FACTORS AFFECTING THE REDUCTION OF CARBON TO NITROGEN RATIO IN COMPOSTED SEPARATED SOLIDS

Senior Project

Presented to the Faculty of the Dairy Science Department

California Polytechnic State University, San Luis Obispo

By

Mark Fagundes

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ABSTRACT

The objective of the study was to determine the factors involved in the reduction of carbon to nitrogen ratio in composted separated solids. A single compost windrow was laid on a 6,000 jersey cow dairy farm located in Madera County. Samples were obtained from six separate positions on the pile, every other day. Direct pile measurements on the date of sampling included pile temperature (surface and core), height, width and curvature. Samples were removed from the windrow during each sampling meeting to determine the percent dry matter content. The collected samples were sent out to Denele Analytical Inc. to determine bi-weekly carbon to nitrogen ratios on pile positions one, three and six, both surface and core. Factors such as rotation frequency, wind speed, outside temperature, humidity and rain were noted on all sample dates. Statistical analysis was performed using the SAS GLMSELECT procedure to identify the significant factors in the reduction of carbon to nitrogen ratio. Fifteen independent variables/factors were run through SAS and four independent variables were found to impact the composting process. Pile area, temperature at the pile core, date of sampling and wind speed were the factors that changed the dependent variable of carbon to nitrogen ratio. Further research is needed to determine if additional factors can impact the composting process and to expand the number of observations of C/N ratios.

Key Words: compost, dairy manure solid, windrow

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INTRODUCTION

Modern dairy farmers in the west have become subjected to public and environmental scrutiny over the handling of dairy waste solids. The National Resources Conservation Service in California has recently implemented a Comprehensive Nutrient Management Plan that is unique to Animal Feeding Operations (AFO) (NRCS, 2011). The objective of the document is to monitor AFO owners and the operator’s plan to manage water, manure and organic by-products. Strategies that decrease the negative effects of dairy waste on the environment are likely to become essential for continued environmental efficiency and to reduce the impacts on water pollution and air quality.

With the pressure from the new established environmental laws, dairy farmers have begun looking for new alternatives and techniques to utilize separated manure solids. Composting of separated solids has become a popular method of recycling organic material. The separated solids are readily available and are easily obtained from flush lanes and lagoons. Composted solids or organic materials provide a less expensive bedding alternative to inorganic materials, such as sand. The benefits of composting separated solids are twofold; the recycling of waste solids help to reduce environmental impacts and help save dairy producers money.

An experimental pile of separated solids was laid out to be examined on a 6,000 jersey dairy farm located in Chowchilla, Ca. The pile was measured every two days from six separate areas on the pile. Samples were gathered from both the surface and core of the pile and were taken back to the lab to gather percent dry matter. Periodic samples were sent to Denele Analytical, Inc. for carbon to nitrogen ratios. Daily temperature, humidity, precipitation, wind speed, pile height, width, curvature, pile rotation, and the pile surface and core temperatures were measured during each sampling day. Previous studies have stated the importance of temperature, pile rotation/aeration and microbial activity, but this study aimed to follow an entire pile from the date it was laid, until the composting process was complete. Statistical analysis was used to determine the significance of the factors in reducing the carbon to nitrogen ratio of the composted separated solids.

The dairy industry has faltered in establishing proper guidelines on the composting of separated solids. This realization illustrated the need to begin investigating the factors involved in composting and the proper method in reducing the carbon to nitrogen ratio from 30:1 to 10:1. The objective was to determine the factors involved in the reduction of carbon to nitrogen ratio in composted separated solids.

LITERATURE REVIEW

Composting: The Origin and Definition

Composting of dried manure solids (DMS) and separated solids is a fairly new standard in the dairy industry, but the initial birth of composting is difficult to specify. The origin of composting has been traced to the ancient Akkadian Empire in the Mesopotamian Valley, who referred to the use of manure in agriculture with cuneiform writing on clay tablets 1,000 years before Moses was born. Composting was initially introduced to North America by both Native Americans and early European settlers of America, who utilized the compost for agricultural practices (Univ. of Illinois Extension, 2012). Dairy farmers and the industry as a whole have been disinclined to search for alternative freestall bedding materials. With decreasing and volatile milk prices, dairymen have begun searching for cheap substitutes to inorganic bedding. The popularity of composted DMS has risen in the past 30 years as a result of this monetary discovery, that composted DMS could be produced on-farm and at a cheaper cost than inorganic bedding.

Researchers, such as C. R. Mote and E. J. Carroll began looking at the bacterial distribution in DMS and explored the effects of composting on bacterial growth. The initial studies dealt with quantifying the survival rates of coliform bacteria and investigating new systems of composting to improve the quality of composted DMS. Later studies, performed by J. R. Bishop and J. J. Janzen looked at DMS as a potential source of bedding. This data which was gathered in the late 1970's and early 1980's laid the groundwork of compost research, and in turn dairy farmers began to look at the potential use of DMS.

Composting has a biological and ecological definition, in which the biological definition differentiates composting from all other forms of decomposition. The ecological definition ties the relations between living organisms and their natural environment. The biological definition according to the United Nations Environment Programme (UNEP) states that, “Composting is the biological decomposition of biodegradable solid waste under controlled predominantly aerobic conditions to a state that is sufficiently stable for nuisance-free storage and handling and is satisfactorily matured for safe use in agriculture”. The UNEP states the ecological definition as, “Composting is a decomposition process in which the substrate is progressively broken down by a succession of populations of living organisms. The breakdown products of one population serve as the substrate for the succeeding population. The succession is initiated by way of the breakdown of the complex molecules in the raw substrate to simpler forms by microbes indigenous to the substrate”.

