Maturity and Stability of Bio-based Nutrients
The NaturTech Biofertilizer Breakthrough

Jim McNelly

jim@composter.com
320-253-5076
www.renewablecarbon.com

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Over 100 variables impact plant growth with the most studied being the three macro-nutrients, Nitrogen, Phosphorous and Potassium (NPK) of which N is the nutrient of greatest concern as its deficiency can result in decreased yield and its form, or surplus, can also decrease yield. Over the past fifty years, agronomists have proven that plants do not use nitrogen directly, but require a complex microbial conversion network in order for microbes to convert nitrogen into various forms that become available and useful by plants.

In virtually all forms of agriculture and horticulture, the farmer relies on microbes ***in the plant root zone t***o effect this conversion. In effect, the same environment where the plant is growing is the where nitrogen is being converted. Unconverted nitrogen can be toxic to plants and some byproducts of nitrogen conversion are also harmful to plants. Using the plant growing environment to convert nitrogen into plant food is inherently limiting, is fraught with risk and ultimately, is the greatest barrier to achieving an optimum crop yield.

Decomposition, of which composting is a controlled form, is a method of achieving microbial conversion of nitrogen into a plant available form in a controlled process separate from the soil and away from growing plants themselves. Decomposition typically operates in a matrix of 30 parts carbon (C) to 1 part N, a 30-1 C/N ratio. This ratio is determined by the physical properties of the roughly twenty microbial organisms that consume N and C and convert these elements into their bodies. As C and N are converted into their bodies, there is a resulting net ratio of 15-1 C/N with carbon dioxide (CO^2), heat or biogas (CH^4) being byproducts. The significant heat generated by controlled composting can be harnessed to kill pathogens and weed seeds that may be present in the feedstocks being composted.

A "perfect" 30-1 C/N ratio will result in a dry weight of 1% N in the finished compost. Thus, a dry ton of 1% N compost has 20 lbs. of N. If a corn crop calls for 200 lbs. of N per acre, this would theoretically require 10 tons of compost per year. Windrow composting and or ageing of organic matter typically loses half of its nitrogen to the atmosphere in the form of ammonia (NH^3) to the atmosphere or nitrate in the form of runoff. Applying chemical nitrogen can also result in similar nitrogen losses. Agronomic loading rates for nitrogen assume a 50% loss of nitrogen in their calculations. If nitrogen had been converted into microbial bodies before it reached the soil, a farmer could utilize half as much nitrogen per acre. The key point is that once nitrogen has been converted into microbial mass, it no longer releases nitrogen to the air or water, yet it is still present in the soil and available in a bio-available form to plants.

To avoid complaints from the release of NH^3 to the atmosphere, most commercial compost is made closer to a 45-1 C/N ratio with ½ of a percent of N or less and is not considered a good source of N. Low N compost is sold more as a soil conditioner or amendment or considered a source of microbes or a water holding filler in planter mixes than a source of available N. Low N compost is rarely used for potting soil due to its inconsistency, low N and problems with density. Poorly made compost may also contain pathogens or weed seeds that are truly undesirable for most applications.

The Inuit People have over a dozen words for "ice" and native Hawaiians have over a dozen words for "lava." In the popular language, we have only one word for decomposition, which is both a noun and a verb, "compost." If any and all forms of decomposition are called "composting" and any and all forms of organic matter can be called "compost," then it is not hard to understand why those in the business of growing plants are reluctant to use the term "compost" when the term can mean a once living material ranging from table scraps under the sink to wood chips.

It became clear in the 1980s that the composting industry needed a new set of definitions, testing methods, practices and standards to differentiate controlled decomposition from simple decay. More importantly was the need to develop standards for compost that would meet the needs of the people in the business of growing plants, whether agriculture, landscaping, silviculture or horticulture. Theoretically, with a thousand different crops, there may be a need for a thousand different formulations of bio-based nutrients and the catch all term, "compost" would no longer suffice.

