Ancient Wisdom Meets Modern Science

Studies & Advances in Composting Technology

by Paul Hepperly, Ph.D. & Christine Ziegler Ulsh

The word "composting" refers to the process of decay that produces stable, high-carbon humus from plant and animal residues or wastes. The composting process transforms these waste materials into a nutrient-rich, soil-like material that can be used to improve garden and farm soils around the world. Compost forms the foundation of modern organic farming, which can be traced back to the work of Sir Albert Howard (see sidebar, page 17), and its importance in sustainable and organic models of agriculture can hardly be overstated.

THE COMPOST UTILIZATION TRIAL

To scientifically assess the value of compost in farming, the Rodale Institute (a nonprofit organization started by J. I. Rodale) initiated a decade-long study comparing the use of compost, raw manure and synthetic chemical fertilizer for the production of a wheat, corn and vegetable rotation. This experiment was started with collaborative review by United States Department of Agriculture research scientists. Begun in 1993, the Compost Utilization Trial (CUT) was designed to measure the long-term effects of these fertilization techniques on soil and water quality.

This study confirmed the superiority of compost — as compared to raw manure or synthetic chemical fertilizers — over a long term as a means to improve soil health and reduce water contamination. Based on the findings, the Pennsylvania Department of Environmental Protection funded the study of a compost amendment mix to further increase the nutrient retention in composts, both during the composting process and in field application.

Researchers started designing the CUT study in 1991 and then began planting its rotations in the field in 1993. The experiment tested seven fertility treatments (five types of compost, along with raw dairy manure and synthetic chemical fertilizer) in a three-year rotation of wheat, corn and vegetable (originally green peppers; later, potatoes), maintained continuously through 2002 (see Table 1).

Yields and nutritional content were measured for all the crops in the rotations, and cover crops were analyzed for biomass and tissue nutrients. Field soils were tested annually for fertility, and soil water was recovered in intact-core lysimeters that were installed below the crop root zone to measure the amounts of nitrates and phosphates that were being lost from the system to the ground water (see Figure 1).

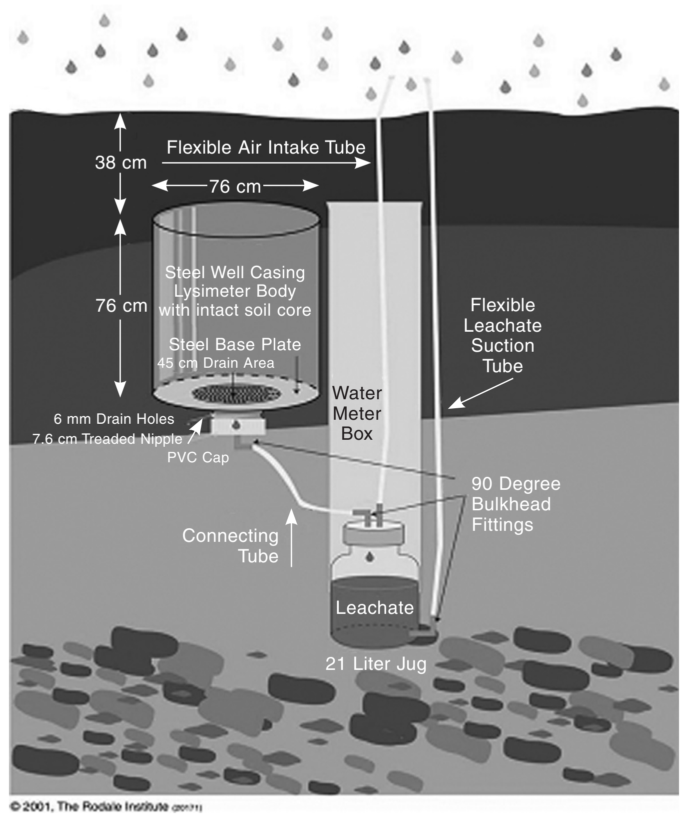

Figure 1. *Diagram of an intact-core lysimeter installed in a field under the crop root zone. The lysimeter's body cylinder was driven into the ground by force to maintain an undisturbed soil profile within the cylinder. The cylinder and core were then raised out of the ground, and the steel base plate was welded into place to collect any water that ran through the core.*

20th Century Compost

The Birth of Modern Organic Agriculture

by Paul Hepperly & Christine Ziegler Ulsh

Compost happens, and has been happening nonstop throughout history. It is referenced repeatedly in the Old Testament. Sir Albert Howard (1873-1947), the father of modern organic farming, found that ancient composting practices were center to maintaining soil fertility and balance, especially in the tropics. These practices have been developed and refined during the last 6,000 years and have stood the test of time.