Types of Bedding

Dairy bedding is used to provide cows with a dry, clean and comfortable place to lie down and ruminate. There are predominantly two types of bedding used on dairy farms; organic, such as rice hulls, sawdust, straw, manure solids, and inorganic, such as sand. Organic bedding materials contain vital nutrients required for bacterial growth, while inorganic bedding materials do not. Once any type of bedding becomes soiled or contaminated with fecal matter or urine, pathogen growth can be supported by the bedding material. Inorganic as well as some composted organic bedding materials such as DMS start out with lower bacterial concentrations than other organic sources. Regardless of these low initial bacterial concentrations, within a 24-48 hour period of being placed in the freestall, pathogen levels in all organic bedding materials rise to similar concentrations. A common rule of thumb has been established stating that bedding materials should be kept below a maximum bacterial count of 1,000,000 colony forming units per gram (cfu/g) of bedding wet weight (Schwarz et al., 2010). Organic bedding works as a great bedding source as long as it is managed properly and kept clean over its lifecycle in a freestall.

Organic Bedding. Separated solids (wet manure) are extracted from manure in the lagoon and stored for a period of time and then used for bedding. Separated solids are used as a non-aerated (anaerobic) source of bedding. The bedding while being stored or stock piled does not reach the temperature necessary to kill pathogens and an ammonia odor is released from the pile. Ideally separated solids are not favored as the primary use for bedding because the anaerobic conditions allow an optimal environment for bacterial growth (Univ. of Minnesota, 2009).

Composted separated solids are manure solids that have been separated from manure in a lagoon, laid out in a windrow or long, vague “U” shaped pile (parabola). It is then composted for a lengthy period of time, typically around 2-4 months depending on the climatic and environmental conditions. Then it is either stored or used as a source of organic bedding. The composted solids are processed using an aerobic system. The pile is exposed to air and microorganisms break down the organic matter into carbon dioxide, water, heat, and humus, a relatively stable end product (Univ. of Minnesota, 2009).

Digested solids are manure that is broken down in a digester and the solids are separated from the digester discharge, and those discharged solids are used as organic bedding. Digested solids are processed through the breakdown of organic material by microbial populations that live in an oxygen free (anaerobic) environment. Manure in a digester starts out as organic solids (CHO) and minerals. Once digestion begins, a small amount of material is lost to pre-digestion.

Around 40-70% of the organic solids are converted to biogas, methane (CH_4) and carbon dioxide (CO_2) (Univ. of Minnesota, 2009). The solids which are left in effluent are then separated to use as organic bedding.

Rice hulls, sawdust and straw were accepted as the dominant source of organic bedding, before the use of organic solids became popular. Organic bedding materials other than organic manure solids classically consist of plant byproducts such as straw, hay, sawdust, wood shavings and shredded paper. They are utilized as bedding because they absorb moisture, work well with manure handling systems, but most importantly are readily available. Rice hulls provide comfortable and soft bedding for cattle. Rice hulls are relatively inexpensive, easy to handle, and perform well with an automated flush system. The big disadvantage of rice hulls is that they tend to have high carbohydrate levels, which readily support the growth of mastitis causing microorganisms. Rice hulls have been shown to be a better medium for microbial growth than any of the more commonly used organic bedding materials (Wallace, 2007).

Wood-based products are one of the most popular bedding material choices for dairy farmers. Wood products provide high-quality cow comfort and also thrive with waste management systems. The availability and accessibility of sawdust and wood shavings can become problematic because they are not as readily available as manure solids. The main disadvantage is that sawdust and wood shavings provide an environment for mastitis causing microorganisms. The small particle size of sawdust supports the growth of bacteria and once soiled requires more bedding maintenance and labor input. Materials of fine particle size tend to stick to the teat ends of cows, eventually leading to an increased bacterial load on the teats and potentially causing an intramammary infection. Wood shavings have a larger particle size and do not cling to teat ends and slow the growth rate of bacteria. Straw hay has been used as a source of bedding, but it is typically used in calving, close up, or hospital pens. The disadvantage of straw is that it needs to be manually removed from beds, because the long particles do not flush or perform well in manure systems. The length of long straw needs to be reduced before it can be placed into free stalls or flushed into a lagoon (Wallace, 2007).

***Inorganic Bedding*.** Sand is considered as the gold standard of bedding materials. It is static and does not support the growth of bacteria. With proper maintenance and free stall management sand provides a comfortable material for bedding. When a cow lies down in sand, the sand particles form to the cow's body and provide a comfortable resting surface. A big disadvantage to using sand is that it settles at the bottom of lagoons and can cause excessive wear on manure spreaders, pumps, and separators (Wallace, 2007). Another disadvantage to using the inorganic sand is that it is not as readily available as other organic materials and it is generally more expensive.

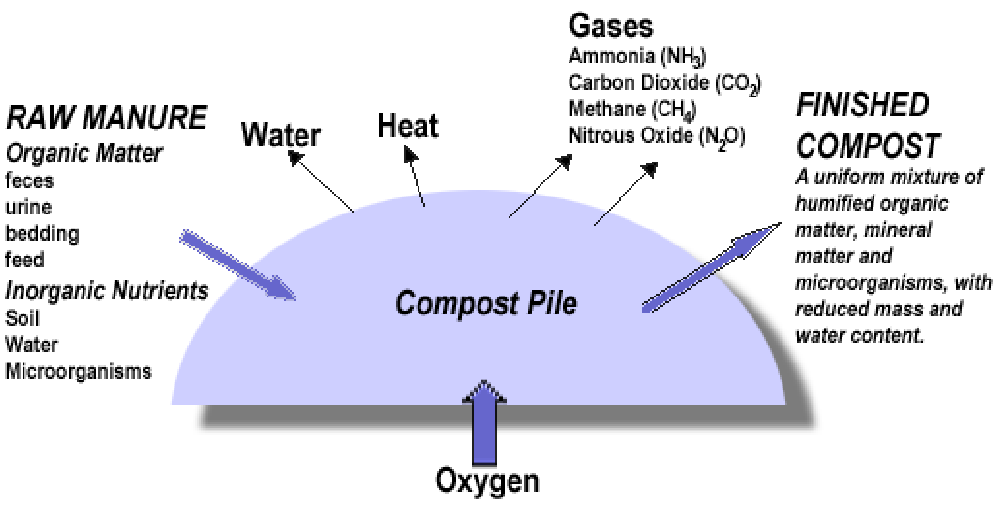

Figure 1. The composting process (Gov. of Saskatchewan, 2008).

