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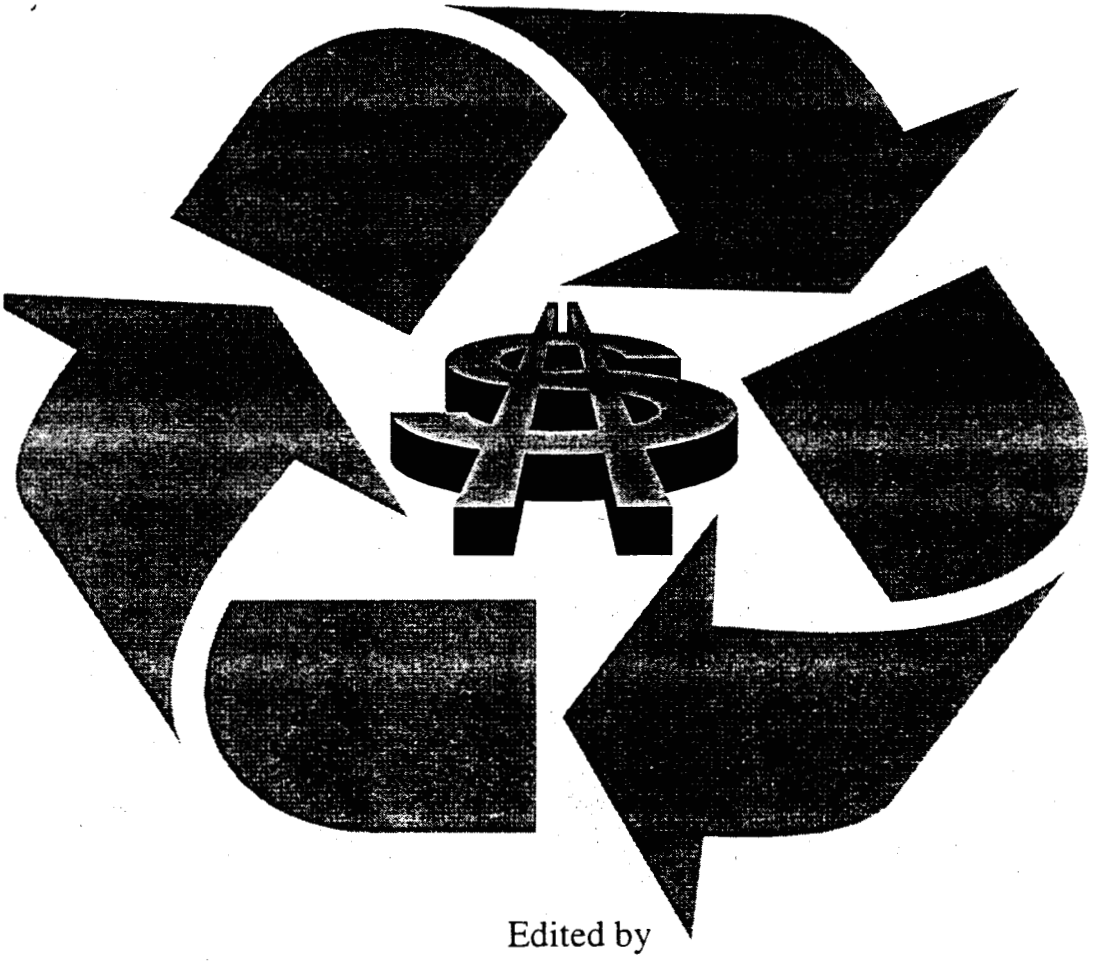
Proceedings of the 1998 Conference

Composting in the Southeast

September 9-11, Athens, Georgia



Edited by

K.C. Das
The University of Georgia

Elizabeth F. Graves
NC Dept. of Pollution Prevention and Environmental Assistance

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PREFACE

The first "Composting in the Southeast - 1998" is a conference that grew out of the "Composting in the Carolinas" a biennial event last held in 1996 in Myrtle Beach , SC. The organizing committee found that there was a need for a forum to exchange the latest news in research and practices within the composting industry in the southeast. With the goal of fulfilling this need, a seven state committee was formed after the 1996 conference and this committee worked towards this 1998 conference in Athens, GA.

The growth of the composting industry will depend on the efficiency with which we exchange information on the successes and failures that we see in day to day practices within the industry. Important issues include improving current processes to reduce costs and odors and improve product quality, special processing related to industrial and agricultural wastes and compost product utilization in traditional areas and exploration of new areas.

I have found these topics and specific papers to be of value in brining me up to date with the current state of the art within the Southeast. These papers are written so facility managers, waste management professionals and operators can gain from the experience of others. I thank each author for their contribution to this proceedings. The conference planning committee thanks those who provided support and encouragement by attending the conference.

K.C. Das, The University of Georgia,
Chairman, Planning & organizing committee
Composting in the Southeast - 1998

DISCLAIMER

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COVERING COMPOSTING WINDROWS: EFFECTS ON THE PROCESS AND THE COMPOST

By

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ABSTRACT: Composting trials were undertaken to study the feasibility of using crucifer or carrot residues with sawdust or straw for composting. Geotextile covers were tested for their influence on different parameters. Two complete composting cycles were monitored. Measurements were taken for compost temperature, moisture, and leachate. Physico-chemical analyses were performed on compost samples. Phytotoxicity tests were done with compost leachate samples. The results showed that the temperature of the covered compost (CC) decreased more slowly during late fall and early winter than that of the non-covered compost (NC). In addition, CC did not freeze as deep over the winter, and it warmed up sooner and faster than NC in the spring. The moisture content of CC was significantly lower than in NC at the end of both composting cycles. CC had a higher mineral content than NC in both cycles, and nitrogen, phosphorus and potassium levels were significantly higher in CC of the second cycle. The carbon/nitrogen (C/N) ratio of CC showed a more important decrease earlier in the cycles observed. The quantity of leachate from CC was significantly reduced compared to NC in the second cycle. Compost leachate showed a high level of phytotoxicity in the first part of the composting cycle and this phytotoxicity disappeared sooner in CC of the first cycle. However the leachate in the second cycle became non-phytotoxic at the same sampling time in both CC and NC. The effects of geotextile covers included a favorable influence on compost temperature in late fall and in spring in a northern climate; a higher retention of mineral elements; an earlier maturation of the compost, and a reduction in the quantity of compost leachate generated. The use of these covers by agricultural producers or other composting operations could result in a better quality compost while releasing smaller amounts of leachate in the environment.

INTRODUCTION

Vegetable cropping systems yield large quantities of food material per surface area and generate considerable volumes of plant waste both in the field and as a result of processing. In order to minimize the environmental impact from improper waste disposal and to turn these plant residues into a valuable resource, some Quebec vegetable producers wanted to investigate the composting option. Several systems are available for composting: open systems with periodically turned piles or with static piles having forced ventilation; closed systems using vertical reactors which have continuous or discontinuous mass of materials, or horizontal reactors where materials are either static or periodically turned (de Bertoldi and Zucconi, 1987). In Quebec, open systems are most often used for farm residue composting (Sauvesty and Tabi, 1995).

Fruit and vegetable wastes are classified as a moderate to wet type of material with a moderate to low C/N ratio depending upon the nature of the waste (Rynk *et al.*, 1992). They are considered to have a poor to fair structure which means that standing piles of these wastes quickly collapse into a wet mess if nothing is done to process them. According to Rynk *et al.* (1992), the moisture content of a compost is particularly critical due to the risk of anaerobic conditions accompanied by odor problems and slow decomposition. In this project, it was expected that the carbonaceous material combined with the vegetable wastes would compensate for the high moisture in the vegetables. Due to a concern about groundwater contamination by compost leachate derived from precipitation water, the research project included the use of geotextile covers on compost windrows. Compost leachate initially results from the decomposition of the organic materials, then subsequently from percolation of precipitation and from runoff along the surface of the piles. There is little work which specifically addresses the phenomenon of leaching. Most of the work done has been concerned with nitrogen leaching (Ballestero and Douglas, 1996; Dewes, 1995; Ulen, 1993). Nitrogen leaching is very dependent on the form of waste being composted and its initial characteristics (Ballestero and Douglas, 1996). The application of plastic sheet covers on compost piles did not reduce total nitrogen losses since

the covers enhanced NH_3 exhalation to such an extent that total nitrogen losses increased (Dewes, 1995). Fleece blankets placed over a compost windrow kept the level of nitrate-nitrogen in leachate consistently lower than when the blankets were removed and the site exposed to rainfall. (Lufkin *et al.*, 1995). Bidlingmaier (1992) noted an increase in the percentage of leachate relative to the rainfall as the compost matured and temperature decreased; this relative increase in leaching was attributed to a decrease in the rate of evaporation of the composting mass.

The parameters studied in relation to the use of the geotextile covers included compost temperature, compost moisture, physico-chemical characteristics of the compost, as well as the volumes and the quality of compost leachate. It is important to follow the temperature evolution in a compost windrow: a high temperature (55-60°C) is desirable for 2-3 days in the first stage, to sanitize the materials, but the rates of microbial activity and drying are greater at temperatures of 38-55°C (Hoitink and Fahy, 1986). In the case of vegetable residues, plant pathogens could be present in this material and should be exposed to adequate temperatures to destroy them.

The objectives of this research project were: to monitor the composting process of vegetable wastes in an intermittently-turned windrow system; to examine the effect of geotextile covers on compost temperature, compost leachate, and compost quality; and to assess the survival of important plant pathogens in a compost made from vegetable wastes (not discussed in this paper).

MATERIALS AND METHODS

The composting trials were run on the Macdonald Campus of McGill University (Ste-Anne-de-Bellevue, Quebec, Canada). This site is in a climatic zone where precipitation averages 940 mm (37 in.) annually, and the temperature ranges from -35°C (-31°F) to +35°C (95°F). Twelve composting platforms were built to provide conditions where leachate could be recovered and measured. Each platform measured 3.5 meters wide by 4.6 meters long; they were arranged in three rows 4 meters apart, with an in-row spacing of 2-2.5 meters between platforms. The randomized block design included 3 blocks of 4 platforms, with 2 replicates within each block. The design was a 2 x 2 factorial experiment (covered/non-covered and with/without pathogens). The organic material used included cauliflower wastes and sawdust (1:1 v/v) the first year; crucifer wastes and wheat straw (9:1(compressed) v/v) the second year. The compost material was mixed and partially shredded with a manure spreader before piling it onto each platform to a height of about 1.5 meters. Only 6 platforms were used in the first year of the project because of a shortage of vegetable residues due to the late start. Starting dates were November 15 in 1994, and October 12 in 1995. The complete cycle lasted 271 days the first year and 288 days the second year.

The geotextile covers (Compostex® by Texel Inc., St-Elzéar, Québec) applied in the covered treatment were made of non-woven fibers (polyester and/or polypropylene), 1.6 mm thick. This material was permeable to air and gas, but water-repellent. They were left on the compost throughout the cycle, being removed only for turning operations. Half of the compost windrows were inoculated with infected plant material representing three phytopathogens: there was a total of 28 samples per pathogen that were distributed in each inoculated windrow. The pathogens samples were either in a fixed determined position or placed at random in the compost windrow.

The temperature was read three times a week at two depths (30 and 60 cm) in two locations for each platform. Moisture was measured from composite samples taken at about 30 cm depth, every 1-2 weeks (except for winter time). The samples were weighed before and after oven-drying. Sampling for physico-chemical analyses was done at the beginning of the cycle (fall), before turning in spring time, and at the end of the cycle. Leachate was collected and measured after each precipitation. Samples of leachate were taken at six different times during the composting cycle for phytotoxicity tests. A germination index was calculated with a cress germination test (Zucconi *et al.*, 1981) performed with the collected leachate samples. Leachate from the first 10-12 days of composting was not included in comparing volumes for the two treatments, since most of this leachate was not a consequence of precipitation. Physico-chemical analyses were done for leachate samples taken at the beginning and at the end of the two cycles.

The temperature and moisture data were analyzed using a spatio-temporal or temporal repeated measures analysis of variance (ANOVAR) (Dutilleul, 1997) in order to check for interactions between time, depth and treatments. The second year data for leachate volume were submitted to an ANOVA after being log-transformed for normality

requirements. Results from the cress germination tests were submitted to ANOVA, checking for treatment main effects at each dilution level within each sampling date.

RESULTS AND DISCUSSION

COMPOST TEMPERATURE

At the beginning of both cycles, temperatures above 55°C were recorded at 30 cm and 60 cm depths, in both CC and NC. CC stayed above 55°C slightly longer than NC (11-14 days vs. 8-10 days) in the two cycles. During the initial thermophilic period of the second cycle, temperatures above 70°C were recorded at the 60 cm depth for both CC and NC treatments. Such conditions are detrimental to the composting process. Microbial activity starts to decline at temperatures above 60°C because even thermophiles no longer have optimum conditions (Miller, 1993). The time required to perform the retrieval and insertion of pathogen samples (for the other aspect of the experiment) reduced the flexibility of the experiment in terms of timing the turning operations. That is why temperatures went above desirable levels before turning could be done.

A significant interaction of time and treatment was identified for the fall (days 15-65) and spring (days 158-189) periods of the first cycle (Figures 1-A and 1-B). This interaction reflected the difference in rates of cooling in the fall and the rates of warming in the spring between the two treatments. The temperatures recorded for the first 47 days (fall period) of the second cycle consistently showed a significant difference between treatments (Figure 2-A). The early spring temperatures for that cycle (first 20 days) also showed that CC was significantly warmer than NC (Figure 2-B). As in the first cycle, there was again an interaction of time with treatment for these same periods. The added protection from the covers prevented the compost mass from freezing down to the center like the non-covered one did, particularly in the second winter. The frozen NC delayed the compost turning operations of the second spring (1996) by nearly 20 days. Although larger size windrows may not be subject to similar freezing problems, this observation underlines the protective effect of the covers against cold conditions. During the summer period when the composts were reaching the maturation phase, the geotextile covers had no significant influence on compost temperatures in both cycles.

The more limited number of replicates in the first cycle did not allow us to obtain statistically significant differences in compost temperatures, with a few exceptions. However, the results showed a definite trend in the effect of the covers on this parameter. The presence of covers not only kept the compost warmer, but it also affected the rate at which the compost cooled in the fall, and warmed in spring time.

COMPOST MOISTURE

Moisture levels were close to 70% at the beginning of each composting cycle. There were no significant differences between treatments for the fall period in either year. In both years, CC did not remain as moist as NC as the cycle advanced. In the first cycle, CC was significantly drier over the period starting on day 174 (May 9) until the end of the cycle (August 14) with one exception (Figure 3-A). A similar moisture pattern was obtained in the second cycle, where CC showed moisture levels significantly lower than NC for the period starting on day 223 (May 21) to the end of the cycle (July 25) with one exception (Figure 3-B).

The factors that could have contributed to better drying of CC include a more prolonged active period in the fall with warmer temperatures in the compost, and the water-repellent action of the covers preventing precipitation water from permeating the compost. As Finstein *et al.* (1992) observed, the heat generated by the decomposition of organic materials vaporizes water, and the vaporization causes drying of the compost. Water vaporization is not impeded by the porous material of the geotextile covers. Drying of the compost is not desirable in the earlier stages of composting, but the time at which lower moisture was observed corresponded more or less to the maturation phase where actinomycetes and fungi are more predominant and more tolerant of lower moisture levels (Zucconi and deBertoldi, 1987). However, moisture levels below 40% will slow down microbial activity and result in a reduction in terms of diversity and numbers of organisms in the compost. Therefore low moisture levels should only be targeted for the maturation phase of a compost, so that the moisture level does not become a limiting factor in the composting process. This research did not provide the opportunity to verify the influence of the geotextile covers on moisture levels of a compost that would be started at a different time of the year, e.g. early summer start. However, it seems

that, given an adequate moisture level at the initial stage, a covered compost would remain moist enough for the active degradation of materials until the maturation phase.

PHYSICO-CHEMICAL ANALYSES OF THE COMPOST

Analyses of the finished composts indicated higher levels of nitrogen (N), phosphorus (P) and potassium (K) in CC for both cycles (Figure 4). The difference was statistically significant in the second cycle only. In both years, the micronutrient levels were all slightly higher in CC, with one exception (copper in the first cycle). The nitrate content of CC was higher than in NC at the end of both cycles and this difference was significant in the second year.

The apparent losses in N and K particularly, from NC demonstrated the influence of precipitation in affecting the nutrient content of a compost. Based on analyses done earlier (spring), it appears that a greater nutrient loss occurred earlier in the cycle before the compost material had reached a certain level of stabilization.

The relative drop in C/N ratio for each treatment showed similar patterns in both cycles. In the first one, after starting with a C/N of 46.3, the compost analyses in spring showed a C/N of 24.7 and 34.9 for CC and NC respectively; these ratios were further reduced to 13.7 and 16.6 by the end of the cycle. This illustrates the effect of the covers in advancing the maturation process of the compost. This fact was confirmed by the higher nitrate content of CC. The presence of nitrates is also an indicator of maturity. As the compost matures, the form of mineral N shifts from ammonia to nitrate (Mustin, 1987).

COMPOST LEACHATE

The volumes of leachate recovered in the first cycle showed more noticeable differences between the two treatments in the first part of the cycle (up to day 163), where CC yielded lower volumes of leachate. In the second cycle, the fall period leachate volumes were not significantly different although NC yielded more leachate. The results for the spring and the summer periods indicate a significantly lower ($P<0.01$) leachate volume from CC (Figure 5). The geotextile covers contributed to a reduction of 79.6% and 63.1% of the compost leachate volume for the spring and summer periods, respectively. Physico-chemical analyses performed on leachate at the beginning and at the end of the cycle did not show any consistent trend in mineral content. More frequent analyses would be required to monitor the nature and concentration of elements that may be present at any particular stage.

The apparent lack of response to the covered treatment in the late spring/summer period of the first year could be explained by the experimental setup. The special platform setup for collecting the leachate included an impermeable membrane that covered a given surface area. While the mass of composting materials was reduced in volume as the composting process advanced, the platform area remained the same. This resulted in having part of the platforms area not being occupied by compost, leaving wide edges exposed. Unless the geotextile covers were pulled tight outside the complete platform area, precipitation water diverted by the covers could still end up being collected as leachate after reaching the ground within the platform area. In the second year, more attention was given to prevent non-leachate water from reaching the collection system in both CC and NC, as the compost mass diminished. The geotextile covers edges were also pulled outside the platform collecting area as much as possible. Therefore, the results of the second cycle are more representative of the effect of the geotextile covers in reducing the occurrence of leachate. The leachate collected in the first stages of composting are somewhat difficult to evaluate, since part of it may be attributed to the water derived from the initial decomposition of the fresh organic materials. Liquid collected in the first 10-12 days of the composting cycle were not included in the statistical analyses since no major precipitation had occurred during that time. Nevertheless, the difference between treatments may have been attenuated in the remainder of the fall period due to the potential contribution of the organic materials to the leachate collected.

The phytotoxicity tests performed with the compost leachate gave variable results. In the first year, leachate from NC resulted in a lower germination index than that from the covered composts. The differences between the two treatments tended to become more significant at higher concentrations. CC leachate at 100% concentration reached the safe threshold (germination index >60) in the samples of May 1995 (day 183), while the NC leachate had reached that stage only at the last sampling date. In the second year, no significant differences were found between treatments at any given concentration or date of sampling. The threshold for absence of phytotoxicity was reached by the third sampling date (day 107) for both treatments. The difference in characteristics of the compost leachate between the

two cycles may reflect some of the modifications that were made after the first cycle. The platform base collecting the leachate was changed from a fine sand base to a two-layer base of gravel and coarse sand. This would have affected the flow and content of leachate going through. The nature of the carbonaceous material was also different: sawdust in the first cycle and wheat straw in the second cycle. However, the trends observed demonstrated that early leachate is highly phytotoxic unless diluted to 10-30%. It is likely that the substrates used and the rate of decomposition will play a role in determining the characteristics of leachate. It was not clear whether geotextile covers influenced the quality of leachate in that respect.

CONCLUSIONS

The application of geotextile covers on compost windrows presents several potential benefits. The protection offered by these covers can allow a producer to start a composting cycle in late summer or fall with the expectation that temperatures will be adequate in the windrows, despite cold air temperatures. The prolongation of warm temperatures within the compost in the fall and spring can result in an earlier maturation of the compost. A covered compost can present a lower moisture content as it nears maturation, making the handling of the material easier. However, the moisture content of a covered compost would have to be monitored to insure that it does not become too dry too soon in the composting cycle. The reduction in leachate volumes results in better retention of mineral elements in the compost, and at the same time, less risks of groundwater contamination. Even in situations where the leachate is recovered for treatment or disposal, the reduction in volumes to handle is also advantageous.

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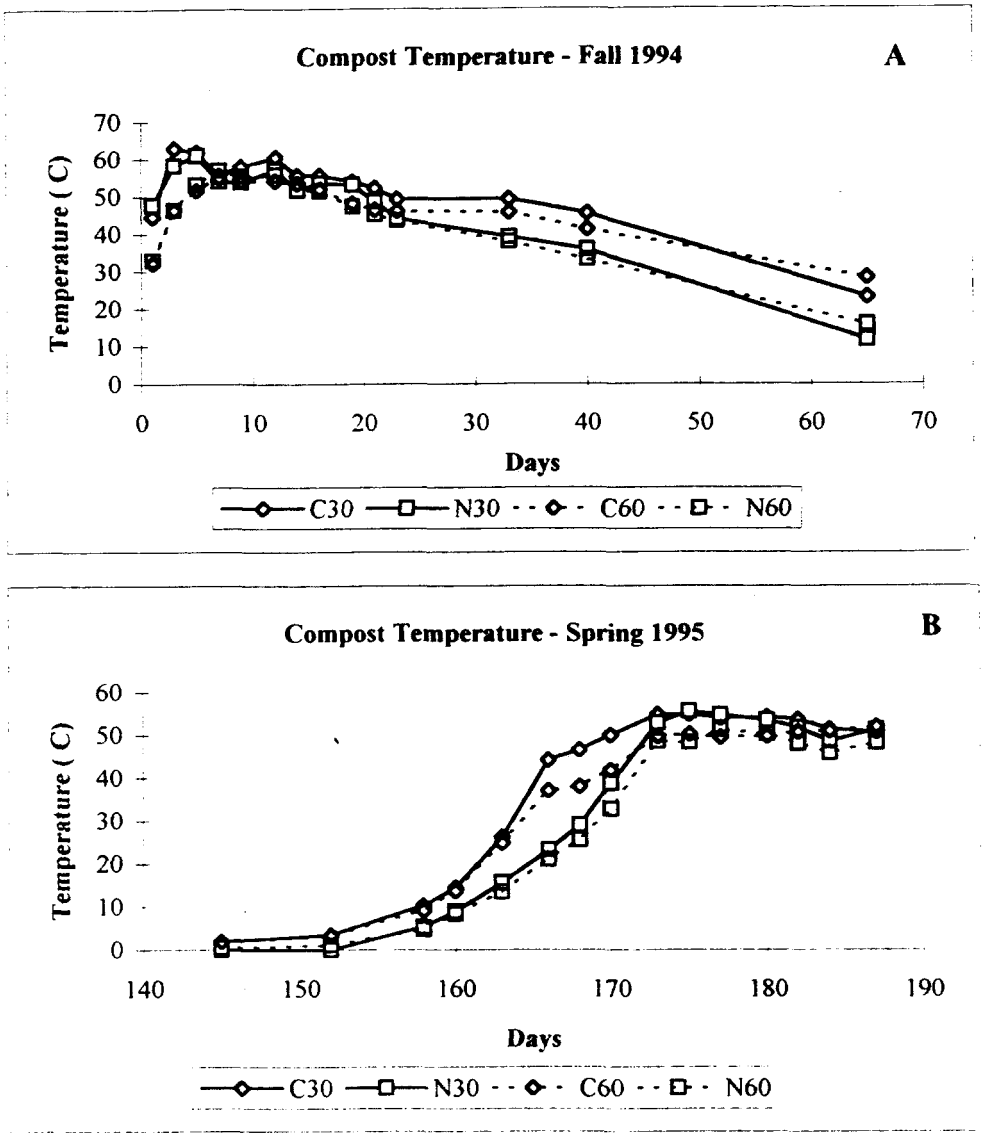


FIGURE 1 - 1994-1995 Effect of covering on the temperature of compost piles at depths of 30 and 60 cm. Each point represents the mean temperature of 3 windrows. Time intervals are as follows: (A) 17.11.94 to 25.01.95, (B) 05.04.95 to 25.05.95 (C30 and C60 are for covered compost at 30 cm and 60 cm depths, N30 and N60 are for non-covered compost at 30 cm and 60 cm depths).

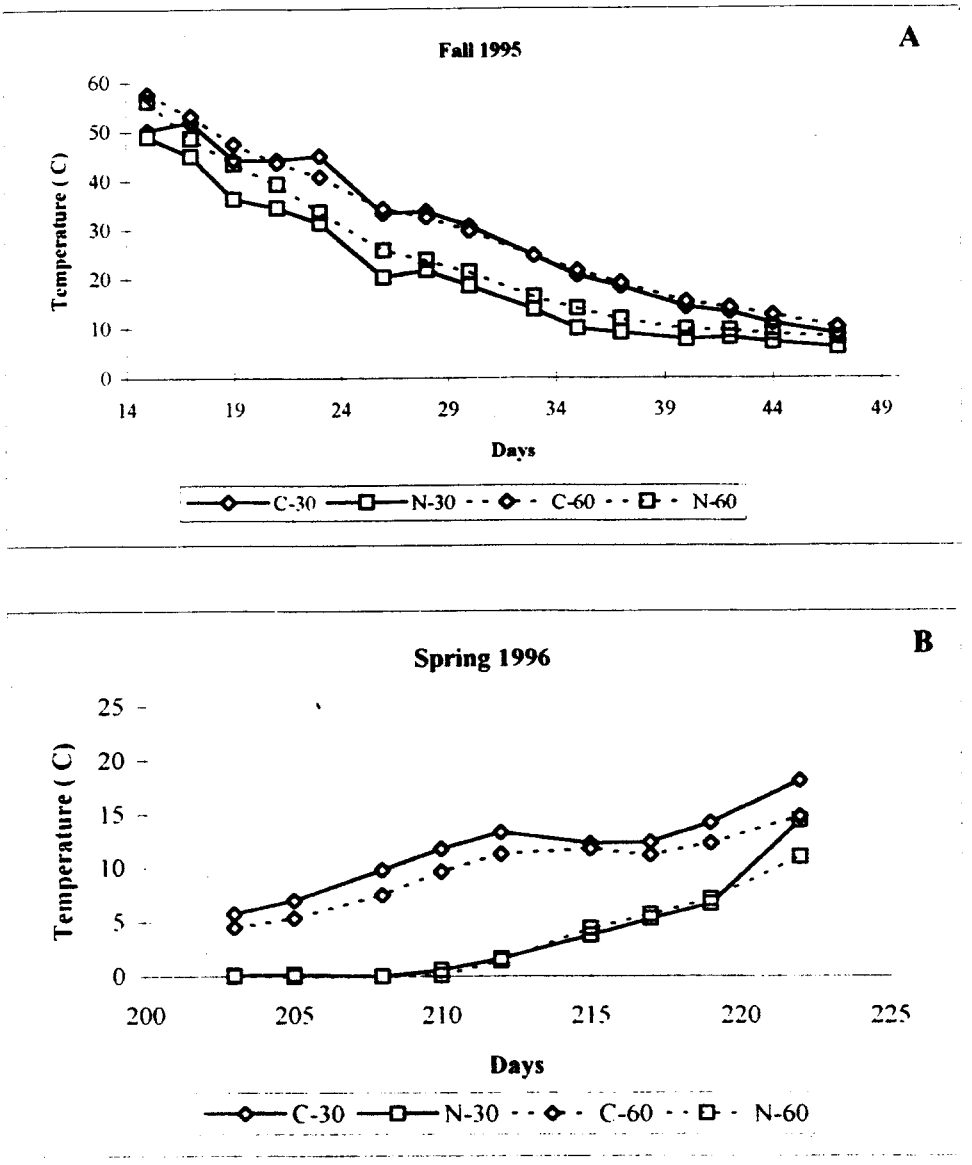
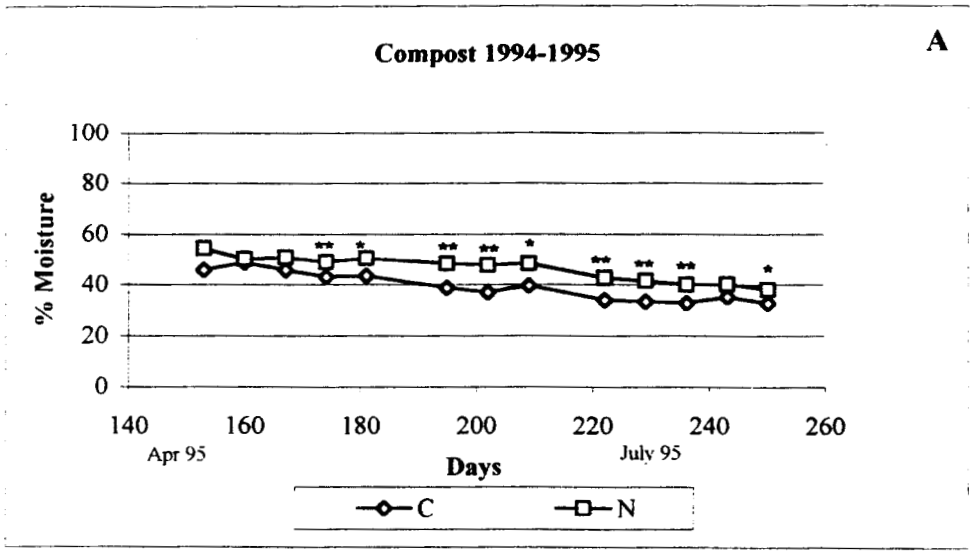


FIGURE 2 - 1995-1996 Effect of covering on the temperature of compost piles at depths of 30 and 60 cm. Each point represents the mean of six windrows. The time periods for each graph are as follows: (A) 25.10.95 to 29.11.95, (B) 28.04.96 to 23.05.96. (C30 and C60 are for the covered compost at depths of 30 and 60 cm; N30 and N60 are for the non-covered compost at 30 cm or 60 cm depths)



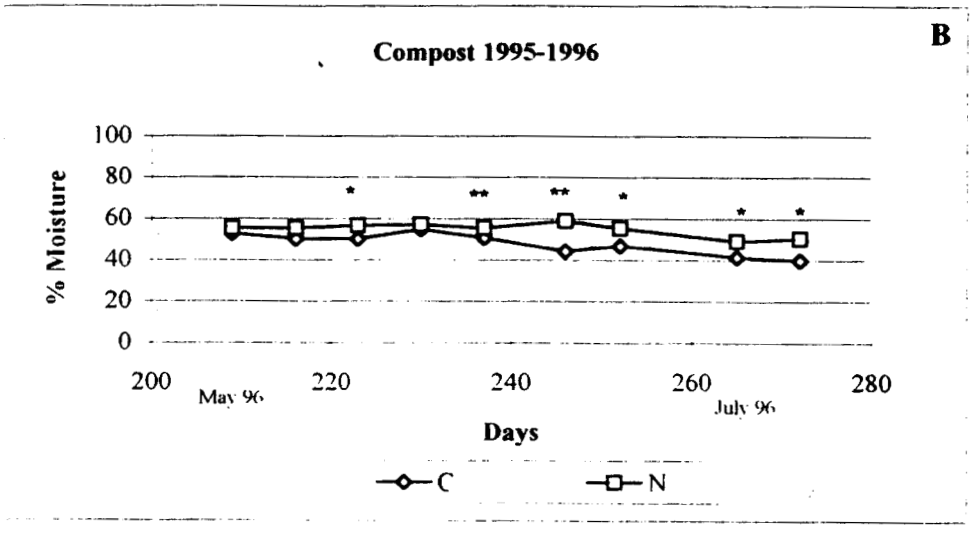


FIGURE 3 - Compost moisture content for the spring and summer seasons of (A) 1995 and (B) 1996. Data points represent the mean of 3 windrows in (A) and of 6 windrows in (B) for covered compost (C) and non-covered compost (N). Significant differences are indicated with * ($p < 0.05$) or with ** ($p < 0.01$) for each date where they occurred.