At the center of the challenge to develop new standards and definitions was the issue of phytotoxicity, the inexplicable death of plants or stress resulting not only from too much N, but from inadequate decomposition. The most common form of phytotoxicity people can relate to is the brown spot in a lawn where the dog peed resulting in the death of the grass due to unstabilized urea in urine. Similarly, the use of windrow compost often times results in phytotoxicity, or plant stress, through mostly decreased seed germination. The phytotoxicity problem with the use of windrow compost could not be fully explained by the presence of unconverted nitrogen alone.

Farmers learned that if they applied compost or aged manure in the fall, by the time they planted their crops in the spring the phytotoxicity problem had largely resolved itself. Due to advances in compost and composting testing methods (TMECC) established by the U.S. Composting Council (USCC) in the 1990s, it is now understood that this previously unexplained toxicity is caused by ***byproducts*** of decomposition, mostly anaerobic decomposition, which can be measured with a variety of "maturity" tests. It is remedied by optimizing aerobic microbes over anaerobic microbes, the same aerobes that convert immature manure or compost into a mature, or stable form over the winter. One of the first of five testing methods to determine compost maturity became NH^3 release rates. Seed germination is another testing method.

In the 1970s, mushroom farmers and USDA researchers discovered that using blowers to force air through composting piles accelerated the rate of decomposition and resulted in a more uniform process of decomposition by ensuring even heat distribution throughout the pile and better pathogen and weed seed kills. In the 1980s, again the mushroom farmers learned that if they used temperature probes and higher rates of air to remove excess heat in the composting pile, faster rates of decomposition could be achieved if lower temperature mesophilic microbes were optimized after the higher temperature thermophilic organisms had done their job of killing pathogens and weed seeds. With increased interest by the compost user, forced aeration resulted in a totally new product, ***aerobic*** finished compost that was fully mature and did not cause phytotoxicity.

At the same time, officials at the South Coast Air Quality Management District in Southern California began sampling air emissions from windrow compost piles and documented significant volumes of smog-generating and greenhouse gas impacting methane (CH^4) and a wide variety of other volatile organic compounds (VOCs). Compost researchers had earlier documented the fact that a windrow used up its oxygen within thirty minutes after turning. The air district data proved conclusively that windrows are actually intermittently oxygenated, heat retaining, uncontrolled anaerobic decomposers. They release NH^3 when the pile is turned which causes odors and a variety of air quality issues.

In order to meet California's air quality rules, commercial decomposition, aerobic or anaerobic, must be controlled in a manner that greatly reduces the release of CH^4, NH^3 and Volatile Organic Compounds (VOCs). By adding biofilters to the exhaust air system of forced air and temperature controlled composting, odors could be mitigated and NH^3 would no longer be emitted to the atmosphere. Rather, odors and NH^3 are captured in the filter medium, which was typically a bed, box or bunker of wood chips. Researchers developed what is now known as Best Management Practices (BMPs) composting, which is largely defined as controlled aerobic composting beginning with a recipe of ingredients to closely control moisture, porosity and the C/N ratio, pressure blowers for forced air, temperature control with heat removal using even greater volumes of air, and air scrubbing using biofilters. Once BMPs were established, operators could increase the starting C/N ratio to 20-1 and produce a 2% N compost.

During the past forty years, a parallel method of controlled decomposition was being developed using up to three different species of redworms in what is commonly called vermicomposting, or earthworm digestion. As the technology has been practiced, various organic materials are moistened to 80% water as compared with BMP composting of approximately 60%. The organic matter is placed on a "worm bed" and the worm population rises to the surface and eats the organic matter, converting the organic matter into vermicompost, or earthworm castings. Literally hundreds of different methods of worm farming, or vermiculture, have been proven to be capable to generate vermicompost. Of interest to this discussion on advanced bio-based nutrient production is the surprising yields achieved in controlled growth studies around the world, particularly by Ohio State University. Ohio State University shows g larger plants, greater root mass and shorter growing times occur with vermicompost compared to aerobic compost that is not digested by earthworms.