Systems of Composting: Aerobic and Anaerobic

The aerobic composting process starts with the gathering of dried manure or separated solids, in order to form a pile or windrow. Aerobic composting takes place in the presence of plentiful oxygen. In this process, aerobic microorganisms break down organic matter. Aerobic composting produces intermediate compounds such as organic acids, but the aerobic microorganisms decompose them further. The heat generated accelerates the breakdown of proteins, fats and complex carbohydrates of plants such as cellulose and hemi-cellulose. The processing time or time to compost the pile to completion is shortened due to the creation of heat from the microorganisms in aerobic composting. Composting destroys numerous microorganisms that are pathogens to humans and plants, provided it undergoes a thermophilic (40-70°C) temperature range. Aerobic composting is considered more efficient and useful than anaerobic composting for agricultural production (Misra et al., 2003).

In the past, anaerobic composting was considered to be a feasible alternative to aerobic composting. Individuals began to doubt the effectiveness of anaerobic composting and by the end of the 1960s, anaerobic composting generally was considered as an unacceptable substitute to aerobic composting. In recent times, the trend has been to consider composting as being a fully aerobic process. Nonetheless, it is now beginning to be recognized that a temporary anaerobic phase is vital in the destruction of halogenated hydrocarbons by way of composting (UNEP, 2005).

In anaerobic composting, decomposition or breakdown of organic material occurs where oxygen is absent or in limited supply. Under this method, anaerobic microorganisms dominate and develop intermediate compounds including methane, organic acids, hydrogen sulfide and other substances. In the absence of oxygen, these compounds accumulate in excess and are not able to become metabolized further. Anaerobic compounds tend to have strong odors and some present toxicity to plant growth (phytotoxicity). Anaerobic composting is a low-temperature process and is unable to destroy weed seeds and pathogens (Misra et al., 2003). The process classically requires more time than aerobic composting and the results will not be comparable to an aerobic process. A small amount of labor input is needed to carry out the anaerobic process and fewer nutrients are lost during the process.

Aerobic Composting: Machine Turned Windrows, Aerated Windrows/Static Piles and In-Vessel. Machine turned windrows involve the collection and placement of manure or separated solids into a long and narrow pile. The windrows are periodically turned by PTO-driven windrow turners to maintain consistent aerobic conditions. The size and shape of the windrow will depend on the type of machinery used for turning and on the characteristics of the pile. The size and shape will also depend on the amount of land available and needed based on the size of the dairy. The typical manure windrow will be one to two m high and three to six m wide (Gov. of Saskatchewan, 2008). The frequency of rotation may be determined by the dairy manager and by the availability of machinery and labor required.

Aeration can either be a passive or active process. In passively aerated static piles, the matter is regularly aerated by a system of perforated pipes placed in the windrow. In actively aerated windrows, the material is placed on top of perforated plastic pipe or tubing through which air is drawn. Actively aerated windrows will compost more quickly because more material is being exposed to air and the microbial population thrives. Periodic rotating of the material will help to redistribute moisture and expose fresh material to microbial activity (Gov. of Saskatchewan, 2008). A major difficulty with the static pile system is the efficient diffusion of air throughout the entire pile, especially with a large particle size distribution, high moisture content and a tendency to clump (Gov. of Alberta, 2004).

In-vessel composting is the process involving confining materials in a building (often long concrete channels) or closed vessel. There is a variety of in-vessel composting methods, most of which rely on forced air and mechanical turning. Although fast, this method can be quite costly, but when high quality compost is required for a particular market, the automated system allows for the greatest control over the composting process (Gov. of Saskatchewan, 2008). The main advantages of the in-vessel system over others are more efficient composting process and a decreased number of pathogens resulting in a safer and more valuable end product. In-vessel composting can maintain a rapid decomposition process year-round regardless of external ambient conditions. Disadvantages of the enclosed vessel method include high capital and operational costs due to the use of computerized equipment and skilled labor. In-vessel composters are generally more automated than active or static pile systems and can produce a top quality finished product on a consistent basis (Gov. of Alberta, 2004).

Anaerobic Composting: Static Pile and Digested Solids. A large static pile that is gathered to compost will lead to anaerobic composting conditions. A large pile with excessive moisture and inadequate porosity makes it difficult for oxygen to enter into the pile. When oxygen is not allowed into a pile the bacterial population is not able to consume the carbon or nitrogen in the pile and the rate of composting is decreased. Composting is viewed as an aerobic process and is not typically performed under anaerobic conditions, unless the material is placed in a digester.

Anaerobic digesters can be designed to operate under specified configurations. They may run as a batch or continuous and as a single or multistage process. In a single stage all of the biological reactions occur in a single sealed reactor. A multistage reaction occurs in different digestion vessels and is optimized to control the maximum bacterial communities living within the system. The three primary products formed from anaerobic digestion are biogas, digestate (solids), and water. The biogas formed consists 60% of methane and 40% carbon dioxide. In the process of digestion the organic matter is acidified and forms intermediate volatile acids. The volatile acids undergo methanogenesis and the end product of biogas contains the methane and carbon dioxide (Univ. of Minnesota, 2009).

Figure 2. Aerated windrow composting (Virginia Cooperative Extension, 2011).