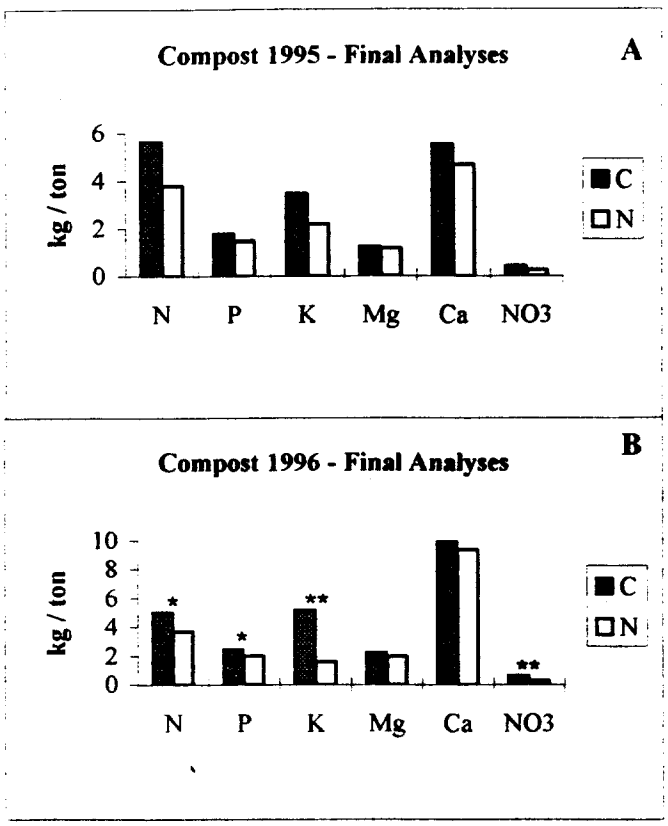


FIGURE 4 - Final physico-chemical analyses results for composts in covered windrows (C) and non-covered windrows (N) in 1995 (A) and 1996 (B). Data represent the mean of three windrows in (A) and of six windrows in (B). Significant differences are indicated with * ($P < 0.05$) or ** ($P < 0.01$).

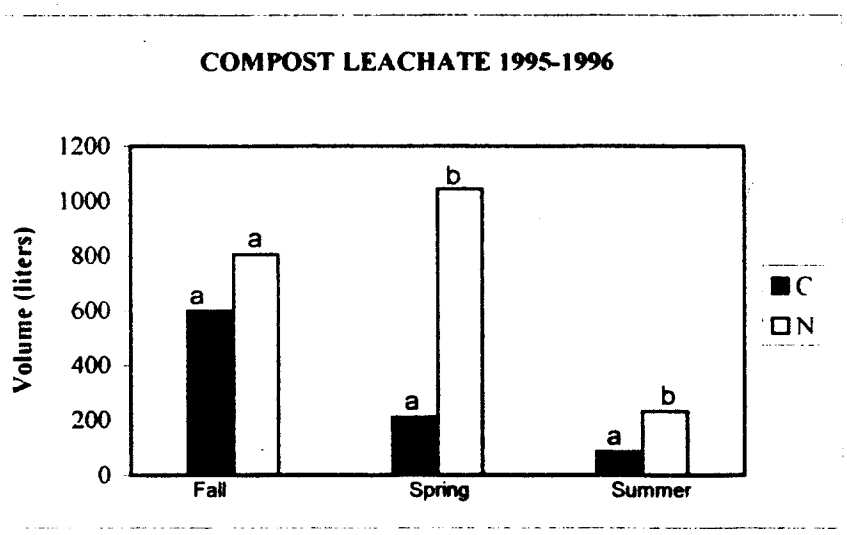


FIGURE 5 - Compost leachate volumes for the year 1995-1996 from covered compost (C) and non-covered compost (N). Data represent the mean of cumulative volumes per platform for each treatment in each of three seasons. Treatments with a different letter differed significantly ($P < 0.01$) within a given season.

COMPOSTING THROUGH CONSORTIUMS

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INTRODUCTION

In many agricultural states throughout the country, such as Iowa, Texas, and North Carolina, the increase of livestock production has created huge quantities of nutrient rich manure to manage. Often, accepted agricultural waste management practices (i.e., land application) have been mismanaged causing both public relations and environmental challenges. For this reason, innovative practices for managing agricultural by-products have been considered, but often are not implemented on a large-scale basis for economic reasons. In many cases, individual farmers do not have the financial resources or expertise to address specific challenges. One viable option to remove or minimize these barriers is by forming consortiums of interested parties. One such group has been formed in northeast Iowa to proactively address farm odors and water quality issues caused by on going land application of manure.

BACKGROUND

The Fayorganite Group was organized through efforts of the Fayette County Economic Development Commission (FCEDC) and the State of Iowa's Rural Action Program. The group was started in January 1995 and has been evaluating the management of farm manure through the development of a composting facility. Both dairy and hog farms are prevalent in Fayette County and it is estimated that approximately 196,000 dairy cows are being raised in Northeastern Iowa. The Fayorganite program was jump started when grant funds were obtained to complete an economic and technical feasibility study as well as a composting pilot project.

At the completion of the pilot project, a cost analysis was performed which included capital, operations and maintenance (O&M), and revenues for the anticipated compost products. The estimated capital costs included access roads, equipment, pads, and utilities. Estimated O&M costs included labor, bulking agents, fuel, maintenance, and utilities. An analysis of potential revenue streams was also completed including tip fees for yard waste/wood waste, tip fees for manure, and revenue from product sales. Two market opportunities for the finished compost were investigated. They were the landscape/nursery industry for use in various horticultural/agronomic applications and local dairy farmers for use as animal bedding. Data relevant to product value was used in the economic analysis. Total annual costs and annual costs per ton of manure for the entire facility were developed as were a conceptual site layout, process flow, and economic analysis.

PILOT STUDY

The pilot composting study was conducted at the Chensvold & Rovang Sanitation recycling facility in West Union, Iowa. It is assumed that the large scale composting facility would be located in West Union because an estimated 12,450 farms are located within 50 miles of West Union. The pilot study was undertaken to determine the most efficient and economical composting technology to utilize as well to evaluate potential bulking agents. The aerated turned window (ATW), unaerated turned windrow (UTW) and aerated static pile (ASP)composting methods were studied with various manure and bulking agent blends.

Pile 1 was a UTW consisting of a 4:1 blend (by weight) of separated dairy manure and shredded paper on half of the pile and a 4:1 blend of separated dairy manure and cornstalks. Pile 2 was an ATW consisting of a 1:1 blend of manure and leaves (by volume). Pile 3 was an ATW consisting of 100% manure. Pile 4 was an ASP consisting of manure and cornstalks. Pile 5 was an UTW consisting of a 7:3 blend of manure and leaves (by volume). Pile 6 was an UTW consisting of 100% manure on one side and a 4:1 blend of manure and cornstalks (by

weight). As a general summary, the piles containing the bulking agents generated heat faster and maintained temperatures longer. Also, piles under aeration dried out faster.

FEASIBILITY STUDY

The Fayorganite project was unique in that the proposed program began as a cooperative effort between livestock managers, the Cooperative Extension Service and the Fayette County Economic Development Commission. It later took shape as a private venture which would benefit both the livestock managers and the facility owner. Ultimately, the facility meets the needs of all parties involved in the Fayorganite program. The overall concept of the program changed when a local garbage hauler became interested in operating the composting pilot study. Because of the interest of a company outside the agricultural sector and because of the potential economic benefits of an integrated composting facility, various conceptual designs were considered. To best consider a wide variety of potential design and economic scenarios, a strictly agricultural type facility and a more commercial type facility were compared.

The commercial facility would receive and process 15,000 tons of wood waste to use as a bulking agent for the manure. The wood would also provide a source of substantial revenue to the facility. The UTW composting method was utilized because of the porous nature of the mix, its drier nature and because turning the pile would improve the physical breakdown of the feedstock (e.g., wood, paper). Manure would be received in 20 cubic yard roll-off containers and placed on an asphalt pad. Wood waste will be delivered and also placed on the open asphalt pad awaiting grinding through a tub grinder or horizontal grinder. The site will also be equipped to receive food waste and unrecyclable paper. The paper would be off loaded by haulers into a three sided building. Mixing of the feedstocks would be performed with a front-end loader and volumetric measurements of the materials will be measured with the front- end loader bucket. The mix ratio will provide a C:N ratio of 30-40:1 and a solids content of 35-50%. In this scenario, the goal is to maximize the use of the wood waste because it provides a tipping fee to the facility, and the manure does not. The mix will be placed into 12 feet (width) by 5 feet (height) windrows and the front-end loader will be used to shape the windrows. Daily temperatures will be taken until PFRP is achieved and the piles will be turned at least five times during a 15 day period in which the pile temperatures are at 131 degrees F. Following active composting, the product will cured for 30 days. The facility will provide three months capacity for curing and storage on the open pad. Within the three sided building, aerated curing for one months capacity of product will be provided to provide enhanced drying of the bedding product. Final screening will be completed on a quarterly basis with a leased screen.

The agricultural facility would primarily receive and compost separated manure supplied by the livestock farmers involved in the consortium. The facility will compost 15,000 tons of manure using the ASP composting method. This method will be used because it can enhance drying of the mix which will possess a higher initial moisture content. Separated manure will again be delivered in 20 yard roll-off containers onto an open asphalt pad. Pre-ground wood and yard waste will be placed on the asphalt pad for storage. Sixty days of storage will be provided, and feedstock blending and pile formation will be performed using a front-end loader. The mix ratio will provide a C:N ratio of 20-30:1 and a solids content of 35-50%. In this scenario, the goal is to maximize the use of the manure because the facility is primarily a manure management facility for the farmers. The mix will be placed over perforated high-density polyethylene pipe, then covered with a one foot layer of coarse wood chips. A six feet layer of mix will be placed over the wood chips and insulated with a one foot layer of unscreened compost. An extended ASP will be created by placing the new mix directly against the face of the previous days pile. Temperatures will be measured until PFRP is met (131 degrees F for 72 hours). The mix will be actively composted for four weeks, then cured in a static pile for an additional month prior to screening. Three months of curing and product storage will be provided on an open pad and screening will be done quarterly using a leased screener.

MARKET RESEARCH

To provide economic data necessary for the economic study, a preliminary market assessment was performed in Northeast Iowa to determine the marketability and value of the manure compost. Two marketing opportunities were investigated, marketing the compost as an animal bedding to the dairy industry and marketing

the product to the landscape/nursery as a soil amendment. Data collection identified research which illustrated the potential usage of compost as animal bedding. Market related data was obtained from various sources and uniform data collection was completed by using standardized surveys. Surveying was completed by telephone and the followed up with face to face visits.

Animal bedding markets were evaluated by obtaining information from the Cooperative Extension Service, the University of Iowa and by surveying dairy farmers and dairy supply companies. Bedding is used in free stall operations as a means to manage the animal's urine and excrement. The majority of farmers use dried sawdust, wood shavings or chopped straw as bedding. The typical price of dried sawdust and wood shavings was identified as $27.00 - $40.00 per ton, with typical prices being $35.00 per ton and above. While some dairymen apply thick layers of bedding, infrequently, many now use rubber mats, then apply a ¼ to ½ inch layer of bedding over the mat. In this type of operation, the mats are frequently cleaned and bedding reapplied. Aside from requiring a product which is absorbent and non-abrasive to the cows, dairymen require a product which will not cause the spread of mastitus. The product must also be somewhat dry, but not dusty. Limited research has shown and many experts know that although compost supports bacterial growth, there is no evidence supporting the belief that the bacteria are transmitted to the cow causing mastitus. Product samples were distributed to local dairymen for evaluation, and overall, the product was deemed acceptable.

The landscape/nursery industry in Northeast Iowa has had little experience with compost. Being a rural area, the industry itself is not well developed. The landscape/nursery industry includes landscapers, garden centers, nurseries, golf courses, etc. Only one-third of the individuals contacted had used or resold compost. Unfortunately, two of the firms trying yard debris compost had poor results; because of unstable compost. Although there was little compost-related experience, interest did exist. Some had evaluated mushroom compost from a regional landscape supply company. Soil conditions vary from rocky to heavy clay and professionals seemed to understand the need to improve the soil. The current local landscape/nursery market is small, but could grow to be substantial. Often, rural markets are not large enough to allow typical commercial landscape/nursery suppliers to spend the time to develop them. However, for a small to medium sized compost facility, they could be developed into a substantial market.

Using standard animal bedding utilization estimates obtained by industry experts and other farm management assumptions, it was estimated that between approximately 116,000 and 143,000 tons of animal bedding are used in the Northeast Iowa dairy industry on an annual basis. For this reason, and the fact that dairymen will be supplying the composting facility with manure, the short-term market focus should be as animal bedding marketed to dairymen. Field testing of the product will be necessary as will the production of a somewhat fine, dry product which is moisture absorbent. Further product development research will be required. Whereas a fully stabilized compost may not be required for an animal bedding application, it will be required for a soil amendment. The landscape, topsoil and garden center markets should also be approached to allow for the development of higher value markets. Because of the lack of compost experience, and some negative prior experience, educating the landscape/nursery industry will be necessary to develop these markets.

ECONOMICS

The capital, and operational and maintenance (O&M) costs of the commercial and agricultural composting facilities are outlined Tables 1-2, attached. The estimated annualized costs of the facilities are $374,100 and $163,550 for the commercial and agricultural composting facilities, respectively (Table 3). Using conservative tipping fees for wood waste brought to the commercial composting facility and conservative compost values of $5.00 per ton for an animal bedding and $14.00 per ton for a soil amendment, the commercial facility shows a net profit of $26,700, while the agricultural facility shows a net loss of $105,200 (Table 4). Profit could be increased at the commercial facility by increasing tipping fees for the wood waste, introducing food waste at a higher tipping, or by increasing the price of compost. The capital construction and O&M costs of the agricultural facility outweigh the revenues generated through compost sales. However, the $11.00 per ton cost to compost manure can be offset through product marketing or by having the cooperating farmers utilize the product, thus reducing the cost associated with purchasing animal bedding. To improve the economic feasibility of the agricultural facility, grants may be obtained to offset capital costs or additional revenue sources should be sought to offset O&M costs. In both cases, the cost of separating (dewatering) the manure must be borne by the farmer.

CONCLUSIONS

The development of consortiums or regional facilities can provide excellent economic development and business opportunities as well as the opportunity for public-private partnerships. Scaling up a composting facility to accept larger volumes improves the overall economics of a facility and can provide excellent environmental benefits. The creativity of such programs will allow for the management of farm by-products in a more sustainable means, while improving economic opportunity for rural communities.

The success of the commercial facility depends on the ability to obtain wood waste at a reasonable tip fee and to market the resultant product. Indications suggest that this appears feasible in West Union. The estimated revenues could be significantly increased by increasing the sales price of the product and by introducing food waste as an additional nitrogen source. The agricultural facility will require a tip fee of $7.50 per ton of manure unless grant funds are obtained to reduce capital costs or existing equipment or land is used. The willingness of the cooperating farmers to utilize the compost as animal bedding on their farms is also important as is developing higher paying horticultural markets. However, it should be understood that although current manure management costs cannot currently offset the cost of composting in this specific scenario, stricter nutrient management regulations will increase over time. This will result in increased manure management costs, thus making composting more economically feasible on a wide scale basis.

TABLE 1

CAPITAL COST SUMMARY

Facility Type	Capital Cost
Commercial - UTW	$1,150,600
Agricultural - ASP	$316,400

TABLE 2

OPERATIONS AND MAINTENANCE COST SUMMARY

	Commercial - UTW	Agricultural - ASP
Labor	$103,100	$63,100
Bulking Agent[1]	$0	$14,100
Maintenance[2]	$32,500	$9,300
Fuel[3]	$18,300	$5,800
Utilities[4]	$12,000	$1,150
Miscellaneous[5]	$29,700	$18,900
Annual O & M Cost	$195,600	$112,350

1 - Assumes $4/ton cost to purchase and transport ground yard waste and/or corn stalks to the site
2 - Includes equipment and site maintenance costs
3 - Based on estimated usage and $.80 per gallon for fuel
4 - Based on estimated usage and $.10 per kilowatt-hour
5 - Includes utilities, insurance, licensing, laboratory analysis of product, product marketing costs, and engineering consulting fees

TABLE 3

FAYORGANITE COMPOSTING FACILITY

ESTIMATED ANNUALIZED COSTS

	Commercial (UTW)	Agricultural (ASP)
Amortized Capital[1]	$178,500	$51,200
Annual O & M Cost	$195,600	$112,350
Total Annualized Cost	$374,100	$163,550

1 - Capital amortized at 8%. Includes land, utilities, engineering, and sitework at 20 years, and equipment at 7 years.

TABLE 4

ESTIMATED FACILITY NET PROFIT (LOSS)

	Commercial - UTW	Agricultural - ASP
Total Annual Cost	$374,100	$158,200
Wood Waste Tip Fee Revenue	$275,000	$0
Compost Sales to Horticultural Market	$41,600	$17,500
Compost Sales to Agricultural Market (bedding)	$84,200	$35,500
Facility Net Profit (Loss)	$26,700	($105,200)

OPERATIONAL CHALLENGES ASSOCIATED WITH A COMPOSTING FACILITY AT THE HIGHEST ELEVATION IN THE EAST

By

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The Town of Beech Mountain provides water and wastewater services to approximately 1800 connections. The town is located in the northwest mountains of North Carolina at an elevation of 5500 feet. Beech Mountain is a summer and winter resort community, with Ski Beech ski resort and the Beech Mountain golf club beginning two of the largest attraction. With a full time population of 263 and a winter and summer increase of almost 10000 operation challenges are a constant.

Composting began in 1990 when the town could no longer send biosoilds to the landfill. After looking at land application, and finding no sites the could be permitted due to the mountainous terrain, and the fact that we had a program for collecting wood chips and yard waste made composting a viable choice for reuse. The operation is comprised of a 200' by 200' asphalt pad with a 200 cfm blower, from a old treatment plant, located next to the Pond Creek wastewater plant .All of the construction was done by the town employees. The facility is permitted for 8 dry tons of biosoilds per year, and has produced a high quality product.

With a town elevation of 5500' and a facility elevation of 3720', what are some of the operation challenges we face? Most are weather related, at this elevation there are 4 true seasons. In the winter you see cold temperatures, rain snow and ice. In spring you have rain, summer warm temperatures, and heavy storms. During the fall things are usually calm. The other challenges are managing product, and finding technical support. How do we deal with these challenges and still produce a quality product?

TEMPERATURE

With heat a major component of the composting process, low air temperatures cause a problem in the treatment of the compost. Beech Mountain uses the " Aerated Static pile" process, on an open pad. Without a cover to protect the process one of the ways we have found to keep temperatures above 55 C. in the winter is to cover the pile with a top layer of wood chips. This is an operational procedure that is done with compost that is mixed in the late fall. Compost is only mixed 3-4 times per year, due to the variations in flow we receive, in May, July, October, and November. This extra cover acts as an insulating blanket to keep the mix warm. One of the problems associated with this is you must use extra long probes to get good temperature readings. The reason for extra length is for not only for the layer of chips, but the fact that Beech Mountain averages approximately 60" of snow per year, and during the past 3 year we have averaged over 100". The snow in some ways helps the process, by insulting the pile and adding moisture to the mix as it melts. This procedure has worked so far and we have been able to see mix temperatures maintain an average of 60 C. during the mix cycle. The use of extra cover is only possible because of the stockpile of bulk material we have. During the summer months one 4 - man crew dose right-a-way clearing, and per town ordnance all yard waste is picked up once each week and brought to the compost facility. These pickups allow us to create a very large stockpile of bulk material for future use.

RAINFALL

Rain and snow may be the greatest operational challenges for this facility. With an average of 54" of rain per year, and 60" of snow, storms and run off can cause major problems. The worse beginning a combination of a 30" snow and a rain event on top of that or a tropical system that makes it to the mountains. During the past 5 years there

have been 3 such events. These storms create two separate problems. 1) With outfalls that begin at 5500' and drop to 3700" in a distance of about 5 miles and the associated I & I problems the influx of water hydraulics the waste system, 2) the facility sets at a bend on the stream itself which can be a flood hazard. In two of the storms water cut out of the stream channel cut across the compost bulk storage and destroyed about half of the compost pad, it then traveled through the lab/blower building and across the wastewater plant. With the drainage from the pad going into the plant this only made the damage to the plant worse. Within 3 months the wastewater plant was shut down and the shaft in the clarifier mixer replaced, along with the drive unit.

Planning is the only way to manage these situations, and sometimes that is not very effective. You must plan when you waste from the plant so that you are mixing compost in the times that it is less likely to be affected by these weather events. The normal procedure is to waste in late March, June, August, and October. This will give the solids time to dry on the beds to about 35 – 39 % moisture, at which point it can be mixed at a ratio 3 parts bulk to 1 part biosoilds. In planning to do most operations in this way the facility is clear of any product that could be harmed.

MANAGING PRODUCT

One of the concerns of starting the compost facility was what to do with the finished product. After mixing at the 3:1 ratio you end up with about 40 tons of product, and possibility 50 tons. The original plans called for placement of all compost on road cuts made by the town developers, with 60 miles of roads this gave a good outlet for the product. Since that time we have found other outlets for this product, such as corner flower gardens, and business and homeowners. The very low metals content and the ability of the process to meet pathogen requirements has also allowed it to be used in some of the roadside overlooks and parks. With so many new ways to use compost, and a very good acceptance by the residents and visitors, the town has not only been able to reuse a waste byproduct, but do so in a way that is cost effective and enhances the natural surroundings.

HOW HAS LOCAL COOPERATIVE EXTENSION PROVIDED SUPPORT

One of the problems Beech Mountain faced in 1990 when it could no longer landfill biosoilds was "What do we do now". Land application was not an option due to the fact there were no suitable sites, and the cost to transport somewhere else would be prohibitive. This where North Carolina Cooperative Extension stepped in, F. M. Pittman from the Avery County office and Dr. A. R. Rubin from North Carolina State provided several forms of assistance, and that assistance is ongoing not only with Beech Mountain but with other municipalities in Avery County.

Cooperative Extension support includes;

1) 'Feasibility Assessment' of the biosoilds facility, by examining the feasibility of alternative management practices, whether it is land application, composting, or lime stabilization.
2) 'Ad – hoc Technical Assistance' by developing solutions to technical problems caused by seasonal fluctuations in population.
3) 'Information Dissemination' by conducting annual meetings to discuss technical, regulatory and public relation issues.
4) 'Other Forms of Assistance' by conducting biosoilds testing and keeping the up – to – date on environmental regulations.

The assistance provided by Cooperative Extension has improved the biosoilds management capabilities, practices, and performance of the municipal facilities. They have helped the town to find quality information, and make informed choices about beneficial reuse. The cooperation and continued work with the extension agents will further improve management practices, save the town money, and produce a safe high quality product that is used in the community.

DOES COMPOSTING IN THE MOUNTAINS WORK

Even with all the problems Beech Mountain faces from weather, to technical problems, to management of product, composting can be done and a quality product produced. With the hard work of the Beech Mountain staff, the North Carolina Cooperative, and the acceptance of the public, Beech Mountain has been able to take what was a waste product and turned it into a recycled beautification product that can help promote the natural surroundings of this resort community.

CLEAN ORGANIC WASTE COMPOST PRODUCTION AND EVALUATION IN SOUTH FLORIDA

By

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INTRODUCTION

Composting is an attractive waste management tool, since 30% to 60% of the waste materials can be composted into an environmentally safe matter (Smith, 1994a). In Florida, municipal solid waste (MSW), yard trimmings (YT) and biosolids are high-volume wastes that could be recycled into compost instead of landfilled or incinerated (Goldstein, 1997). Smith (1994b) reported that the largest portion of solid waste is MSW (12million tons) followed by YT (3 million tons and animal manure (0.5 million tons) in Florida. Using compost in agriculture reduces the need to expand landfills or build incinerators. Additionally, amending Florida's sandy soils with compost may reduce the frequency and rate of irrigation and inorganic fertilizer applications (Ozores-Hampton, 1993). New technology and development of processed solid waste materials have made high quality products available to the agricultural community (Bryan and Lance, 1991). From the Urban viewpoint, compost production represents a safe disposal method for thousands of tons of waste materials produced each year (Ozores-Hampton, et al., 1998). Based on these facts, the need to recycle food wastes produced in south Florida into clean composts evolved.

An investment of two years work and $328,000 of Dade County taxpayers money produced an effective and successful Clean Organic Waste (C.O.W.) compost pilot project. This success was attainable by the contribution, cooperation, assistance and guidance of consultants, engineers, researchers, administrators, regulators, technicians, managers, scientists and commissioners in Florida mainly in Miami-Dade County. South Dade Soil and Water Conservation District (SDSWCD) was instrumental in obtaining the funds to support this project and preparing and submitting quarterly reports to the county. A final report was published on C.O.W. compost in 1997 (Levy et al., 1997).

In this manuscript construction of C.O.W. facility; compost production, compost evaluation, marketing of C.O.W. compost, benefits of the C.O.W. project, problems encountered, conclusions and recommendations will be discussed.

CONSTRUCTION OF C.O.W. SITE

The Metro Dade County Department of Solid Waste Management (DCDSWM) provided funding for the project. The 0.8 ha C.O.W. facility was designed by Stone and Webster Engineering Corp., Miami, Florida and was constructed by C.A. Associate, Inc., Miami, Florida. It began in February 1995 and was turned over to SDSWCD five months later. The facility was permitted to process 3,000 tons of C.O.W. compost per year at University of Florida Tropical Research and Education Center (UF-TREC), Homestead, Florida.

The 4 segments of the facility were: 1) a mixing pad, 2) four asphalt compost pads, 3) an elevated leachate pond and 4) a storage area. The compost production at each segment is discussed in detail in the compost production section.