Sir Albert Howard was trained as a conventional agronomist in Great Britain and served many years in the British Overseas Service addressing agricultural issues in tropical regions. During an early assignment in the British West Indies, he discovered that fertilization practices that worked well in temperate climates were much less effective in the tropics. This was due in part to the predominance of acid soils in the humid tropics that are made even more inhospitable with use of acid-generating ammoniated fertilizer. Compost, unlike ammoniated fertilizer, is neutral or slightly alkaline and has a buffering effect on acid-related toxicity (such as aluminum and manganese toxicity).

Working with these acid soils, Howard had an epiphany that led to the development of modern organic agricultural theory and practice. He noticed that nature and native agricultural practices recycled plant materials to conserve and increase soil fertility. After his time in the British West Indies, Howard worked from 1905 to 1933 in India, where he became a reporter, supporter and developer of compost technology.

In contrast to Justus Liebig, who promoted a fertilization approach to plant nutrition, Howard championed a big-picture view of plant production, recognizing the importance of soil organic matter in meeting all the nutritional needs of the plant.

MODERN COMPOSTING

Howard's experiments demonstrated that compost generated higher plant productivity than either fertilizer or raw manure. In Howard's classic treatise on organic agriculture, *An Agricultural Testament* (1940), the greatest single topic he covered was the Indore composting method, identified, studied, and adapted from practices in Indore, India.

The Indore composting method features layering of diverse materials to promote an optimized carbon-nitrogen ratio for optimal composting. The layered materials are periodically mixed to aerate them and stimulate healthy aerobic decay (anaerobic decay can generate toxic by-products, see "Let Your Compost Breathe" in this issue). This method reduces the volume of the initial materials by 60 percent or more and creates a finished humus-rich product that is ideal for use in the field as a soil fertility amendment. This final product is often referred as black "gold" — J. I. Rodale called it "pay dirt."

The Indore system, as applied in compost windrows, has evolved to become the primary approach of most modern municipal compost operations. And although the technology to turn the compost windrows has advanced impressively over the years, the compost recipe has remained largely unchanged.

J. I. Rodale, the pioneer of American organic agriculture and gardening, was instrumental in popularizing the use of composting for organic food production. In 1942, Rodale selected Howard as the first scientific editor for his landmark *Organic Farming and Gardening* magazine. Like Howard, Rodale considered compost to be the mainstay of the organic method, as explained in his book *Pay Dirt* (1945).

INITIAL FINDINGS

Crop yields were generally similar among all treatments, indicating that compost or raw manure generated little or no production penalty and can provide the same yields as conventional fertilizer (see Figure 2). Moreover, at the later part of the experiment wheat and corn yields tended to be higher in both yield and protein content when compost was used.

Note that over time, wheat and corn yields from both compost treatments (broiler litter and dairy manure base) increased from 9 to 25 percent, while yields from conventional fertilizer increased by only 1 to 8 percent over the experimental period. This indicates that, in a longer trial, compost would probably continue to accumulate benefits over conventional synthetic fertilizer applications.

Overapplication of crop nutrients is a growing concern as water pollution and health issues increase. Crop nutrients can be overapplied in any farming system, conventional or organic, unless farmers take care to fine-tune their nutrient applications to meet (and not exceed) the needs of their crops. In CUT, composts were found to reduce nitrate leaching into the soil water by over 50 percent compared to raw manure or fertilizer application (see Figure 3). No significant differences in phosphate leaching were found among treatments. Because nutrient amendment application rates were based on estimated soluble nitrogen content, the composts were applied at much higher rates than the raw manure or synthetic fertilizer. Contrary to conventional thinking, applications of compost can both increase soil nutrient levels and reduce leaching as compared to recommended uses of either raw manure or conventional synthetic fertilizer.

Soil carbon levels increased from 1.97 percent to 2.50 percent in the dairy manure leaf compost treatment, representing an increase of 0.53 percent in the top

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Entry Point 1	**MAIZE**	**PEPPERS;** wheat	**WHEAT;** sorghum; crimson clover	crimson clover; **MAIZE;** rye	rye; **PEPPERS;** wheat	**WHEAT;** hairy vetch	hairy vetch; **MAIZE;** rye	rye; **PEPPERS;** wheat	**WHEAT;** hairy vetch	hairy vetch; **MAIZE;**
Entry Point 2	**OATS;** sorghum	**MAIZE**	**PEPPERS;** wheat	**WHEAT;** red clover	red clover; **MAIZE;** rye	rye; **PEPPERS;** wheat	**WHEAT;** hairy vetch	hairy vetch; **MAIZE;**	rye; **PEPPERS;** wheat	**WHEAT;** hairy vetch
Entry Point 3	**SPINACH; PEPPERS;** wheat	**WHEAT;** sorghum;	**MAIZE**	**PEPPERS;** wheat	**WHEAT;** red clover	red clover; **MAIZE;** rye	rye; **PEPPERS;** wheat	**WHEAT;** hairy vetch	hairy vetch; **MAIZE;**	rye; **POTATOES;** wheat

