The Connecticut Agricultural Experiment Station, New Haven

COMPOST: The Process and Research

BY ABIGAIL A. MAYNARD

Bulletin 966

July 2000

SUMMARY

Using compost in the garden has many benefits. For most vegetables and cut flowers, recent research at The Connecticut Agricultural Experiment Station has shown that fertilizer can often be eliminated when the soil is amended annually with 1 inch of leaf compost. However, optimum yields are obtained when leaf compost and some inorganic fertilizer are used, usually half the normal rate, and after 2 or 3 years of consecutive compost amendments. Optimum yields can also be achieved using compost and organic fertilizers but they are generally less effective, especially on sandy soils. For vegetables that demand higher amounts of nitrogen, a cover crop incorporated into the soil in addition to the leaf compost amendment may be necessary for optimum yields. Compost is most effective when applied in the spring before planting. For optimum results, leaf compost may be applied every year, especially in sandy soils, and can also be safely applied at higher rates if compost is available.

When using a manure based compost with a higher nitrogen content, application may be limited to 1-inch in three consecutive years to avoid nitrate leaching. Yields will not decrease if no compost is applied every fourth year. Application rates of greater than 1-inch with a manure based compost is not necessary and may cause excess nitrate to leach to the underlying ground water, especially in sandy soils.

As compost increases the water holding capacity of the soil, compost-amended soils take longer to warm in the spring. If the spring is cool and wet, early crops, such as peas and radishes, can have reduced yields on compost-amended soils because germination is delayed and the seeds eventually rot. Plant density can be improved by either treating the seeds with a fungicide or seeding at a heavier rate to compensate for seeds that rot.

Undecomposed leaves can also be used as a soil amendment. While there is usually no significant improvement in yields as compared to compost applications, there are virtually no detriments to soil or plants if undecomposed leaves are applied the previous fall. An application of 100% oak leaves or 100% maple leaves shows no adverse effects to soil or plants. A beneficial effect occurs as organic matter of the soil increases slowly if yearly applications occur.

Two inches of compost applied as a mulch are effective for weed control. While not completely eliminated, weeds will be reduced to numbers that can easily be controlled by hand. Control, however, is limited to 1 year.

This bulletin is divided into two major sections. In the first section, the basics of composting are outlined and guidelines are suggested for the backyard gardener who wishes to compost his yard waste. The second section is a review of 10 years of compost utilization research that I have conducted at the Station.

Compost: The Process and Research

By Abigail A. Maynard

Composting Essentials ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇

Since decomposition is a natural process, it will eventually occur, however slowly. The primary objective is to create an optimum environment for the microorganisms doing the decomposing. Bacteria are the first to break down plant tissue. Fungi and protozoans soon join the bacteria. Centipedes, millipedes, beetles, and earthworms also participate by tearing and chewing the materials into smaller pieces, making them more suitable for the microbes.

Although there is no one "right" way to compost, the process of composting can be accelerated and made more efficient. The microorganisms in the compost pile require the same basic essentials of most living organisms: nutrients, air, and water. If the microbes are abundant, the compost pile will decompose rapidly.

Materials

The two most important nutrients that the microbes in the compost pile require for their metabolism are carbon (C) and nitrogen (N). Carbon is oxidized for energy while nitrogen is a major component of amino acids, the building blocks of proteins. The ideal C/N ratio for most compost organisms is 30:1; about 30 parts of carbon are used by microbes for each part of nitrogen. Efficient composting with C/N ratios between 25 and 35:1 has been reported (Lambert, 1931). When the C/N ratio is too low (too little carbon), nitrogen may be lost in the form of ammonia because the microbes do not have enough carbon to utilize the nitrogen. Materials too high in carbon (high C/N ratio) require more time to complete the process. The C/N ratios of commonly composted materials are presented in Table 1.

What materials can go into a compost pile? First, they must be of biological origin. This may include wood, paper, kitchen trimmings, garden wastes, weeds, manure, and grass clippings. A combination of green, moist, high nitrogen materials like grass and food scraps and dry, brown, high carbon materials like leaves and woody matter provides an ideal, nutritionally balanced mixture for microbes. The best mixture is one or two parts green to three or four parts brown. Such a mixture is more efficient than a single material source. In addition, if more than one material is used, there is less chance of matting, which can cause the pile to go anaerobic and results in odors. Matting and odors are especially common when composting grass clippings alone.

A way to speed the composting process is to chop the material into smaller pieces to provide more surface area for the microbes. Running over materials with a lawnmower, using a leaf shredder, or chopping the materials with a shovel are effective.

Table 1. C/N ratio of various materials used in composting.

HIGH CARBON	
Wood	700:1
Sawdust	500:1
Paper	170:1
Straw	80:1
Cornstalks	60:1
Leaves	60:1
HIGH NITROGEN	
Alfalfa	13:1
Table Scraps	15:1
Green Clover	16:1
Grass Clippings	19:1
Rotted Manure	20:1
Mature Clover	23:1
Fruit Wastes	35:1

Some materials are best avoided in a compost pile:

- Meat, grease, and dairy products create odors, which attract animals to the pile.
- Dog and cat feces and diseased plants have harmful pathogens which could survive the composting process.
- Seeds of weeds that have gone to seed could survive the high temperatures created during the composting process and germinate in the garden when the compost is used.
- Invasive plants such as ivy, Bermuda grass, and morning glory may also be avoided to prevent their spread.

There are several inoculants or "starters" on the market, but independent tests indicate that no benefit is gained from these products (Ruttle, 1992). The microbes that do the decomposing are already on the surfaces of the materials to be composted and will flourish under the proper conditions. Adding soil to the compost pile is also unnecessary because it contains the same microorganisms in the other materials.

High nitrogen fertilizers, such as blood meal or urea, are also sometimes added to a compost pile to speed decomposition of materials with a high C/N ratio such as leaves. Experiments at The Connecticut Agricultural Experiment Station demonstrated that, while these fertilizers gave the piles of leaves an initial boost and helped them heat faster, the unfertilized piles attained the same temperatures in a few days and there was no difference in the overall composting time (Hill, unpublished data).