COMPOST PRODUCTION

The facility included a mixing pad of 61m x 12.5m for commercial and institutional food residuals and shredded mulch from nurseries and yard wastes (Figs.1 and 2). A conveyor belt and a hammer mill to shred large wood pieces were located on the mixing pad (Figure 3). A front-end loader pushed approximately 1part food scraps and 1 to 2 parts mulch into a pile. A tractor drawn Scat Model 482B windrow turner mixed food wastes with yard mulch. It also aided in aerating and turning the piles on the mixing pad (Fig. 4). Periodic turning of the piles and addition of enzymes through a spray applicator attached above the elevator conveyer were done with the windrow turner (Fig. 4). These enzymes were necessary to eliminate anaerobic fermentation, odor problem and accelerate the composting process. The process took 2-4 weeks before piles were moved to one of the four asphalt composting pads. Compost pads were designed for 30m long, 5 m wide and 2m high windrows (Fig. 1). Two pads received mechanical turning of the piles for aeration and the other two pads received forced air aeration for static windrows through PVC pipes (Figs. 1 and 5). A layer, 0.5 m thick, of wood chips was placed over aeration PVC pipes as a bed for the compost. This facilitated aeration of the static aerated windrows. Piles were watered with sprinkler system set between the piles. At this stage, frequency of turning the piles (about twice a week) depended on piles' moisture and oxygen contents, and temperature. Periodically, temperature and moisture samples were taken from windrows at 45 and 90 cm deep. Piles remained in turned windrows for 4-5 weeks before they were ready to be moved to the storage area. Static aerated windrows required over 12 weeks to mature the compost. An elevated aerated leachate pond of 322,000 liters capacity was built next to the 4 compost pads to collect runoff during heavy rainfall (Fig. 1 and 6). Piles were screened then moved to a storage area (Fig. 1). The purpose of this step was to screen out the small rocks, large wood chips and other extraneous material from compost piles. Samples for quality inspection and analyses were taken from windrows during the composting process.

Figure 1. Schematic diagram of Clean Organic Waste Composting Site Plan.

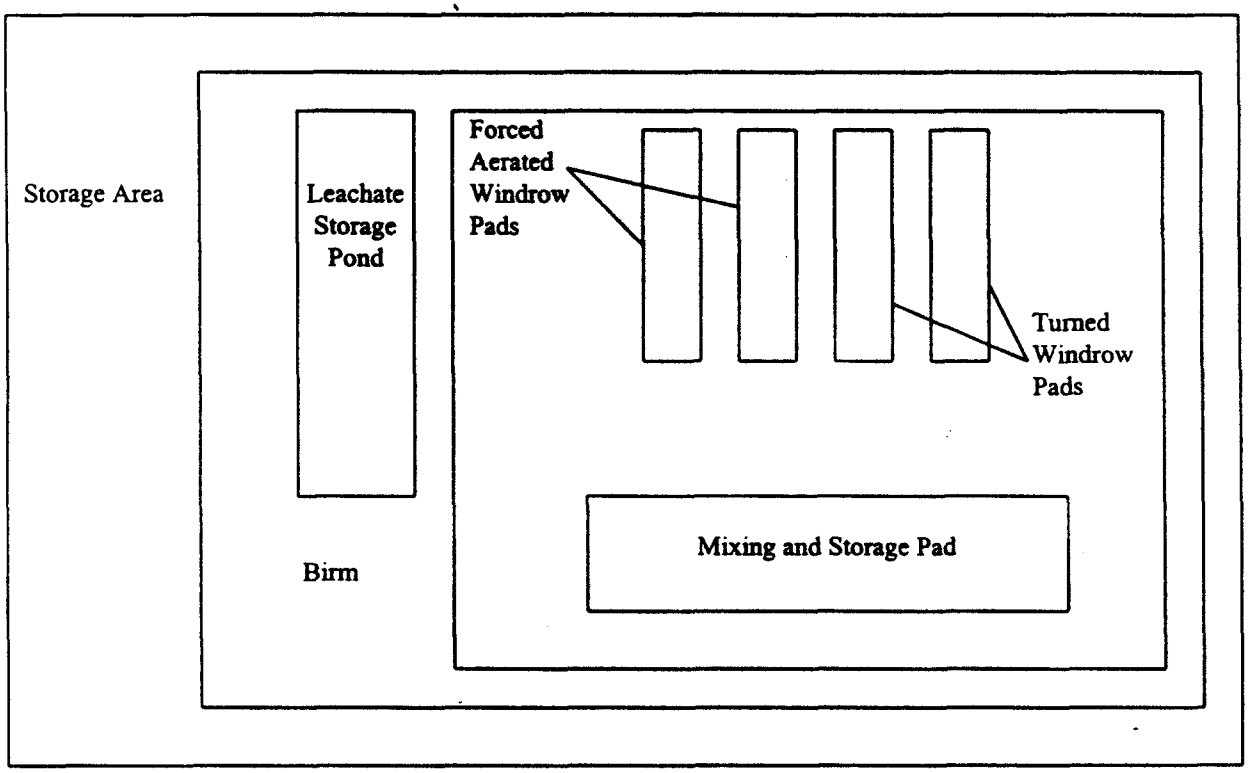

Figure 2. An aerial view of C. O. W. compost site at UF-TREC, Homestead, Florida.

Figure 3. Hammermill, Conveyer and Mixing Pad.

Figure 4. Scat windrow turner with enzyme spray boom above the conveyer.

"A PRELIMINARY REPORT ON A GEORGIA CITY'S INNOVATIVE COMPOSTING PROJECT COOPERATION BETWEEN THE CITY OF DOUGLAS AND THE UNIVERSITY OF GEORGIA, COLLEGE OF AGRICULTURE."

By

Danny Lewis; K. C. Das; Rick Reed; Glen Harris; L. Mark Risse; Randy Roberts; Larry Royal; Jackie Wilson; Jerry Lott
(Complete addresses at back of paper)

INTRODUCTION

Cities across Georgia and this nation are challenged and sometimes even mandated, to operate more efficiently and effectively. Likewise we are all forced to serve a more populated community whether in an urban setting or in rural America.

About four (4) years ago, we started to dream about how to reduce our city contributions to the Coffee County operated landfill. It wasn't just a cost savings approach, it was a common sense approach to our landfill's future - and yes, to our future.

The dream began with a yard trimmings grinding project, then a distribution of the ground yard trimmings to residents, then to the development of our compost and finally to distribution or completed compost to our customers.

We were interested in developing a project that would work in rural America and not just a mega project that could only be afforded by our urban counterparts.

OUR BACKGROUND

We are a rural community in extreme south Georgia. Douglas is the county seat of Coffee County Georgia. Our city population is estimated at approximately 14,000 presently and our county overall population is just under 35,000.

We are situated between Valdosta and Waycross, Georgia and about 70 miles north of the Florida line.

Our community generates 35 tons of yard trimmings every day. This is an extremely large amount of trimmings for our size community, comparatively speaking. As in every community, we looked at all of our community's available waste products, as we began the project.

AVAILABILITY

Although we don't refer to everything officially as waste, at one time or another it is considered as waste in most communities. In Douglas we looked at nine (9) different waste elements. Our major waste products for consideration, however, were:

Yard Trimmings - including pine straw, leaves, grass clippings, azalea trimmings, limbs, sticks, trees, and other such trimmings from yards. We average 35 tons per day.

Cotton Gin Trash - As cotton has returned as "king" in rural south Georgia, also has cotton gin trash been generated as a by product. Douglas has two (2) modern cotton gins operating within its city limits. Cotton trash is, at best, used as a low grade roughage for cattle.

Tobacco Trash - Douglas has been known for years as tobacco capitol of Georgia. Along with this, significant quantities of tobacco trash are generated by the market warehouses.

Municipal Sludge - We installed a dewatering system at the Douglas Water Pollution Control Plant in 1997. We are generating between 6-11 dry tons of sludge on a daily basis. This dried sludge requires proper disposal. Although the cost at our landfill is only $12.00 per ton, to have and dispose of sludge the cost is near $35.00 per ton.

Poultry Litter - Douglas is the second largest poultry producer in Georgia. Although the poultry houses are not in the city, there is a large amount of poultry litter produced daily in our county. At the present time, farmers are able to spread the poultry litter on farmland and there is no excess litter available. This could change in future years as state agriculture and environmental rules might dictate, and therefore would be a great asset to add poultry litter to our composting operation.

THE RESEARCH AGREEMENT CONTRACT WITH UGA

The City of Douglas contracted with the University of Georgia, College of Agriculture, on the 15th day of April 1997 to develop this conceptual plan. The contract agreement was for $28,544.

This project was under the supervision of:

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Department of Biological &
Agricultural Engineering
University of Georgia
Athens, GA 30602
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Fax (706) 542-8806
email tgill@bae.uga.edu

For negotiations contact: (UGA)
Paula Tolbert (706) 542-5939

AGREEMENT CONTENTS

* **Project Title:** "Pilot Scale Evaluation and Demonstration

of Composting Biosolids, Yard Wastes and Cotton Gin Trash"

* **Project Duration**: 9 months

* **Overall Objective**: To develop a work plan based on laboratory investigations of the waste streams and to perform a field sized pilot demonstration of the composting of mixed waste streams.

* **Our Planned Objective**: To look at all available waste products in the Douglas-Coffee County area and determine through laboratory tests, on-ground tests and windrowing, the best compost mix.

IN THE BEGINNING

As we began the project, I feel that no one on the "team" had any preconceived idea as to what our mixture nor end product would resemble. This was important for the project to be a success.

Samples of all types of available waste material from our waste-stream were furnished to the University of Georgia. Dr. K.C. DAS and his Athens team developed the best "recipe" for the compost. Larger amounts or samples were also delivered to the University of Georgia Experiment Station at Tifton, Georgia - (Contact Dr. Glen Harris).

EARTH WATCH KICKS IT OFF

This "dream" began over five (5) years earlier. The City of Douglas hosted an "Earth Watch" program in the local gymnasium. This program gave citizens and students an opportunity to view mulching, composting and generally to leave with ideas about saving the earth. This program was important as it gave our citizens a true hands-on approach to how <u>they</u> could get involved.

The University of Georgia Extension Service and City of Douglas followed this with visual and training assistance on how to start back yard composting projects. Printed brochures were also provided by the Extension offices.

DEMONSTRATION SITES DEVELOPED

City and Extension officials developed city operated demonstration sites adjacent to the Community Services Department and Satilla Regional Library. School led groups and private citizens took advantage of the location to learn more about composting.

Both local newspapers assisted by writing articles of back yard composting. But - even with all this effort, <u>very few people</u> were known to have developed any backyard compost sites. The type

of development was minimally successful.

MULCHING

The city was generating 35 tons of yard trimmings per day on the average. At that time, it was all being hauled to the Coffee County landfill for disposal.

The city considered and even accepted bids to purchase a 12 foot tub grinder. This would allow the city to grind its own yard trimmings. The Board of Commissioners and City Manager of the City felt it would be more cost efficient to contract the services on an annual basis. Thus a considerable savings was realized due to this arrangement.

Annually the city currently contracts with GreenCycle of Smyrna, Georgia, to grind its yard trimmings. (Contact Charlie Slade 770-435-9490).

As the process of grinding evolved, the general public began requesting the ground trimmings for weed control and general mulching of flower beds. The city began loading trucks and trailers on Saturday mornings at no charge. The city also agreed to deliver mulch to city residents at no charge. About 50% of all grindings were being given away. (Note: Other cities will not load for citizens and others indicated they will load for free and deliver within the city limits for $40.00 per load, as example).

At about the same time, the State of Georgia began restricting yard trimmings from the landfills in Georgia. Even though, the city had already eliminated its yard trimmings for approximately two (2) years before the mandate.

Mulching proved to be effective. It was not a free program to the city - but we made it a free program to our constituents. It was a highly favorable program to our citizens. The elected officials, likewise, received high marks from constituents.

But it wasn't 100% effective, remember we were only distributing 50% of our grindings. Therefore, a surplus was being realized.

DEWATERING PROGRAM BEGINS

The City Commission gave authority to the City Manager to contract with Jordan, Jones & Goulding to develop a dewatering plant at the Water Pollution Control Plant (WPCP). Sawcross Inc. was contracted to install a dewatering system. The contract was completed in January 1998 for a cost of $1,500,000.00.

COMPOSTING PROGRAM BEGINS

Now the fun began, as we contracted with UGA officials to

develop the composting "recipe" for this pioneer program.

Samples were furnished to Athens and Tifton offices and the project was ready to begin.

EQUIPMENT

The following equipment is needed to operate the mulching/composting project in Douglas. (This could vary in other communities based on needs or size of your project):

** 1 Tub Grinder - 12 foot
** 1 Rubber Tire Loader
$ 48,000. per year for contract of services
** Contract Equipment not owned by City

EXPENSES - CITY EQUIPMENT:

* 1 Aeromaster Windrow Compost Turner	$ 28,250.
* 1 Rubber Tire Loader - Cat Model 914G	$ 74,000.
* 2 Side Discharge Trailers #SC1000-1	$ 59,286.
* 1 Top Dresser/Small Spreader #F12D	$ 6,657.
* 1 John Deere Tractor 6400JD 85-+ HP	$ 37,968.
* 1 1 1/2 Ton Dump Truck	$ 33,373.
Equipment Purchases	$239,534.
UGA Technical Assistance	28,544.
Total Expenses	$268,078.

* Actual Purchases by City

FUNDING

GEFA Grant	$ 200,000.
City Funds	68,078.
Total Revenues	$ 268,078.

FACILITY

The city already owned a 4.5 acre site which was a portion of the site already EPD permitted for our Water Pollution Control Plant (WPCP). It had been used for two (2) years previously at the city - operated mulch site.

Actually, after the project started it was determined to expand the site to its present size. It is important to have expansion capability on any site selected.

Also water is important to a compost operation. Our site has a 16 acre pond on the southern boundary and has city water on site. It might be necessary to add water or even water with inoculates or chemicals during the process. Our suggestion is to use pond water in lieu of city (chlorinated) water.

It is important to catch any drainage from the site and return to the WPCP for retreatment. We are doing it through a 4" sewer

line and a small retention pit. The drainage from the property ends in the pit and is transported to the head end of the WPCP for retreatment.

THE PROCESS

Use the greenest possible mulch available. (Do not believe that the older the mulch the quicker the process will work - won't happen). We use 2/3 green material and 1/3 brown (dewatered sludge).

The mulch is ground and stored for no more than a period of three (3) months during which time its moisture content is about 16%. The moisture content of the sludge is about 84%. The mix of 2/3 to 1/3 provides an initial moisture about 50% and a C/N ratio of 70. These parameters have been the best for successful composting under rapid heating conditions.

Our windrows are approximately 200 yards long and about 6 feet wide at the ground level and about 3 feet wide at the top. We usually have 9 to 11 windrows.

We put down about 2 1/2 feet of green material then 1 1/2 feet of dewatered (to about 18-20%) brown material and then top with about 2 feet of additional green material.

Now the windrows are developed, we began our turning process with our compost windrow turner. It is of upmost importance that your tractor have a creeper gear. (not just a turtle gear, but a special creeper gear!). If it's turned too quickly, it will defeat the process.

Typically the windrow is well mixed on the first day and allowed to sit for three (3) to five (5) days. Depending on environmental conditions (such as rainfall) the temperature exceeds 131 F within two (2) to four (4) days. Once the temperature had reached this point we turned the windrow once every three (3) days for about three (3) weeks. At the end of the 21 days, regulatory requirements relating to pathogens are completed and turning further is based on temperature of the windrow.

THE PRODUCT

When composting is completed, the product will be usable as a soil amendment, overspread as fertilizer on pasture land and hay fields, turf builder in borrow pits, mulch around plants, plant material mixture for nurseries and floral growers, top dressing for croplands like cotton, corn and soybeans, etc.

We are presently considering bagging and selling the product to individuals and lawn/garden shops. This process could be by city crews or thru private contractors.

Our parks department and grounds maintenance departments are

considering what are the best uses for the finished product. The small spreader/top dresser will be used by the parks department for application.

THE DISTRIBUTION PLAN

The local Extension Office is working to determine the best way to distribute the product. The City really doesn't want to be involved with the distribution "beyond the gate".

(Contact): Rick Reed or Randy Roberts
709 East Ward Street
Douglas, GA 31533
Phone (912) 384-1402 - FAX (912) 389-4007

The Extension Service is also conducting field trials and land application test to help us evaluate and market the product. This should aid us in determining the agronomic value and establishing agriculture markets.

We probably will still load for private individuals. The farmer will probably contract to have it spread on his property or spread it using his own vehicle or equipment.

The primary mode of dispersement will most likely be:
1) By bag if private contractor bags and sells.
2) By private vehicle.
3) By spreader truck.
4) In bulk truck.

THE COST

It is the city's intention to distribute it at NO COST in 1998 (the initial year). We then will make a determination as to the future costs, if any.

SUMMARY

It is a great idea, that took much planning and minimal cost compared to the annual rewards to the city and its constituents.

There are many more "Douglas'" in the world than metro Atlantas. If it works for Douglas, why not in all communities.

It would not have been possible without the cooperation of the University of Georgia and City of Douglas Mayor and Board of Commissioners. It has truly been a team effort.

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STRATEGY FOR COMPOST MARKET DEVELOPMENT IN FLORIDA

By

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INTRODUCTION

Generation of various wastes continue to grow nationwide. America may lead the world in waste generation per capita, as with municipal solid waste (MSW) generation in the U.S. had increased from 250 tons in 1989 to 307 tons in 1994 and to 340 tons in 1997(Glenn, 1998). These problems with recycling and if necessary disposing are not unique.

Management of municipal wastes, both liquid and solid, continues to be major concerns for governments throughout the U.S. Conventional waste disposal methods have serious environmental problems and are becoming too expensive. For example, in 1994, landfill disposal costs ranged from $36 in Florida to $75 in Minnesota to $125 in long Island, N. Y. (Christopher & Asher, 1994). In respohse, many states, counties, and local governments in the U.S. passed legislation to reduce the quantities of materials entering landfills and/or implemented alternative methods of waste disposal. This resulted in a positive impact. For example, in 1985, about 83% of MSW was land filled compared with 72% in 1994 (Carra and Cossu, 1990; Christopher & Asher, 1994). The number of landfills reduced from 8,000 in 1988 to 2,514 in 1997 (Glenn, 1998). It is projected that the number of landfills will decrease to 1,200 by the year 2010 (Christopher & Asher, 1994).

Mandatory regulations for a diversion of waste streams from landfills, increasing cost of landfill disposal and public support for resource conservation is causing many communities throughout the U.S. to plan and/or operate composting facilities by the public and private sectors. Composting of organic wastes is increasingly advocated as an environmentally benign, affordable recycling method. As a result, the number of composting facilities has drastically increased during the last decade and the trend is continuing.

In 1992, thirty seven states planned to enact, or had already enacted, legislative bans on land filling yard trimmings in the U.S. Thirty five states had solid waste diversion mandates with deadlines 1991 to 2010 (Glenn, 1992). As a result of legislation banning yard trimmings from landfills, there has been a dramatic proliferation of yard trimming composting facilities throughout the U.S. The number of yard trimming facilities increased from 900 in 1990 to 2,200 facilities in 1992 and to 3,484 facilities by 1997 (Glenn, 1998). This trend is expected to continue in future years.

The number of biosolids operating plants in the U.S. increased from 61 in 1983 (Richard, 1991) to 261 in 1997 (Goldstein and Block, 1997), while the number of MSW composting facilities increased from one in 1983 to 7 in 1989 (Goldstein and Riggle, 1989) and to 14 in 1997 (Glenn, 1997).

Florida is a leader in composting organics with 12 permitted composting facilities in nine counties as of February 1997 (Florida DEP, 1997). This number of composting facilities does not include the exempted composting facilities (i.e., yard trimming composting facilities exempted per FDEP policy, small facilities and normal farming operations). If the exempted facilities are included, the total number would exceed 45 facilities (FDEP, 1996; FDEP, 1997). The number of biosolids composting facilities that include yard trimmings in their operation is 11 (Goldstein and Block, 1997), while MSW composting facilities are two (Glenn, 1997). Some of these composting facilities are among the largest commercial facilities in the U.S. For example, the Enviro-Comp facility in Jacksonville is one of the largest yard trimming composting facilities, Palm Beach Solid Waste Authority operates one of the largest and most successful co-composting facilities (biosolids +yard trimmings), and Sumter County composting facility, with the longest continuous

operating experience in MSW composting known to us.

In 1996, about 23 million tons of MSW were collected in Florida (FDEP, 1997). If an organic fraction of this waste stream is biologically decomposed, it is estimated about 5.5 million tons of composts could be generated. This estimate raises a number of questions that need to be addressed:

1. Will the market capacity in Florida be sufficient to utilize the compost produced?
2. What is the present market capacity fro the composted products?
3. How to build markets for composted products?

Battlelle's study (Slivka et al., 1992) on the practical potential applications for compost in Florida found that as much as 42 million tons of compost could be used annually within a 50-mile radius of urban centers with populations more than 100,000. Agriculture alone could use more than 20 million tons each year. The distance constraint was added because of the perceived limit on the economic viability of shipping further.

If the total production of compost is estimated to be approximately 5.5 million tons a year, this study shows that the potential use for composted products in Florida is more than 7.5 times the production of composts each year. Therefore, what we have is a market development challenge, not a lack of a market.

Since the growth of composting in the U.S. is not driven by demand for compost products in marketplace, communities developing composting facilities will have to devote a great deal of attention to compost market development . Product quality, safety of compost and benefits for users must be demonstrated once the facility is operating.

For any type of compost to be marketable, regardless of origin, it must pass the minimum product standards for protection of public health, safety, and the environment. And, the quality of compost should meet the market specifications and requirements for end-user(s). Passing the minimum product standards and having a high quality does not always secure a market for a compost product. Although this is a big step, effective market development strategies are required to secure markets.

The long-term feasibility of composting depends largely upon building a market for the compost by demonstrating the safe use and establishing the values associated with the benefits of compost application. Definitive information needs to be generated about the safety and potential benefits of compost utilization. Once the information is generated, effective methods should be employed to disseminate the findings to end-users. Effective methods of information dissemination for developing ongoing working relationship with end-users include, but is not limited to: media outreach to grower and trade associations, the Farm Bureau, and local newspapers; workshops, and field days to demonstration findings and newsletters to regional audiences. A comprehensive compost market development program conducted by a group of researchers, and Extension educators at the University of Florida is an example of this strategy. This program, managed by the Center for Biomass Program received support from the Florida Department of Environmental Protection through the Center for Solid and Hazardous Waste. It consisted of 6 projects--two projects to address compost safety, three projects for the demonstration of compost benefits, and one project for the establishment of management and outreach programs.

A. DEMONSTRATION OF COMPOST SAFETY

To remove barriers to compost acceptance, two projects were designed to: 1) demonstrate the biological and chemical remediation of pesticides during composting and 2) evaluate compost maturity/stability measures important to N and toxic metal availability and accumulation in crop parts. Composts from various facilities in Florida were used for pesticides assays.

1. DEMONSTRATION OF THE BIOLOGICAL AND CHEMICAL REMEDIATION OF PESTICIDES DURING COMPOSTING - The objective of this project was to evaluate the remediation of several commonly used pesticides applied to yard foliage and other organics composted in Florida. Commercial compost was evaluated for pesticides. These sites included two municipal solid waste sites, one cow manure site, one mushroom site, and two yard trimmings sites. A Quality Assurance (QA), Quality Control (QC) testing protocol was established for pesticide (endrin,

lindane, methoxychlor, toxaphene) and herbicide (2,4-D, silvex) detection in compost. Samples tested have confirmed the hypothesis that pesticides are not present in mature/stable composts. This is either from not being present to begin with or from remediation of the chemicals through the composting operation. To date, no herbicides or toxaphene was found in the samples tested this far. Thus, based on the sites sample so far, commercial composts are free of harmful pesticide levels.

Air-tide composters were designed to study the bioremediation when composts are "spiked" with known quantities of a pesticide. Radio-labeled atrizine was the model herbicide chosen. This project is being continued to also include analysis of heavy metals not previously assayed (E.I. arsenic, etc.)

2. COMPOST MATURITY/STABILITY MEASURES IMPORTANT TO NITROGEN AND TOXIC METAL AVAILABILITY AND ACCUMULATION IN CROP PARTS - Feedstocks and composts at different grades of maturity, from three compost facilities, Palm Beach County Solid Waste Authority, Enviro-Comp in Jacksonville, and Bedminister Bioconversion Corporation (Sevierville County, TN) were studied. Several methodologies were utilized to measure the maturity/stability of the compost products. These methods include total C/N ratio, water-extractable organic C and N and also its ratio, optical density of the water-extract, and a short-term (3 days), easy and low cost respiratory study based on CO_2 evolution. The most reliable and clear indicator for compost maturity/stability was determined to be the respiratory procedure.

Although the total nutrient and heavy metals quantity varied in different composts, in all cases the levels were far lower than the limits established by the Department of Environmental Protection (DEP) regulations. Water-extractable metals were also low verifying that the bioavailability of metals from these materials do not pose serious risks.

B. DEMONSTRATION OF COMPOST BENEFITS

A set of projects was designed to demonstrate the benefits of compost applications to:
1) sandy soils used for vegetable crop production,
2) compost applied to landscape beds to enhance establishment of woody ornamentals, and
3) turfgrass soils to determine effect on nitrogen release and on leaching of nutrients and organic compounds.

Several compost types materials were utilized in these projects. These included yard trimming compost obtained from Enviro-Comp (Jacksonville, FL), biosolids composted with yard trimmings from Palm Beach Solid Waste Authority (Palm Beach, FL), municipal solid waste (MSW) composted with biosolids from Bedminster Bioconversion, and MSW compost from Sumter County, FL.

1. BENEFITS OF COMPOST APPLICATIONS TO SANDY SOILS USED FOR VEGETABLE PRODUCTION - This project was initiated to build upon the base knowledge obtained in 1992 and 1993. Compost was applied to tomatoes planted in rotation with bell peppers. The experimental design was a 4 x 4 x 2 factorial in a randomized complete block, split-plot design with four replications. The main plot factor was cropping system, either fall tomatoes followed by spring watermelons, or fall bell pepper followed by spring watermelons. The subplot factor was application schedule, either a full rate applied once at the beginning of experiment to last 2 years, or a half rate applied twice, at the beginning of each year. The sub-plot factor was compost source, either none, Bedminster, Enviro-Comp, or Palm Beach Solid Waste Authority compost (SWA). The Bedminster and Enviro-Comp 2-year application rate was 40 dry tons per real estate acre (80 tons per treated acre). The SWA compost application rate was 13.3 dry tons per real estate acre (26.6 tons per treated acre). The soil series at the field site was pomello fine sand, which contained about 1% organic matter.

Compost application resulted in yield increase and improved fruit quality of bell pepper and tomato plants. Extra-large tomato yield was significantly greater where Enviro-Comp compost was applied compared to unamended soil. Marketable yield in 25-lb cartons per acre was 1158 for Enviro-Comp in comparison to 939 for the unamended soil. The unamended treatment produced the largest yield of medium tomatoes (410 cartons in comparison to 325, 370, and 337 cartons for Bedminster, Palm Beach County, and Enviro-Comp, respectively), had the highest percentage of fruit with "Yellow shoulder" (28% in comparison to 9%, 16%, and 7% for Bedminster, Palm Beach County, and Enviro-Comp, respectively), and produced the firmest tomatoes.

'Fancy' bell pepper yield was greatest in the Bedminster compost treatment compared to the other treatments. The

Envio-Comp treatment produced the firmest peppers, and the unamended treatment produced the softest. There was no difference between treatments in terms of fruit color or post-harvest variables measured. Yield was significantly greater where Palm Beach compost was applied to watermelon compared to unamended soil. The yield difference was attributed to larger individual fruit weight rather than more melons harvested per acre. Watermelon grown with PBC compost was also "sweeter" compared to fruits grown in the other treatments as measured by the brix of a fruit extract.

2. COMPOST APPLIED TO LANDSCAPE BEDS TO ENHANCE ESTABLISHMENT OF WOODY ORNAMENTALS - The objectives of this project was to determine if composts incorporated in landscape soils hastens establishment of container grown woody shrubs and the causes for the improvement in root growth and other measures.

Two types of compost were evaluated. One was a yard waste and biosolid co-compost produced and marketed by West Palm Beach Solid Waste (WPB). The other was a municipal solid waste compost (MSW) produced and marketed by Bedminister Bioconversion.

The experiment was designed as a split plot, with two irrigation frequencies as the main plot and 4 levels of compost and the control soil constituting the sub-plot. Irrigation frequencies were initially set at 0.5 inch daily (High) or 0.75 inch on alternate days (Low). After 5 weeks, irrigation frequency was reduced to alternate days (High) and every third day (Low). Four months after transplanting, frequencies were reduced to twice or once weekly, for High and Low, respectively; and the application rate was increased to 0.75 inches per event for the High frequency. Soil treatments consisted of 1 and 3 inches of MSW compost, 2 and 4 inches of WPB compost, and an unamended control (0 inches).

Incorporation of compost in landscape beds prior to transplanting generally increased both root and shoot growth compared to transplanting into unamended soils. Bulk densities decreased with compost amendments as the 2-inch WPB and 3-inch MSW compost treatments increased air porosity. Changes in the soil physical properties did not adequately explain differences in root or shoot growth measured in the faster growing species. Irrigation frequency had no effect on leaf areas for any species nor shoot dry mass for all species except ligustrum. For the faster-growing species of virburnum and ligustrum, irrigation frequency had a significant impact of overall canopy size, with greater growth occurring at the higher frequency. Overall, the largest canopy growth occurred in soils amended with 4 inches of WPB compost under high irrigation. For the larger growing species, incorporation of 2 inches of WPB compost produced the best hedge.