Table 1. *Compost Utilization Trial crop rotations from 1993-2002. Entry points 1, 2 and 3 occurred in each year for each of the seven fertilization treatments. Capitalized names in bold indicate crops that were harvested that year. The rotation was changed in 1995 to include hairy vetch as a legume green manure after wheat, and in 1996 a rye cover crop was added after maize. Finally, in 2002, potatoes replaced peppers in the vegetable phase of the rotation.*

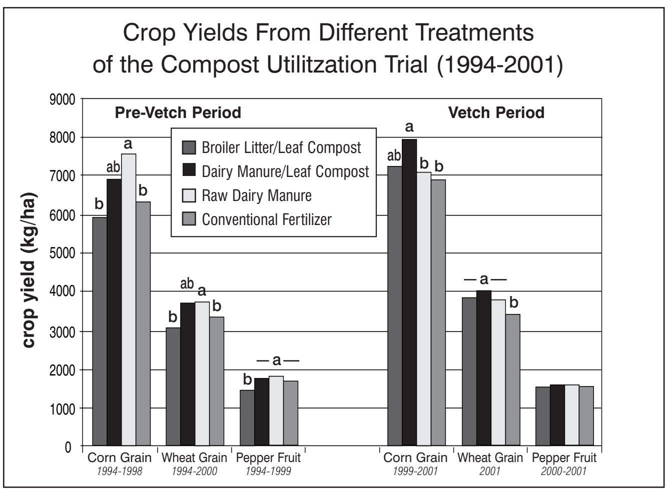

Figure 2. *Crop yields (dry weight) for the three cash crops grown under different fertilization treatments, assessed both before and after hairy vetch was added to the crop rotation. Treatments in a crop grouping with the same letter are not significantly different at the P <0.05 level.*

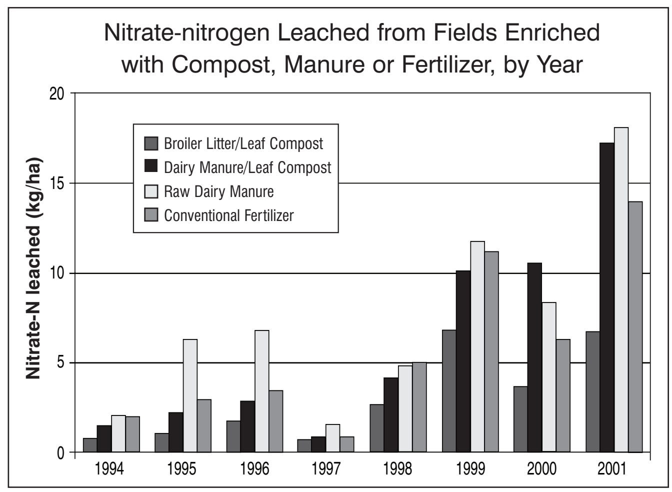

Figure 3. *Nitrate-N leached from fields treated with compost, manure and synthetic fertilizer.*

9 inches of the soil profile (see Figure 4). Given that the top 9 inches of soil adds up to about 3,000,000 pounds per acre, this increase in organic matter adds up to 15,900 extra pounds of carbon per acre over the life of the study, with a water-holding capacity of 636,000 pounds per acre (an increase of 26.9 percent over the 59,100 pounds of carbon per acre found in the soil at the start of the trial). Calculated annually, compost application increased soil carbon by up to 2,000 pounds/acre/year, while manure application generated an increase of less than 200 pounds/acre/year, and synthetic fertilizer treatment did not improve soil carbon levels at all.

This point is important because other Rodale Institute research has shown that, when agricultural practices raise levels of soil organic matter, corn and soybean yields can increase by up to 30 to 40 percent in drought years, compared with unimproved soils. Thus, compost-based improvements in soil organic matter levels can go a long way to help protect crops against drought damage. The programmatic increase of soil organic matter can be seen as an effective way to drought proof crop production systems under rainfall and an effective to reduce way demand of irrigated crops.