Factors Affecting the Composting Process

Temperature. Composting proceeds through three phases, with the first being a mesophilic range, where temperatures are between 10ºC and 40ºC. The temperature rises into a high-temperature or thermophilic phase, and this is called the active composting stage. The thermophilic phase can last from a few days to several months, with the decomposition occurring rapidly over 60ºC. The thermophilic phase is followed by a descent to the mesophilic level, which can last several months as a cooling and maturation phase. Biochemical reaction rates approximately double with each 10°C increase in temperature. The compost process is more or less adversely affected at temperatures above 65°C. The reason is that microorganisms characterized by a spore-forming stage do so at temperature levels higher than 65°C. Unless they are thermophilic, other microorganisms either lapse into a resting stage or are killed. Low outside temperatures may also slow the composting activity down, while warmer temperatures speed up decomposition. Compost temperatures will generally decline if moisture or oxygen is insufficient or if the carbon source is exhausted. The temperatures can exceed 70°C, but many microorganisms begin to die, which stops the active composting stage. Cooling the material by mechanical rotation helps to keep the temperature from reaching these damaging levels. The temperature of composting is also related to the amount of heat produced by microorganisms versus how much heat is being lost to conduction, convection, and radiation (Univ. of Minnesota, 2009).

pH. The optimum pH for microorganisms involved in composting lies between 6.5 and 7.5. The pH of most animal manures is approximately 6.8 to 7.4 (Gov. of Alberta, 2004). Although the natural buffering effect of the composting process lends itself to accepting material with a wide range of pH, the pH level should not exceed eight. At higher pH levels, more ammonia gas is generated and may be lost to the atmosphere (Misra et al., 2003). Composting alone leads to major changes in materials and their pH as decomposition occurs. The pH level of the composting mass typically varies with the passage of time. With a higher pH above 9, ammonium is forced to form into a gas causing a bad smell. The acids serve as substrates for succeeding microbial populations. (UNEP, 2005).

Dry Matter. Moisture is vital to feed the composting bacteria. Mixtures that are too dry will inhibit the bacterial activity. Piles that are dense and wet can result in slow decomposition, odor production in anaerobic pockets and nutrient leaching. The composting process slows when the moisture content drops below 40%. When the moisture content exceeds 60%, nutrients are leached, porosity is reduced, odors are produced (due to anaerobic conditions) and decomposition slows. This condition limits air movement and results in an anaerobic pile.

Moisture levels can also change throughout the composting process as water is added in the form of rain or snow, or evaporates from the pile. The moisture content of the pile decreases during composting since more water evaporates from the pile than is added. Moisture plays an essential role in the metabolism of microorganisms and indirectly in the supply of oxygen. Moisture content between 50 and 60% (by weight) provides adequate moisture without limiting aeration. If the moisture content falls below 40%, bacterial activity will slow down and will cease entirely below 15% (Gov. of Saskatchewan).

Physical and Particle Size. The physical size and shape of the compost system must be a sufficient size to prevent rapid dissipation of heat and moisture, yet small enough to allow good air circulation (Univ. of Minnesota, 2009). When the pile or wind-row is too large, anaerobic zones occur near its center, which slows the process of composting in these zones. On the other hand, piles or wind-rows that are too small lose heat quickly and may not achieve a temperature high enough to evaporate moisture and kill pathogens and weed seeds. To minimize heat loss, larger piles are suitable for cold weather. However, in a warmer climate, the same piles may overheat and in some extreme cases, above 75°C, catch fire (Misra et al., 2003).

Particle size will encourage microbial activity and increase the rate of decomposition with increasing surface area. The particle size will also affect the availability of carbon and nitrogen to bacteria. Particles that are too small will compact air circulation through the pile and become inhibited. Essentially, composting will proceed more quickly if you have larger, relatively uniform particles to ensure that there are air spaces throughout the pile. Usually, mixtures of manure and straw are sufficiently bulky to compost successfully (Gov. of Saskatchewan, 2008).

Aeration and Rotation Frequency. Aeration is crucial for the metabolism and respiration of aerobic microorganisms and for oxidizing the various organic molecules present in the waste material. Once the pile is formed and decomposition starts, the only technique for improving aeration is turning. The frequency of turning is crucial for composting time. When the rotation rate is increased to the appropriate amount, the bacteria thrive and are better able to break down the organic material, thus reducing the composting process.

The minimum desirable oxygen concentration in the composting material is 5%. Greater than 10% is ideal to avoid anaerobic conditions and high odor potential. Aeration adds fresh air in the center of the composting material. Aeration occurs naturally when air warmed by the compost rises through the material, drawing in fresh air from the surroundings at the base of the windrow.

Carbon to Nitrogen (C/N) Ratio. The C/N ratio is a major nutrient factor as carbon is an energy source for microbes. Carbon is roughly 50% of the mass of microbial cells. Based on the relative demands for carbon and nitrogen in cellular processes, the theoretical ratio is 25:1. The ratio is weighted in favor of carbon, because uses for carbon outnumber those for nitrogen in microbial metabolism and the synthesis of cellular materials. Carbon is utilized in the cell wall and membrane formation, protoplasm, and storage products synthesis, an appreciable amount is oxidized to CO_2 in metabolic activities (Univ. of Minnesota, 2009).

Nitrogen is a crucial component of proteins and it is needed for rapid growth. On the other hand, nitrogen has only one major use as a nutrient and essential constituent of protoplasm. Generally, the ratio is higher than 8 to 10 parts available carbon to 1 part available nitrogen. In compost practice, it is on the order of 20:1 to 25:1. The general experience is that the rate of decomposition declines when the C/N exceeds that range. On the other hand, nitrogen probably will be lost at ratios lower than 20:1. A C/N ratio of 30:1 is an appropriate starting point and finished compost should be close to 10:1. The compost will contain an earthly smell to it once the compost process is near completion (UNEP, 2005).

MATERIALS AND METHODS

Data Collection

Data from a single aerated windrow was collected from August until October 2010. The separated solids laid to form the windrow were extracted from a 6,000 jersey cow dairy located in the central valley. The cows are fed a TMR adhering to the National Research Council nutrient requirements (NRC, 2001). The length of the initial windrow was 255 m and 6 sample measurements were taken on the pile at 50.9 m intervals, offset by the previous day's measurements by 1.5 m, with the sixth sample spot taken at 44.5 m. The sample position for the sixth spot changed as the composting process proceeded, but the new position of sampling on the sixth position was noted in the data sheet. To begin the data collection the pile was sampled every two days and pile surface and core temperatures were measured using a Reotemp fast response windrow thermometer (Reotemp Instruments Corp., 2012). The thermometer was driven .3 m into the pile to record the surface temperature, and then driven all the way into the pile to record the core temperature at each position, one through six. The windrow was periodically turned by PTO-driven windrow turner to maintain consistent aerobic conditions.