Analysis of data suggests that canopy effects are opposite to those measured in the roots. Plants grown in highest levels of compost appear to have larger canopies, smaller roots and higher levels of tissue nitrogen. High nitrogen levels in the tissue my explain what appears to be lower root:shoot ratios. All compost amendments appear to have completely substituted for fertilization requirements.

3. EFFECT OF COMPOST IN TURFGRASS SOILS ON NITROGEN RELEASE AND ON LEACHING OF NUTRIENTS- The objectives of this projects were to determine the rate of nitrogen mineralization in three composts (yard trimmings, biosolids/yard trimmings, MSW) and identify laboratory indices related to the mineralization.

Field, greenhouse, and laboratory studies were conducted to evaluate N release from three compost sources. Three compost sources were used: Enviro-Comp, Palm Beach Solid Waste Authority, and Bedminster Bioconversion. In the field, the composts were incorporated into a sandy soil and sodded with St. Augustinegrass. At periodic intervals, the St. Augustinegrass turf was rated visually, and clipping samples were collected and analyzed for N to gauge N mineralization from the compost. The same compost sources were used in a companion study in the greenhouse that utilized N uptake by Bermudagrass as a measure of N mineralization from the compost. In the laboratory, a study was conducted to evaluate the effect of temperature on N mineralization of the three composts used in the field and greenhouse studies. Columns of compost-soil mixes were leached monthly by 0.01M $CaCl_2$, and the leachates were analyzed for N. $CaCl_2$ extracts from the compost-topsoil mixes in the temperature chambers, and those of topsoil alone, were analyzed for volatile and semi-volatile organic compounds. On several dates, surface tension was determined in the $CaCl_2$ leachates.

The Palm Beach source containing the biosolids had the highest content of N, and the Enviro-Comp compost

comprised of just yard debris had both the lowest content of N and the highest C/N ratio of the sources used in the studies. In the field study, visual appearance ratings and clipping weights of grass generally were highest for the Palm Beach source, followed rather closely by the Bedminster source. Enviro-Comp source produced poorer results. These data are consistent with the N content data. The greenhouse data are generally consistent with the field data in terms of clipping weights, except that results from the Enviro-Comp source are relatively closer to the other two sources. No volatile or semi-volatile organics were found in the $CaCl_2$ extracts from the compost-topsoil mixes. However, surface tension was found to be lower, though inconsistently so, in leachates from certain soil-compost mixes, as compared to unamended soil, indicating the presence of materials with surfactant properties.

C. PROGRAM MANAGEMENT AND OUTREACH TO ENHANCE COMPOST MARKETING

The objective of this project was to develop effective reporting, interactive communications among all participants in compost research and demonstration programs to end-users and expand outreach to enhance marketing among compost producers, distributors, users and regulators.

All project sites were visited and discussions were held with the researchers to gain a thorough understanding of their experiments and the results being obtained. Photographs and reports on the field and laboratory experiments were compiled for use in outreach materials. An informational video and fact sheet on the projects were produced and distributed among the compost users, producers and regulators. The 10.5-minute video entitled, "Composted Organic Wastes Show Their Market Potential" was produced featuring the sites where compost was being produced and the research sites which were part of this project. Other related activities included arranging field days for various compost projects. The results of the projects have been and will be published in appropriate journals. These materials are being used to inform about and promote the use of compost materials, thus enhancing their markets.

The research projects presented here are addressing several important compost parameters and utilization opportunities. These projects revealed that application of a compost pose no serious threats and if mature, compost is safe and can result in benefits to plant production.

There are several other ongoing research projects by the UF scientists at various locations in Florida. These are designed to further establish markets for composted products by demonstrating the benefits and showing the safe use of composts when used in various utilization schemes.

ACKNOWLEDGMENTS

The research projects presented here are completed or are ongoing by the following University of Florida researchers: R.C. Beeson, J.L. Cisar, D.A. Graetz, J. Kidder, M. Marshall, T. Obreza, G.H. Snyder, A. Shiralipour, W.H. Smith, C.S. Vavrina, M. Weaver, C.I. Wei, W.B. Wheeler.

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QUANTIFYING LOSSES OF PLANT NUTRIENTS AND ELEMENTS DURING WINDROW COMPOSTING OF VARIOUS FEEDSTOCKS

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INTRODUCTION

The viability of composting as a practical alternative for disposal of the large quantities of organic wastes generated by municipalities, industry and agricultural processing depends, to a large degree, on adequate local markets for finished compost. In many areas, the use of composts as soil amendments in nearby agricultural fields offers a large potential market. The benefits of adding stabilized organic matter on water dynamics and other physical and chemical soil properties is well established. Often, however, these benefits do not result in sufficient improvement in crop performance to offset the costs of producing, shipping and applying composts. When composts also supply a portion or all of the soil nutrients required by crops, their value as a soil amendment is greatly enhanced by reducing need for industrially produced fertilizers to produce high-yielding crops.

During composting, microorganisms utilize N, P and other essential nutrients contained in the organic wastes to mineralize readily available carbon substrates. As these substrates are depleted, the ratios of organic C to the various crop nutrients tends to decrease. The C:N ratio has been used extensively to indicate compost maturation. As a general rule, when the C:N ratio is less than 30:1, the supply of N is considered sufficient to meet microbial demand and the compost can be added to soils without possibility of inducing immobilation of plant nutrients. While application of mature composts minimizes the risks of immobilization of plant nutrients present in soils, it does not ensure that the nutrients contained in composts will be released to meet the demands of a growing crop. The capacity of finished composts to recycle essential plant nutrients in organic wastes and to supply them to crops varies greatly among composts derived from various feedstocks. Composts derived from carbonaceous wastes, such as municipal solid waste and wood wastes, appear to have a limited capacity to supply N, P and other nutrients. In contrast, composts derived from nutrient-rich materials such as municipal biosolids and animal wastes, can supply substantial amounts of nutrients when used as soil amendments.

The capacity of composting to recycle plant nutrients in organic wastes is reduced when substantial quantities of nutrients are lost during the composting process. Gaseous emissions of ammonia and dimethyldisulfide during the alkaline phase of composting commonly exceed odor thresholds (Dunson, 1993). These emissions also represent potentially significant losses of N and S. Most studies of nutrient losses during composting have focused on losses via leachate and runoff. For example, Stilwell and Sawhney (1993) reported that leachate from MSW compost contained 2.5 mg Cu/L, 32 mg Zn/L, 1 mg Pb/L and 0.11 mg Cd/L. While total losses are difficult to calculate from such data, evidence for elevated concentrations of nutrients and regulated metals in leachate serves to underscore a potential concern for compost facility managers. Cumulative leachate losses over a large number of composting cycles may result in potentially hazardous levels in pads and the sediments and discharge from collection basins. Nienaber and Ferguson (1992) reported that the soil underlying a feedlot manure composting facility contained nitrate levels exceeding the drinking water standard of 10 mg/kg to a depth of 6 m and in excess of 75 mg/kg. In addition, they reported P levels in excess of 400 mg/kg and K near 3000 mg/kg in the surface 0.15 m.

The potential for nutrient loss during composting may be disguised by the apparent increases in concentration of N and other nutrients that frequently occur as organic C is oxidized and released as CO2. These increases in nutrient

concentrations, however, may not be sufficient to fully account for the loss of mass that occurs during the process. When the loss of total mass during decomposition is known, the expected final concentration of a nutrient can be calculated. For example, if half of the mass of an initial feedstock was lost during composting, a doubling in nutrient concentration would indicate no nutrient loss. Similarly, if the nutrient concentration in the finished compost was similar to that of the initial feedstock, we can assume that half the amount of nutrient initially present was lost. Unfortunately, obtaining reliable estimates of nutrient losses during windrow or other large-scale composting is hindered by the difficulty in obtaining reliable direct measurement of total mass lost. Fluctuations in pile geometry and bulk density, especially during the initial stages of composting, contribute to large errors in such measurements. Comparing changes in nutrient concentrations to that of an element that is conserved during the composting process offers an alternative approach for estimating the extent of nutrient loss. Haug (1993) proposed the use of ash as an internal standard for monitoring changes in organic C to determine compost biodegradability.

The principal objectives of the work reported here was to (1) assess the suitability of using ash content or concentrations of other elements as an internal standard for estimating nutrient losses during composting and (2) to use the most promising internal standard to calculate the losses of organic C, N, P and K during composting of nine windrows comprised of different feedstocks.

MATERIALS AND METHODS

Windrow Composition and Maintenance

Windrow composting of selected feedstock materials was performed at the LSU Organic Recycling Center located in Baton Rouge, LA. Eight windrows were constructed using each of the following feedstocks: hardwood bark (Bark), ground rice hulls (Hulls), cotton gin trash (CGT), horse barn bedding (HBed), bull barn bedding (BBed), spoiled silage (Silage), bagasse, and filterpress mud (FPM). Bagasse and filterpress mud are wastes generated during sugarcane milling. Bagasse is comprised of crushed stalks remaining after sugar extraction and filterpress mud is comprised of finely ground cane residues and mineral soil. An additional windrow was constructed using a 1:1 ratio by volume of filterpress mud and bagasse (FP&Bag). The bagasse used in this windrow showed signs of substantially greater decomposition than that used in the windrow containing only bagasse. Bagasse and hardwood bark were ground prior to windrow construction using a TORO Progrind® 1000 Tub Grinder (Bloomington, MN) to a 5.5-cm maximum size.

Windrows were constructed of approximately 20 m in length, 2 m in height, and 2 m in basal width. Internal windrow temperatures were monitored but not used to determine when to turn the piles. The windrows were turned weekly (7 d intervals) using a tractor drawn Wildcat® Turning Machine (Wildcat Manufacturing Co., Freeman, SD). Although little self-heating was evident in windrows after 90 d, turning of windrows at 7 d intervals was continued to ensure thorough mixing prior to sample collection. To control odors and pests, the windrow consisting of spoiled silage was turned two additional times during the initial 21 d of composting. Moisture levels of windrows were initially adjusted to approximately 60% (total weight basis) and maintained at that level by addition of water prior to turning of windrows.

Sampling of Windrows

Windrows were sampled upon construction and after each turning thereafter over a 141 day period. Each windrow was divided into three 1-m sections (one located at half the length of the windrow and the other two located 2-3 m from each end) to serve as replicate sampling sites. At each sampling, composite samples of approximately 5 L were collected from three horizontal levels at each of the sample sites at an approximate depth of 1/4 the width of the pile. The subsamples were well mixed by tumbling and ~1 kg representative sample was obtained for laboratory analysis.

Sample Preparation

Moisture content and pH were determined on fresh samples immediately after collection. The remaining samples were dried at 35°C for 48 h in a forced-air drying oven. Dried samples were then ground in a Thomas-Wiley® Model 4 Cutting Mill to pass a 1-mm screen. Samples were thoroughly mixed and a 5 g subsample collected for

elemental analysis was then ground in a Tecator Cyclotech® Model 1093 Sample Mill (Fisher Scientific, Pittsburgh, PA) to pass a 100-mesh sieve. Ground samples were re-dried (65°C; 12 h) and stored in air-tight containers until use.

Compost Analyses

Moisture was determined gravimetrically on fresh samples using a Cenco Model 26680 moisture balance (CSC Scientific Company, Inc., Fairfax VA). The pH values were obtained on fresh samples with a flat surface electrode and an Corning® model 250 Ion Analyzer. Total organic C and N concentrations were determined using a Heraeus CHN-O-Rapid® Analyzer (UIC, Joliet, IL) which employs modifications of the Pregl-Dumas dry combustion technique. Ammonium and nitrate concentrations (mg kg^{-1}) were determined in 1:10 dilutions of a 1 N KCl extract of each ground sample using an automated NH_3 diffusion technique initially described by Carlson (1978).

Total elemental analysis was preformed using a modified method as described by Bernas (1968). A 0.10 g sample of ground, oven-dry material was treated with 2-mL nitric acid and 3-mL hydrofluoric acid in 50 mL Teflon® inserts for stainless steel bombs. The assembled bombs were heated to 140°C for 8 h. After cooling, the bombs were opened and 1.4 g of crystalline boric acid were added and mixed well with the insert contents to complex any remaining hydrofluoric acid . The contents were then quantitatively transferred to 50 mL volumetric flasks and brought to volume with deionized water. After capping and shaking by inverting the flasks 4 times, a 11 mL sample was decanted into a 12 mL plastic culture tube. The samples were then analyzed for elemental content on a Perkin Elmer Optima® model 3000 Inductively Coupled Plasma Ion Spectrometer (Norwalk, CT).

Ashing of samples was accomplished by first determining the weight of 25-mL ashing thimbles dried 105°C and cooled in a desiccator. Ground samples were then placed in the thimbles which were then dried and cooled as above, then weighed for dry-weight determination. The thimbles and samples were then ashed in a muffle furnace at 550°C for 2 h, allowed to cool to near 100 °C, then cooled to room temperature in a desiccator. The ash weight was calculated and expressed as g ash/g dry weight of sample.

Internal Standard Evaluation and Selection

Correlations between various elemental concentrations and those of organic C and the standard deviations and coefficients of variation were calculated using Statistica (StatSoft, Inc., Tulsa OK). Only the averages of the sums of nutrient and elemental concentrations for feedstocks and finished composts are presented here due to the extensive amount of data.

Calculating Losses of Plant Nutrients and Elements

Nutrient and metal losses were calculated based on an internal standard were calculated using the following equation:

$$\% L = \{1 - [(Nf/Ni)/(Si/Sf)]\} \times 100$$

,where

%L = Percentage of nutrient or element lost from compost
Nf = elemental concentration in finished compost
Ni = Nutrient or element concentration in initial feedstock
Si = Concentration of internal standard in initial feedstock
Sf = Concentration of internal standard in finished compost

RESULTS AND DISCUSSION

To initially identify possible chemical properties suitable for use as an internal standard, the elemental compositions of samples collected from the nine windrows at weekly intervals were correlated with organic C concentrations. Because much of the mass loss during composting is known to result from the mineralization of organic C to CO_2, an element that was conserved during composting would be expected to display a strong inverse correlation with organic

C. Conversely, a weak correlation with organic C would be expected of elements that were readily lost. Ash displayed the strongest inverse relationship (r^2=-0.93). Si and Al, constituents of soil minerals, were also strongly correlated as were several trace metals. The precision by which a soil property can be measured is an important consideration in selecting a suitable internal standard because the error associated with this measurement compounds with that of measuring individual nutrients when calculating nutrient loss. Table 1 shows the average standard deviations and coefficients of variations (CV) within replicate samples collect from the nine windrows at various times. Because of the wide range in mean values for the properties tested, the CV is a more useful in indicating the contribution of the error associated with an internal standard. Ash displayed a significantly lower CV (2.6%) than the other elements tested. Because of its ability to reflect change in organic C concentration and the low error associated with its measure, ash content appears to be the most suitable property for use as an internal standard for monitoring losses of nutrients during composting.

Table 1. Average mean, and average standard deviation and coefficient of variation within three replicate samples of chemical properties displaying the strongest inverse correlations to organic C concentrations during composting.

Property	Mean	Std Dev	CV	Correlation to Org. C
	------- mg/Kg	-------	%	r^2
Al	11212	1420	16.3	-0.83
Ash	39490	0.91	2.6	-0.93
Be	1.8	0.23	20.1	-0.74
Fe	8532	974	15.2	-0.77
Na	2568	177	12.7	-0.83
Si	115740	7646	8.1	-0.89
Ti	1064	80.8	11.4	-0.85
V	24.8	2.6	23.6	-0.81
Zn	113	15.5	17.6	-0.58

To determine losses of various plant nutrients and metals during windrow composting, the elemental composition of finished composts were compared to the corresponding initial concentrations in samples obtained immediately after construction and initial turning of windrows. Using ash content as an internal standard, the expected concentration of nutrients and trace metals in finished compost was calculated. The average values obtained from the nine windrows are shown in Table 2. On average, finished compost contained 51.3% less organic C than the feedstock from which it was derived. Concentrations of N, P and K, the principal nutrients supplied in fertilizers, were greater in final compost than in initial feedstocks, but these increases were less than expected when ash content was used to adjust for total loss of mass. Losses of N, P and K averaged 26.6%, 30.7% and 30.1%, respectively. Appreciable losses of the cations Ca (34.2%) and Mg (40.2%) were observed. Losses of Na, however, averaged only 11.4%. Sulfur losses averaged only 11.9%. With the exception of silage, windrows remained aerobic during the composting cycle, and the distinctive odor of reduced organosulfur compounds was not detected. No losses of Fe were detected.

Average losses of regulated metals, presumably in leachate and runoff, varied greatly among metals and within windrows (Table 3). Losses of As were negligible in most windrows, whereas an average of more than 50% of the Co, Cu and Ni initially detected in feedstocks were not recovered in finished compost. Windrows comprised of bagasse and hardwood bark displayed the greatest losses of metals. Although the initial and final concentrations of all metals were within the ceiling limits established for land application of biosolids under EPA Part 503 Rule, the magnitude of these losses suggests vigilance on the part of managers of uncovered facilities where repeated compost cycles may significantly enrich the regulated metals concentrations in porous pads and the underlying soil. It is noteworthy that the errors associated with replicate analyses of most regulated metals were large, especially in the initial samples collected from newly constructed windrows where it is difficult to obtain an adequately representative

sample from the heterogeneous compost matrix. Directly measuring the concentrations of regulated metals in soils, basin sediments and discharge waters would likely prove a more reliable technique for monitoring accumulation of potentially hazardous regulated metals.

Table 2. Average initial, final, and expected final concentrations (ash basis), and percent losses of principal plant nutrients in nine windrows composted for 141d.

Element	Initial conc.	Final conc.	Expected conc.	Loss
	mg/kg			%
C	320200	242600	498490	51.3
N	9526	11376	15444	26.3
P	3681	3970	5730	30.7
K	8945	9736	13925	30.1
Ca	15434	15808	24028	34.2
Mg	3523	3279	5485	40.2
Na	1949	2690	3034	11.4
Mn	467	533	726	26.6

Table 3. Average initial, final, and expected final concentrations (ash basis), and percent losses of regulated metals in nine windrows composted for 141d.

Element	Initial conc.	Final conc.	Expected conc.	Loss (ash basis
	mg/kg			%
As	64.2	88.4	87.1	-1.5
Cd	6.0	6.4	9.4	31.1
Co	15.2	10.4	23.2	55.0
Cr	84.7	72.9	121.4	39.9
Cu	38.3	28.3	59.7	52.5
Ni	104.5	53.9	162.7	66.9
Pb	71.5	90.7	111.3	18.6
Zn	106.4	120.5	165.6	27.2

The total mass lost during windrow composting ranged from 5.4% in the windrow comprised of a mixture of filterpress mud and aged bagasse to 76.5% in the windrow comprised of spoiled silage (data not shown). The average mass lost in the nine windrows was 37.3%. Losses of total mass were inversely correlated with initial ash content (r^2 = 0.60) and strongly correlated to losses of organic C (r^2 = 0.83), as expected. Composting the mixture of filterpress mud and aged bagasse resulted in a loss of 22.5% of the organic C initially present (Fig. 1). The corresponding reduction in organic C in compost derived from spoiled silage was 88.2%. Spoiled horse barn bedding lost substantially less organic C (35.1%) than did spoiled bedding from a bull barn (75.7%). The bedding from the horse barn contained approximately 2 ½ times the amount of soil as the bedding from the bull barn, and was more

decomposed prior to use for windrow construction. These findings illustrate the fact that mineral contamination and the state of decomposition are important considerations when estimating biodegradability of organic wastes.

N losses during composting ranged from negligible to more than 63% of the total N initially present in feedstocks. (Fig. 2). Although N losses from Silage and CGT exceeded 56%, finished composts of these feedstocks contained appreciable amounts of mineral N after 141 d. Losses of N were much less in windrows constructed of partially decomposed organic material. This finding is consistent with the observation that a substantial portion of the N lost during composting occurred within the initial 28 d, though N losses were detected throughout the composting process. Stepwise regression to identify compost properties correlated with N loss indicated that initial ash content was the most reliable indicator. Rice hulls were an exception, possibly because they contain significant amounts of silica but offer little cation exchange capacity to retain ammonium. An additional experiment (not reported) to compare N losses from windrows comprised of rotted cotton gin to those comprised of 2:1 mixture of rotted gin trash and silt loam soil showed confirmed that the presence soil was highly effective in reducing N losses. In that study, N losses from rotted gin trash averaged approximately 7% whereas no losses of N were detected in the windrow constructed of a mixture of gin trash and soil.

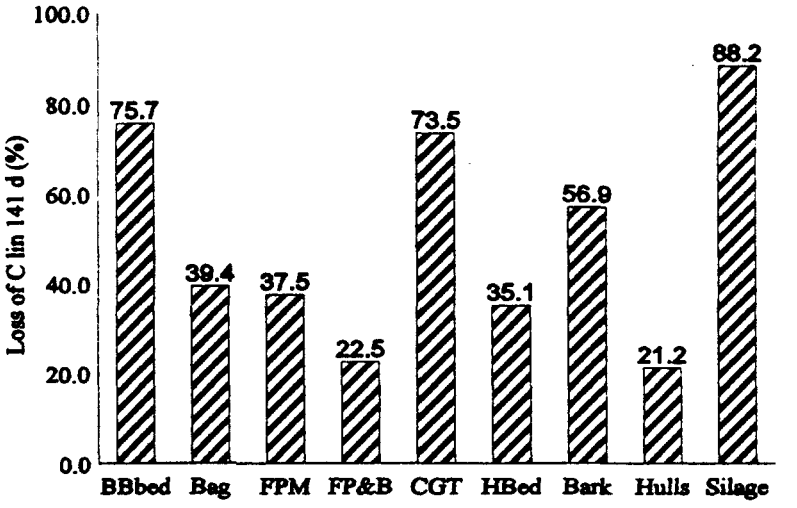

Figure 1. Percentage of C lost after windrow composting various feedstocks for 141

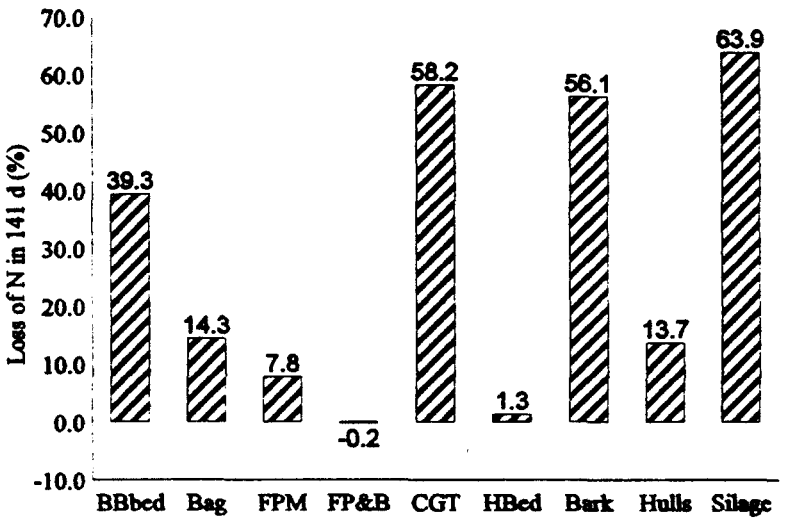

Figure 2. Percentage of N lost after windrow composting various feedstocks

Losses of P ranged from 9% to more than 70% of the P initially contained in feedstocks (Fig. 3). Such losses represent a substantial loss of this nonrenewable essential plant nutrient. As with N, the greatest losses of P occurred in windrows that contained low amounts of mineral matter. While the mechanism of loss was not studied, leaching of organically bound P or of orthophosphate may have been responsible for the losses observed. Regression analyses indicated no relationship between the magnitude of P losses and the amount initially present in feedstocks.

Losses of K during composting also varied greatly among windrows constructed of different feedstocks (Fig. 4). As with N and P, the greatest losses occurred in windrows of Silage, Bark and CGT, feedstocks that contained large amounts of readily degraded organic substrate and low amounts of mineral matter. The smallest losses occurred in windrows where organic matter contained appreciable amounts of clay and other soil contaminants.

These findings indicate that windrow composting of some feedstocks does not provide efficient recycling of plant nutrients contained in these feedstocks and nutrient losses reduce the fertilizer value of finished composts. Composting of partially decomposed organic matter generally resulted in a smaller proportion of nutrients lost than did composting of fresh material. It is possible, however, that partially decomposed feedstocks lost significant amounts of their essential nutrients prior to windrow construction. The presence of soil contaminants appears to reduce losses of the nutrients in feedstocks. Additional research is needed to determine if addition of mature composts or soil during windrow construction can effectively reduce losses of nutrients and regulated metals during windrow processing.

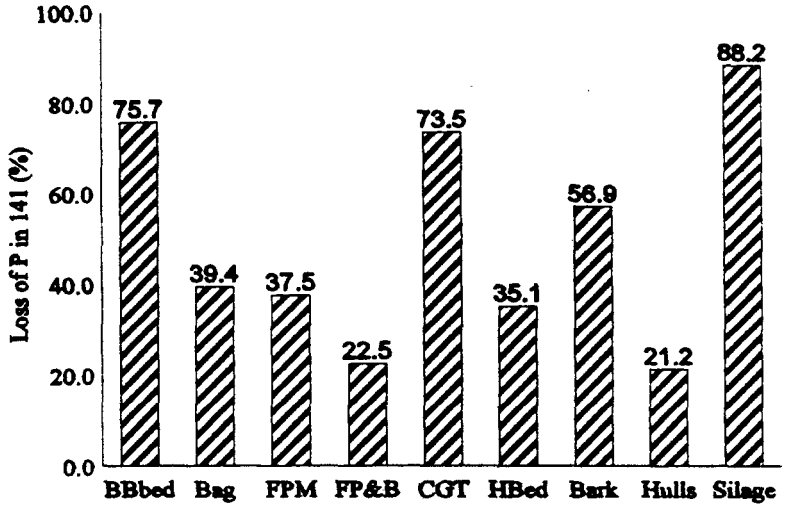

Figure 3. Percentage of P lost after windrow composting various feedstocks

CONCLUSIONS

The use of an internal standard to calculate nutrient losses during composting of various feedstocks provided satisfactory results. The principal limitation of this approach lies in difficulty in obtaining representative initial samples, especially from compost piles constructed of different feedstocks that tend to naturally segregate. High variability was a more severe limitation when estimating losses of metals that occur in low concentrations than when estimating losses of macronutrients. Ash content was found to be the most suitable internal standard because of its strong relationship with organic C loss and low sampling and analytical errors. Losses of N and other important crop nutrients varied greatly during composting of different feedstocks. Regression analyses suggested that greater losses of plant nutrients occurred when composting readily degradable feedstocks that contained low amounts of mineral matter than when composting partially decomposed feedstocks containing appreciable amounts of soil. Some feedstocks lost substantial proportions of their regulated metals in addition to nutrients, suggesting the possibility that enrichment by potentially hazardous contaminants may develop with time at uncovered compost facilities in the humid south.

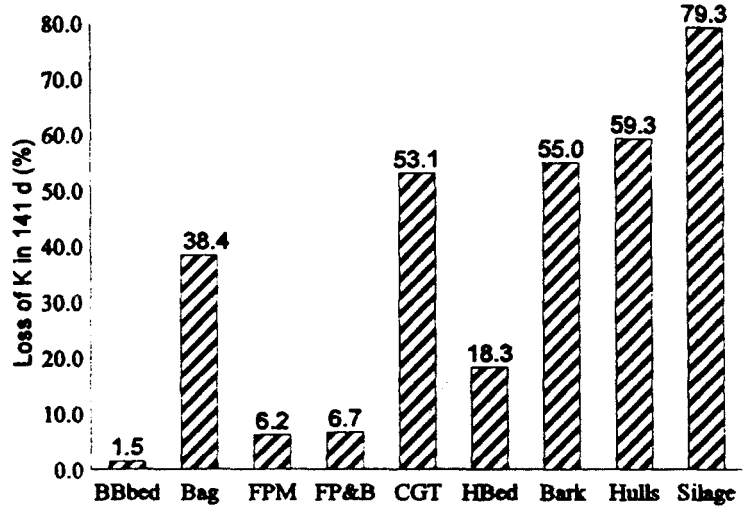

Figure 4. Percentage of K loss after windrow composting for 141 d.

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HALL COUNTY WAXED CORRUGATED CARDBOARD COMPOSTING PILOT PROJECT

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INTRODUCTION

Hall County is located in Northeast Georgia and encompasses 392 square miles and a population of approximately 113,000. Gainesville, the county seat, is situated 52 miles northeast of Atlanta. The County is home to Lake Sidney Lanier, a 38,000-acre lake built by the U.S. Army Corps of Engineers. The 607-mile shoreline provides recreational activities for over 16 million visitors annually and is of vital economic importance to the area. Lake Lanier served as the canoe/sprint kayak site for the 1996 Summer Olympics.

Agribusiness has always been the cornerstone of Hall County's economy. With Hall County leading the way, Georgia has been one of the top poultry producing states in the nation since 1957. Other leading products are corn, sorghum, soybeans, wheat, rye, oats, pulpwood, dairy and beef cattle, granite and limestone. As of August 1993, there were 871 farmers located in Hall County with a total of 10,200 harvested acres. Hall County's industrial base includes poultry processing and equipment, commercial printing, window and door components, soft drink bottlers, paint, furniture, textiles, and automotive components.