Compost applications also increased soil nitrogen levels (see Figure 5). Under our field conditions, every 2 percent increase in relative soil carbon levels has coincided with a 1 percent relative in soil nitrogen content. The build-up of soil nitrogen reserves via compost incorporation reduces the need for application of nitrogen amendments over time. This effect cannot be duplicated by chemical fertilizers, which have a tendency to *reduce* soil nitrogen reserves and, as such, require repeated annual application. The

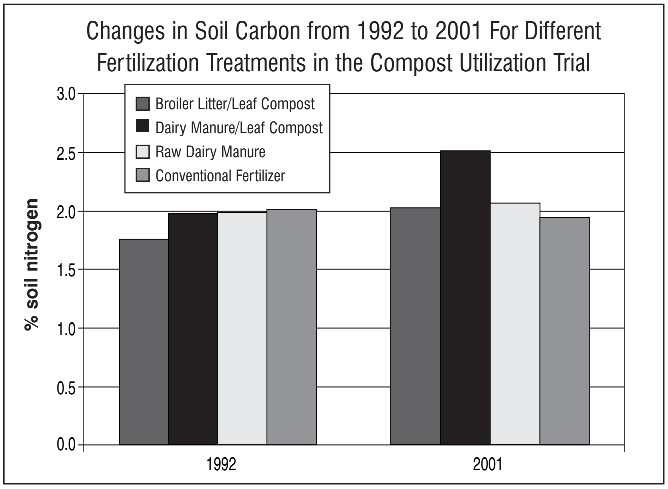

Figure 4. *Soil carbon (0-20 cm) changes by treatments from 1992 to 2001. BLLC = broiler litter leaf compost; CNV = conventional mineral fertilizer; DMLC = dairy manure leaf compost; RDM = raw dairy manure.*

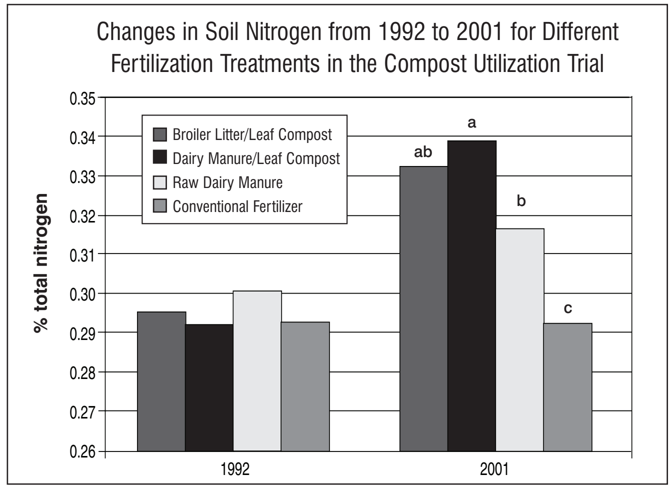

Figure 5. *Soil nitrogen (0-20 cm) changes in 1992 and 2001 as influenced by nutrient sources. Different lower-case letters above bars indicate significance (P = 0.05) between treatment. NSD = not significantly different at P <0.05. BLLC = broiler litter leaf compost; CNV = conventional mineral fertilizer; DMLC = dairy manure leaf compost; RDM = raw dairy manure.*

use of compost adds to the soil nitrogen bank account, which over time allows the farmer to live off the interest of this account. In the case of synthetic fertilizer, as much or more nutrient input is needed each year, and the soil bank levels actually decreases.

Because compost is a certified organic production practice, farmers can use it to meet crop nutrient needs during organic transition, eventually allowing them to capture the economic benefits of premiums, which run anywhere from 40 to 267 percent for grains and have averaged about 105 percent for the last four years according to Organic Price Index data for corn.

Some farmers have been reluctant to try making compost at the farm scale due to the potential costs of added equipment and/or time that compost turning entails. However, with some planning and a bit of practice, large quantities of compost can be turned with a regular bucket loader. Before the Rodale Institute developed its compost turner (see below), farm workers developed a system to turn a 150 foot-long windrow of compost with a bucket loader in a little under two hours. Use of existing equipment — and making compost in the winter when other operations require less time — can allow farmers to try their hands at composting without making an initial capital outlay.

For farmers who find composting to be a good fit for their operation, Jeff Moyer (farm manager for the Rodale Institute) worked with a neighboring farmer and metal worker to develop a homemade compost turner, constructed from parts of an old dump truck and other cast-off equipment. Information about the design and assembly of this turner can be found online at *www.newfarm.org/features/0804/compost/slideshow/turner1.shtml* — making efficient and reasonably inexpensive compost turning possible for the innovative farmer.