The pH of the compost pile changes naturally throughout the composting process. Initially, the pH is acid because organic acids are released during the early stages of decomposition (Poincelot, 1975). As the temperature rises, the pH increases and becomes slightly alkaline (Gray et al., 1973). Lime may not be added to a compost pile because ammonia forms readily with the addition of lime, leading to a loss of nitrogen by volatilization and possible odor problems.

Temperature

There are two populations of bacteria in the compost pile that flourish at different temperature ranges. Mesophilic bacteria are dominant at temperatures up to 105F and thermophilic bacteria thrive at temperatures from 105 to 160F. Mesophilic bacteria consume the most readily decomposable carbohydrates and proteins (Gray et al., 1971). Thermophilic bacteria initially decompose proteins and non-cellulose carbohydrates and eventually attack the lipid and hemicellulose fractions (Forsyth and Webley, 1948).

If conditions are favorable, the interior of the compost pile warms rapidly from the activity of the decomposing microbes. The thermophilic stage (105F) usually occurs in 2-3 days. The temperature in the center of the pile normally stabilizes at 140-150F for several days or weeks and then gradually cools to ambient temperatures as the material in the center of the pile is consumed. When the temperature at the center falls to ambient levels, the pile should be turned to introduce fresh, undecomposed material to the center of the pile where most of the composting takes place. The pile then reheats as the fresh material decomposes. Generally, each turning cuts the composting time by about a half.

It is important for the temperatures to reach beyond 105F because thermophilic decomposition is fastest and most efficient (Waksman et al., 1939). High temperatures also are more likely to kill weed seeds and plant pathogens. Special thermometers with long probes to measure temperatures in the center of the pile are available. The temperature can also be checked by hand. The material should start to feel warm 6 or 8 inches below the surface. At elbow depth, the composting material is almost too hot to touch if it is in the thermophilic range.

Volume

To maintain temperatures in the thermophilic range, the heat generated from microbial activity in the center of the pile must be retained. The minimum size to hold the heat is 3 X 3 X 3 feet. (27 cu. ft.). Smaller piles will also compost but will take longer.

There are several containers available on the market for composting or one can construct a compost bin from wood, snow fencing, wire mesh, or concrete blocks. The advantages of a bin are many. It is possible to have a taller pile in the same area and the reactive area near the center is larger. Some bins are rodent resistant and generally look neater. On the other hand, an advantage of unconfined compost piles is ease of turning. Although there are also compost tumblers on the market, their volumes are sometimes not large enough for sufficient heating to occur.

Oxygen

There are two kinds of microorganisms in a compost pile: those that require oxygen (aerobes) and those that do not (anaerobes). Under aerobic conditions, the primary breakdown products are carbon dioxide and water. Under anaerobic conditions, organic acids are produced which may cause odor problems. How can a compost pile be aerated to insure that the microorganisms are receiving enough oxygen? First, the pile is aerated whenever it is turned. Poking the pile with a pitchfork occasionally may also help aerate the pile. Another way to ensure that there is enough oxygen is to thrust a board (2 X 4), stick, or pole into the middle of the pile and then withdraw it a little at a time to allow air into the middle of the pile.

Moisture

Water is essential for all the organisms in the compost pile to live and move in. Moisture also keeps nutrients in solution so microbes can assimilate them. Unless there is enough moisture to keep ammonia in solution, it becomes a gas, evaporates into the air, and creates odors. The moisture content in the compost pile should be as high as possible, while still allowing air to filter through pore spaces. The optimum moisture level is 50 to 60% or about as moist as a wrung out sponge; i.e. no water should drip from a sample squeezed by the hand. If the moisture content exceeds 60%, many of the air spaces will be filled with water and limit oxygen for the aerobic organisms. Moisture becomes limiting when it falls below 45 to 50% by volume. Bacterial activity ceases at 12 to 15% (Golueke, 1972).

If autumn leaves are dry when collected, they should be moistened as the compost pile is formed. Rainfall alone is usually not adequate as the surface of the pile sheds water and the center of the pile, where most of the decomposition occurs, gets little moisture. In fact, Ruttle (1992) suggested adding the right amount of water as the pile is made, then covering the top with a water-resistant tarp or plastic garbage bags to slow evaporation and to keep rain out.

Compost Maturity

The two important problems encountered in a compost pile are failure to heat and a foul odor. Solutions to these problems, discussed earlier, are summarized in Table 2.

Table 2. Troubleshooting Guide.

IF COMPOST PILE FAILS TO HEAT:

- *The pile may be too dry*—moisten the pile while turning
- *The pile may be too small*—collect more material and mix in so the pile is at least 3 X 3 feet
- *The pile may lack nitrogen*—mix in more nitrogen such as from fresh grass clippings, manure, or food scraps

IF COMPOST PILE EMITS ODORS:

- *The pile has too little air*—turn the pile to aerate it, have a mixture of least two materials in the pile, and make sure that the pile is not too wet

There are several ways to tell if the compost is fully mature. Compost should be homogeneous, like a dark rich crumbly soil, and not contain recognizable pieces of the original material. In addition, the pile should no longer be warm to the touch. If the compost is not fully mature, applying it to the soil several weeks before planting would mitigate any adverse effects.

Leaf Mulching or Sheet Composting

In sheet composting, undecomposed material, such as leaves, compost directly in the soil where crops will grow. The whole or chopped leaves are placed in a layer or sheet 4 to 6 inches thick on the surface of the soil and then incorporated into the soil by rototilling or discing. Sheet composting can be done in fall or spring, but some crops respond better to leaves applied in the spring. Crops are then planted directly into the amended soil. The leaves will decompose by July.

The advantage of this method is that no space is needed to form a compost pile and time and labor are saved. The benefits to the plants are, however, not as great as when compost is used.