There are several large sources of waxed corrugated cardboard (WCC) in the waste stream. Locally, these include (in order of importance) the poultry industry, grocery stores and restaurants. It is a problem material for waste management. Technically, it can be recycled. However, due to increased energy requirements, higher processing costs and availability of cheaper and more suitable feedstocks, it cannot be recycled practically. It may also make a suitable feedstock for energy recovery. A search of the literature suggested it may also be composted.

WCC is high in carbon and can absorb moisture once shredded and mixed with other materials. An existing waste stream from the poultry industry is the poultry manures and litter which can form an excellent nitrogen amendment. The combination of these two waste streams that have mutually compatible characteristics can be effectively used in composting to produce a quality end product.

Not much is known of the feasibility of this concept and the ability to perform composting in large scale. The evaluation of the feasibility of composting as a tool to treat these wastes and its demonstration in full scale is the focus of this project.

PROJECT OVERVIEW

To plan this project, a work group consisting of a subcommittee of the Hall County Comprehensive Solid Waste Management Plan Implementation Committee, representatives from Georgia Mountains Regional Development Center, Chestatee-Chattahoochee Resource Conservation & Development, Georgia Poultry Federation, allied poultry industries, UGA and grocers, was assembled. The work group began meeting in 1995 and met throughout the project planning and implementation phases to provide input into project design and project oversight.

As identified by Hall County's Comprehensive Solid Waste Management Plan, seven percent of the waste stream was estimated to be waxed corrugated, representing the largest single waste stream component yet to be subject to reduction activities. This amounts to an estimated 7,000 tons annually in Hall County alone. Currently, there is no option other than disposal for this material.

The subcommittee met first to explore options for dealing with WCC. Recycling did not seem feasible. The only time WCC might be in demand as a feedstock by paper mills would be in times of high prices and shortages of corrugated cardboard. Since these conditions could not be relied upon, recycling was dropped from further consideration. The energy recovery option was also considered, but due to the distance from our area to facilities equipped to utilize this type of material, freight charges proved prohibitive. Use of ground, WCC was explored for possible use as layer bedding or cellulose product. The high friction caused by the material in the processing equipment nearly caused a fire. Source reduction was also considered but was felt to be too difficult to implement due to the many, varied sources of the material and the health and sanitation aspects of reusable containers.

Composting was chosen as an option warranting further exploration because:

1. It can be a low tech approach that can be done locally;
2. Markets for the finished product may be developed locally;
3. Organics contamination is not problematic;
4. Poultry manure is available in abundance as a nitrogen source; and
5. It may solve two problems at once-- beneficial utilization of waxed corrugated cardboard and poultry litter (manure).

The goal of the pilot project was to amass 40 tons of WCC in advance of composting. Various poultry processing firms were contacted to obtain the material. There was at first some delay in getting the material from processors. As with any new program, adjustments were needed in the way the material was being handled at the point of generation. After this inertia was overcome, sufficient material was quickly gathered. Tractor-trailers were used by generators to haul the material to the Hall County Recycling Center in Gainesville. Boxes were flattened and placed on pallets for ease in off loading using a forklift. After the material was unloaded, it was baled and stacked outside on a paved surface.

The pilot project was comprised of two distinct parts-- controlled laboratory and windrow composting.

THE POULTRY INDUSTRY

The project is of special importance to the area. The largest employer in the area is the poultry industry, which generates WCC from further processing operations, such as deboning, breading, etc. WCC is used internally as intermediate containers during processing and as shipping containers for finished product. They are useful due to their ability to maintain strength under high moisture conditions.

A considerable percentage of waxed corrugated is expected to be contaminated. In poultry processing, the material may come in contact with poultry processing liquids, blood and poultry itself. Grocery stores may discard waxed corrugated boxes with vegetable matter from preparation for store presentation as well as outdated produce. This mixture could itself be composted, but will not be part of this pilot study, as this has been studied previously and results published in the literature. The pilot project investigated composting of WCC with both broiler litter and layer manure. As Table 1 shows, broiler litter tends to have lower moisture and lower nitrogen due to being mixed with wood shavings in poultry houses. Layer litter is higher in moisture and nitrogen.

Poultry litter disposal or utilization through land application is expected to become increasingly difficult, given the rate of residential growth and reduction in open space. This can be dealt with by composting with sufficient carbon material. It is believed the demand for carbon containing material can be met by waxed corrugated cardboard. In this way, a disposal alternative for waxed corrugated will be provided.

Table 1. Properties of materials used in the composting trials. Values were either measured or estimated from the literature.

Material	Moisture, %	Carbon, %	Nitrogen, %	Density, lbs/yd^3
Cardboard - shredded [1]	6.2	55.1	0.1	251
Layer Manure - fresh[2]	64	8	6	1300
Layer Manure - old	64	6	2	-
Broiler Litter	26	18	3.5	750

[1]Measured ash percentage was 091% (ASTM method for determination of volatiles and ash content of organics). The carbon content was measured and nitrogen content was taken from the literature values of cardboard materials. Typical lignin content of corrugated cardboard is known to be about 12. 9 % and the biodegradable fraction is 47 % (Tchobanoglous et. al., 1993).
[2] All data relating to the manure and litter was provided by Mr. J. Sargent.

CONTROLLED LABORATORY TESTING

OBJECTIVES

The objective of this project was to evaluate the compostabiltiy of old waxed corrugated cardboard from the poultry industry, using poultry manures and broiler litter as nitrogen amendments. Initial laboratory screening identified the mixes to use and characterized the products of composting, as shown in Table 1. A full scale composting demonstration was to be performed based on the laboratory study and scale up factors and products were to be evaluated.

MATERIALS AND METHODS

The WCC was shredded using the tub grinder at the windrow site and mixed with two nitrogen sources--broiler litter and layer manure. Two levels of application of nitrogen amendments were evaluated, namely, a high rate and low rate. The effect of addition of a compost starter mix was also evaluated. These tests were performed August 28 to September 30, 1996. The use of poultry manure was found to be superior to the use of broiler litter as an amendment. Although poultry manure did not mix well in the test vessels, the available nitrogen was higher and aeration of the mixture was easier. It is possible to use high rates of poultry manure in the mixes and reach a stable product in 60 days.

Composting was performed in 30 gallon steel drums insulated with 2 inches of Styrofoam. Insulation minimizes the conductive heat loss from the vessel thereby simulating behavior within a large compost pile. Temperature of the material in the vessel was monitored at three locations (6 inches from the surface, middle of the drum and 6 inches from the bottom) using T-type thermocouples. The vessels were aerated using a temperature feedback control with an adjustable set point that was set at a temperature of 55°C. When the compost temperature exceeded the setpoint, the fans would operate at a high flow rate resulting in cooling of the materials. Airflow rates were set at a value of 1.84 cfm in all of the barrels.

The composting test vessels were emptied at each mixing and sampling event (approximately once a week) and the material mixed in a large plastic drum. The material was rewet when necessary to raise the moisture content to approximately 50% (wb). Two representative samples were removed, one for moisture and volatile solids analysis and the second sample for stability/phytotoxicity analysis. Moisture was evaluated by drying in the oven at 105°C for 24 hours. The sample, after complete drying, was ground fine and ashed at 550°C for 6 hours to estimate the volatile solids and ash content. A portion of the ground sample was retained in storage for future chemical and nutrient analysis. The sample for stability/phytotoxicity testing was frozen and analysis was performed at the end of the experimental period.

Table 2. Mixes used

Treatment # Barrel #	Mix	Percentage Amendment in mix (volume basis)	Moisture Adjustment
1	20 gal Layer manure 30 gal WCC	40% manure	moisture added
2	20 gal Broiler litter 30 gal WCC	40% litter	moisture added
3	10 gal Layer manure 30 gal WCC	25% manure	moisture added
4	10 gal Broiler litter 30 gal WCC	25% litter	moisture added
5	20 gal Layer manure 30 gal WCC with compost starter	40% manure with starter	moisture + starter
6	20 gal Broiler litter 30 gal WCC with compost starter	40% litter with starter	moisture + starter

Respiration index is a reliable measure of the stability of the compost and is reported as the microbial respiration rate in mg(oxygen)/g(dry matter)/hr. Higher availability of nutrients result in higher respiration rates and therefore the material is considered unstable. The quantitative respirometry procedure used in this project was described by Iannoti et al. (1993). In brief, the samples were allowed to reach room temperature, sample preparation was performed, and the samples were allowed to incubate at 37°C for 16 to 24 hours. Sample preparation included screening for fines (< 9.1 mm) and adjusting to a 50% moisture content. After the standardization of the sample and 16 to 24 hours incubation, the microbial populations would have reached a high level of activity that is limited only by the substrate availability. A standard weight of 60 g (dry weight) of each incubated sample was now placed in a 500 ml flask which was placed in a water bath at 37°C and aerated for a one hour period. Following aeration the flask was capped with a dissolved oxygen measuring probe. As there was no air gap between the probe and the neck of the flask, the probe measured the oxygen concentration within the flask which reduced with time due to microbial consumption of oxygen. The oxygen uptake rate was calculated based on the measured oxygen concentration profile for a one hour period, the volume of the flask and the weight of the sample. Generally a respiration index of < 0.15 mg(oxygen)/g(VS)/hr is considered as stable levels for most compost (Barberis and Nappi, 1995).

The effectiveness of using a compost starter was evaluated (see Table 2). Comparison was made by using the compost starter mix as recommended on two treatments and comparing to two identical treatments without the starter. The compost starter used was the B.D. compost starter sold by the Pfeiffer Foundation, Inc. of Spring Valley NY. The starter came in the form of a powder and was mixed in 1 gallon of de-ionized distilled water at the recommended rate of 2 grams/100 lb. of compost. The mixture of compost starter with de-ionized water was kept in the laboratory at room temperature overnight and applied to the compost the following morning while mixing the compost thoroughly.

Interstitial oxygen concentration and quantitative odor evaluation were performed. A four feet stainless steel air sampling probe was inserted into the compost bed and the interstitial air was pumped into a field oxygen meter (Teledyne Brown Inc.) at a flow rate of 0.6 lpm. The sample pump was allowed to run for two minutes in order to clear the sampling lines and stabilize the meter. Oxygen concentration measurements were recorded at the end of the two minute period. An odor monitor (Sensidyne Inc.) was used to measure the odor intensity of the exit gas from the headspace. A gas sampling probe was inserted into the top 1 inch of the compost and gas was pumped through the sample pump. In order to ensure the flushing of the gases within the compost matrix, the composting vessels were aerated for one minute prior to sampling and the highest odor level in a two minute interval was

recorded. Typically the measured value reached a maximum and remained at the maximum reading for the whole two minute period.

TEMPERATURE PROFILES AND RATE OF SELF HEATING

Comparing the temperature profiles, the highest activity was found in T2 which sustained temperatures above 50 °C for most of the 30 days. Treatment 6, which was identical to T2 but had the compost starter added, had lower temperatures throughout the composting cycle. In treatment 1, which was the manure treatment, the high rate of composting occurred for the first 15 days (until the end of the first turn), thereafter the temperature was below 40 °C for both the levels of layer application (T1, T3 and T5). Both the litter treatments T3 and T4 were active for longer periods of time.

It was noticed that the pressure drop across the compost was higher in the litter treatments compared with the manure treatments. At the start of composting, the manure treatments exhibited pressure drops in the range of 0.08-0.25 inch(water)/ft(compost) and the litter treatments 0.12-0.64 inch/ft. Towards the end of composting, the pressure drops had reduced to 0.01-0.07 inch/ft for manure mixes and 0.09-0.30 inch/ft for litter mixes. This indicates higher energy cost if forced aeration was used, and less airflow under natural ventilation conditions.

VOLATILE SOLIDS LOSS DURING COMPOSTING

The samples removed at the start and at each mixing operation were dried and ashed to determine dry matter content and volatile solids content. Drying was done in an oven at 105 °C for 24 hours and ashing of the dried samples was performed by placing the samples in a muffle furnace at 550°C for 6 to 6.5 hours.

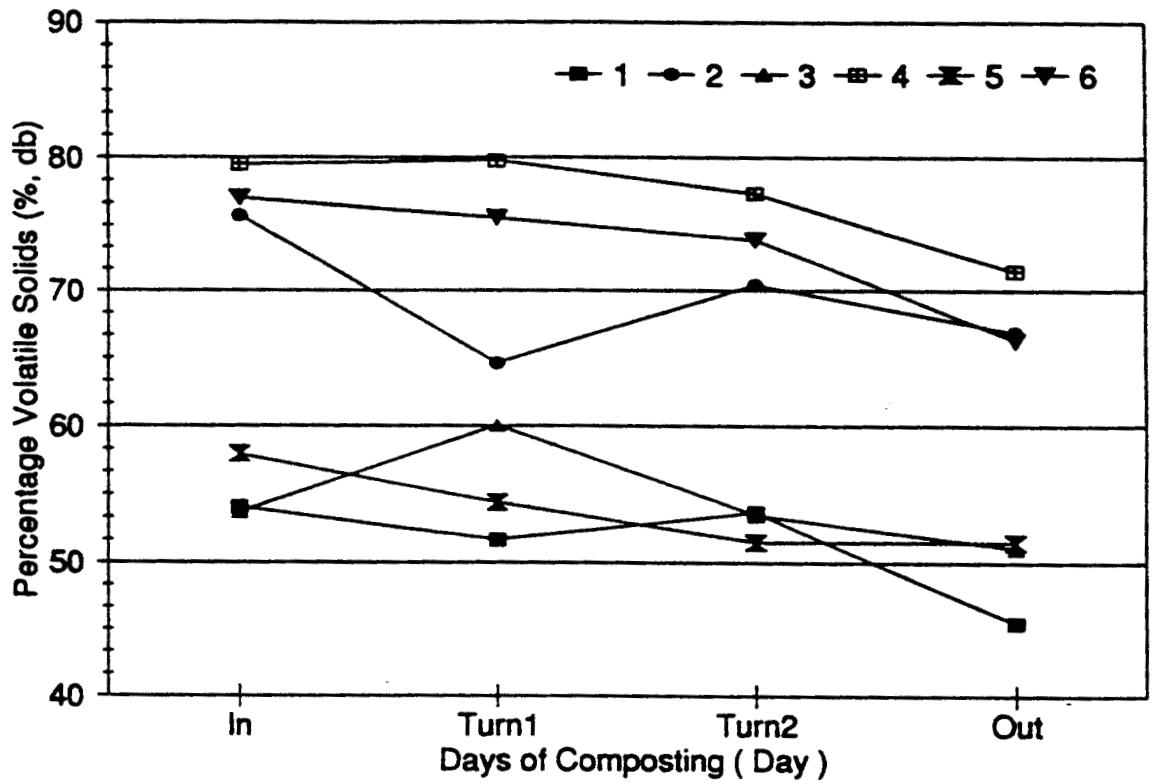

Figure 1. Degradation of volatile solids during composting. Legend indicates numbers 1-6 representing treatments 1-6.

The measurements and changes of volatile solids during composting are shown in Figure 1. It was seen that all of the treatments resulted in reductions ranging from 7 to 11% absolute. Although individual variations existed, broiler litter treatments showed marginally higher total degradation. This result indicates that although higher manure content resulted in more available nitrogen, total degradation was reduced as less cardboard was available. The physical nature of the manure also affected degradation by the clumping and non-homogeneous mix described earlier. A more thorough mixing procedure at the start and during composting may alleviate this problem. The degradation was comparable in all treatments.

INTERSTITIAL OXYGEN CONCENTRATIONS

Except for the first few days all of the treatments had sufficient oxygen during composting. In the first 57 days biological activity was high and oxygen concentrations below 5% were reached when the fan was not operating even for a small period of time. Treatment 2 was the most reactive based on oxygen demand. This may also be due to the lesser air void space in the bed, which also results in higher pressure drops. On days 6, 13 and 20 the oxygen levels were below 5%, which is considered the ceiling for anaerobic activity. Similar situations occurred in treatment 4 and 6 indicating the difficulty in oxygenating these piles due to the higher pressure drops, lower porosity and potential non-uniform airflows. Treatments 1, 3 and 5 stayed above anaerobic levels throughout the duration of composting. The low oxygen concentrations during the first few days indicate a necessity for agitation or steady aeration during this period.

AMMONIA RELEASE AND ODOR ISSUES

An odor monitor (Sensidyne Inc.) made it possible to obtain quantitative measurements of odor released based on a butanol concentration scale. These are shown in Figure 2. The odor intensity data was collected only from day 13 to the end of composting. The odor levels were closely correlated with oxygen levels inside the barrel. The broiler litter treatment 2 and 6 were the high odor producers. As the materials reached the end of composting, a more earthy odor was perceived.

EFFECT OF COMPOST STARTER ADDITION

An evaluation of the use of a compost starter was performed by adding two treatments (T5 and T6) that were identical to T1 and T2 but with the addition of the compost starter. In T1 and 2 an equivalent quantity of water with no compost starter was added to compensate for the addition of moisture. Based on an analysis of temperature profiles, volatile solids destruction and odor released, it can be concluded that the compost starter did not have any observable effect on the process. Treatments 1, 2 were compared with 5, 6 for these interpretations. The results of the tests were identical. Additional replicated studies will be necessary to completely rule out any other possibility.

CARBON LOSS AND C/N RATIO

In all of the mixes the initial C/N ratios were in the range of 18 to 26. Generally, higher levels up to 30 are considered acceptable in composting. All of the treatments reached levels of 11 to 17 at the end of composting. This renders the compost more suitable for application to soils without resulting in a N depletion in soils when compost is applied. Highest carbon loss was found in treatment T3 which reduced from an initial of about 39% to a final carbon concentration of 27%. The corresponding C/N ratio was found to be 11. This shows that the 25% manure amended treatment is possibly a better mix when carbon degradation (cardboard disposal) is the focus.

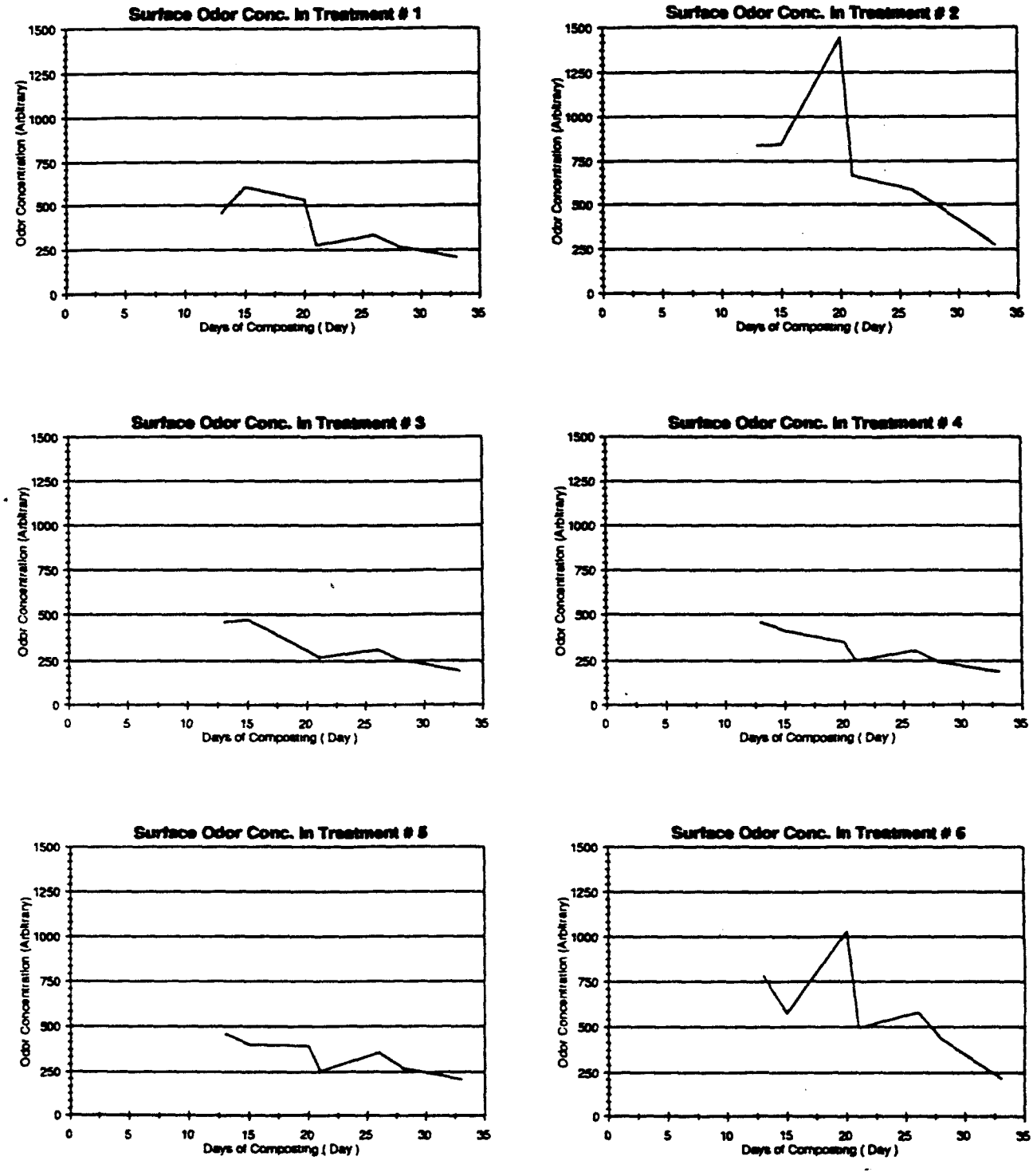

Figure 2. Surface odor concentrations in the test vessels during the composting of waxed corrugated cardboard. The six treatments are respectively on a volume basis 40% manure, 40% litter, 25% manure, 25% litter, 40% manure with compost starter, and 40% litter with compost starter.

Table 3. Plasma emission spectrograph results of final product from composting of mixes of waxed corrugated cardboard with poultry manure and litter. Refer to Table 2 for mix ratios.

Species[1,2] (EPA - Limits)	T1	T2	T3	T4	T5	T6
Metals						
As (4.1)	1.8-2.2	14.4-15.4	1.7	10.4-10.5	1.8	15.2-15.9
Cd (39)	0.19-0.16	0.27-0.34	0.17-0.20	0.3-0.35	0.06-0.18	0.3-0.37
Cr (1200)	1.9	2.5-2.6	1.7-1.8	2.4-2.5	1.8	2.6-2.7
Cu (1500)	1.8	33-36	2.0-2.2	15.5-16.2	1.5-1.7	32.9-34.4
Pb (300)	0.7-1.0	1.3	1.0	1.3-1.5	0.7-1.0	1.3-1.4
Ni (420)	2.5-2.7	2.0-2.1	2.0-2.4	1.6-1.7	3.3-3.4	2.1-2.3
Zn (2800)	4.0-8.9	110-140	6.1-10.5	89.9-92.7	4.4-6.3	103-122.5
Macro nutrients						
N	21800-23700	18400-19600	23300-25500	21900-24800	24900-25400	23100-26400
P	6493-7730	10486-11085	6464-6953	7808-8426	6531-8609	11031-11955
K	22205-25885	21073-23319	19423-20204	18789-18898	25011-25172	23109-24096
Ca	5352-9704	11285-11380	9495-10424	8824-8990	6018-9359	10574-11365
Mg	1160-1270	1176-1196	1134-1143	1161-1188	1170-1219	1215-1232
Na	6540-7614	5679-6205	6182-6462	6071-6089	7242-7249	6208-6260
Se	3.6-4.0	4.2-4.7	3.8-4.1	4.8-5.0	3.8-3.9	4.5-4.8
Mo	0.2-0.24	0.43-0.53	0.14-0.20	0.38	0.14-0.17	0.51
Micro nutrients						
Fe	1.6-3.5	43.3-47.3	3.0-4.1	26.8-27.4	1.5-2.3	44.0-51.4
Mn	21.3-43.1	226.9-234.4	32.0-44.6	209.8-218.4	27.4-37.4	236.7-241.0
B	25.8-29.6	33.8-36.6	24.4-25.5	42.4 -44.3	26.3-27.7	38.6
Co	0.13-0.16	0.29-0.34	0.11-0.12	0.22-0.24	0.13-0.14	0.23-0.29

[1]All units are in ppm (by weight).
[2] Results indicate total species by dry weight fraction. This does not necessarily imply plant available, microbe available or leachable fractions.

LABORATORY CONCLUSIONS

The results of this project clearly indicate that manure is a superior amendment in the composting of old waxed corrugated cardboard. The final nutrient and metals concentrations are presented in Table 3.

The following are some of the important reasons and some additional conclusions.

1. Manure amended mixes reached higher levels of stability at the end of the high rate composting.

2. Manure amended mixes were found to be mature, based on the 70% germination index, at the end of the curing phase. Curing of at least 30 days is required for these composts.

3. Manure amended mixes exhibited lower pressure drops at the same air flow rates. This suggests higher porosity and more aeration. This factor is also related to the fact that these mixes did not become anaerobic during composting and had relatively less odors generated.

4. Manure treatments had a higher rate of degradation and showed less activity after the 14th day of high rate composting. This suggests that the materials can possibly be removed from high rate composting and transferred to curing at this time.

5. Good mixing is absolutely essential with manure mixes. These mixes showed a very high tendency for clumping and this results in poor composting. Broiler litter amended mixes were more homogeneous; however, the higher packing factor resulted in lesser porosity and higher pressure drops in these mixes.

6. Final nutrient concentrations indicated that the product had a NPK equivalent of a 2:1:2 fertilizer. The plant availability of these nutrients is not known and further plant growth tests are required.

7. The broiler litter treatments had higher concentrations of metals leading to a product that had a relatively higher metal concentration.

8. Boron was rather high in all of the products. A threshold of 50 ppm can become dangerous to certain plants. However, at less than 50ppm, compost may be applied at normal application rates with low to no concern.

9. The use of the compost starter showed no benefit to the composting process. Further evaluation has to be performed to rule out any other possibility.

10. These experiments were performed with composting mixes in the moisture range of 50-55%. Higher moisture levels need to be used, and an evaluation of this is required in full scale testing.

WINDROW COMPOSTING

The windrow portion of the study was carried out by Sargent Nutrients, Inc., a long standing composting firm in north Georgia. The location chosen was the Lee Arrendale Correctional Institute in Habersham County. This seemed a natural choice since all the necessary equipment would be at this site due to the startup of the Institute's own food waste composting program. The same contractor would be providing oversight on the Institute's project startup under the auspices of Chestatee-Chattahoochee Resource Conservation and Development.

In advance of start up at the site, the baled WCC was loaded onto tractor-trailers for transport to the composting site. Weights were recorded for each load leaving the recycling center. A total of 75,120 pounds was shipped, slightly below the goal of 40 tons. Of the 40 tons hauled to the site, approximately 30 tons were used in our project. The remainder was used in the Institute's program. Approximately 5 tons of broiler litter and 5 tons of hen manure were also hauled to the Lee Arrendale Correctional Institute composting site. The approximate ratio (by weight) of WCC to poultry litter was 3:1 or 75% WCC to 25% litter, approximating that used in laboratory treatments 3 and 4.

A DuraTech 8 Tub Grinder was used to preprocess the WCC. Problems occurred with the tub sensor for the first two days, resulting in lost time. It was felt the material would process better if the bales were cut apart and allowed to soak up moisture (rain). Through trial and error, it was discovered that the material processes much better when dry and even better when mixed with poultry litter. After shredding, the cardboard handled very well. Most pieces were in the two to three inch range. The DuraTech did a good job after fine tuning our methods. Other machinery might be better suited to the task on a daily basis, however. After grinding the WCC, a windrow of poultry litter and WCC was mixed to an approximate C:N ratio of 30 to 1. Hen manure and waxed cardboard was also mixed together with the same ratio.

Table 4. WCC windrow composting monitoring

Date	Weather	Moisture	Odor	Broiler Litter 30'	Broiler Litter 60'	Hen Manure 90'	Hen Manure 120'
09/09/96	SUNNY						
09/16/96	SUNNY	35%	MILD	150°	144°	154°	146°
09/19/96	SUNNY 88 °	35%	MILD	134°	138°	140°	138°
09/20/96	SUNNY 88°	35%	MILD	138°	144°	146°	148°
09/23/96	SUNNY 86 °	45%	N/A	140°	150°	144°	140°
09/25/96	SUNNY 86°	45%	MUSTY	144°	146°	146°	142°
09/27/96	RAIN 72°						
10/01/96	CLOUDY 62°	45%	MUSTY	130°	136°	136°	136°
10/03/96	SUNNY 76°	45%	MUSTY	138°	134°	134°	140°

The windrow was set September 7, 1997 into one row--broiler litter and cardboard at one end and hen manure and cardboard at the other. Upon formation of the windrow, it was decided the moisture level was too low and needed adjusted. Moisture was added using a tanker truck and fire hose. Approximately 2,400 gallons of water were added on this and subsequent occasions on September 24 and October 24.

Temperature and turning schedules were established. A Wildcat turner pulled by a farm tractor was used. Initially, turning was done every 3 days. Temperature was monitored before each turning. By the end of the first week, as shown in Table 4, temperatures reached 150 to 154 degrees Fahrenheit. For two days following each addition of water, increases in temperature were observed.