REDUCING NUTRIENT LOSSES

Soil aggregation (clumping of soil particles) has been pinpointed as a key indicator of soil quality and structural integrity, helping the soil better retain water, air and nutrients. A soil's tendency to aggregate is primarily a function of its organic matter content: The higher a soil's organic matter levels, the more likely it is to aggregate. Dr. Frank Stevenson, soil chemistry professor at the University of Illinois, determined that an effective way to stabilize organic matter in soil is to foster its combination with clay.

Because organic matter particles and clay particles are both negatively charged, Stevenson also found that a positively charged particle, such as calcium, iron and aluminum, are essential to bonding the organic matter and clay, creating an aggregate. The positively charged calcium ions serve as ionic "glue" to catalyze aggregation of all the particles into soil clumps. Soil aggregates form empty spaces (pores) between them, which improves water and air penetration. In addition, as hollow spheres, their interior spaces are bladders that fill with water, air and nutrients, essential to support vibrant crops (see Figure 6).

DEP COMPOST RESEARCH

Dan Desmond, technology director for the Pennsylvania Department of Environmental Protection, challenged the Rodale Institute to develop technology that would further improve the nutrient-retention properties of manure-based composts, both in the pile and on the field. DEP's interest in composting is driven by the need to reduce application of raw manure on farm fields, particularly in Lancaster County, where raw manure applications have been proven a primary cause of nutrient pollution in the Chesapeake Bay and surrounding watershed.

The Rodale Institute thus developed a study to measure the amounts of crop nutrients that leach off compost piles during the composting process, and then to apply the composts to the field in conjunction with raw manure and chemical fertilizer to compare soil nutrient

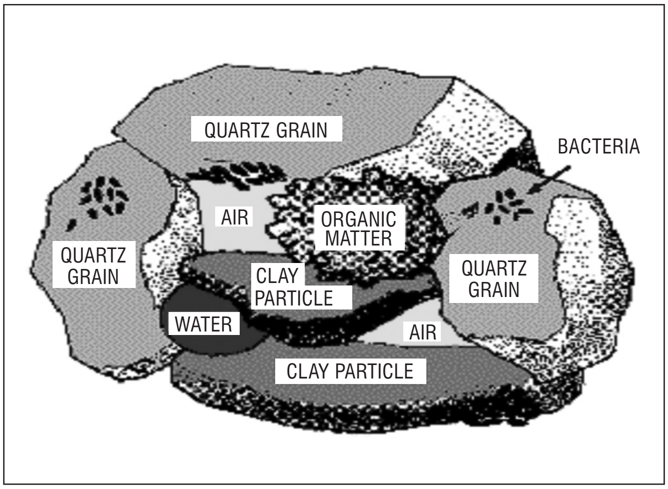

Figure 6. *Clay and organic matter bond with the aid of calcium, iron and/or aluminum to create a stable soil aggregate (clump) that contains pore spaces to hold water, air and nutrients to support plant growth and soil microbial life.*

Figure 7. *Compost pad with collection system. The inset picture shows the concrete pad on which the compost piles were constructed and aged. The drain grids in the middle and front of the pad collect water that runs through the compost pile and send it into a septic tank (the bottom picture, one tank for each pad) for later analysis.*

run-off and crop yields. As part of this trial, researchers tested three different compost formulations:

1. Raw manure allowed to age by itself (unmixed with other materials);

2. A standard leaf-manure compost mix (three parts leaves, one part manure, by volume);

3. An amended compost mix that incorporated clay, calcium, and humic acid (an stable organic carbon based material). The recipe for the amended compost, as mixed for the study, incorporated seven buckets (1 cubic yard each) of leaves with two buckets of manure, one bucket of clay (taken from the farm's subsoil), 45 pounds of calcium sulfate, and 55 pounds of humic acid (purchased from Terravita Inc., SP85).

All the compost treatments were piled and aged on beveled concrete slabs with a drain grid that fed into an underground septic tank for water collection (see Figure 7). The piles were monitored for temperature (daily), material nutrient content (at the start and end of the composting cycle), and nutrient and bacterial content of the water that leached through the pile (collected from the tank several times throughout the composting cycle).

Figure 8. *Three of the broiler litter compost piles on the composting pads. The pile on the left is the amended compost mix, the middle pile is broiler litter alone, and the right pile is the standard manure-leaf compost mix. Note that the two compost mixes have reduced in volume compared to the manure alone (all piles were the same size at the start of the composting cycle). Volume reduction of compost piles is a good indication of effective composting.*

Two rounds of compost were generated, one based on poultry manure that was mixed and matured from May to October 2005, and another based on dairy manure that was made from October 2005 to April 2006 (see Figure 8). During each round, each of the three compost treatments (manure alone, manure-leaf compost, and amended manure-leaf compost) was replicated twice. In order to reduce nitrogen and carbon loss to the air, the mixed compost piles were specifically layered with leaves on the bottom and top and the manure "sandwiched" in the middle (with the amendment mix in those treatments) and allowed to stand, unmixed, for two weeks before the first turning. The goal of the layering was to allow the leaves to capture any nitrogen that might off-gas from the manure during that initial period.