Nutrients in Compost

Compost is not considered a fertilizer because its nitrogen, phosphorus, and potassium (N-P-K) percentages are relatively low. Depending on the materials used, the nitrogen concentration of finished compost can vary from 0.5% (leaf compost) to 2+% (manure or biosolid compost).
Although these concentrations are low, the amount of nitrogen added to the soil can be high compared to a fertilizer. Since 1-inch of compost is equivalent to 50 T/A, the nutrient contribution becomes significant because, even for leaf compost, 50 T/A supplies 500 lb N/A. Unlike inorganic fertilizers, most of the naturally occurring nutrients in compost are not immediately available but are released slowly at a rate at which the plants can use them most profitably for optimum growth. Soil microbes release more nutrients from compost when temperatures are warmer and crops are actively growing.

Compost Experiments ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇ ◇

Many experiments have been conducted at the Experiment Station to determine proper utilization of compost. For the most part, crops respond favorably to compost amendments. A few exceptions will be explained later. The following is a review of 10 years of compost utilization research that the author has conducted at the Station. If the results of an experiment have been published in a scientific journal, the citation is listed in the heading. Additional details can be found in reprints of these articles which are available from the author.

◆ *Garden Demonstration Plot (***Maynard and Hill, 1994***)*

Preliminary studies for this plot were done by David Hill in the late 1970s while assisting in an inner city community garden program in New Haven. More than 75 garden plots (20 X 20 feet) were tended by neighbors on a site where houses had been razed. In a preliminary evaluation, it was estimated that the sandy material used to fill the cellar holes and level the lot had a low moisture holding capacity and would require frequent waterings to produce normal crop growth. Addition of 3 inches of leaf compost rototilled to a depth of 6 inches increased the moisture holding capacity to 2.5 times that of the sandy fill and provided retention of almost a 7 day supply of moisture to growing plants. This treatment also provided the greatest yields compared to plots amended with 6 inches of topsoil or where newspaper mulch was used to reduce evaporation (Hill, 1978).

To determine if an annual 1-inch amendment of leaf compost could partially or completely fulfill the fertilizer and lime requirements of typical garden vegetables, a 40 X 62 foot garden-sized plot at Lockwood Farm in Hamden was subdivided into five 10 X 40 foot plots in 1982, separated by 3-foot aisles. Four of the five plots were amended with 1-inch of leaf compost each spring which was incorporated into the upper 6 inches of the soil by hand forking or rototilling. The four compost-amended plots received varying amounts of fertilizer and lime starting with a full rate (1300 lbs 10-10-10/A and 2200 lbs lime/A), two-thirds the rate, one-third the rate, and no fertilizer and lime. The fifth plot or control received no compost, but the full rate of 10-10-10 fertilizer and lime. Vegetables were either seeded or transplanted into the plots during the growing season according to horticultural recommendations. The vegetables grown varied from year to year.

After 17 years, the cumulative yield of all vegetables from the plot receiving the full rate of fertilizer and lime plus compost exceeded the no compost control by 25%. Similar cumulative yields were obtained from the plot receiving two-thirds fertilizer and lime plus 1-inch compost. The plot receiving only one-third the fertilizer and lime plus 1-inch of compost yearly had cumulative yields 18% higher than the unamended control. The plot amended with yearly additions of 1-inch of compost but no fertilizer and lime had cumulative yields only 1% less than the fully fertilized control. Thus, it appeared that compost alone can fulfill the fertilizer requirement for most vegetables when applied over many years. It also appeared that high yields can be attained by using annual amendments of compost and reducing fertilizer and lime needs by one-third.

To completely fulfill the fertilizer requirement, compost must be applied every year. Compost not applied for three consecutive years resulted in a 38% decrease in cumulative yields from the plot that had been received only compost and no fertilizer compared to the full fertilized control. The plot amended earlier with compost and one-third the rate of fertilizer and lime maintained similar yields to the fully fertilized control.

Individual vegetable crops responded differently to annual compost applications, mostly due to variations in weather during each growing season. Cauliflower, cucumbers, leeks, and yellow squash responded favorably to compost additions at least 70% of the time. On the other hand, beets, carrots, Chinese cabbage, peas, and radishes yielded less on the compost-amended plots at least 20% of the time. With the exception of Chinese cabbage, these crops were direct seeded and the poor yields were the result of poor germination. Compost additions increased the organic matter content of the soil to 12.6% compared to 5.9% on the unamended control. The higher percent organic matter increased the water holding capacity of the soil, slowed soil warming in spring, delayed germination, and increased rotting of seed. Protection of the seed with a fungicide would improve germination and yields. Alternatively, direct-seeded crops can be seeded at a heavier rate to offset rotting in the compost-amended soil. Yields of seeded vegetables from compost-amended plots also improved when springs were warmer and drier.

On the other hand, increasing the water holding capacity of the soil by adding compost helped all crops during summer droughts by reducing periods of water stress. The amount of water in a plow layer (8 inches) of the compost-amended soil increased to 1.9 inches compared with 1.3 inches in unamended soil. Since vegetables require 1 inch of water a week, at field capacity, the compost-amended soil held a 2-week supply of water. Organic matter also promoted aggregation of fine soil particles and reduced soil crusting after summer rains.

The increased organic matter content of the compost-amended soil had a direct effect upon the bulk density, or weight of a known volume of soil. The unamended control had a density of 1.21 g/cc while the plot receiving 1 inch of compost yearly had a density of 0.97 g/cc. Reduced density of the soil enables plant roots to penetrate more readily and scavenge a greater volume for nutrients.

Summary. This demonstration plot showed that annual amendments of leaf compost improved the soil by decreasing its bulk density, increasing its organic matter content as well as providing nutrients to the plants. Most vegetables respond to compost additions by increasing their size and yield so that less inorganic fertilizer is necessary to obtain optimum yields. However, seeds planted early in the season may require protection by a fungicide or planting at higher densities to offset losses due to rotting in cold, moist soil.

◆ ***Fertilizer/Compost Experiment*** (Maynard, 2000)

The garden demonstration plot is still being used but, since it was not replicated, the results could not be statistically analyzed. A similar experiment was initiated in 1995 with replications at Lockwood Farm in Hamden and at the Valley Laboratory in Windsor to study the response of vegetables to compost in two different soil types. Windsor has a sandy terrace soil with somewhat limited moisture holding capacity and Hamden has a loamy upland soil with moderate moisture holding capacity.