After one month, the WCC was observed to form small ball-like masses the size of nickels. This appeared to be due to the mechanical action of turning. These structures did not seem to retard decomposition as at first feared. By the end of two months, these structures had disappeared, and it was difficult to distinguish any WCC in the compost mixture. By the end of the third month, a stable, dark brown compost was obtained.

CONTAMINENTS IN WCC

The Clean Washington Center (CWC) study done by E & A Environmental Consultants, Inc. in 1993 identified potential contaminants in WCC. Potential contaminants include trace metals (printing inks), boron (adhesives), and volatile and polycyclic aromatic hydrocarbons (petroleum waxes).

Compost produced in our pilot project exhibited very low metals concentrations. In fact, metals concentrations from compost produced in our pilot were many orders of magnitude lower than those produced in the CWC study. For example, the CWC identified lead at 11 mg/kg in finished compost containing WCC while Hall County's results were <0.10mg/kg, as shown in Table 5. This is undoubtedly due to the fact that the WCC used in the CWC study was from grocery stores. WCC from grocery trade tend to be more heavily imprinted with labels, logos, etc. WCC from poultry industry sources are largely used internally and need not be imprinted. The boxes are basically ink free.

Boron found in compost made from WCC originates from borax, which is added to starch glues for improving adhesion in the construction of corrugated cardboard boxes (WCC and OCC). Although boron is a plant micro-nutrient, exceedingly high levels can be phytotoxic at 100 ppm and can terminate the composting process completely at the range of 1000-2000 ppm (Davie). Boron concentration found in our composite sample from the field trial at 20 ppm was remarkably similar to concentrations found in the CWC study where 10% by weight WCC was composted (ranged from 18 to 21ppm).

Table 5. Windrow composite sample[1] test results

Parameter	Results As Received	Dry Basis	USEPA 503[2]
Moisture	35.28 %		
pH	7.64		
Phosphorus	0.59 %	0.91 %	
Nitrogen	0.68 %	1.05 %	
Potassium	0.65 %		
Carbon	10.50 %	16.23 %	
C:N Ratio	15.4:1		
Copper	0.71 mg/kg		1500 mg/kg
Zinc	0.61 mg/kg		2800 mg/kg
Lead	<0.10 mg/kg		300 mg/kg
Chromium (total)	0.005 mg/kg		N/A
Cadmium	0.01 mg/kg		39 mg/kg
Nickel	0.12 mg/kg		420 mg/kg
Arsenic	0.04 mg/kg		41 mg/kg
Barium	<0.15 mg/kg		N/A
Boron (total)	20 mg/kg		N/A

[1] A composite compost sample (broiler litter/hen manure) was taken on 12/19/96.
[2] 40CFR503 federal regulations for utilization of biosolids (sewage sludge) compost

The Clean Washington Center study also examined the material safety data sheets (MSDS) for several Citgo wax coatings used in WCC. These MSDS's indicate that the wax coatings are not toxic, carcinogenic, animal carcinogenic, mutagenic, or teratogenic. The WCC boxes are also approved by FDA for use in food packaging containers.

PROJECT CONCLUSIONS

Waxed corrugated cardboard is a very good source of carbon and may be composted with broiler litter or hen manure successfully. Good composting practices should apply with this material as well as any other of this type. From our tests, we do not see any problems that would limit the use of the compost. The finished material may be marketed in the horticultural as well as the agricultural area and used at normal application rates without problem.

The project has the potential to eliminate a substantial amount of the solid waste stream. There is currently no practical disposal alternative for waxed corrugated cardboard. The project supports north Georgia's poultry industry, which is the region's largest employer and economic base. The project stands to offer a viable disposal alternative cheaper than the cost of landfill disposal, while producing a valuable, value-added product. While the major benefit may be derived by the poultry industry, the economic importance of this business sector is of such importance to the region that benefits will cross boundaries. Landfill life will be extended to the benefit of everyone. The project will result in the reuse of a resource as well as offer improvement to our soils, which lack humus.

We were fortunate to have a facility made available to us by Lee Arrendale Correctional Institute and the help of the Chestatee-Chattahoochee RC&D Council, Inc. and feel that both should be recognized for their efforts in this project.

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DEVELOPMENT OF SWINE WASTEWATER DEWATERING/COMPOSTING FACILITY AND END PRODUCT USE

By

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INTRODUCTION

Swine production in North Carolina is second only to Iowa of hogs on farms (Graham, 1995) with 8.3 million head. Cash receipts from 1994 sales exceeded 980 million dollars representing 15.4 percent of total agricultural cash receipts. Using the underfloor flush-lagoon treatment system of manure management is reported to produce 950 gallons per year per pig capacity for growing-finishing operations. Disposal of such large volumes of wastewater containing 0.5-3.0% solids from these production facilities in an environmentally safe and economically sound manner is a current concern. The current method of handling these wastewaters is by land application which has many limitations including risks of ground and surface water contamination by leachates and runoff from overflowing lagoons during inclement weather and excess rainfall.

Existing and pending regulations for handling swine manures may require new handling systems and reduce agricultural acreage due to buffer zones by rivers and streams.

Composting is a natural biological process which can be utilized for processing manures into a beneficial product but requires an integrated approach consisting of (1) enhancement of the solids content of wastewater, (2) composting using sawdust-woodchips as bulking materials and (3) development of guidelines for use of the final product for various crop production systems.

OBJECTIVES

The project is an endeavor to develop and demonstrate an integrated program for handling swine manures which assures compliance with all regulatory requirements, produces a beneficial product and develops potential uses for the product.

The specific objectives were:

1. Evaluate systems for enhancement of the solids content of swine lagoon liquids.
2. Develop an aerated bin (in-vessel) composting facility
3. Characterize the chemical and physical properties of the compost.
4. Establish beneficial use criteria for utilization of the compost.

PROCEDURES

Aerated compost bins. The composting study was conducted at the Northpork Porcine Composter, Bowen Farms, Inc. in Belhaven, North Carolina. Existing 8' x 16' x 6' compost bins located at this facility were divided into 8' x 8' and fitted with BioPlates™ (Fiberstone Technical Affiliates Inc.) which are used for aeration of the bins (Cunniff and Edwards, 1996). Squirrel cage fans with 500 cfm capacity were installed as an air supply.

Solids separation. A Key Dollar™ Model 100 separator was supplied by the Key Dollar Co., Inc. of Milton-Freewater, Oregon. The separator was fitted with a screen having 1/16 inch openings.

Following an initial trial with the 1/16 inch screen, a 1/32 inch screen was installed for further evaluation.

Compost feedstock blends. Three feedstock combinations used for composting evaluations were:

1. Manure solids from separator (straight)
2. Manure solids + woodchips - equal parts by volume mixed (1:1)
3. Manure solids woodchips - equal volumes layered approximately 3 inch depth.

These blends were placed in bins to a depth of approximately 4 ft. Temperatures were monitored with a Campbell Scientific CR 10 data logger.

Compost analyses. Compost was analyzed for C, N, P, K, Ca, Mg, Mn, Zn, Cu, Pb, Ni, and Cr by the Analytical Services Laboratory-Department of Soil Science, North Carolina State University. C and N were analyzed using a Perkin Elmer Model 2400 CHN Elemental Analyzer (Perkin Elmer Corp., Norwalk, Connecticut). P, K, Ca, Mg, Mn, Zn, Cu, Ph, Ni, Cd, and Cr were determined by ICP using a Perkin Elmer Plasma 2000 emission spectrometer following a dry ashing in a muffle furnace at 500°with dissolution in HCl.

Greenhouse studies. Two plant species. Dwarf nandina cv. Fire Power and Dipladenia are being grown in the following 5 mixes a) compost only (SW), b) commercial media (CM), c) 75% SW + 25% CM, d) 50% SW + 50% CM, e) 25% SW + 75% CM. Fertility rates of 0, 5 or 10 lb yd^3 of 14-14-14 Osmacote was mixed with each mix, 4 replicates of Dipladenia, 5 replicates of Nandina.

RESULTS AND DISCUSSION

Separator results. An initial trial with the Key Dollar Model 100 separator using the 1/16 inch screen to which pit discharge waste containing 2.08% solids was pumped at 100 gpm resulted in removed solids of 20% solids. Replacement of the screen with 1/32 inch screen resulted in 74% solids removal from a pit discharge of 2.85% solids. The solids content of material from the 1/32 inch screen was 24.2%. The primary effluent from the separator contained 0.75% solids and the secondary effluent (after the roller press) contained 1.24% solids.

Composting results. The temperature regimes for the three bins are shown in Figure 1. The bin containing no wood waste reached a maximum temperature of 130°F, slightly below PFPR requirements, and was maintained for about 1 week followed by a general decline until turned mechanically after which temperature increased to 115°F before being terminated. This material with a high moisture content settled increasing density and limited aeration. Larger fan with higher static pressure capability may have overcome this problem and should be tested further. Composting of straight material would be desirable because of less labor requirement and increased efficiency of the bin capacity. Both bins containing wood waste as a bulking material achieved PFPR requirements. These bins required several loading days to fill the bin and thus a drop in temperature at each loading. There was some evidence here of inadequate fan capacity which may have limited maximum temperatures achieved in other composting projects.

Compost analyses. Chemical analyses and bulk density of the two wood amended composts were comparable and only the analyses of the 1:1 mixed feedstocks are shown in Table 1. This was the product used for the greenhouse studies. The pH of the samples ranged from 7.2 with wood swine solids layered to 7.8 with the straight swine waste. Bulk density ranged from 860-931 lbs/yd^3 in the wood amended compost as compared to 1303 lbs/yd^3 where only swine waste was used. Soluble salts ranged from 128-182 mhos x 10^{-5} in the three composts as compared to 220 mhos x 10^{-5} in the uncomposted raw waste.

Table 1. Characteristics of Swine Waste Compost from 1:1 mixed feedstock.

Parameter	%	Parameter	mg kg^{-1}
C	48.6	B	8.0
N	1.25	Mn	343.2
P	0.76	Zn	289.0
K	0.42	Cu	92.3
Ca	0.96	Ph	16.0
Mg	0.23	Ni	4.6
S	0.39	Cd	<1
Fe	0.89		
		Na	146.0
		Cl	289.3
Soluble Salts		128 mhos x 10^{-5}	
pH (2:1)		7.6	
Bulk Density		931 lbs/yd^3	

Cucumbers, a salt sensitive crop, were seeded in each of the composted materials and in uncomposted manure. Cucumber germination and growth were inhibited in the uncomposted manure but normal growth occurred in all of the compost products.

Early growth of dipladenia shows a positive response to the compost at low fertilizer rates but high rates of compost resulted in a decrease in growth at 75 and 100% compost.

Growth response of nandina was similar to that with dipladenia but plants growing in high compost rates are exhibiting symptoms of iron deficiency which may be due partially to the relatively high salt content and the competitive effects of zinc and copper contained in the compost. Final growth quality analyses will be presented at the conference.

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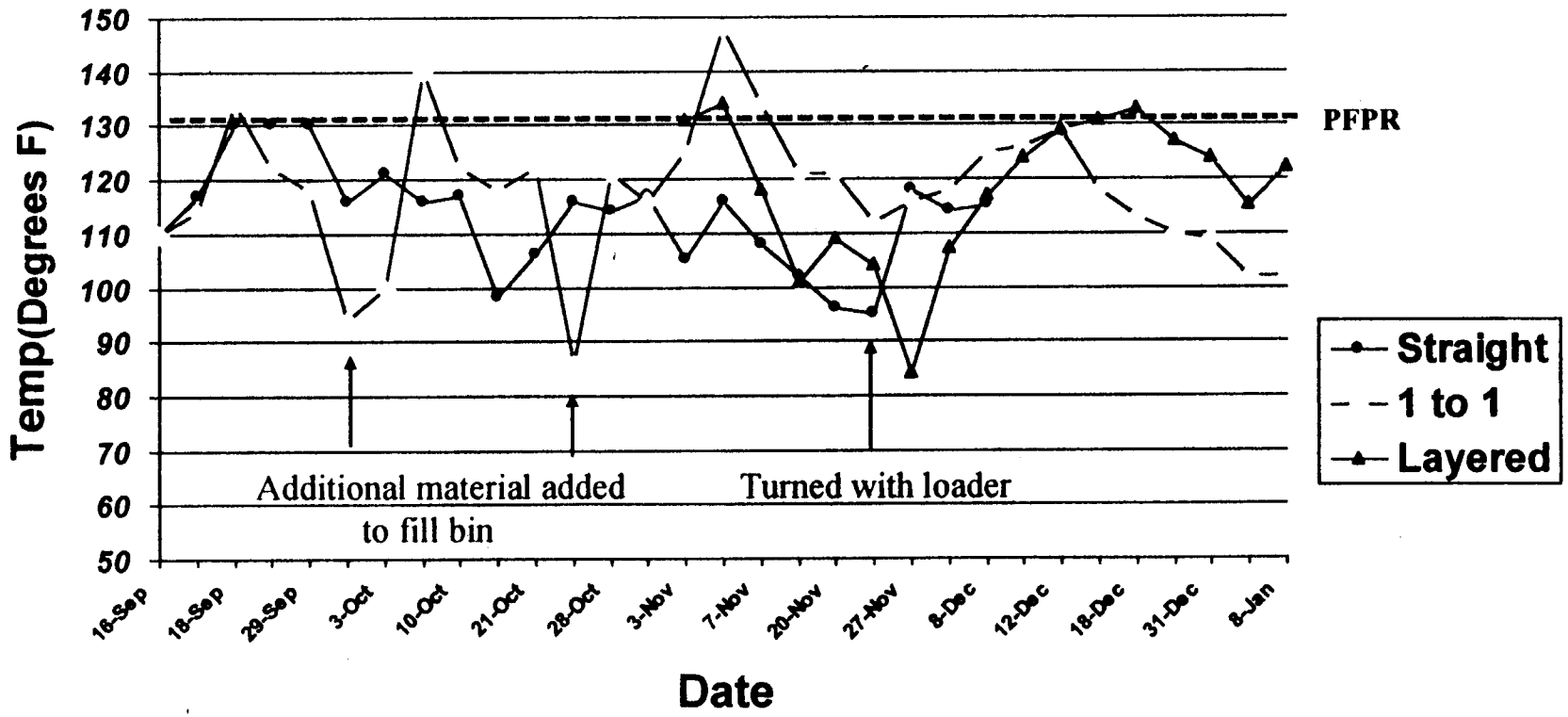
Fig. 1. Northpork Swine Wastewater Compost Temp. Regime



POULTRY LITTER COMPOST PRODUCTION, A MEANS OF DISTRIBUTING EXCESS NUTRIENTS[1]

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ABSTRACT

Alternate technologies of compost manufacture from poultry litter (manure) were studied as a means of producing a value added product for the landscape and nursery industry. Static pile and turned windrow technologies were investigated on a commercial scale with the composting of nearly 1,000 tons of material. The major difference between the technologies is the amount of energy and labor required. Static pile systems require less energy but more time than windrow turned systems. There was no process advantage found for passively aerated static piles over static piles but costs of passive aeration for pipes and labor was higher than for static piles. Machine turned windrows completed active temperature production within 100 days while portions of both the static and passively aerated piles continued to actively compost past 300 days. Process operational costs and compost quality were similar among the compost methods studied. Production operational cost is driven by the cost of compost ingredients and accounted for 60 to 70 percent of the cost in the pilot study. Ingredients were poultry litter, wood chips and sawdust. Screened compost was produced at an operational cost of $30 while unscreened compost could be produced for $20 per ton of compost. A production scheme where poultry litter is static pile composted on farms for later transport to regional processing centers appears feasible. This two part composting procedure will eliminate the transport of raw litter and improve poultry biosecurity. Most likely, a private compost business would provide the expertise, on-farm compost procedures and operate the regional facility.

INTRODUCTION

Estimates of poultry litter (manure) production on the Delmarva Peninsula indicate some areas of potential nutrient excess in conflict with Tributary Strategy goals of reduced nutrient input (Brodie and Lawrrence, 1996). Solutions to the problem of excess manure nutrients include the transport of treated manure to areas where it can be assimilated as a soil amendment or fertilizer in an environmentally neutral manner. One opportunity is to develop compost products desired by the nursery industry. Nursery needs are continually increasing and represent a vast potential market for the movement of poultry litter away from the concentrated poultry rearing areas (Bissman and Wheeley, 1997). But can compost from poultry litter be produced in sufficient quantity and quality at low enough cost to satisfy the demands of this market?

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Can poultry litter be partially composted on-farm for later transport to a central facility for further processing? Several cooperative arrangements have been proposed between farmers and composters that can move compost products to market (Brodie, 1996). One proposal was the partial composting of litter on-farm with later transport to a central composting facility for finishing, blending and sale. This paper reports on a study at a large scale compost production site that compared static piles, passively aerated piles and mechanically turned windrows in an effort to establish an economic and compost quality comparison between the methods. The static piles were managed as would be expected on farms and then blended to simulate the activities as would be expected at a central finishing facility.

METHOD

The composting of poultry litter was demonstrated at the New Earth Services composting facility near Hurlock, Maryland. Approximately 520 tons of ingredients were composted in mechanically turned windrows in 1995 and approximately 300 tons of ingredients were composted in static, passively aerated and mechanically turned windrows in 1996 (Table I).

Compost ingredients consisted of poultry (broiler) litter, chipped wood and sawdust. Multiple samples of each ingredient were mixed to produce a composite sample for laboratory analysis. All analysis was performed by the University of Maryland Soils Testing Laboratory using standard methods. Table II is a summary of the average ingredient properties. Analysis results were utilized to develop compost recipes which provided the desired C:N ratio and moisture content (Brodie, 1994).

Sawdust and wood chips represent a large portion of the cost of compost ingredients. It is anticipated that farmers will attempt to minimize cost and therefore use lesser quantities of wood product than is normally recommended. Recommended C:N ratios for compost mixes range from 25 to 35 (Rynk, 1992). In this demonstration the C:N ratios were depressed to 15 to simulate what might happen on farms (Table II).

Windrow compost mixed in December, 1995 (pile 6 in Table I) was measured as truckloads. Weigh tickets from county operated scales were used to determine the mix ratios. The mixed compost was formed into three windrows each with a triangular cross section of ten feet wide by five feet high and four hundred feet in length. A total of 528 tons of ingredients were used. The mix ratio was approximately 30 percent poultry litter; 35 percent wood chips; and 35 percent sawdust by volume.

Compost was mixed in October 1996 to allow time and motion study and development of a cost of the compost using different production techniques. The production techniques consisted of static with and without a compost cover; passively aerated static with and without a compost cover; and mechanically turned windrow. Compost ingredients were delivered to the compost site by truck. Ingredients were moved to the mixing area by tractor bucket loader. Volume ratios for mixing were measured by the bucketful. Ingredients were proportionately stacked in a windrow that was then mixed by two passes of the compost windrow turning machine. Mixed materials were then stacked as static piles or as turned windrows using the bucket loader.

Four static piles (piles 1,2,3,4 in table I) were constructed with base dimensions approximately fifteen feet by forty feet and a seven to eight foot height with 100 cubic yards of ingredients. The cross sectional shape was triangular. The piles were placed on a sixteen inch deep bed of wood chips placed on the ground to improve aeration capacity. Each static pile bed utilized an additional 36 cubic yards of wood chips most of which were reclaimed at the finish of the compost process and could be utilized in the production of new compost.

Two static piles (pile 2 and 4 in Table I) were covered with a six inch deep layer of previously made compost to act as an insulating blanket and odor control biofilter. Two static passively aerated static piles (piles 3 and 4 in Table I) were constructed on a wood chip bed which contained a twelve inch diameter perforated pipe under the center of the pile and extended the entire pile length. The pipe was laid in one continuous forty foot length in the center of the bed. The pipe was fitted with three rows of one inch diameter holes on one foot spacing to allow air transport into the bottom center of the compost pile.. Static and passively aerated piles were made with 23 percent

Table I. Demonstration piles of poultry litter compost

compost pile		process	process dates	ingredient volume cu yds
1		static	10/12/96 - 9/27/97	
	a	turned once		50
	b	turned three times		50
2		static with compost cover	10/16/96 - 9/27/97	
	a	turned once		50
	b	turned three times		50
3		static passively aerated	10/25/96 - 9/27/97	
	a	turned once		50
	b	turned three times		50
4		static passively aerated with cover	10/28/96 - 9/27/97	
	a	turned once		50
	b	turned three times		50
5		mechanically turned windrow	10/29/96 - 05/12/97	100
6		mechanically turned windrow	12/08/95 - 05/01/96	1,700

poultry litter; 39 percent wood chips; and 38 percent sawdust by volume (3:5:5 in Table II). Static piles were then subdivided such that half the pile was turned once and half the pile was turned three times during the period of composting. Turning was accomplished using a bucket loader in a manner that the wood chip bed and aeration pipe were undisturbed during the process.

Two turned windrows were constructed with a triangular cross section of ten feet wide and five feet high with a combined total length of one hundred feet (pile 5 in Table I). These windrows were not placed on a wood chip bed. Turned windrows were made with approximately 25 percent poultry litter; 37 percent wood chips; and 38 percent sawdust (2:3:3 in Table II).

No water was added to the ingredients during initial mixing or subsequent turning. It was assumed that farmers would not be equipped to provide water. The resulting mixes had moisture contents of 40 to 45 percent which is below the desired moisture level of 50 to 60 percent.

This project is considered a demonstration of compost production and the data generated are specific to the individual compost piles monitored. The inference of trends may be considered subjective in that there was insufficient replication of ingredient mixes and pile configurations to allow statistically meaningful measurement. However, because the demonstration was conducted on a commercial site using methods and employees normal to large scale composting, it is assumed that the experience is realistic.

RESULTS AND DISCUSSION

Ingredient mixing

The mixing of materials for the production of compost must be accomplished in a manner that approximates the desired proportions of the various ingredients. Although simple in concept the task is not so simple in practice at compost sites not equipped with expensive material metering equipment. The ingredients for windrow compost produced in 1995-96 arrived at the site in December. The 27 trailer loads of poultry litter, wood chips and sawdust were each weighed and then deposited in parallel rows such that removing material from the rows in equidistant proportions would approximate the ratio of the ingredients required of the compost recipe. Although expressed in the affirmative, the concept was not understood by the bucket loader operator as was evidenced by exhaustion of

Table II. Average compost ingredient and initial mix properties

parameter	units	poultry litter	wood chips	sawdust	3:5:5 volume mix calculated	2:3:3 volume mix calculated
moisture	% wet weight	40	29	61	42	42
nitrogen	mg/kg dry weight	59,000	3,000	3,200	18,900	20,100
ammonium nitrogen	"	13,000	0	0	3,500	3,800
phosphorous	"	22,000	550	0	6,400	6,800
potassium	"	34,000	1040	530	10,010	10,800
calcium	"	19,000	1100	0	5,800	6,200
carbon	"	385,000	127,900	492,000	275,000	279,200
magnesium	"	12,000	1370	560	4,100	4,400
sulfur	"	10,000	180	1,010	3,200	3,400
volatile solids	"	787,000	380,000	969,000	616,500	621,600
manganese	"	500	80	38	185	194
zinc	"	540	50	6	178	188
copper	"	850	14	3	248	266
C:N	ratio	7	44	153	15	14

the poultry litter pile while having excess wood products. After the error was discovered the remaining wood product was then distributed on the three windrows of mixed materials that had been made. It is important that operators be trained in the concept of ratios and that they understand the needs of the recipe mixing process.

The ingredient mixing for the 1996-97 compost trials of static, passively aerated static and windrow turned piles was accomplished under direct supervision which provided the desired proportions of ingredients in October 1966. The materials were measured by volume through counting the bucketfuls of each ingredient used. Ingredients were proportionally placed in a windrow that was then mixed using the windrow turning machine. The mixed ingredients were then placed in the respective piles or windrows. Each pile contained approximately 100 cubic yards of ingredients which when mixed reduced to 84 cubic yards. The reduction in volume is a result of a filling of voids between large particles with smaller particles of different materials. The percentage change in volume is dependent on the physical properties of the particular materials used.

The operator of a bucket loader cannot achieve a consistent bucket volume of different types of ingredients or of the same ingredient when the resource pile changes shape. During this demonstration an overflowing bucket of sawdust was common while only about two-thirds of the bucket was filled with poultry litter. The operator may not be able to see the amount of bucket fill and may not be able to judge the quantities moved. Ingredient quantity deficiencies were corrected by adjusting the required number of bucket fills to make up for the lack of volume placed in the bucket. However, if the bucket operator fails to occasionally stop and observe the bucket capacity being moved the desired recipe may not be achieved.

Composting process

The windrows constructed in December of 1995 were turned using the compost turning machine on a schedule determined by the site operator. Temperatures, oxygen concentration and turning event data were not sufficiently recorded by the operator to allow a description of the compost process for these windrows. Piles and windrows constructed in October of 1996 were monitored for temperature, oxygen concentration and physical appearance with enough regularity to describe the process.

Compost oxygen concentration was less than one percent in all piles and windrows for all depths in the mass for several months after construction. The consistency of this low reading discouraged the operator from taking

regular measurement resulting in a lack of oxygen data for the entire project. Sporadic measurements indicated an increase of oxygen concentration to three to four percent within eighteen inches of the pile surface but less at deeper regions. For the static piles this low oxygen concentration was independent of whether the pile was passively aerated or covered with compost. However, after pile turning higher oxygen concentrations could be measured directly over the aeration pipe.

The lack of oxygen concentration would normally be indicative of anaerobic processes accompanied by cold temperatures, water saturated mass, blackness of the material and offensive odor. Machine turned windrows did not have these characteristics. Inspection of turned portions of the static piles showed some blackness of the mass but no major regions of water saturation. The only odor present was ammonia which was anticipated because of the low C:N ratio used in the mix recipe. There was no foul odor as is usually associated with anaerobic processes.

Compost temperature was rigorously measured by the operator with a long stem dial thermometer. Measuring temperature is more rewarding than measuring oxygen in that the numbers change and trends can be noticed. Therefore, temperature monitoring is more acceptable to site operators than oxygen monitoring even though oxygen monitoring can be used to predict a problem while temperature indicates that a problem may have already occurred.

Temperature histories for each treatment are shown in Figure 1. Each pile and windrow was monitored in six locations and the temperatures are shown as the mean for the pile on the day of record. The temperatures of the different treatments were different in timing and degree. All temperatures averaged more than 55°C for five or more consecutive days at some time during the process.

In general:

* piles with compost cover (2 and 4) had lower temperatures than uncovered piles (1 and 3)

* static piles that were turned three times (1b,2b,3b and 4b) had higher average temperatures than piles that were turned only once (1a,2a,3a and 4a) but the latter piles had the higher peak temperatures which occurred after turning

* passively aerated static pile (3) showed little difference in temperature as compared to static pile (1)

* all static piles (1,2,3 and 4) reached temperatures higher than the machine turned pile (5)

* the machine turned pile (5) cooled to ambient after 100 days of processing indicating a completed process

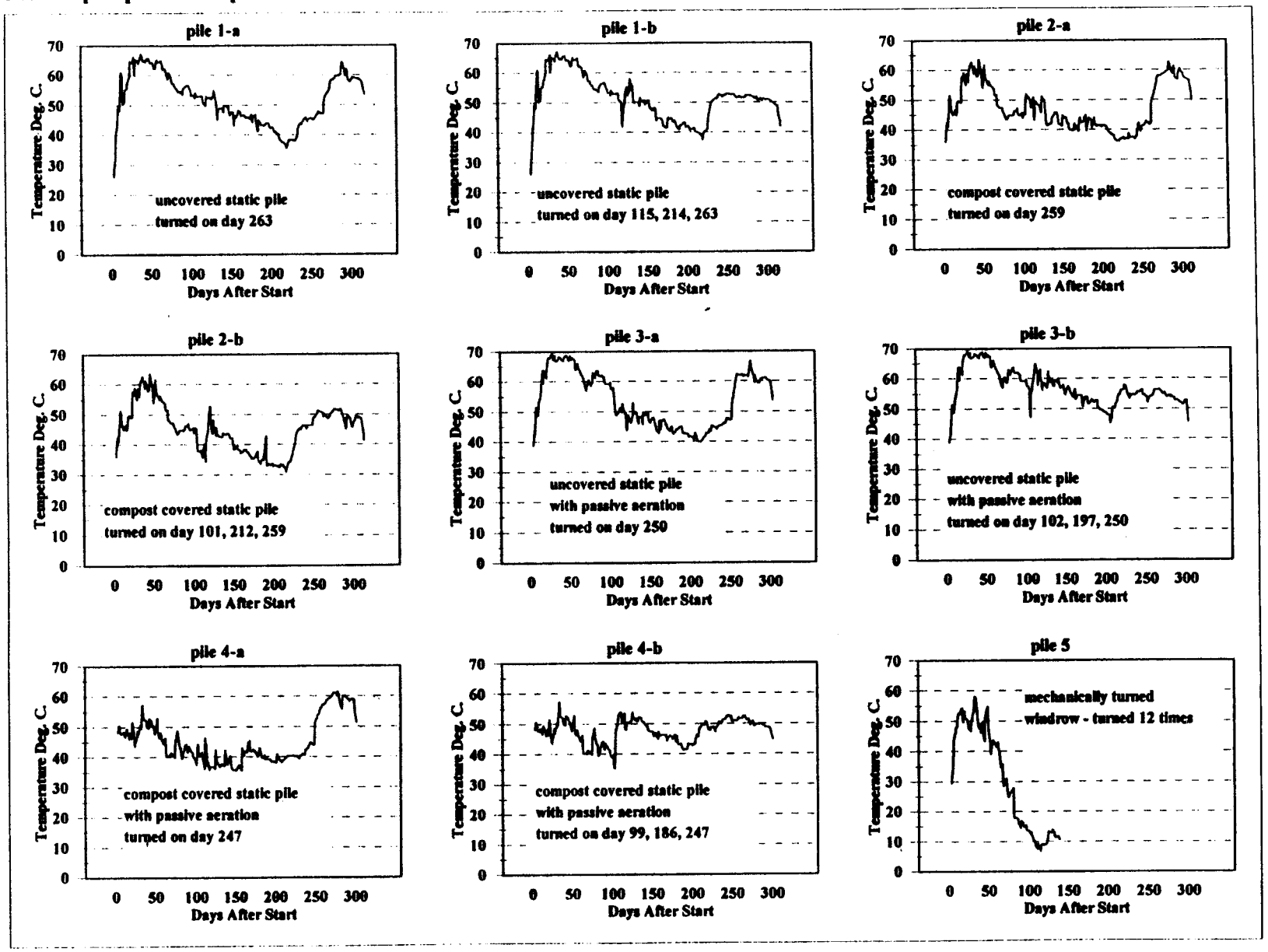
* all static piles (1,2,3 and 4) after 290 days of processing had temperatures above 50°C

* all static piles had temperatures on the side exposed to the winter sun consistently higher than temperatures on the shadow side

Reasons for the process differences can be postulated based on the temperature information and other observations during and after the turning of the piles.