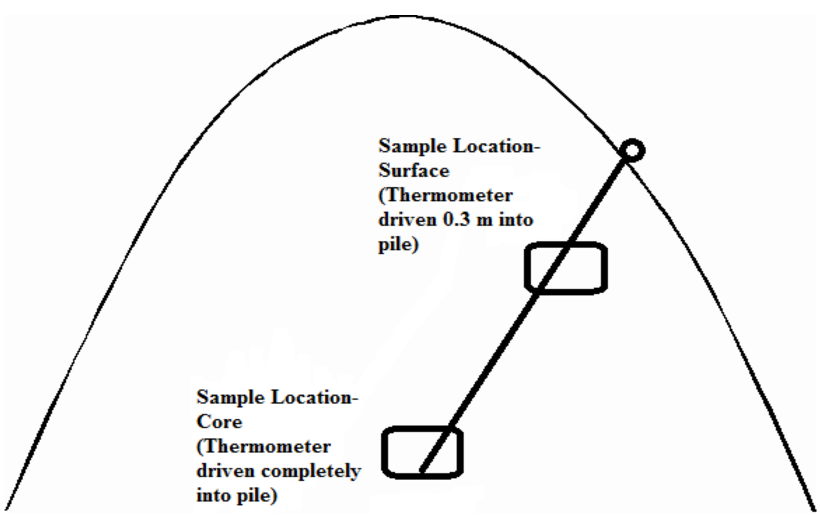

Figure 3. Cross section of compost pile-location of temperature and sample collection.

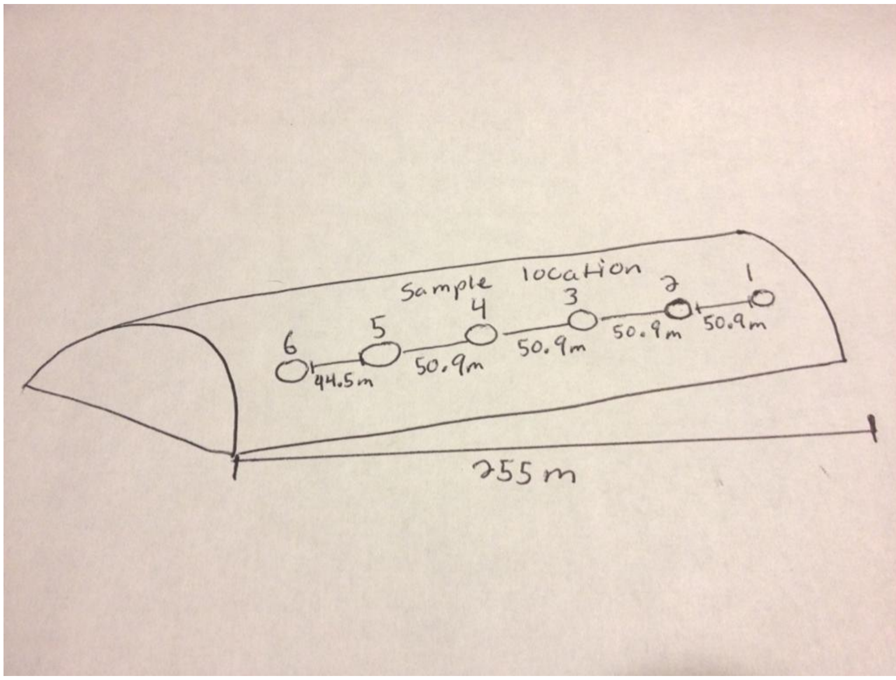

Figure 4. Sample locations on compost windrow.

The top pile curve was measured using a 91.44 m fiberglass long tape. The tape was laid at the base of the pile on the north side and pulled across the top and down to the base of the pile on the south side. Pile height and width were also recorded. The height was recorded using two long PVC pipes that measured 1.83 m tall. A level was positioned on the top of each PVC pipe to ensure the width of the pile was being measured from a leveled position. The level helped to standardize the measurements because each time a pile width was taken; the pipe's had to be level with each other. The PVC pipe was positioned at the base of the pile on each side and the fiberglass long tape was extended across the top of the pile to measure both the height and width.

Once the two PVC pipes were in place, the fiberglass long tape was extended across the top of the pile. Two small levels were then attached to the measuring tape on each side of the tape near the PVC pipes. Every time a measurement was taken both the PVC pipe and measuring tape were leveled. The pile width was measured from pipe to pipe or essentially from the north to the south base. The height was determined at the same time as the pile width, by marking the position on the PVC pipe were the bottom of the tape touched the tip of the pile. The measuring tape was then taken and ran across the bottom of the PVC pipe to the position marked to determine the width of the pile.

Pile samples from locations 1-6, both surface and core were taken during each sample day to determine dry matter percentage. Samples were extracted using a post hole digger. A measuring wheel was used to note the positions of each sample spot. To remove a surface sample the top 0.02 m of compost was removed, then the post hole digger was inserted into the pile to grab a sample size weighing more than 500 g. After obtaining the surface sample the post hole digger was used to dig down into the core of the pile and just before reaching the bottom of the pile a sample was collected. If the sample contained dirt, then the hole was dug too deep and a new, clean sample was gathered.

Pile rotation was noted before and after each sampling day. The pile was rotated periodically by an employee from the dairy. There was no specific schedule for rotation, but each rotation on the pile was noted in a journal log. The climatic conditions were also noted by looking up the historical weather data online (Weather Underground, 2010). Humidity, wind speed, and precipitation were also gathered from the online source and placed into the master datasheet. Excel was used to arrange the data into a clear and concise datasheet.