Unscreened 2-year-old leaf compost produced in a passive pile turned two or three times yearly was applied in spring to plots at both sites for three consecutive years at the rate of 50 T/A (dry weight basis) (1 inch on the surface) and rototilled into the soil to a depth of 6 inches. The pH (1:1 suspension) was 6.5 and the soluble salts were 0.6 mmhos/cm. The nutrient values, determined by the Morgan Soil Test (Lunt et al., 1950), were NO_3-N: 3 ppm, NH_4-N: 80 ppm, P: 100 ppm, K: 250 ppm, Ca: 1200 ppm, and Mg: 125 ppm. Three sets of the compost-amended plots were fertilized with commercial grade 10-10-10 (N-P_2O_5-K_2O) at three rates: 0, 650, and 1300 lb/A. Another set of compost-amended plots was fertilized with an organic fertilizer, cottonseed meal (6.6-3.0-1.5) (N-P_2O_5-K_2O), at a rate of 2166 lb/A. Each 20 X 20 foot plot was separated by 3-foot aisles and replicated four times in a random block design. Yields from the compost-amended plots were compared to unamended control plots fertilized with 10-10-10 at a rate of 1300 lb/A.

Lettuce, broccoli, and cauliflower were grown in spring; peppers, tomatoes and eggplant in summer; and broccoli and cauliflower in fall. All crops were grown from transplants that were started in a greenhouse 6-8 weeks before planting in the field. Recommended cultural practices were followed for each vegetable; each crop was harvested at maturity. Weeds were controlled by cultivation. Diseases and insects were controlled as needed, except organic practices were followed in the plots treated with organic fertilizer. Plots were irrigated with overhead sprinklers as necessary. Plants were removed from the plots at the end of the growing season and the land left fallow over winter.

Soil samples were collected at the end of each growing season. Available soil nutrients were measured using the Morgan Soil Test (Lunt et al. 1950) and percent organic matter was measured by loss on ignition.

As shown in the garden demonstration plot, the experiment at Lockwood Farm confirmed that compost applied yearly for 3 years can completely replace fertilizer. To achieve optimum yields, however, a combination of inorganic fertilizer and compost is required but not the full rate of fertilizer. Tomatoes, eggplant, and peppers responded to the compost amendments in the first year. Lettuce, broccoli, and cauliflower did not obtain optimum yields on the reduced fertilizer plots until the second and third years. For these crops, it appeared that more than one compost application must be made to accumulate sufficient nutrients to support optimum yields.

The crops in the sandy soil at Windsor responded somewhat differently. Tomatoes again had optimum yields in the first year in compost-amended soils with reduced inorganic fertilizer, but the other vegetables required more than one application of compost. The coarse textured sandy soil at Windsor warms quickly in the spring and promotes more rapid microbial decomposition. Thus, the accumulation of organic matter in the coarse textured soil is slower than in the finer textured soil at Lockwood Farm and its effect on crop yields may be delayed.

The plants treated with organic fertilizer behaved differently on the two soil types. On the loamy soil at Lockwood Farm, the yields from the organic plots were similar to the control plots amended only with inorganic fertilizer in the first year and to the plots amended with compost and half the rate of inorganic fertilizer in subsequent years. On the sandier soil at Windsor, yields on the organic plots were lowest for all the treatments in all years. Again, the microbial conversion of organic nitrogen to nitrate nitrogen is more rapid in Windsor but the coarse soil texture also allows rapid leaching. In addition, the insect pressure at Windsor was greater than at Hamden. Control by spraying Sevin and malathion on the non-organic plots was more effective than organic methods (rotenone) on the organic plots and may have contributed to the decreased yields.

Summary. This experiment showed that for optimum yields of most vegetables, a combination of leaf compost and 10-10-10 fertilizer is preferred, although the full rate is unnecessary. Half the rate of fertilizer plus compost is sufficient for optimum yields on loamy soils and for most years on sandy soils. To achieve optimum yields on sandy soils, additional side dressings of nitrate supplying fertilizer may be required after heavy rainfalls during the growing season. Additional soil tests can determine nitrate levels during the growing season. Organic fertilizer with compost can also be used on loamy soils but may not provide satisfactory yields on sandy soils. This experiment demonstrated the importance of knowing soil type when using compost.

◆ ***Using Composted Animal Manures*** (Maynard, 1993a and 1994a)

Compared to leaf compost, composted animal manure has a greater amount of nutrients, particularly nitrogen. This experiment (1989-1991) was designed to determine if optimum vegetable yields could be achieved utilizing only manure compost without additional fertilizer.

Of particular concern when using high rates of animal manure compost is the possibility of nitrate leaching. To address this problem, wells were installed at Windsor to monitor the ground water beneath each of the treatments. Windsor's soil is ideally suited to studying nitrate leaching because it is very sandy with a high water conductivity rate and a shallow water table perched over impervious clay beds.

The two composts used in the experiment were produced by Earthgro Inc. (Lebanon, CT). Spent mushroom compost (SMC), consisting of horse manure and bedding amended with some chicken manure, gypsum, cottonseed meal, and cocoa bean shells, was composted outdoors for about 6 months in static piles turned monthly. The total nitrogen content was approximately 0.5% (dry weight basis). Chicken manure compost (CMC), consisting of a mixture of chicken manure, horse manure, spent mushroom compost, and sawdust, was composted for about 20 days in an in-vessel (closed) system utilizing forced air and an agitated bed. The total nitrogen content was approximately 2% (dry weight basis). Both composts were applied in the fall at Lockwood Farm and Windsor and incorporated into the soil the following spring at the rates of 25 or 50 T/A, equivalent to a layer of about ½ inch and 1 inch of compost, respectively. No fertilizer was added to plots receiving compost. Control plots received a conventional rate of 10-10-10 fertilizer (1300 lb/A), but no compost. The fertilizer was applied in spring just before planting of each crop. Additional plots at Lockwood Farm receiving the low rates of compost were amended with 10-10-10 fertilizer at the full rate (1300 lb/A) and half rate (650 lb/A). Another experiment was conducted at Windsor in which compost was applied in the spring to determine whether time of application affected yields.