The compost cover on static piles was reasoned to collect odor and ammonia which may be released from the composting mass, to act as an insulating blanket to promote heat retention and to provide a barrier to fly attraction to the raw poultry litter in the mix. It appears that the cover did not have an exceptionally beneficial effect on temperature retention and may have been responsible for reduced temperature by dampening the air flow through the pile. Small flies or gnats were present at all piles and it could not be differentiated if the cover provided any insect advantage. None of the static piles developed obnoxious odor. Therefore, it can be suggested that the effort and cost of placing a compost cover on static piles is unwarranted when using the combination of ingredients provided in this demonstration.

Figure 1. compost process temperatures



The use of a single large pipe for passive aeration appears to have allowed slightly increased temperatures in piles without a compost cover and in covered piles that had been turned and in the process lost the compost cover. Oxygen concentrations when measured were not different between passively aerated and static piles. All of the uncovered piles reached temperatures above 60°C independent of passive aeration. It appears that the sixteen inch depth of wood chips was a sufficient base for air movement without the pipe.

The number of times the pile was turned effected the maximum temperature reached and the timing of the occurrence. All static piles which were turned once after 250 to 260 days sustained temperatures of between 50 and 70°C for four to five weeks after turning. This was independent of compost cover or passive aeration. All static piles which were turned three times in 250 days showed an elevated temperature after each turning but only the passively aerated pile without a compost cover sustained temperatures above 60°C for an extended period of time after turning. This elevated temperature is an important aspect of the process because the previously unturned static piles were producing a dense crop of weeds on the surface which added available nutrients and energy when mixed with the internal compost mass. The elevated temperature is necessary to destroy the weed seeds. It appears that with these recipes sufficient process heat can be generated with a single late turning of a static pile.

During the first turning of piles turned three times the compost was inspected for odor, color and moisture. Generally ammonia was released during turning but no other objectionable odor was noted. Moisture was 50 to 60 percent as determined by the hand squeeze method. The wettest regions were in a twelve inch layer approximately sixteen inches below the outside surface. This was probably a combination of rain infiltration combined with internal vapor condensation as the vapor migrated toward the colder outside regions of the pile. Compost covered piles were wetter than piles not covered. Passively aerated piles were drier in the center than non aerated piles. Some regions of black material were present in all piles but were not accompanied with odor. The chip bed was dry and light colored in passively aerated piles while non aerated pile chip beds were dark and moist but not saturated. These conditions were less noticeable at subsequent turnings.

During the turning of piles turned only once after 260 days of process there was little difference in appearance between the compost piles. Ammonia was released but not objectionable odor. Moisture was still high with laboratory samples ranging from 32 to 50 percent water.

After 320 days all static piles were cooling but had not reached ambient temperature. The material from all piles was combined into a windrow and machine turned twice in two weeks. The temperatures climbed in all windrows to 50°C that lasted for several days then declined. Ammonia release was no longer evident. The static pile compost was ready for screening 350 days after initial pile construction. During this period excessive rainfall increased the moisture content of all the compost to between 40 and 45 percent.

The machine turned windrow was turned twelve times in 120 days after which the process was considered complete. During the process period temperatures of greater than 50°C were not sustained throughout the mass for periods of more than several days. The turning process in mid winter may have excessively cooled the composting mass. In addition, the small windrow shape required for mechanical turning provided a large windrow surface to mass ratio that easily lost heat to the cold winter atmosphere. The low profile shape and the broad surface area allowed these windrows to capture rainwater that may have reduced porosity needed for air exchange in the mass. A temperature history for similar windrows operated during the summer would most likely show higher compost temperature than experienced with this demonstration.

The demonstration experience indicates that a combination of static and machine turned compost processing is suitable for poultry litter combinations with wood chips and sawdust at less than optimal C:N ratios. Winter and wet season composting in uncovered unturned deep static piles on wood chip beds that are converted to machine turned windrows in warmer and dryer months can be recommended.

Compost yield and quality

The dry mass and volume of the ingredients are reduced through composting as a result of the conversion of carbon to carbon dioxide and the reduction of particle size through microbial degradation. The wet mass may not

show a significant reduction because although water is lost to evaporation, water may be gained through rainfall infiltration on compost processed on sites open to the elements. As compost activity and temperature declines at the end of the process there is less air movement through the mass and the compost develops sponge like characteristics with respect to water retention from rainfall.

It is very difficult to measure compost volume and mass reduction on a commercial scale production facility because all of the product cannot be weighed or measured in known volume containers. Additionally, the bulk density and the volume of the compost changes every time it is stacked or unstacked. Therefore, bulk densities of representative samples and volumetric estimates of non uniform piles and windrows must be accepted as indicative of compost yield from a known quantity of ingredients.

Screening compost is necessary for some markets to assure a desired particle size range and remove unwanted wood chips. The effectiveness of a screen is reduced as the moisture content of the compost is increased. Ideal compost moisture for screening is in the 30 to 40 percent water range. Wetter compost forms balls that roll off the screen with the rejects and may clog the screen mesh resulting in less screened compost and more rejected material than with dry composts. The rejected material is not thrown away but is recycled through the compost process with new mixes in place of some of the wood or sawdust. Although the recycled material may reduce some of the new wood product input, the cost of lost saleable product and of the additional processing of already composted material may exceed the value of the new wood not purchased.

The compost of 1995-1996 produced in machine turned windrows started in December as 528 tons and 1,724 cubic yards of material as delivered to the site. By April 1996 the measured windrows held an estimated 800 cubic yards of compost or about 47 percent of the volume of the initial ingredients. The compost had a moisture content of 48 percent water which was too high for effective commercial screening.

The compost of 1996-97 produced in static piles started in October as 192 tons and 400 cubic yards of ingredient material not including the wood chip bed. Mixing the materials reduced the volume to 336 cubic yards divided equally among four piles. By September of 1997 after the piles had been separated from the wood chip bed and shaped to windrows for curing, the measured windrows contained approximately 67 percent of the volume of the initial ingredients. After commercial screening with a 3/4 inch mesh at about 40 percent moisture the compost yield was 33 percent of the volume and 50 percent of the dry weight of the initial ingredients.

The compost of 1996-97 produced in machine turned windrows started in October as 49 tons and 100 cubic yards of ingredients. Mixing the materials reduced the volume to 84 cubic yards. By June 1996 the measured windrows contained approximately 59 percent of the volume of the initial ingredients. Hand screening several samples through a 1/2 inch mesh at approximately 48 percent moisture the compost yield was 39 percent of the volume and 50 percent of the dry weight of the ingredients.

Screened compost can be bagged and sold at higher market value than unscreened compost that is sold in bulk. The rejects from the screen consist of wood and clumps of wet compost that are recycled into a new ingredient mix in place of purchased wood chips. Used in this manner the rejects have economic value. The chip bed retrieved after moving the static piles can also be used in the ingredient mix but not as a new bed. The purpose of the bed is to allow air flow under the pile and used chips are contaminated with small wet particles which reduces the porosity of the bed. Chips for bedding must be clean and uniform and are more expensive to procure than the tree trimmings or chipped pallets used in the ingredient mix.

Compost chemical content

The chemistry of compost is highly dependent on the chemistry of the ingredients used in the initial mix. During composting dry mass is lost through release of carbon dioxide, ammonia and other compounds to the atmosphere. Other elements that are not part of these gaseous products are retained and their concentrations increased in the finished compost. Table III lists the chemical concentrations found in composite samples of the final composts.

Table III. Chemical concentrations in poultry litter compost

constituent	units	turned windrows Dec95	turned windrows Oct96	combined static piles Oct96
H_2O	% wet wt	41	22	42
N	mg/kg dry wt	16,000	10,100	12,600
P	"	27,000	10,500	11,400
K	"	14,000	6,800	8,300
Ca	"	16,000	16,500	20,200
Mg	"	7,000	4,900	4,800
S	"	na	3,100	2,600
Mn	"	490	300	398
Zn	"	550	240	286
Cu	"	300	230	282
conductivity	mmhos/cm	na	5.5	9.26
percent of initial mix by dry weight				
poultry litter	%	45	30	28
sawdust	"	23	20	21
wood chips	"	32	50	51
percent of initial mix by volume				
poultry litter	%	30	25	23
sawdust	"	35	37	38
wood chips	"	35	38	39

NOTES: na means not available
-- Dec95 windrow was started in December of 1995 and finished in May 1996
-- Oct96 windrow was started in October of 1996 and finished in April 1997
-- Oct96 static piles were started in October 1996, mixed in windrows in August 1997 and finished in October 1997

All composts had elevated electrical conductivity above 5 mmhos/cm (a measure of soluble salts). Utilization of the compost in nursery potting mixes requires electrical conductivity between 2 and 3.6 mmhos/cm. Other applications such as field nursery and landscaping where the compost is mixed with soil are more tolerant of the salt levels in the compost because of the mass dilution and eventual salt leaching.

All of the methods of composting demonstrated in this project produced compost of similar quality when similar ingredient recipes were used. Even the December 1995 compost that used different proportions of ingredients and was mixed and managed with uncertainty produced a product similar to the October 1996 compost. Differences in chemical data may be a result of mixing and sampling variations. It can be concluded that with the materials and methods used, the compost process is very forgiving if the basic conditions of porosity, nutrient and moisture balance are established.

Production costs

Time and motion were measured during the mixing, pile building and turning processes (Table IV). The total time required was proportional to the number of steps required. Windrows for machine turning were made almost twice as rapidly as static piles and slightly less than three times faster than passively aerated static piles covered with compost. However, the times recorded are dependent on the configuration of the site and distances between locations of materials moved as well as the skill of the operator and the capacity of the bucket.

Table IV. Times for processing compost at the demonstration site

operation	static pile	static pile compost covered	passively aerated pile compost covered	passively aerated pile	machine turned windrow
making compost mixes and piles		100 cubic yards of ingredients			
lay pipe - minutes	0	0	15	15	0
place chip bed - minutes	24	24	24	24	0
get ingredients - minutes	55	55	55	55	55
mixing with turner - minutes	10	10	10	10	10
place mix in pile - minutes	40	40	40	40	0
cover with compost - minutes	0	12	0	12	0
total time - minutes	129	141	144	156	65
time - minutes/cubic yard	1.3	1.4	1.4	1.6	0.7
cubic yards/hour	47	43	42	38	92
turning piles minutes/event	20	20	20	20	6
making curing windrows minutes/pile	40	40	40	40	30
turning curing windrows minutes/event					35
screening cubic yards/minute					1.1

The time and motion information was used to develop the operational costs for producing compost to compare the use of static piles and turned windrows. A summary is shown in Table V. The comparison only includes the actual machine and labor time and space costs based on 100 cubic yards of material mixed. This operational cost is somewhat independent of the total mass and was not considered responsive to economies of scale. The additional costs of machine maintenance and ownership, profit return to management, and other overhead items associated with the business were not included in this comparison. These additional costs are responsive to economies of scale and their analysis is beyond the scope of this project.

The processes used for static pile 1a were compared with the machine turned windrow. The use of compost covers, passive aeration and multiple turnings for the static pile were considered of no advantage for improving process time or compost quality. The machine turned windrow required slightly more operational cost than the static pile because of the number of turnings required of the process. However, the static piles required more ingredient cost because of the wood chip bed even when given credit for use of recycled chips. Screening adds operational cost but also reduces finished compost volume by half or more. Although the screen rejects are given credit for being recycled the loss of finished compost exceeds the value of new ingredients. A complicating factor not included here is the value of the screened compost as compared to the unscreened compost. In this example, screened compost would have to be sold for slightly less than twice the price of unscreened compost to make up for the cost of screening.

The cost of ingredients represented 60 to 70 percent of the cost of producing compost in this demonstration. The charge for wood chips and sawdust was equal at $10 per ton. However, depending on the supply of wood residuals there are periods of the year when sawdust or chips may arrive at the site for more or less than $10. In the spring of 1998 the cost of available wood products reached $20 per ton. Wood is usually not available in rural areas of Maryland because residuals from tree trimming, land clearing and other operations are rarely moved from the place of origination and may be left to rot or are burned. The project utilized wood chips that were generated in the metropolitan region approximately 90 miles from the compost site. Looking for wood is a constant exercise of compost management.

Table V. Compost production cost summary

type of compost (100 cubic yard batches)		screened		unscreened	
		static pile	machine windrow	static pile	machine windrow
required time days		350	185	350	185
litter processed tons		13	14	13	14
compost produced tons		22	26	44	39
compost produced cubic yards		34	39	67	59
ingredient cost					
litter	$	130	142	131	142
sawdust	$	149	147	151	147
chips in mix	$	200	197	203	197
chip bed	$	284	0	284	0
chips recycled value	$	(320)	(102)	(144)	0
net cost of ingredients	$	444	384	624	486
operations cost					
loader use	$	80	51	48	33
turner use	$	15	92	15	92
screen use	$	65	57	0	0
energy cost	$	24	28	14	21
site rent	$	11	7	11	7
sample analysis cost	$	40	40	40	40
record keeping cost	$	50	53	50	53
total cost of operations	$	235	275	127	194
total cost of ingredients and operations	$	729	712	802	733
cost of compost production $ per unit of finished compost					
$ per ton		33	28	18	19
$ per cubic yard		22	18	12	12
cost of processing $ per ton of litter used		56	50	61	52

NOTE: Costs are based on a $ per unit time charge for labor, equipment and space and do not consider aspects of ownership and profit which may be affected by the volume of material processed. Compost cost is very sensitive to material yield. The windrow turning machine was used to mix ingredients for the static pile.

The cost of poultry litter was also $10 per ton. Farmers consider poultry litter a tradable fertilizer commodity rather than a waste product. Unlike urban compost operations that can collect tipping fees for incoming wastes, poultry litter composters have to buy the waste. This condition may change if and when government places restrictions on the land application of poultry litter. Use restrictions will reduce the value of the litter and improve the economic situation for composters.

Compost production scenarios

Problems with developing a business to compost poultry litter include but are not limited to the logistics and cost of obtaining ingredient material, actual and perceived environmental impacts of large processing sites and biosecurity. The poultry industry is very concerned about the potential spread of bird disease through the movement of litter carrying trucks moving between farms. All activities must be accomplished with biosecurity in the forefront if composting is to become a viable business.

It is evident from the demonstration project that an advisable scenario would be to mix and static pile compost poultry litter on the farm which produced the litter. After 200 or more days the static pile would be turned. After

an additional 30 days the compost could be removed to a regional processing facility for blending with compost from other farms, curing, screening and preparation for sale.

This scenario could be accomplished by a compost company utilizing trucks, bucket loaders and portable ingredient mixing equipment. Farm to farm traffic could be minimized and biosecurity measures could be controlled by the compost company. Only composted poultry litter would be removed from the farm and the regional processing facility would handle only composted products which would minimize environmental and biosecurity impact.

The production costs developed in this study require adjustment to account for the conditions of the on-farm composting agreements. Adjustments would be based on whether the farmer or the compost contractor is responsible for supplying ingredients, equipment, manpower, and transportation.

SUMMARY

The composting of approximately 2,200 cubic yards of materials from 1995 to 1997 on a commercial scale demonstrated the production of poultry litter compost using turned windrows and static piles. The compost produced had similar qualities regardless of the technology applied when similar ingredient mixes were used. A static pile consisting of poultry litter, wood chips and sawdust with an initial mixture moisture content of 42% placed on a wood chip bed produced desirable process temperature with one turning after 260 days. Process variations including covering the static pile with a layer of mature compost, installing pipes for passive aeration and earlier and more frequent turning did not appear to significantly improve the process. Machine turned windrow processing allowed the production of compost in less than half the time required of static pile composting. The volume of compost produced before screening ranged from 50 to 67 percent of the volume of the initial ingredients. Screening reduced the compost yield to 30 to 40 percent of the ingredient volume. Screen rejects are recycled through new compost. The operational cost of static and turned windrows was similar on a per unit of compost produced basis which averaged $20 per cubic yard of compost screened and $12 per cubic yard unscreened. Ingredients accounted for 60 to 70 percent of the production cost. A combination of on-farm static pile composting and regional center processing for marketing may be a commercially viable enterprise. Good quality compost can be produced for field nursery and landscape use with static piles and/or machine turned windrows at a cost that can be marginally covered by the sale of the compost.

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TESTING OF AN IN-HOUSE LAYER MANURE COMPOSTING SYSTEM UNDER FIELD CONDITIONS

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Abstract: Many of the problems that have currently beset the commercial egg layer industry have arisen because of methods of handling the manure output from large flocks. Alternative techniques for handling of animal manure within animal production facilities will need to be developed to satisfy current and future zoning and environmental criteria placed on these types of operations. This paper discusses tests conducted in a commercial high-rise layer house involving an in-house deep litter manure management system. This involves layers at commercial densities, depositing their manure onto stacked litter materials located directly beneath the cages. Regular turning of the litter facilitates composting within the layer house resulting in a reduction of manure volume and weight.

Keywords: In-House Composting, Commercial Layers, Manure

INTRODUCTION

Animal agriculture is facing more problems today than just those associated with the proper care and feeding of animals to maximize production. Producers are having to deal with both state and federal regulations involving the manner and rate at which they dispose of their waste materials, potential litigation involving "good neighbor" practices associated with insect control and odor problems, zoning problems as subdivisions and cities encroach on farm lands and even the question in some states of farmers "right to farm."

Senator Tom Harkin (D-Iowa), ranking member of the Senate Agricultural Committee, proposed a bill in the current congress. The requirements of this bill included that: 1) integrated animal production companies will be responsible for all animal manures in an environmentally sound manner, 2) nutrient management plans for animal manures will have both nitrogen and phosphorus application requirements, and 3) strong Civil penalties will be levied against producers and persons violating the requirements of this act. While this bill was introduced late in the congressional session and did not make it out of committee, animal agriculture can expect that in future sessions similar legislation will be proposed and perhaps even passed.

Odor and insect control are becoming critical parameters in the design of animal production facilities. A large Alabama egg producer using a manure scrape system is involved in litigation because of complaints from neighbors caused by fly and odor problems. The neighbors are demanding that this poultry operation, containing 600,000 layers be closed. Much of the portion of the 1993 North Carolina state legislative session that was devoted to environmental issues was taken up with matters of odor abatement (Williams and Schiffman, 1996). Effective January 1, 1997, all waste management plans in North Carolina for animal facilities must include provisions for odor and insect control (Crouse, 1997). Animal agriculture is going to have to adopt more of a "good neighbor" policy in the future by controlling on-site odor and insect problems (Arends, 1996).

Alternative waste management systems are being investigated to alleviate producers of problems associated with manure production. Kauffmann (1997) reported on a deep-litter fermentation system for fattening pigs, in which sawdust was used as a ground cover in place of straw. An optimum depth of sawdust of 45 to 50 cm was found to be better than conventional ground covers such as wood chips or straw. The bedding material was turned every two weeks with no detrimental effects on biological activity. The dry bedding product had a final nitrogen content less than that normally observed with slurries. This was believed caused by a release of ammonia from the deep-bed material while in the house.

Many of the problems that have currently beset the commercial layer industry have arisen because of methods of handling the manure output from large flocks. While the egg industry is not necessarily at fault for all of the problems associated with disposal of animal manures, it is becoming increasingly important that better ways to manage layer manure be developed

and adopted. This paper will discuss an in-house layer manure management system which has been tested both under controlled conditions at the UGA Poultry Farm and currently in a production layer house. This paper will discuss how the system works and some of the effects observed in using such a system.

MATERIALS AND METHODS

Tests were conducted in a 100,000 hen capacity, curtain-sided, high-rise commercial layer house located in south Georgia, to determine if an in-house compost system would work under commercial conditions. The test house was chosen because of its concrete floor within the manure area which helped in using the mobile compost turner. Tests were started on October 28, 1997 and concluded on July 1, 1998.

The commercial layer house was approximately 150 m long by 12 m wide. Forty meter long sections of 0.12, 0.25 and 0.38 m deep piles of pine shavings, approximately 1.5 m wide, were initially placed beneath the cage rows so that the birds could directly deposit their manure onto the shavings. On a regular basis the piles were turned to incorporate any newly deposited manure material into the shaving manure mixture. Tests were conducted in only a portion of the house so that comparisons could be made between the test area and comparable areas under normal management. The birds were White Leghorns. The manure was deposited on the shavings at the rate of 0.017 m^2/bird. The commercial layer house was equipped with adjustable curtains which could be raised and lowered, and depended almost entirely on natural ventilation within the area containing the manure. During the Winter months (approximately November to April) the curtains were almost completely raised providing only minimal ventilation within the manure area.

The composting material was turned at two-week intervals using a mobile compost turner built by Farmer Automatic of Register, GA. The turner is a prototype model built specifically for these experiments and is not commercially available. The mobile compost turner is approximately 2 meters wide, 1.3 m tall and 2 m long and uses a gasoline powered engine. The compost turner was equipped such that the depth at which the tines on the turner operated could be adjusted. During the turning process the curtains were lowered to provide ventilation within the manure area. It is believed that growers would be less likely to use such a manure management system if the turning procedure needs to be done more often than once every two weeks.

Data Collection:

Gases:

Ammonia (NH_3), carbon dioxide (CO_2) and hydrogen sulfide (H_2S) was monitored every six weeks before, during and after turning of the litter material. Gases were sampled using a Matheson Toxic Gas Detector Model 8014K. Gases were sampled, prior to turning of the litter, at the four corners of the test area and in the center of the test area to determine the background gases within this region. Gases were also sampled in the middle of the house and within the cage area above the center of the test area and in the middle of the house. During the turning process, ammonia was sampled next to the turner where the operator would stand, at the rear end of the turner where the material exits the machine and then 5 m behind the machine to determine its zone of influence.

Nutrients:

Analytical sampling of the litter was performed every two months to determine the concentration of N, P, K and trace minerals. Grab samples were taken from different points within the piles to determine the nutrient concentration of the material.

Compost Temperature and Moisture:

Temperature measurements were taken every two weeks prior to turning of the litter. Temperature measurements were taken using thermocouple probes placed at different locations within the 0.12 m, 0.25 m, 0.37 m and raw manure piles. At two other times (during cold weather conditions and warm weather conditions) continuous temperature measurements (one hour sampling rate) were taken using an OM-5000 Omega data logger to determine the temperatures of the piles during the two-week turning cycle.

Pile Volumes and Manure Accumulation:

The volumes of the compost piles were monitored by measuring the cross profile of the compost on a monthly basis. Cross profiles were taken after turning of the compost at two different locations within each row. Manure accumulation by weight

was monitored every two months by cross-sectioning and weighing a 0.41 m length cut of each compost pile. Cuts were made at two different locations within the compost row. The material volumes and weights were compared to the buildup of manure within a layer line of raw manure.

Flies:
The compost was examined for the presence and density of fly larvae, pupae and pupae castings. Sheet metal pans were placed at the base of each pile to determine if the migration of fly pupae from the compost piles and the raw manure could be monitored. The fly population within the house was not monitored since the test area only covered a portion of the house and there would not be a way of knowing where in the house the flies came from and what generated them.

RESULTS AND DISCUSSION:

Figure 1, shows the cross-section profile of the raw manure over the first 181 days of testing. On day one of these tests the house was cleaned of all manure within the test area. As would be expected the pile grew according to the manner in which the manure was deposited by the birds and stacked. Drop boards exist on the cage battery system above and some manure piled on the drop boards prior to being deposited in the area below. This might explain some of the variation in the shape of the pile. This raw manure pile occupies almost the entire width of the bay within which the material is contained and the width of the pile is wider than that of the cage battery system above. In this pile the raw manure forms a thin fragile crust on the top and remains fairly wet within the central regions of the pile. The odor of the raw manure is the typical putrid, septic smell normally associated with layer manure.

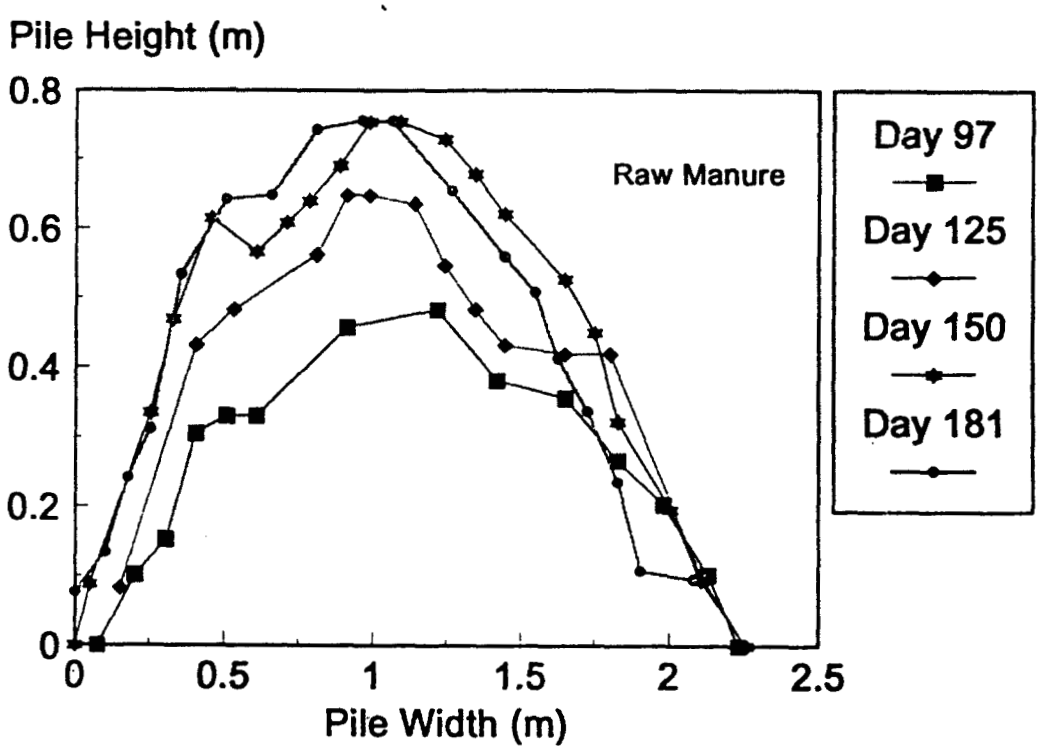


Figure 1. Cross section profiles of the raw manure pile over 181 days of testing within the commercial layer house.