Our goal was to turn the piles as little as possible, to retain as much nitrogen and carbon as possible in the pile, and to allow the aggregation process and fungal development to proceed unhindered. The turning schedule was based on the temperature cycle of the pile: When temperatures dropped below the starting temperature of the previous cycle, the pile would then be turned again (see Figure 9). Following these guidelines, we turned the piles a total of three times over the six-month composting cycle.

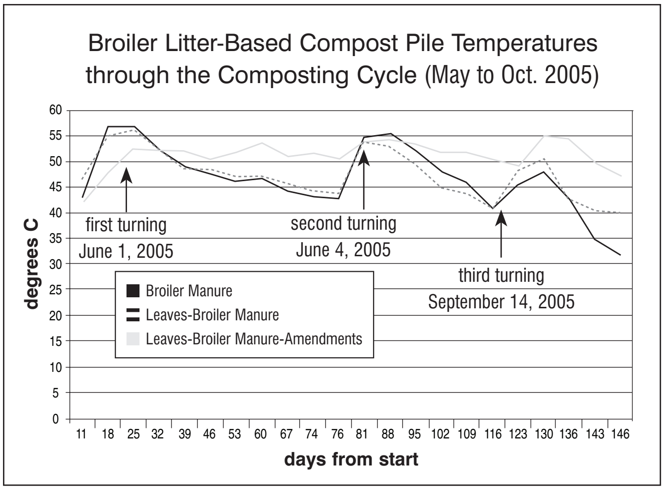

Figure 9. *Temperature fluctuates in broiler-litter compost treatments. Arrows indicate points at which the piles were turned. Temperatures in the manure alone never changed much over the cycle, indicating limited aerobic microbial activity. The temperature curve suggests that the amended compost cooled and "finished" a little more quickly than the standard compost mix.*

Figure 11. *Compost leachate collected from tanks below the compost piles. Manure alone leached many sediments and nutrients, while the standard compost leached fewer, and the amended compost leached least.*

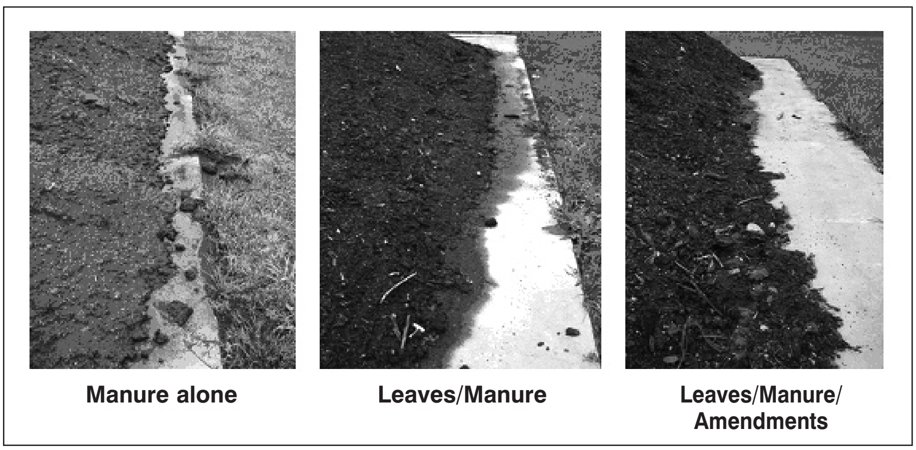

Figure 10. *Surface leaching of pile nutrients and sediments after a heavy rain. The unmixed manure pile leached a greasy, smelly colloidal liquid (left), while the standard compost pile leached only a few odorless sediments (center), and the amended compost leached almost no water at all.*

RECENT FINDINGS

Within one week after piling, the amended compost emitted no ammonia or sulfur odors, while the standard compost mix required three to four weeks to eliminate the smells. The manures, when piled alone, never lost their odor (particularly the broiler litter, which still smelled a year later). As a shrewd farmer from New York State noted, "If it smells, you are losing your nutrients." Thus, odor reduction is not merely an aesthetic concern or neighborly courtesy; it is essential to improve the nutrient retention and value of compost.