Nine crops of vegetables were grown: three in spring (broccoli, cauliflower, lettuce), three in summer (eggplant, peppers, tomatoes), and three in fall (broccoli, cauliflower, spinach). All crops were grown from transplants except spinach was direct seeded. Recommended cultural practices were followed for each vegetable and each crop was harvested at maturity.

All crops varied in their response to the animal manures, their rates, and timing of application. Yields of crops increased 12 to 133% when compost was applied in the spring rather than fall. There were a few exceptions. Spring or fall application of either compost had no effect on yields of fall broccoli and lettuce. Chicken manure compost applied at a rate of either 25 or 50 T/A provided enough nutrients for all crops, except lettuce, to exceed yields from the control plots at both sites for 3 years. There was, however, a negative cumulative effect of the CMC additions for eggplant and peppers after 2 years. Spent mushroom compost, with its lower nutritive content, produced lower yields of most vegetables compared to the fertilized controls even at high rates of application. The exceptions were eggplant and tomatoes which had yields exceeding the control with either rate of compost at both sites. The addition of half the rate of fertilizer to the SMC amended plots improved the nutrient content so that all the crops had yields greater than the control at both sites. There was a negative cumulative effect on peppers and eggplant after three consecutive years of SMC application.

Nitrogen in finished compost is primarily in organic forms and must be converted by soil microbes to nitrate, the form most readily utilized by plants. Nitrate not utilized by plants is readily leached from the soil. The conversion of organic nitrogen to nitrate in the compost-amended plots was so slow that plants readily assimilated what was converted. Concentrations of nitrate in ground water beneath all compost-amended plots remained below 10 ppm throughout the study. In the control plots amended with inorganic fertilizer containing nitrate, all of the nitrogen was readily available to plants; but in an unusually wet spring, excess nitrate leached to ground water and increased its concentration to 15 ppm, well above health standards. Nitrate concentrations in ground water from CMC plots amended at 50 T/A peaked at 9.2 ppm after three consecutive years of compost application. The cumulative effect in the soil was substantiated by soil analysis.

Summary. The results from this experiment indicate that manure composts can be applied for three successive years at rates high enough to supply the fertilizer requirement of most vegetables without contaminating the ground water with nitrate above public health standards (10 ppm). Most of the nitrogen in the composts was in organic forms in the soil and not susceptible to leaching. Because of the cumulative effect over time, it appeared that lower rates of compost could be applied in subsequent years to lessen the chance of nitrate leaching, especially with nitrogen-rich composted chicken manure. Safe application rates of compost depend on the type of compost, rate of mineralization, and soil factors which influence the conductivity of water.

◆ ***Municipal Solid Waste (MSW) Composting Demonstration Project*** (Maynard, 1993b and 1995)

In 1992, the towns of Fairfield and Greenwich conducted a trial of municipal solid waste (MSW) composting. The waste, separated by homeowners, included food waste, yard waste, wet and soiled paper, dry paper packages, diapers, sanitary products, and pet waste.

A trial was conducted at Lockwood Farm from 1992 to 1994 on 10 X 10 foot plots surrounded by 3-foot aisles and replicated four times. The MSW compost was applied at the rates of 25 or 50 T/A, equivalent to a layer of about ½ inch and 1 inch of compost, respectively. The compost was incorporated into the soil by rototilling. Control plots received no compost. All plots were fertilized once before planting with 10-10-10 fertilizer at a rate of 1300 lbs/A. Ten tomato plants per plot were grown from transplants. Vegetative suckers were removed to the first flower cluster and the plants were staked. Weeds were controlled by hand cultivation and no pesticides were used. Marketable tomatoes were harvested from each plot weekly from August to October. At the end of each growing season, plants were removed and the land was left fallow.

Average yield (lbs/plant) from plots amended with 50 T/A MSW compost was significantly greater all 3 years (average +38%) than from the unamended controls. Yield from plots amended with 25 T/A MSW compost was significantly greater than from the unamended control only in 1993. The average number of tomatoes/plant and the average weight of each tomato were also greater from the compost-amended plots. The greater yield was due primarily to increased organic matter, pH, and nutrients, especially nitrate-nitrogen, which increased three fold.

The leaves and fruit were sampled and analyzed for 17 elements. In tomato fruit, Na and P increased and Cd and Be decreased in MSW amended soil compared to unamended controls (Stilwell, 1993). In tomato leaves, Na increased and Cd, Cu, and Mn decreased in MSW amended soil compared to unamended controls.

Summary. Source separated MSW compost applied for 3 years at 50 T/A produced significantly higher yields of tomatoes for all 3 years when compared to unamended controls. There was a cumulative effect of yearly compost additions on several soil properties including organic matter percentage, pH, and nutrient content. In subsequent years, it appears that lower levels of fertilizer can be applied in MSW compost-amended soils to lessen the possibility of nitrate leaching.

◆ ***Growing Onions in Compost Amended Soil*** (Maynard and Hill, 2000)

Although onions grow in a wide diversity of soil types, soils rich in organic matter with good drainage are preferred. Compost added to a light, sandy, soil, improves the water holding capacity. It is especially important to hold moisture near the surface of the soil to promote growth of onions whose adventitious roots are shallow. The objective of this experiment was to determine the impact of repeated applications of leaf compost on the yield and size of onions over 3 years.

The study was conducted at the Valley Laboratory in Windsor. A 20 X 40 foot plot was divided into two 20 X 20 plots. Leaf compost was applied to one plot in April 1994, 1995, and 1996 at a rate of 50 T/A (1 inch on the surface) and rototilled into the soil to a depth of 6 inches. The unscreened leaf compost was produced in a passive pile turned two or three times yearly for 2 years. The pH of the compost (1:1 suspension) was 6.5 and the soluble salts were 0.6 mmhos/cm. Both plots were fertilized prior to planting with commercial grade 10-10-10 (N-P_2O_5-K_2O) at a rate of 1300 lb/A.