Data Processing

Dry matter was measured on each sample taken by either the Koster tester or microwave method. The initial dry matter (DM) was gathered with the Koster tester, but this method seemed to lose sample yield because the manure particles were small and light. The Koster tester contains a fan that would blow a small percentage of the sample away. A 100 g sample was weighed and placed into the Koster Tester and the sample was heated for 30 minutes. After the sample was done heating the sample was gathered and reweighed to collect the DM. Once this fault was discovered the DM was measured from that point on using the microwave method. Using the microwave method, 100 g of sample was taken and weighed. The sample was weighed on a tared paper plate. The paper plate and sample were placed in the microwave with a cup containing water. The water helped to keep the manure from burning. The sample was run on 50% heat for 5 minute intervals until the final and previous weight was within 2 g of each other. Collected samples in which DM was not taken immediately were stored in the refrigerator over time to help maintain the correct moisture in the sample. Collected samples were never stored in the freezer.

Carbon to nitrogen ratios, were obtained periodically throughout the process to identify progression of composting. Samples were sent to Denele Analytical, Inc. and to A & L Western Agricultural Laboratories. Samples were sent to both laboratories to compare the results to see if the outcome was similar between the two laboratories.

Statistical Analysis

Statistical analysis on the dependent variable, C/N ratio was performed using the GLMSELECT procedure in SAS (SAS Institute, 2008). The initial data analysis over the 71 day composting span had to be limited to the days in which C/N ratios were submitted to the lab. In the end, 9 total sample days were chosen for the statistical analysis. The dependent variable C/N ratio was fit to a general linear model using a stepwise regression, which contained all 13 possible independent variables. The independent variables consisted of temperature pile surface, temperature pile core, dry matter surface, dry matter core, outside temperature high, outside temperature low, average outside temperature, wind, pile area, humidity, pile rotation, location and date. Rain was initially noted but no rainfall occurred during the sampling dates, so rain was not included as an independent variable.

Three different initial potential models were specified for the GLMSELECT procedure. The first model contained all the original 13 independent variables. A second model was created that changed the independent variable of location into two separate independent variables of pile location and sample location. This change was performed in order to differentiate between the pile locations, one through six. Pile locations deal directly with the pile area measurements. The sample locations of one through six also contain the sample surface and core, which in turn are twelve measurement positions. This separation allowed the model to be able to differentiate if there was a difference between the pile surface and core data. The second model was run using the same procedure as the previous mode, but this time pile and sample location increased the number of independent variables to 15. A third model was assembled which consisted of the same 15 independent variables as in the second model, but this time one of the independent variables was excluded from the model. The parameter of wind that was excluded in the third model was not initially thought to impact the C/N ratio, so it was dropped from the third model to validate if it actually contains statistical significance.

A fourth and final model was selected that contained all 15 independent variables and the same GLMSELECT procedure was run on SAS. A stepwise regression was used, but this time a non-linear model (quadratic) was used on four specific independent variables, that showed up as estimated parameters in the three previous models.

RESULTS AND DISCUSSION

Results

Summarized in table 1 is the distribution of the significant factors (P<.05) involved in reducing the C/N ratio in composted separated solids. The four factors; temperature at the pile core (Tc), pile area (E*E), wind (W) and date (oday), were consistently present as parameters in each of the four models. Wind was excluded from the third model and therefore was not expressed as a parameter in the third model. To avoid bias, the parameter wind was reintroduced into the fourth model and as a result was found to be both linear and a significant factor to the C/N ratio in each of the three models it was present in. Pile area was found to have a non-linear, quadratic relationship to the C/N ratio.

Table 1. Parameter estimates in the GLMSELECT procedure

Parameter	DF[6]	Estimate[7]	Standard Error	t value	p value[8]	Model R-Square[9]
Intercept[1]	1	3069.373442	332.64032	9.23		
Tc[2]	1	-0.074297	0.019624	-3.79	0.0083	0.7603
E*E[3]	1	0.996129	0.15613	6.38	<.0001	0.724
Oday[4]	1	-0.163726	0.017871	-9.16	<.0001	0.6172
W[5]	1	-0.340467	0.125191	-2.72	0.009	0.7917

[1]Intercept is the Y-intercept of C/N ratio value.
[2]Tc stands for the temperature at the pile core.
[3]E*E stands for pile area and the *indicates a (quadratic) non-linear relationship.
[4]Oday stands for the date of measurement.
[5]W stands for wind speed.
[6]DF stands for degrees of freedom and is equal to 1 unit of each parameter.
[7]Estimate states that for every 1 unit (DF) increase in the parameter the C/N ratio increases or decreases by the amount of estimate stated for each parameter.
[8]p value expresses the parameters that are significant in the reduction of C/N ratio.
[9]Model R-Square is measured between 0-1 and states the importance of knowing X (the parameter) helps to determine Y (the C/N ratio).

Interpretation

A reduced C/N ratio could be seen with a higher pile core temperature (Figure 5). Thermophilic bacteria are heat loving and survive in hot environments. These groups of bacteria utilize the carbon as food for energy production. As the temperature at the pile core is increased, additional carbon is consumed and the C/N ratio will decrease. Pile area is an indication of the total volume contained within the windrow. As the pile area decreases in volume, there is less surface area for microbes to consume the carbon and nitrogen. Figure 7 shows the non-linear relationship of pile area, which gave a positive estimate of 0.996129. Meaning that as the pile area increases by one unit of degree of freedom the C/N ratio increases by the estimate amount. The C/N ratio increases as the pile area increases and vice versa.

Over an extended period of time (Figure 8) the C/N Ratio will become depleted as the Thermophilic become Mesophilic bacteria. The longer the pile composts, the more time available for optimal aerobic conditions, rotation and porosity reduction.