Nutrient losses were also easy to assess visually. After a particularly heavy rain near the end of the poultry manure composting cycle, the pile of unmixed manure leached a greasy colloid material that looked and smelled bad. The standard compost leached a little water off its edges, but the liquid contained only a little sediment from the pile. At the same time, the amended compost mix leached almost no water at all (see Figure 10). Extending the down-home logic of our New York State neighbor — if your pile is weeping, you are losing nutrients.

Differences could also be seen in the leachate collected from the tanks below the pads. Leachate drawn from the unmixed manure piles was black and thick like motor-oil, while the standard compost leached a liquid the color of dark tea, and the amended compost leached a liquid that more resembled light tea (see Figure 11).

Leachate drawn from the amended composts contained much less nitrogen and phosphorus than that drawn from the standard compost or manure alone (see Figure 12). (The data, while showing a clear trend, were not significant due to replication constraints enforced by the number of compost pads.) In addition, both amended and standard composts eliminated *E. coli* in their leachate, but the amended compost did so twice as quickly as the standard compost (data available upon request). The raw manure continued to shed *E. coli* in its leachate throughout the compost cycle (and presumably beyond).

Aggregate formation became evident in the amended composts within seven to 20 days, as compared to 60 to 80 days for standard compost. In contrast, even after a year, the poultry manure alone was still wet, gooey and smelly, showing little sign of any aerobic composting. The dairy manure alone composted somewhat better due to the presence of bedding (carbon-rich materials) and digestive bacteria inherent in the manure. However, even after a half-year of composting, little

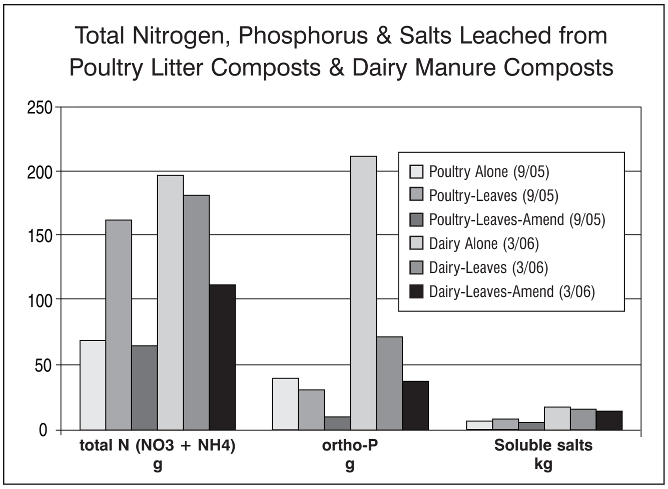

Figure 12. *Nutrients and salts leached from poultry manure composts (green) and dairy manure composts (brown) throughout the composting cycle.*

aggregation had occurred in the dairy manure alone, and the piles still smelled faintly.

The final nutrient analyses of each of the compost revealed that the amended composts most closely achieved a 2:1:2 N:P:K ratio, most ideal to support plant growth and the basis for most chemical fertilizer mixtures (see Figure 13).

The raw manures tended to be high in phosphorus and potassium relative to nitrogen, a situation that could lead to overapplication of these nutrients to meet a crop's nitrogen needs. Over time, these overapplications would likely lead to nutrient leaching from the soil into both ground and surface waters. Soil testing data confirm that, by mid-season, soils that received raw poultry manure had significantly higher nitrogen concentrations than the other treatments.

Nutrient leaching data from field applications of the compost were generally inconclusive, but corn yield data showed that, in that single year, conventional fertilizers supported higher yields than the amended dairy manure compost. All the other composts and manures supported yields that were not significantly different from either the conventional fertilizer or the amended dairy compost.

These data indicate that we may have overestimated the nitrogen availability of the amended dairy compost, attesting to its ability to retain nutrients. However, as data from the Compost Utilization Trial showed, composts were able to build up soil organic matter and nutrient content to support yields equal or better than conventional fertilizer or raw manure when applied over a few years. As such, future compost research should be planned to cover at least five field seasons to show a more realistic picture of soil fertility and crop yields across treatments.

CONCLUSIONS

The ancient practice of composting is an ideal solution to modern agriculture's nutrient waste issues. Compost applications improve soil organic matter content, nitrogen content, and its ability to support crops under drought conditions, while raw manure and chemical fertilizer do not offer these long-term benefits. Multi-year research shows that compost also reduces nitrogen losses to water systems when compared to raw manure or chemical fertilizer.

What's more, for one of the first times in the history of composting, research has found a way to actually improve the basic chemistry of the composting process, beyond the balance of "greens," "browns" and moisture. With the addition of the clay-calcium-humic acid amendment, we have found that soil aggregation processes can be expedited as part of the composting process, and these aggregates can increase compost's positive impact on soil fertility and structure.