Four cultivars of onions were grown: Daytona (Spanish), Ole (Spanish), X-201 (Spanish), and Corona (Storage). In March, rows of seed were sown in shallow trays and placed in a greenhouse maintained at 50-70F. Seedlings in the trays were lightly thinned to avoid overcrowding after reaching 1-1.5 inches in height. After 5 weeks, the seedlings were moved to a coldframe for hardening before planting in the field. Water soluble 20-20-20 fertilizer (N-P_2O_5-K_2O) (0.5 oz/gal) was added to the seedlings 1 week before transplanting in May. The seedlings were transplanted 6 inches apart in 40-foot rows that were 18 inches apart. Cultivar rows were randomly planted in three replications for 2 of 3 years. Plots were irrigated once following transplanting and again after initial application of the herbicide Dacthal 75W (10 lb/A).

Yields from the unamended control plots (52% variation) fluctuated more than the compost-amended plots (3% variation) in response to variable rainfall from year to year. After 3 years of compost additions, yields from the compost-amended plots of the three Spanish onion cultivars were significantly greater than yields of these cultivars grown in unamended plots. The greater yields were due to both increased bulb weight and greater percent harvested. In 2 of 3 years, the compost-amended plots produced a greater percent of the more marketable colossal (+4 inches) and jumbo (3-4 inches) sized onions. The incidence of soft rot disease was also reduced in the compost-amended plots. This was especially evident in the more susceptible Spanish cultivars (Ole and X-201) and in wetter than average years when more disease was present. On the sandy soil, more than 1 year of leaf compost amendments at 50 T/A was required before some disease suppression was achieved.

Summary. Amending a sandy soil with leaf compost for 3 years affected onion production in several ways. First, yields from the unamended plots fluctuated more than from the compost-amended plots in response to the variable weather from year to year. Second, repeated compost additions reduced the incidence of soft rot disease, especially in susceptible cultivars in years with higher than average precipitation. Third, compost amendments increased the yields of most onion cultivars. As with disease suppression, there was a cumulative effect with more than 1 year of compost amendments required on a sandy soil before the yields were improved. Fourth, in 2 of 3 years, the compost-amended plots produced a greater percentage of colossal and jumbo sized onions in all cultivars.

◆ ***Utilization of MSW Compost in Nursery Stock Production*** (Maynard, 1994b and 1998)

In the "ball and burlap" method of tree harvest, common in many nurseries, topsoil is removed with every tree. After the harvest of successive crops, the topsoil may become depleted, rendering the land less suitable for further plantings. Soil amended with compost between plantings of nursery crops could mitigate topsoil loss. However, the response of trees to compost amendment must first be determined.

This experiment was part of an overall Northeast applied research project in which the same compost was used in a variety of applications (trees, turf, corn, wildflowers, grapes, potting media). MSW/biosolid compost was obtained from the Delaware Solid Waste Authority in Dover, DE. Biosolids is sludge produced by sewage treatment plants. The

MSW:biosolids volume ratio in the compost was 2:1 and contained no yard waste. Before the compost was delivered, approximately 20% yard waste compost was blended into the MSW/biosolid compost to approximate the amount of yard waste typically found in the MSW stream.

Compost was applied in 1992 at the rates of 0, 25 (0.5 inches), and 50 T/A (1 inch) and rototilled into the soil before planting. Other plots received 100 T/A (2 inches) of mulch after planting or were treated with herbicide to control weed growth. All plots contained four rows, one each of red maple, sugar maple, white pine, and pin oak. Annual measurements of crown height, crown width, and caliper (stem diameter) were made the following three winters.

Three out of four species of trees had a positive response to MSW compost in one or more growth parameters. Sugar maple had significant increases in height, crown development, and caliper, even at a low compost application rate (25 T/A or 1/2 inch) compared to the unamended soil. Increasing the amount of compost to the soil beyond 25 T/A had little additional effect on sugar maple height and crown growth but a small positive effect on caliper growth. Red maple had significant height and crown growth with increasing amounts of compost but little effect on caliper. Pin oak had a positive response in caliper growth to compost additions (both rates) but a slightly negative response in height growth. The growth index (average of height and crown growth) showed no response to compost additions indicating that negative responses in height growth were offset by positive responses in crown growth. Growth of white pine showed little response to compost additions at either application rate.

Mortality in the first year was the parameter in which large differences between the pines and the other species were observed. For pin oak, there was virtually no first-year mortality in any of the plots. For both red and sugar maple, there was a significant difference between the compost treatments with mortality decreasing as the rate of compost application increased. This could be due to increased water holding capacity of the compost-amended soil that contained a higher organic matter content. The organic matter content at both sites increased as much as 48% in the compost-amended soil. The increased water holding capacity of the compost-amended soil surrounding the roots could alleviate transplanting shock.

In general, mulching maples with 2 inches of compost appeared to provide the best protection for the stressed whips in the first year of establishment. The mulch also provided adequate weed control in the first year. While weeds were not completely eliminated, their numbers were reduced so that they were easily controlled by hand. In the second year, numerous weeds invaded the mulched plots but were suppressed by mowing after the trees became established. In subsequent years, the mulched maples grew more than maples in the unamended controls.

First-year mortality of transplanted white pine seedlings, on the other hand, increased with increasing amounts of compost. The mortality could be due to either the high conductivity of salts or the high ammonium concentration of the MSW compost, indicating that the compost was not fully mature. Breslin (1995), using the same compost in a sod production experiment, observed a delay in germination of turfgrass seeds in compost-amended soils which was attributed to compost immaturity. In this experiment, white pine was affected more than the other species because the small 12-inch seedlings were in smaller holes in the rototilled soil than the deeper holes for the 5-6 foot other species and were in more direct contact with the compost. The immaturity of the compost could have been remedied by allowing the compost to age in the pile before application or by delaying planting if the compost had already been incorporated into the soil. There were no negative impacts on white pine growth after the first year.

