity problems. He also writes that ragweed is indicative of "complexed" (unavailable) potassium. At Tunwath ragweed predominated on a patch of soil on which fababeans were stunted; the plants exhibited potassium deficiency symptoms, and soil analyses indicated very low available potassium. The more I understand about weeds, the more I appreciate the truth of the statement "weed problems indicate fertility problems."

PESTS

Pest problems are also indicative of fertility problems. There were no serious pests on this farm, except when we experimentally fertilized plots with N. Almost invariabley this resulted in insect or fungal or weed problems, or lodging of the crop, or all four! High levels of soluble N result in high levels of free amino acids in crops, which make them more attractive and nutritious to pests. Then they have higher rates of reproduction, and even high levels of natural enemies may not be able to keep them from reaching destructive levels.

CONCLUSION

Observations made in 1979/80 convinced us that the potential existed to increase yields on this farm without additional inputs of N, or of mineral fertilizers, but it took 3 more years to determine that the key to doing so lay in the management of crop residues.

Tunwath differs from most organic farms in that most of the straw is retained in the field. Retention of straw has some advantages: it stimulates N_2 fixation, increases biological activity, reduces leaching losses, and I suspect, enhances the weathering of rocks and release of potassium. On the other hand, it makes tillage operations more difficult, and can cause phytotoxicity problems, which may not be readily identifiable as such.

Two practices were especially important in getting the Tunwath system to function effectively. The first was a regular rotation of crops. Aside from benefits related to weed and pest control, recycling of nutrients etc., it allowed us to discern sequential relationships that we would probably not have discerned had crops been rotated on a more ad hoc basis, i.e. the inhibition of oats following certain crops but not thers. This problem was in turn rectified by the ridging practice, a relatively simple operation that had dramatic effects on yields.

Phytotoxicity problems can be expected to occur in other systems in which large amounts of residues are being incorporated. For the best practical advice on managing residues in temperate systems, that I know of, I urge the reader to consult Don Schrieffer's "From the Soil Up" (available from ACRES USA, POB 9547, Kansas City, MO 641123, $US20 ppd).

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David Patriquin is an Associate Professor in the Biology Department at Dalhousie University in Halifax where he has been since 1974. His PhD work was concerned with nitrogen fixation in the marine environment. His interests in agriculture were stimulated by stints in microbiology labs at Macdonald College and at an agricultural station in Brazil, but most of all, he says by visiting Tunwath farm in 1977. He is currently working on farms in the Maritimes and Ontario, and collaborates with organic agriculturalists in several developing countries.