This simple amendment mixture demonstrated a marked ability to (1) accelerate the compost process, (2) greatly reduce odors that coincide with nitrogen and sulfur nutrient losses, (3) provide faster and more durable aggregation of the recycled compost materials and (4) more quickly eliminate *E. coli* leaching in the composting process.

Composting represents multiple benefits that farmers and agricultural professionals are just beginning to fully

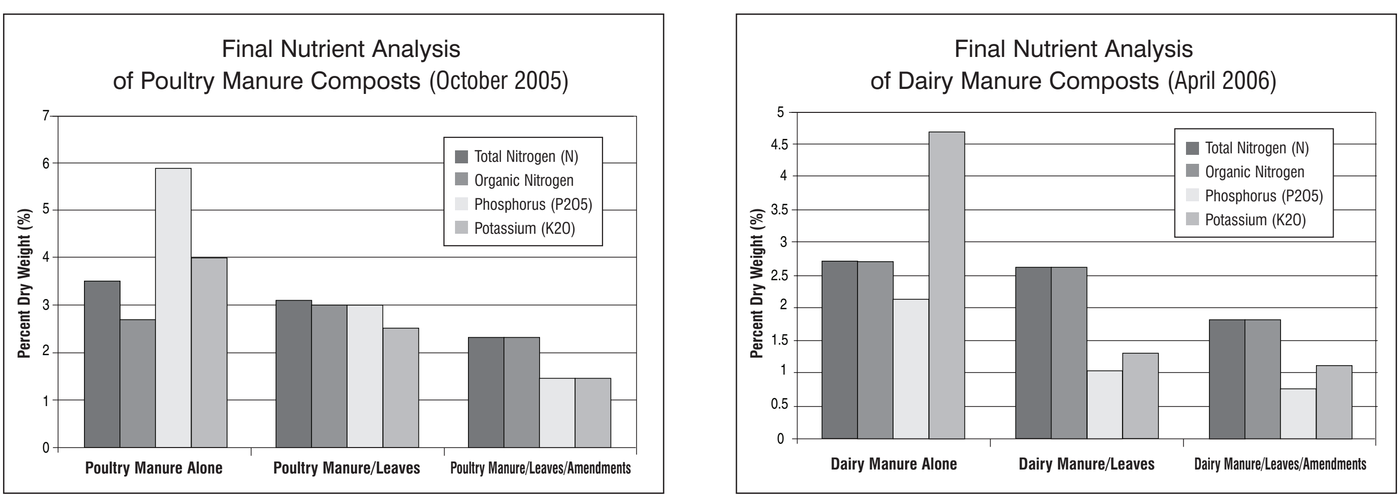

Figure 13. *Nutrient ratios for the finished poultry manure composts and dairy manure composts.*

appreciate. By expanding and improving compost production and use, the agricultural community increases its opportunities to recycle waste materials (particularly manure), improve soil health and productivity for generations to come, and also improve atmospheric health through the capture of greenhouse gases (carbon and nitrogen) in the soil. The greatest power of compost production and use lies in the fact that, as farmers adopt these practices to improve their own bottom line, they also constructively impact other people and the planet as a whole by producing healthier food from healthier soil, cleaning up waterways, and reducing global warming.

Carbon credit programs could be an excellent way to encourage farmers to start making and using compost. These programs can act as an affirmative "carrot" to the "stick" of increasingly strict agricultural water pollution regulations, which can also be met through compost production and use. The Rodale Institute will continue to work with the Pennsylvania Department of Environmental Protection and Department of Agriculture to develop compost production models that will reward farmers for their ability to positively impact the environment and human health through this simple, ancient, powerful practice.

Dr. Paul Hepperly serves as the Research and Training Manager at the Rodale Institute. He grew up on a family farm in Illinois and holds a Ph.D. in plant pathology, an M.S. in agronomy and a B.S. in psychology from the University of Illinois at Champaign-Urbana. He has worked for the USDA Agricultural Research Service, in academia, and for a number of private seed companies, including Asgrow, Pioneer and DeKalb. He has overseen research in Hawaii, Iowa, Puerto Rico and Chile, and investigated such diverse crops as soybeans, corn, sorghum, sunflowers, ginger and papaya. Christine Ziegler Ulsh is a research technician at the Rodale Institute She holds a B.A. in Biology from Smith College and a M.S. in Forestry at the University of Massachusetts. Her career has included research at the university and with the USDA Forest Service, natural foods retail sales, administration and farm work. More information at *www.rodaleinstitute.org.*