Summary. In general, red and sugar maples responded to MSW compost additions with increased height and canopy growth. Sugar maple also showed increased caliper growth. Caliper growth in pin oak increased as the application rate of the compost increased but height and canopy growth responded little. White pine had no growth response to the compost additions. Small bare-rooted seedlings such as white pine may be sensitive to high levels of ammonium and salts if the compost is not properly aged.

◆ ***Leaf Mulching Experiment*** (Maynard, 1996 and 1997)

Farmers have been sought by towns to accept leaves to be used in their growing operation. Incorporation of uncomposted leaves into agricultural soils effectively composts the leaves in place (leaf mulching) as microorganisms degrade the organic material and release nutrients to be utilized by crops the next year. There is concern, however, that nitrogen may become immobilized in the soil when leafy materials with a high C/N ratio (60:1) are applied.

Undecomposed leaves were layered about 6 inches thick on one set of plots at Lockwood Farm and the Valley Laboratory in November and another in April for three years from 1992 to 1994. The leaves were incorporated into the soil by rototilling in two directions, perpendicular to one another. Eggplant, peppers, and tomatoes were grown from transplants. Yields from the leaf amended plots were compared to yields in plots amended for 3 years in April with 1 inch of leaf compost and unamended controls. All plots were fertilized with 10-10-10 fertilizer at a rate of 1300 lb/A.

Tomato yields from all the amended plots (leaves or compost) were greater than or equal to the control plots at both sites. Thus, there were no negative effects such as nitrogen immobilization by using undecomposed leaves. Eggplant and peppers responded in a similar manner at both sites with the greatest yields from plots amended with compost and the smallest yields from plots amended with leaves in the fall. The lower yields in plots amended with leaves in the fall appears unrelated to nitrogen immobilization. Soil analysis verified that nitrogen and other plant nutrients were greater or equal to concentrations in the unamended control plots throughout the three growing seasons.

Reduced yields from plots amended with leaves in the fall could be due to the phytotoxicity of phenolic substances released during decomposition. The release of phenols is greatest during the early stages of decomposition. In this study, phenols from leaves applied in the fall were held in a frozen state during winter, so they would be in contact with the newly emerging roots of the transplants the following spring. In leaves applied in the spring, initial decomposition took place during the winter before application. Phenols released during the early stages of decomposition did not come into direct contact with plant roots when the leaves are applied the following spring.

Summary. This study showed that the greatest eggplant and pepper yields were obtained when the soil is amended with fully-mature leaf compost. If compost is unavailable, spring application of leaves stockpiled over winter provides a suitable material. Consistently high tomato yields were also obtained from plots amended with leaf compost but applications of undecomposed leaves in fall or spring did not reduce yield.

◆ *Leaf Mulching with Oak or Maple Leaves*

A leaf mulching experiment is currently being conducted in which plots have been amended only with oak or maple leaves. Since 1995, 6 inches of leaves have been applied to the plots in the fall and rototilled into the soil. Yields from these plots are compared to yields from the unamended control plots. Each 10 X 10 foot plot is separated by 3-foot aisles and replicated three times in a random block design. All plots receive the same amount of fertilizer (1300 lbs 10-10-10/A) each year. Lettuce, tomatoes, eggplant, and peppers are grown from transplants each year.

Summary. After 5 years of annual additions of either oak or maple leaves, yield differences between the treatments were small and insignificant. There were no negative impacts by using either undecomposed oak or maple leaves. In some years, increases in yields were observed on the amended plots compared to the unamended control plots. There was also little difference in various soil characteristics, including pH, between the treatments. Soil organic matter, however, increased slightly on the leaf amended plots. Clearly, this method of disposing of leaves is viable. Although the benefits are not as great as when compost is used, there are no negative impacts.

◆ *Using Compost in Cut Flower Production*

Preliminary trials conducted at Lockwood Farm and Windsor compared annual cut flower yields from soils amended with leaf compost and varying amounts of inorganic fertilizer. A randomized block plot was established in 1999 with four treatments and four replications with individual plots 10 X 15 feet separated by a 3 foot aisle between each plot. The four treatments included: compost plus 1300 lb/A 10-10-10 fertilizer, compost plus 650 lb/A 10-10-10 fertilizer, compost alone, and 1300 lb/A 10-10-10 fertilizer with no compost (control). One inch of leaf compost (50 T/A) was applied in April and rototilled into the soil. The fertilizer was incorporated into the soil before planting. Four species of annual cut flowers were grown from transplants: cosmos, zinnia, black-eyed Susan, and snapdragon. The flowers were harvested weekly. Soil analyses determined nutrient levels at the end of the growing season.

After 1 year, some preliminary observations were made. For all the species, the greatest yield (stems/plant) at both sites were from plots amended with compost and half the rate of fertilizer with yields increasing 3 to 17% compared to the unamended full-fertilized control. In plots amended with compost only, most yields decreased 3 to 10% compared to the fertilized control plots except zinnia whose yield equaled the control. Unless the harvested stems were counted, the decrease in yields for the other species in the compost only plots would be likely unnoticed by a backyard gardener.

The leaf compost used in 1999 was not fully mature because the leaf piles were not turned regularly throughout the winter. Black-eyed Susan transplants developed some foliar necrosis which only occurred on the compost-amended plots. The plants outgrew the problem and final yield did not appear affected. The adverse effects could have been avoided if the compost was incorporated into the soil several weeks before planting the seedlings.

Summary. It appears that compost plus half the rate of fertilizer produces optimum yields of cut flowers. This experiment will be repeated for two additional years with leaf compost applied each April. Yields of flowers from the compost only plots may improve in subsequent years as the cumulative effects of the annual compost amendments build in the soil.

◆ *Using Compost in Sweet Corn Production*

Sweet corn requires large amounts of nitrogen throughout the growing season. For that reason, it is difficult for organic growers who grow sweet corn to obtain optimum yields because nitrogen levels early in the growing season tend to be lower in soils amended with only compost and organic fertilizers.