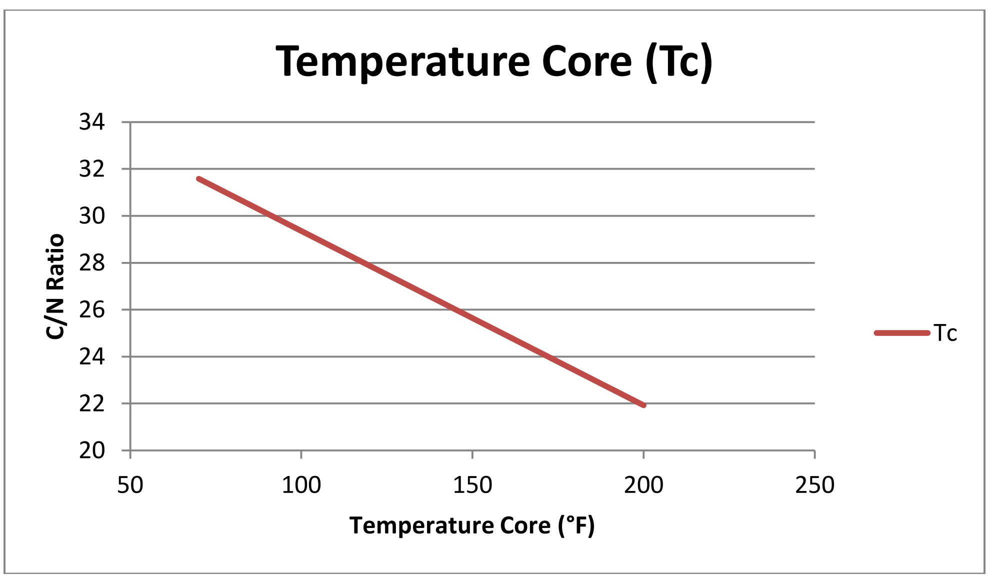

Figure 5. Line chart of linear regression between temperature core and C/N ratio.

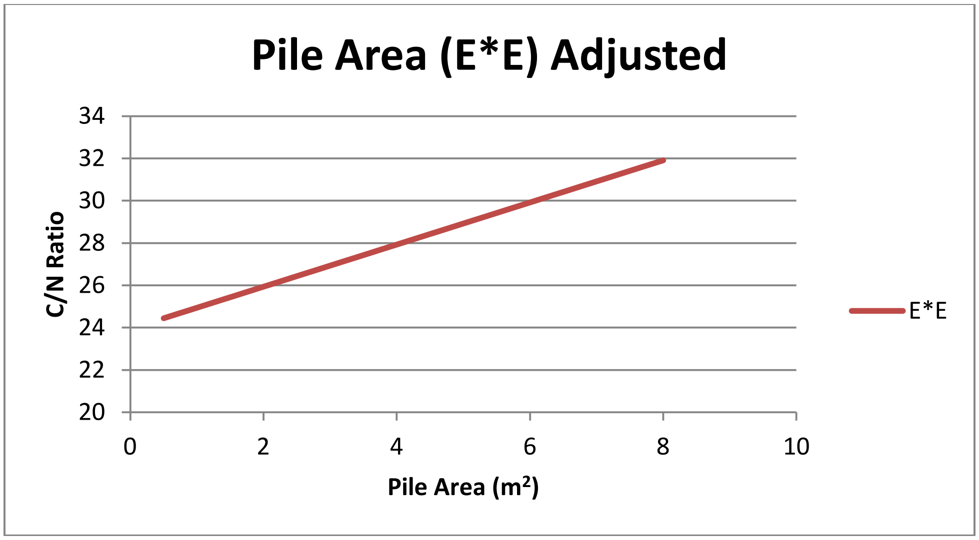

Figure 6. Line chart of non-linear regression between pile area and C/N ratio (After Adjustment-Quadratic).

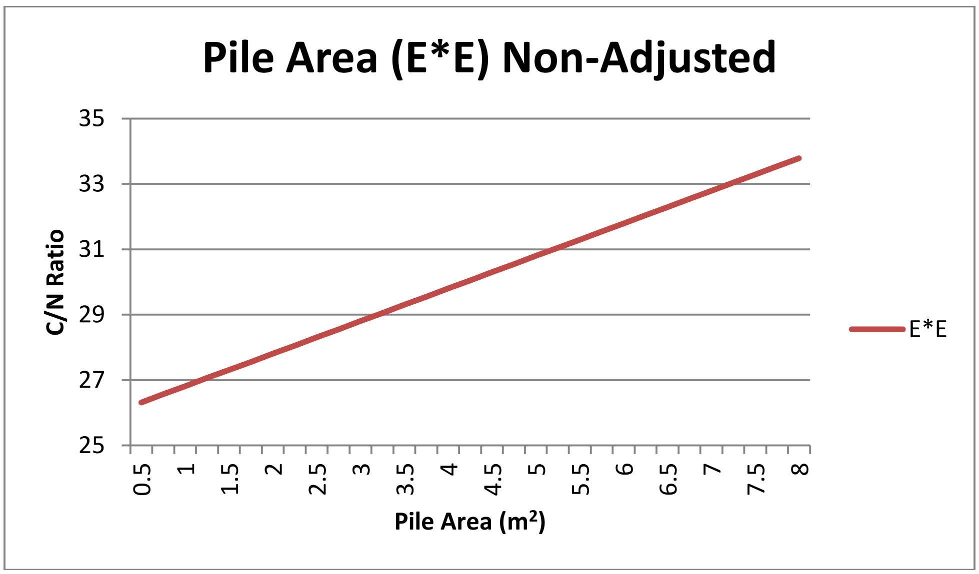

Figure 7. Line chart of non-linear regression between pile area and C/N ratio (Non-Adjusted).

Wind was determined to be a factor because as the wind speed increases oxygen is penetrating into the pile. Wind increases the amount of aerobic activity within the windrow and promotes the growth of beneficial carbon consuming bacteria. Initially wind speed was not thought to be a factor and was removed from the third statistical model. Once removed from the model, wind did not display as a parameter and no further independent variable replaced wind as a final parameter. The three previous parameters of pile core temperature, date of study, and pile area persistently resulted as final parameters throughout the four models. Wind was found to express the least amount of statistical significance P=0.009 (Table 1), but nonetheless was determined to impact the composting process. Increased wind speeds can decrease the pile size by blowing away light compost particles. Wind may support in the rotation frequency based on the amount of penetration into the compost windrow. When the pile is being rotated, if the wind speeds are large enough, an increased area of the pile will be exposed to additional oxygen.