There is a feature of vermicompost that is not fully understood, but largely referred to as "unknown growth factors" or UGFs. The academic consensus is that UGFs are most likely plant growth hormones such as cytokines, gibberellins' and auxins. In addition, it has been shown that earthworm activation results in greater nitrogen and mineral availability, which accounts for some of the unexpected plant growth benefit. The percentage of benefit from the use of vermicompost in a planter mix was realized, depending on the crop growing in the planter mix, at 10% to 15% by weight, after which yields decreased, presumably due to the physical structure of vermicompost compared with sphagnum peat that was used in the comparison growth studies. The significance is the fact that vermicompost is a fully stabilized and mature compost as measured by the five standards of maturity.

Not unlike the problems of the composting industry before the development of standardized testing methods and definitions, the vermiculture industry is unregulated and undefined. Any worm farmer can claim they are making vermicompost and sell their product based on the planter mix user's risk. Simple questions like, "What species of worms are you using? What ratio of worm mass to decomposing mass is achieved? How is the vermicompost removed? What is the feedstock for the worms? What temperature are the beds kept? How long is the retention time? What are the provisions for pathogen destruction? How are weeds killed? Can parasites survive vermicomposting? As in composting, if the compost is to be used commercially, vermicomposting requires consistency, standards, testing methods as well as assurances for quality control and a consistent product.

I began raising redworms in 1973 and operated a commercial potting soil blending and bagging business from 1976 through 1987 under the trade name, NaturSoil Potting Soil that included earthworm castings. I terminated commercial worm growing operations when I realized that vermicomposting, the use of earthworms to effect 100% of stabilization, did not fully treat the feedstock for parasites and weed seeds and while viral and microbial pathogen counts as measured by fecal coliform numbers, vermicomposting alone did not achieve risk mitigation levels sufficient for commercial operations with a risk of product liability lawsuits for weeds or pathogens. I concluded that while earthworms have a role in compost, but only after an aerobic composting phase using BMPs is completed. Instead of vermicomposting, I pursued vermistabilization, the use of earthworms to finish the decomposition process after a hot composting stage.

Ironically, the "earthworm contact test", an ASTM methodology for determining toxics in soils, is a sixth method to determine compost stability. Anaerobic digestate and relatively fresh windrow compost, being mostly anaerobic, are toxic to earthworms! In addition, the roughly 20 to 30 days required to effect anaerobic or windrow digestion removes much of the nutrient base that redworms need to thrive. This meant that BMP composting, where pathogen and weed seed kill can be achieved in 72 hours, was a necessity. This is when I pursued in-vessel composting technologies, working with rotating drum composting systems that made excellent worm food, but did not meet pathogen destruction objectives. In 1992, I built the first containerized composting system using BMPs and began the NaturTech Composting System. Since that time, I have built close to 20 facilities, including small batch, under two tons per day capacity CM-Pro systems.

It was in the small batch technology that the first 10-1 C/N ratio mixes were attempted, even a 6-1 C/N ratio test. After approximately five days of BMP composting, earthworms finished the digestion and stable N levels at 5.6% were achieved! When the samples were sent to a lab that uses USCC TMECC test procedures, the technician called and told me that the results were incredible and they had never seen stable compost over 2% N in thirty years of compost testing. In the small batch, aeration was facilitated by poking holes in the material being composted instead of using the typical wood chips for porosity. We knew that this would not be practical in the larger NaturTech containers with 20 to 40 tons in a batch.

When we attempted commercial scale batches with wood chips, the excess carbon in the decomposing wood chips were such that we could never achieve over 15-1 C/N ratios and batch after batch resulted in stable N levels ranging from 2.7% up to 3%. Even then, we found the batches extremely difficult to control as we could not deliver enough air to keep the batch from overheating. In BMPs, a target of 60°C is the goal for 72 hours after which the temperature is reduced down to 45°C. In the 20 ton batches at 15-1 C/N ratio, the temperatures quickly went over 65°C and the aerobic organisms began to self-pasteurize, resulting in process failure.

Like rocket scientists watching missiles explode on the launch pad, we tried again and again, eventually substituting reusable plastic bulking material for porosity, adding urea to the mix to try different C/N ratios and eventually used 11% N chicken feathers as the feedstock. We learned that we would need to run one biofilter per batch reactor instead of the typical one per four or five composting containers to handle the excess ammonia coming from the high nitrogen reactor. After one failed, overheated batch on a Friday, we came to the site on Monday to discover the air was still flowing and the batch was still hot, around 70°C. Composting organisms do not generate heat at these temperatures and what we were observing did not seem possible. The batch ran for ten days at high temperature with fill air flow before it dried out and cooled down.