This 3-year experiment, begun in the fall of 1998, is comparing the yields of sweet corn grown in five compost/vetch cover crop/fertilizer combinations at Lockwood

Farm and the Valley Laboratory. A randomized block plot was established with six treatments and four replications with individual plots measuring 12 X 24 feet each separated by a 3 foot aisle. The six treatments included: vetch plus compost plus 1300 lb/A 10-10-10 fertilizer, vetch plus compost plus 650 lb/A 10-10-10 fertilizer, no vetch plus compost plus 1300 lb/A 10-10-10 fertilizer, no vetch plus compost plus 650 lb/A 10-10-10 fertilizer, 1300 lb/A 10-10-10 fertilizer with no vetch or compost and 650 lb/A 10-10-10 fertilizer with no vetch or compost. One inch of leaf compost (50 T/A) was applied in April 1998 and 1999 and incorporated into the soil by rototilling. Two-thirds of the 10-10-10 was applied preplant and one-third side-dressed 4 weeks after germination. Vetch was planted in the fall as a winter cover crop and incorporated into the soil the following spring before the compost was applied.

Each plot contained two cultivars of sweet corn, four rows/cultivar. Yields of each cultivar were determined from all four rows. Ears from the two inner rows were randomly sampled for weight and length. Observations were made on diseases and insect infestations. Recommended cultural practices were followed and the crop was harvested at full maturity.

Preliminary results after two growing seasons indicated that the greatest yields in the first year were from plots amended with vetch, compost, and the full rate of fertilizer, and the smallest yields were from the control plots amended with only half the rate of fertilizer. Plots amended with compost and half the rate of fertilizer had yields equivalent to the full-fertilized controls. In the second year, the greatest yields were from plots amended with compost, vetch, and half the rate of fertilizer and the smallest yields were from the control plots amended with half the rate of fertilizer. Plots amended with compost and half the rate of fertilizer again had yields equivalent to the full-fertilized controls.

Summary. It appears, so far, that when leaf compost is used in sweet corn production, fertilizer rates can be reduced by one half. However, to obtain optimum yields a cover crop of vetch should be planted the preceding fall and incorporated into the soil before compost is applied.

CONCLUSION

Use of compost by both commercial growers and backyard gardeners is increasing throughout the country (Eddy, 2000). This increase is due to the rising demand for organic vegetables and the increasing amount of organic materials banned from landfills in many states. This research has shown that compost not only improves the soil and crop yields but also benefits the environment by decreasing the amount of inorganic fertilizer needed and preventing nitrate leaching to ground water.

REFERENCES

Breslin, V.T. 1995. Use of MSW compost in commercial sod production. BioCycle 36(5):68-193.

Eddy, D. 2000. Waste Not, Want Not. American Vegetable Grower. February 2000.pp. 32-33.

Fosyth, W.G.C. and Webley, D.M. 1948. The microbiology of composting. II. A study of the aerobic thermophilic bacterial flora developing in grass composts. Proc. Soc. Appl. Bact. 3:34-39.

Golueke, C.G. 1972. Composting, a study of the process and its principles. Rodale Press, Inc., Emmaus, PA. 110 pp.

Gray, K.R., Sherman, K., and Biddlestone, A.J. 1971. A Review of Composting - Part 1, Process Biochem., 32-36.

Gray, K.R., Biddleston, A.J. and Clark, R. 1973. A Review of Composting - Part 3, Process Biochem., PP. 32-36.

Hill, D.E. 1978. Leaf-mold for Soil Improvement in Home Gardens. Connecticut Agricultural Experiment Station Bulletin 774, 8 pp.

Lambert, E.B. 1931. Synthetic compost for growing mushrooms. U.S.D.A. Journal Agr. Research 48, 971-980.

Lunt, H.A., Swanson, C.L., and Jacobson, H.G.M. 1950. The Morgan soil testing system. Ct. Agric. Exp. Sta. Bull. 541.

Maynard, A.A.1993a. Nitrate leaching from compost-amended soils. Compost Science and Utilization 1(2): 65-72.

Maynard, A.A. 1993b. Evaluating the suitability of MSW compost as a soil amendment in field-grown tomatoes. Compost Science and Utilization 1(2):34-36.

Maynard, A.A. 1994a. Sustained vegetable production for three years using composted animal manures. Compost Science and Utilization 2(1):88-96.

Maynard, A.A. 1994b. Effect of annual amendments of compost on nitrate leaching in nursery stock. Compost Science and Utilization 2(3):54-55.

Maynard, A.A. 1995. Cumulative effect of annual additions of MSW compost on the yield of field-grown tomatoes. Compost Science and Utilization 3(2):47-54.

Maynard, A.A. 1996. Cumulative effect of annual additions of undecomposed leaves and compost on the yield of field-grown peppers. Compost Science and Utilization 4(2):81-88.

Maynard, A.A. 1997. Cumulative effect of annual additions of undecomposed leaves and compost on the yield of tomatoes and peppers. Compost Science and Utilization 5(1):38-48.

Maynard, A.A. 1998. Utilization of MSW Compost in Nursery Stock Production. Compost Science & Utilization 6(4):38-44.

Maynard, A.A. 2000. Applying leaf compost to reduce fertilizer use in tomato production. Compost Science & Utilization (in press).

Maynard, A.A. and Hill, D.E. 1994. Impact of compost on vegetable yields. BioCycle 35(3):66-67.

Maynard, A.A. and Hill, D.E. 2000. Cumulative effect of leaf compost on yield and size distribution in onions. Compost Science & Utilization 8(1):12-18.

Poincelot, R.P. 1975. The biochemistry and methodology of composting. Ct. Agric. Exp. Sta. Bulletin 754. 18 pp.

Ruttle, J. 1992. Rubbish. National Gardening. May/June ’92 pp. 38-41.

Stilwell, D.E. 1993. Evaluating the suitability of MSW compost as a soil amendment in field grown tomatoes Part B: Elemental analysis. Compost Science & Utilization 1(3):66-72.

Waksman, S., Cordon, T, and Hulpoi, H. 1939. Influence of temperature upon the microbiological population and decomposition processes in composts of stable manures. Soil Sci. 47:83-114.