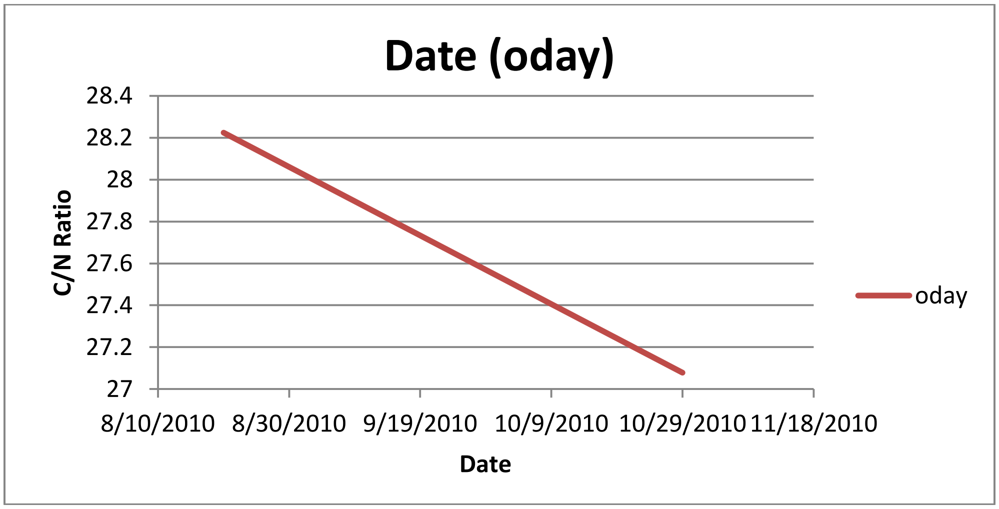

Figure 8. Line chart of linear regression between date and C/N ratio.

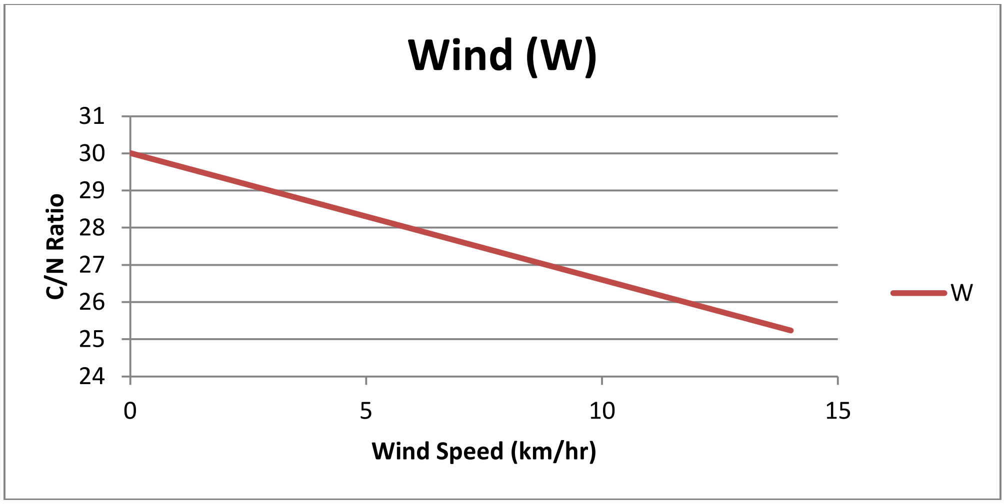

Figure 9. Line chart of linear regression between wind speed and C/N Ratio.

Compared Results

Dairy manure solids can become a suitable bedding material for freestalls if composted correctly and this truth agrees with J. R. Bishop's research (Bishop et al., 1981). A reduction in the C/N ratio was associated with a higher pile core temperature, which could be explained by the already known effect of temperature on bacterial species diversity in thermophilic solid-waste composting (Strom, 1985). The date or length of day allows added time for beneficial bacteria to consume the carbon and nitrogen. The pile area reduction gave a non-linear relationship and is correlated to particle size as explained in chapter eight of the solid waste management handbook (UNEP, 2005). Wind is needed to penetrate the pile and aid in increasing the aerobic environment, which explains the reduction in C/N ratio. Current research on windrow composting has not discussed the importance of wind, but this research shows an inverse linear relationship, stating that as the wind speed increases, the C/N ratio decreases.

Critical Analysis

The research performed differs from other work due to the fact that a single windrow of separated solids was selected and followed throughout the entire composting process. Data was collected every two days and the researchers involved viewed and observed changes the entire time the pile was composting. Following a pile and determining the dry matter after each sample date allowed for real time data and results could be seen each time a sample was collected. The factors of wind speed and pile area that were collected became extremely important in the end results and there is minimal data published on the effects of wind and pile area on the reduction of C/N ratio. The time and effort spent into the research helped to predict and determine future models/protocols of collecting samples on compost piles.

Limitations

The study was limited by the lack of funds available for C/N ratio sampling. Therefore C/N ratios were only taken every two weeks, which in reality they should have been taken weekly. The data was constrained to the days in which a C/N ratio was taken and ended up being 9 out of 71 total days in the entire study. For future studies, sampling on a pile should be done weekly and C/N ratios need to be sent to the lab with each sampling date. Factors such as particle size and pile pH need to be included during each sampling date. In summary, future studies should sample the pile once a week, but during the sampling date additional factors need to be measured.

CONCLUSION

Data analysis indicates that the time, pile area, pile core temperature and wind speed directly impact the C/N ratio in composted separated solids. The most important factor in the composting process is the pile core temperature. Thermophilic bacteria are essential to the composting process and help to reduce the carbon and nitrogen in the pile. The other eleven factors were not found to be statistically significant on the data set. Limited data on the amount of C/N ratios obtained could have been one factor that limits the ability of the irrelevant factors to actually be statistically significant.

Further research is needed to obtain information about the effect of wind speed on composting and to verify any other factors that could be involved. The research should include data on particle size, pH and any other factors that may be beneficial in reducing the C/N ratio.

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