The finished compost was 4% N and no longer releasing NH^3 and 50% to maturity in only ten days! After sending samples to a biology laboratory we were told the microbes that were present were "extremophiles", meaning high temperature organisms that are typically found in volcanic steam vents or hot springs. They are found in the soil and in compost piles, but are typically dominated by other microbes. It seemed that once we killed off the regular composting organisms with temperatures over 65°C, a completely different group of decomposers began working. We discovered that the unexpected microbes love the high nitrogen, high oxygen and high temperature environment.

We realized that we had developed a form of nitrogen fermentation that did not involve conventional composting organisms. By introducing chemical urea into the initial mixture, we also knew that we can consistently make a biofertilizer product at 4% N and the ammonia absorbing media in the biofilters can consistently produce a biofertilizer at 3.4% N. We also know that we can use our proprietary vermistabilization process to enhance ordinary BMP 2% N compost and our two biofertilizer products that are high in N and have vermicompost available as well.

Experimenting with the process further, a new patent was filed and protected internationally as US Patent 6524848. When coupled with the Intermodal bio-container patent and previous composting system patents, this is a protected methodology that is radically different from all previous forms of nitrogen delivery and conditioning.

Renewable Carbon Management LLC has invented a controlled batch, aerated bio-reactor system that can convert virtually any organic matter into custom formulations for virtually an unlimited range of plant growth applications. Some crops will do better with partially matured biofertilizer where higher solubility of nitrogen is desired while other crops require the fully mature, stable formulas. In seed starting, transplanting and propagation containers, vermicompost in various ratios mixed with peat, bark and perlite is very beneficial. On field cropping, pre-fermenting urea into bio-forms will virtually eliminate nitrogen loss into ground and surface water and NH^3 escape to the atmosphere. This results in a saving up to 50% of the need for additional nitrogen.

Many types of organic matter such as livestock manure, poultry bedding, food scraps, yard trimmings, leaves, windrow compost and field residues can be reformulated and fermented using the NaturTech Containers. Stabilized nitrogen can remain in the soil for at least five years vs. unstabilized N that lasts only a few weeks. This leads to accumulated fertility over time and increased microbial populations in the soil that assists in the decomposition of dead roots and surface litter. Increased organic matter in the soil also aids tilth and water holding capacity to reduce irrigation and water consumption. The concept is that growing media and biofertilizers can be produced from low value commodities and converted into uniform, pathogen free, weed free and rich-earth smelling biofertilizers in virtually unlimited quantities at significantly lower cost than sphagnum peat, bark and other common soil mix ingredients.

Composting has been long recognized as a method of stabilizing otherwise undesirable organic materials into value-added soil amendments. Recently, the US Composting Council's Testing Methods for Evaluating Composting and Compost (TMECC) Laboratory Methods has more clearly defined previously vague definitions such as "stability" and "maturity" of various composts and bionutrients. Stability is often determined by reduction of vectors (diseases, odors, and pests); whereas maturity is often determined by seed germination, oxygen uptake and off-gassing of ammonia. Although uncomposted biofertilizers are similar to composts in organic matter content, they differ from composts in characteristics and form of nitrogen. Most mature compost products are limited to 1% to 1.5% N while unstable chicken manure, for example, can contain 8% N. Uncomposted, or unstable biofertilizers, can be phytotoxic to plants, seeds and nitrate sensitive ornamental plants. Using our biofertilizer technique, nitrogen levels in finished composts can now approach 5% while maintaining safe and nontoxic nitrogen release rates.

The closest analogy to our breakthrough is to consider the process of making wine. Aged manure, or unprocessed organics, is similar to raw grapes. Anaerobic digestate and windrow compost is similar to grape juice. Compost made with BMPs is wine. Organics fermented with high nitrogen using the patented containerized system results in an outstanding vintage of fine wine.