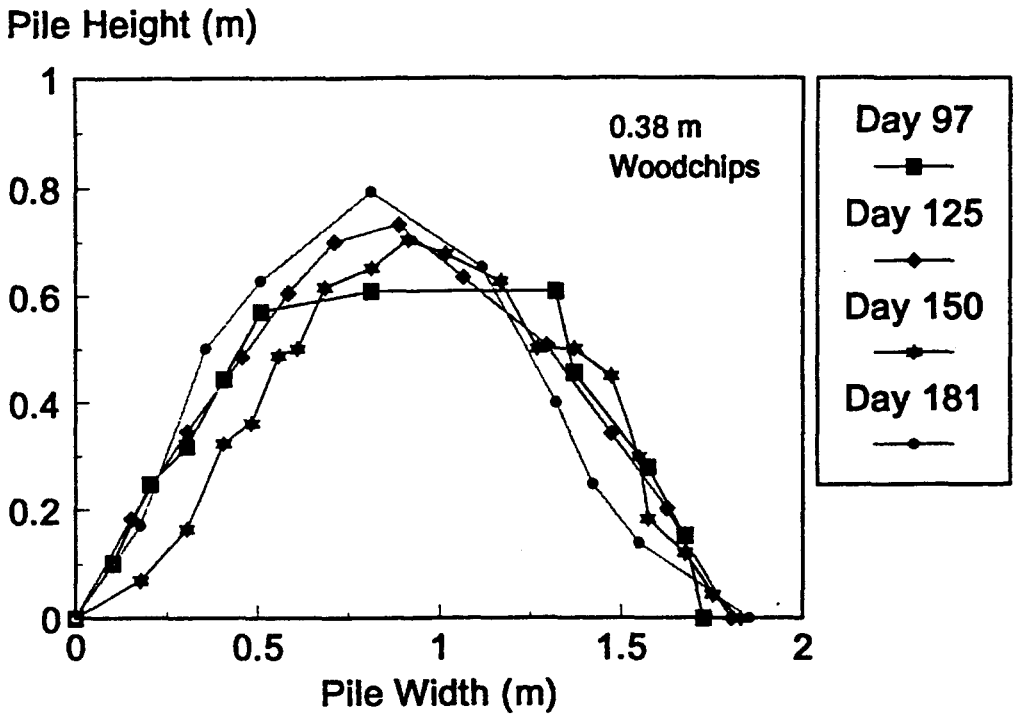


Figure 2. Cross-section profiles of the 0.38 m woodchips and manure over the first 181 days of testing within the commercial layer house.

In Figure 2, is shown the cross-section profile of the 0.38 m woodchip treatment over the first 181 days of testing. On day one of these tests a bed of woodchips 0.38 m tall and approximately 1.5 m wide was placed on the floor of the house. Since that time the manure from the birds located above was deposited onto the woodchips and then incorporated together using a mechanical turner which turned the material every two weeks. The cross-section profile above was measured after turning of the pile. The shape of the pile was formed by the mechanical turner as the compost material exits the machine. Very little variation in pile shape can be observed over the entire 40 m length of the test area. Only in those areas which were affected by excess water was the pile shape any different. In those regions the pile sides were much more steep and sometimes formed a vertical face caused by compression of the wet material against the interior sidewalls of the turner. The pile is slightly wider than the exit dimensions of the turner mechanism in that material sluffs off the slopes of the pile after it leaves the machine. Between turnings, this pile retains its approximate shape throughout the entire two-week cycle, with only a slight increase in width from material sliding down the pile slopes. This pile is approximately the same width as the cage battery system above. The turned material does not have the septic odor typical of the raw manure.

In Figure 3 is shown a comparison of the cross-section profile of the 0.38 m woodchip treatment and the raw manure pile after 208 days of testing. The woodchip manure mixture is obviously narrower and shorter than the raw manure. The 0.38 m woodchip pile has retained the same approximate dimensions as those observed after 181 days of testing while the raw manure continued to increase both in height and width. The woodchip pile originally started with 0.18 m^3 of woodchips per meter length of pile and after 208 days has increased in volume by only 41%. This figure shows the volumetric reduction which can be achieved using the in-house manure composting system. For this treatment a 34.5% reduction in volume was observed over that of the raw manure. If the whole house was littered, and a similar volumetric reduction was obtained, this would represent over 328 m^3 (11,600 ft^3) less material which would need to be removed by the grower during clean out operations.

In Figure 4 is shown the pile volume for each treatment over the first 208 days of testing. On day 208 the raw manure had the largest pile volume, followed by the 0.12 m, the 0.38 m and the 0.25 m woodchip treatments. The volume of the 0.25 m treatment and the 0.38 m treatment piles were approximately the same between days 100 and days 208. Many of the properties (volume, moisture contents, pile temperatures, and nutrient density) were similar for these two treatments

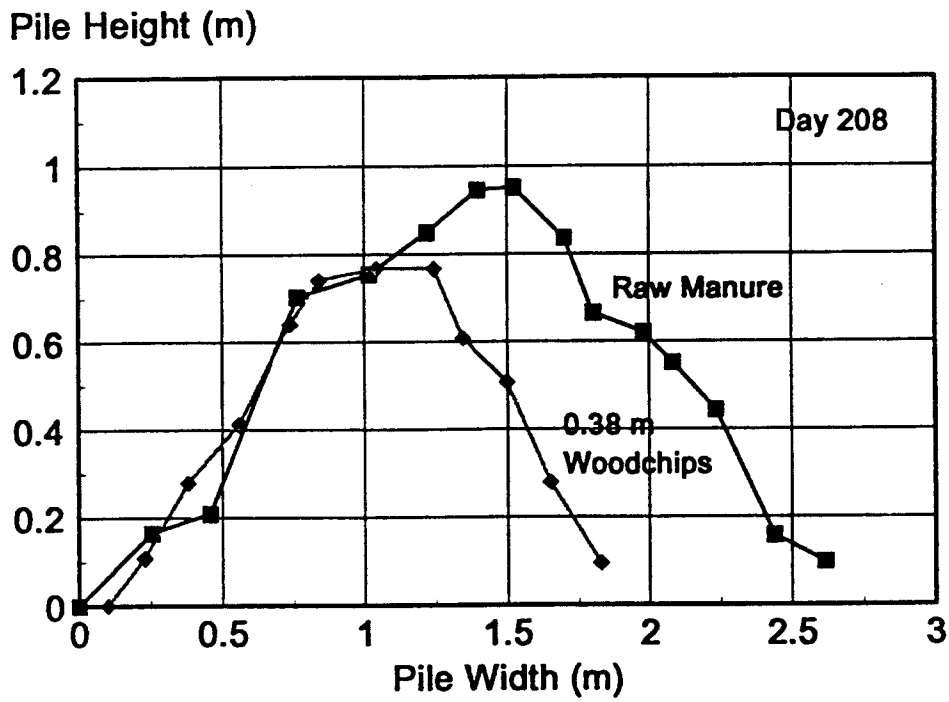
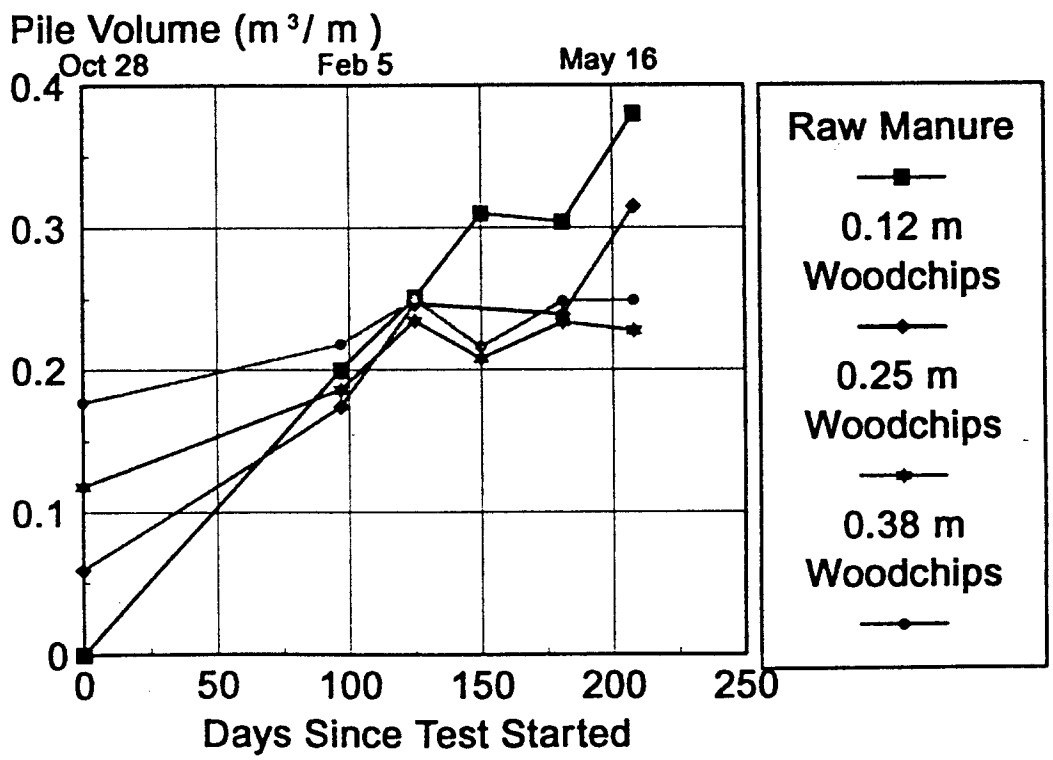


Figure 3. Comparison of the cross-sectional profile of the 0.38 m woodchip manure compost and the raw manure after 208 days of testing.

Figure 4. Volume per meter length of pile of the raw manure and the three woodchips treatments after 208 days of testing.



throughout this experiment. It appears that both the 0.25 m and 0.38 m depths were sufficient to allow composting to occur at this bird density and manure deposition rate over the duration of these experiments.

It is believed that more composting would have occurred and an even greater reduction in volume could have occurred in both the 0.25 m and 0.38 m treatments if the mechanical turner had been equipped with a larger engine. Because of power limitations, the tines of the turner could not be set at a depth nearest the floor. Therefore, not all of the woodchips were incorporated into the woodchip manure mixture for composting. However, the machine was a prototype model and at the beginning of these experiments the power requirements for such a system were not known.

Over parts of the 0.12 m woodchip pile leaking drinkers cause sections to become overly wet, which made this treatment difficult to turn with the mechanical turner. However, even in portions of the pile where moisture was not a problem it appeared that moisture from the deposited manure was building up within the pile and hindering the composting action. This pile was no longer turned after approximately the 125th day of these experiments. It appears that at this bird density and manure deposition rate this depth of woodchips is too shallow to allow the composting process to occur over a long period of time. For the 0.12 m woodchip manure mixture no volume measurements were taken on day 150, however, volume measurements for this pile was taken on both day 181 and day 208. Between day 181 and day 208 the volume of the 0.12 m woodchip pile and the raw manure pile increased the same amount. At this point in the experiment the 0.12 m woodchip pile treatment was not being turned and it performed in much the same way as the raw manure.

Between day 125 and day 181 the volume measurements decreased or stayed approximately the same for all treatments. During this time the weather changed and the curtains were lowered, providing much more ventilation within this region of the house. This would have allowed additional drying to occur. The birds were also molted during this time period. Induced molting of the birds involves an extended period of feed withdrawal (up to two weeks) followed by a period of another two weeks in which feed consumption is less than that of hens in production. This would have caused a decrease in manure volume output during this time period.

It is believed that one of the advantages of the in-house manure composting system is that it could be used over long periods of time because of the reduction in manure volume, thus extending the time between clean out. Based on these experiments no volumetric savings would occur using the in-house composting system if composting occurred for less than 70 days using the 0.12 m treatment, 90 days using the 0.25 m treatment and 125 days using the 0.38 m treatment. However, this manure management system could also be used over short periods of time, such as during Winter months, if desired. While short composting periods would only provide small reduction in volume, the woodchip manure compost would be much drier, easier to handle and have fewer objective odors than that of the raw manure, even over the short term.

In Figure 5 is shown the pile mass of the raw manure and the woodchip treatments over 208 days of testing. The pile mass is an estimate of the total mass of each pile over the 40 m test length. These estimates are based on data collected by cutting the pile (0.41 m cuts) at two different locations and weighing all the material contained within the pile across the cross-section. These tests were conducted on days 55, 125, 181 and 208. On day 208 the 0.12 m woodchip treatment was not weighed, since this pile was no longer being turned using the mechanical turner. The weight of the 0.25 m and 0.38 m woodchip treatments have been very similar throughout the experiment and were approximately the same on day 208. The weight of the raw manure has been higher than either of these two treatments since day 125. On day 208, a 24% reduction in weight on average was observed for these two treatments over the raw manure. If the whole house was littered and a similar reduction in weight was observed throughout the house, this reduction in manure weight would represent 188 metric tons less material which would need to be removed by the grower during clean out operations.

In Figure 6 is shown the manure mass and the percent reduction in the raw manure and the three woodchip treatments after 208 days of testing. The total amount of manure is the total weight of manure which was added to each pile over the 208 days of testing. This amount was determined by multiplying the average amount of manure produced by a layer per day by the number of birds by the number of days of testing. For the three woodchip treatments the total amount of manure also included the weight of the woodchips used in each treatment. For the raw manure, a 47.4% reduction in manure mass was observed during this test period while for the 0.25 m and the 0.38 m treatments, reductions of 63.9% and 68.5% were observed, respectively. This reduction in mass is believed caused by drying of the material as well as decomposition of the organics within the manure woodchip mixture. Patterson (1994) reported, after long-term manure storage in fan ventilated high-rise commercial layer houses, losses in manure mass consistent with a presumed loss of 50% or more in volume. While

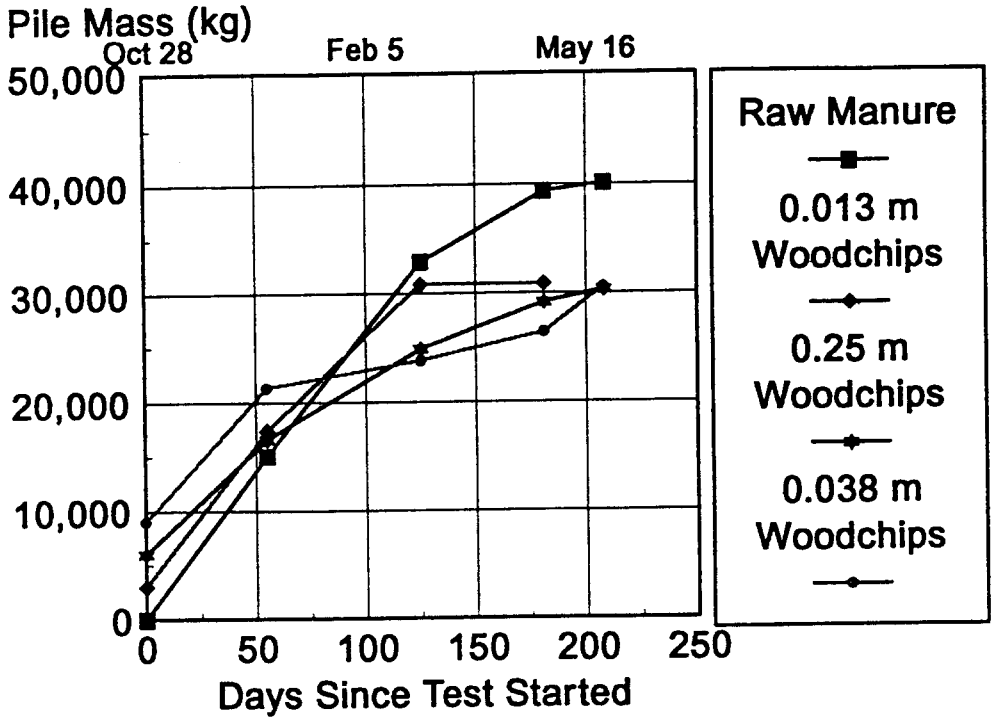
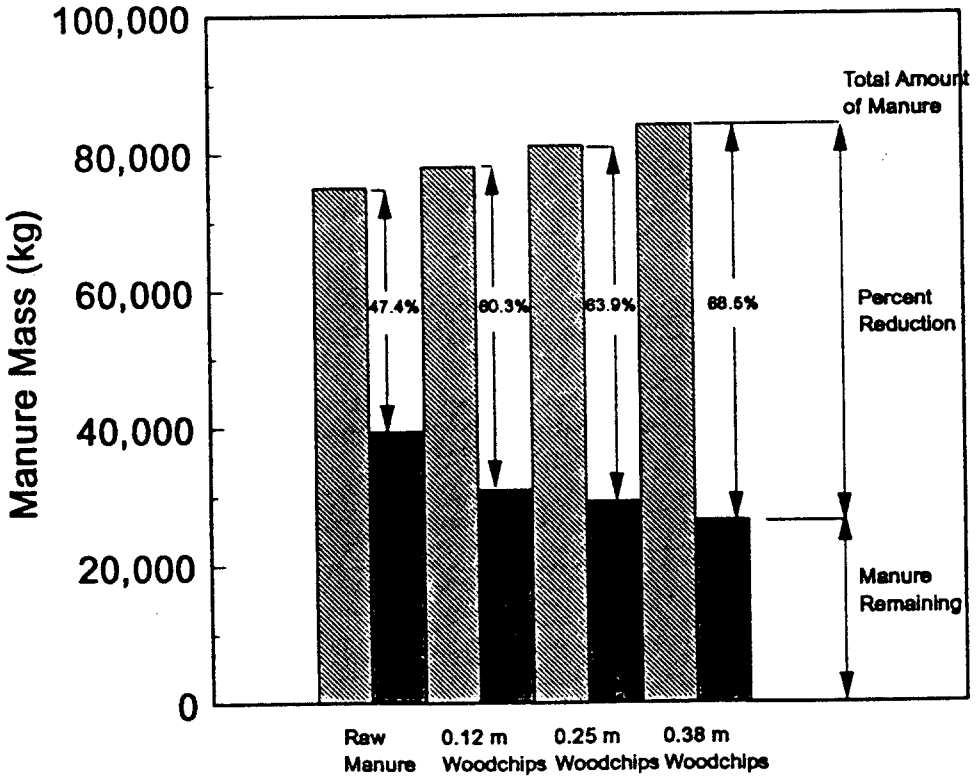


Figure 5. Pile mass of the raw manure and the three woodchip treatments after 208 days of testing.

Figure 6. Percent reduction in manure mass of the raw manure and the three woodchip treatments after 208 days of testing.



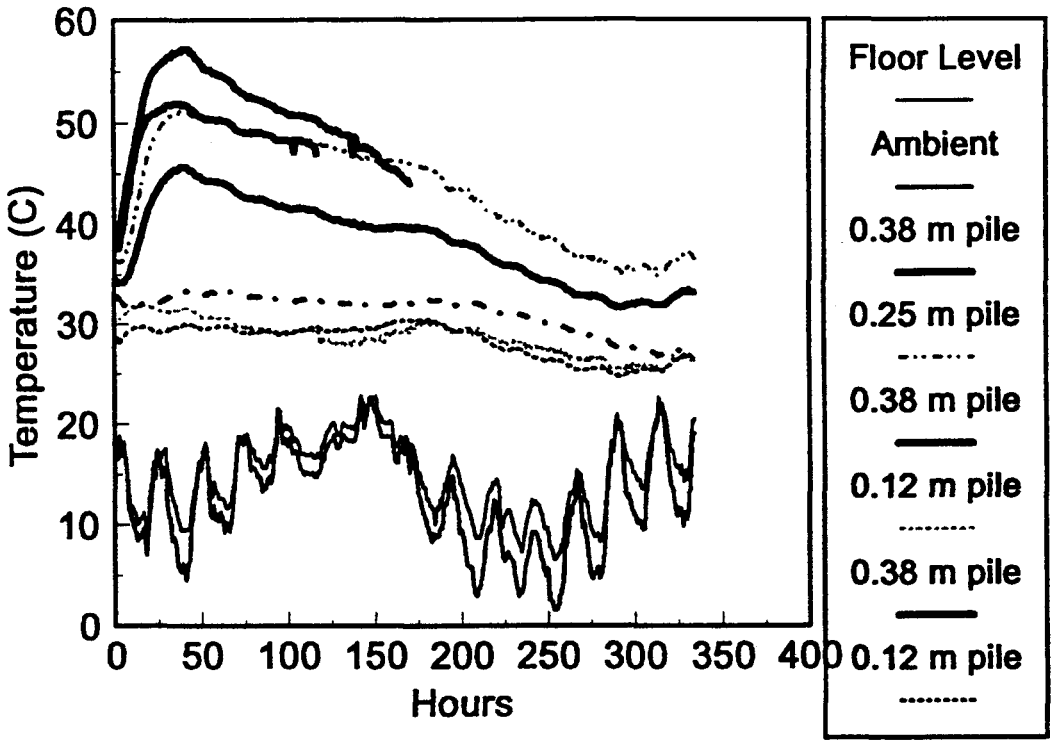


Figure 7. Temperatures within the layer house and the treatment piles between March 2 and March 16, 1998.

Patterson did not actually calculate any reduction in weight, this 47.4% loss in manure weight would correspond well with that reported by Patterson. It should be expected, since only natural ventilation was used in the house in this study, a somewhat smaller amount of manure reduction would be observed.

In Figure 7 are shown the temperatures measured within the layer house over a two-week cycle between March 2 and March 16, 1998. Temperature measurements were taken on an hourly basis using thermocouples placed in the manure treatments and throughout the house. Hour zero represents the time immediately after turning of the woochip piles by the mechanical turner, while hour 340 would be the time just prior to the next turning Two thermocouples failed during these experiments, therefore, the temperatures plots for these two thermocouples do not extend over the entire time period. Ambient (approximately 2 m above floor level) and floor temperatures were measured in the manure storage area and are shown in the figure as the two lowest curves within the figure. Ambient temperatures ranged between approximately 0 and 20 °C over this time period. Temperatures above 45 °C, which would be sufficient for composting (Haug, 1993), were observed to occur in both the 0.25 m and 0.38 m compost, while temperatures in the 0.12 m woodchip treatment remained at approximately 30 °C throughout this time period. Temperatures of the 0.12 m pile were by this time in the experiment not that much different than that of the raw manure. The low temperatures observed in the 0.12 m pile were believed caused by the high moisture content of the material which were greater than those normally associated with good composting conditions. In regions within the 0.25 m and 0.38 m piles where excess moisture existed, caused by leaking drinkers, very little increase in pile temperature was observed after turning. This manure management system is very moisture sensitive, as are other composting systems, and if a grower cannot control drinker problems within a house then this system should probably not be considered.

Ammonia (NH_3), carbon dioxide (CO_2) and hydrogen sulfide (H_2S) was monitored before, during and after turning of the material. It was difficult to get an accurate estimate of the zone of influence which turning had on the gas concentrations

within the house, since this house depends on natural ventilation within the downstairs manure storage area. Because of this, wind direction plays an important part in how the gases disperse within the house. Gas measurements were made before turning, during the Winter months, with the sidewall curtains raised. Turning of the litter treatments was always performed with the sidewall curtains lowered. Concentrations of H_2S were negligible throughout the house during these experiments. The only time when noticeable values of H_2S occurred was when the machine became bogged down during the turning process in regions in which moisture had been a problem. CO_2 concentrations were measured on the outer borders of the test region and also in the upstairs of the house. With the curtains raised average CO_2 concentrations of 800 to 900 ppm were measured in the manure storage area of the house, with a maximum CO_2 concentration within this region of 1500 ppm. In the upstairs of the house, where the birds were caged, CO_2 concentrations were very similar to those measured downstairs with a maximum CO_2 concentration of 1400 ppm. Before turning, background levels of NH_3 were measured in the manure storage area with the curtains raised. In the manure storage area of this house background concentrations of ammonia of from 5 to 47 ppm were measured in the test area with the curtains raised. These tests were conducted on one end of the house. At the very end of the house very little ventilation occurred and the concentration of background NH_3 were normally higher in this region than in the center of the house. In the upstairs portion of the house background concentrations of NH_3 were not greater than 10 ppm. NH_3 was noticeable during the turning process with a maximum concentration of 400 ppm observed during January (day 69) of these experiments. On that same day concentrations of NH_3 of 68 ppm were measured 5 m behind the turner. Between days 97 and 208 of these experiments the concentration of NH_3 has not reached levels comparable to those observed in January. As the manure accumulated within the house the speed at which the mechanical turner could move through the piles decreased. Under ideal conditions the machine could go as fast as 1.5 m per minute on day 208 (May 24) while in January with little accumulated manure the turner was moving through the pile at speeds almost twice that fast. During the early parts of this experiment the tines of the turner were also operating as close to the floor as possible. The concentration of ammonia might be related to the operation of the machine and to these two parameters. However, the concentration of NH_3 measured during turning could also be influenced by the properties of the compost, which may have changed over this time period. While NH_3 was noticeable during the turning process around the machine, after the turning process was completed enough ventilation existed within the manure area such that the concentration of NH_3 returned to its background level shortly thereafter. This was similar to experiments performed under controlled conditions at the UGA Poultry Farm. In totally enclosed conditions in which ventilation fans were used, the concentration of NH_3 returned to approximately that of the background concentration 5 to 10 minutes after turning was completed.

Fly pans were placed at the base of each pile to determine if some fly control was provided by the compost treatments. Analysis of the material collected from the pans has not yet been done. Based on the temperatures measured during the two-week cycle, temperatures were achieved which should kill any fly eggs which were mixed back into the piles during the turning process. It is believed that some fly control is achieved by using this system, however, this has not been experimentally determined at this time. During the latter stages of these experiments, large quantities of darkling beetles were observed on the surface of the woodchip litter treatments after turning. The beetles were assumed to live in the piles. However, it is not known if these treatments provide an environment conducive for the beetles to live within and some control should be provided, or if they just live on or near the surface of the piles where the fresh manure is deposited and the turning process brings them to the surface.

In Table 1 is shown the nutrient density of the raw manure and the three different woodchip treatments after 181 days of testing. Also shown is the nutrient density for a manure and leaf compost made from yard wastes. Turning of the 0.12 m woodchip and manure mixture had ceased by this time and the moisture content of this treatment was much higher than either the 0.25 m or 0.38 m treatments. By in-house composting the product will leave the house with a dry basis nutrient density of approximately 2% N, 8% P_2O_5 and 4% K_2O. This product is much like that of the manure and leaf compost with very little odor and improved handling properties over that of the raw manure. Patterson (1994) reported the nutrient density of commercial layer manure for samples taken from a 8 different flocks of birds, housed in fan-ventilated commercial layer houses, during long term manure storage. Values for samples reported to have a high and low nutrient density are shown in Table 2. The values reported in this experiment are between those reported by Patterson for high and low nutrient density, with the percent N closer to those reported for the low sample while the percent P_2O_5 and K_2O were more towards the middle of the reported range. Patterson reported that the variation in nutrient density of layer manure could be traced to the age of the birds, bird diet and the management of the waste materials. While the nutrient density of the raw layer manure and the woodchip treatments are not significantly different, the moisture content of the raw manure is much higher than that of any of the other treatments. Obviously, this decrease in moisture content within the 3 woodchip treatments is related to the decrease in manure weight and manure volume which were previously reported in this study.

SUMMARY

The in-house composting system under commercial conditions produced a significant reduction in both weight and manure volume over conventional methods in which the manure is only stacked under the house. A 34.5% reduction in manure volume was observed in the 0.38 m woodchip treatment when compared to raw manure. This particular treatment started with 0.18 m^3 of woodchips and increased in volume by only 41% over 208 days of testing. Both the 0.25 m and 0.38 m woodchip treatment showed a significant reduction in manure weight with a 24% reduction in weight on average when compared to the raw manure. The 0.12 m woodchip treatment does not appear to provide enough carbon source to keep the compost process working over a long period of time. For this particular treatment tests were only conducted over less than 125 days because of excessive moisture in the manure deposited by the birds and leaking waterers within the cage system. The success of this system is dependent on the control of water, therefore, monitoring of the drinking system by the grower for leaking drinkers must be done on a regular basis. The woodchips layer manure mixture has many of the same properties as a leaf manure compost. The layer manure compost has a dry basis nutrient density of approximately 2% N, 8% P_2O_5 and 4%K_2O. From a material standpoint, the composted material is an improvement over that of raw layer manure, in that it has a decreased moisture content, improved handling properties and less odor.Gas concentrations of ammonia, carbon dioxide and hydrogen sulfide were monitored. Levels of carbon dioxide were not excessive and hydrogen sulfide was not detected, except where particularly wet section of manure compost was encountered during turning. Ammonia was much more noticeable during the in-house composting process. . During the actual turning of the litter ammonia was noticeable adjacent to and sometimes 5 m behind the machine. However, the zone of influence of the machine was difficult to determine since the area within which the manure was stored was ventilated using natural ventilation. During the early stages of this experiment the concentration of ammonia was higher. This may be related to the speed at which the turner moved through the piles as well as the properties of the compost during these early stages. However, as the compost matured the level of ammonia produced during turning appeared to decrease. After turning, the concentration of ammonia decreased quickly to that of the background levels.

Table 1. Nutrient density of the manure and compost after 181 days (Oct. 28 to April 27) of testing.

	N	P_2O_5 (%db)	K_2O	M.C. (%wb)
Manure and Leaf Compost	1.7	7.5	4.2	41.2
Raw Layer Manure	1.8	8.1	3.5	69.0
0.12 m Woodchips and Manure	1.9	8.5	3.7	57.7
0.25 m Woodchips and Manure	2.1	8.3	3.6	49.0
0.38 m Woodchips and Manure	2.0	8.6	3.5	46.7

Table 2. Nutrient density of layer manure. (Patterson, 1994).

	N	P_2O_5 (%db)	K_2O
High Nutrient Density	9.42	11.73	5.72
Low Nutrient Density	1.98	3.71	2.16

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EVALUATION OF TECHNIQUES FOR MEASURING AIR FILLED POROSITY IN COMPOSTS OF MUNICIPAL BIOSOLIDS AND WOOD CHIPS

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ABSTRACT

Air filled porosity, or free air space (FAS), is a fundamental operating parameter of aerobic composting and is a generally accepted measure of the amount of air contained in a compost material. Lack of an adequate FAS can cause anaerobic conditions and lead to prolonged composting time and/or incomplete and unsuccessful composting. Previous studies have found the optimal range of air filled pore volume to be between 30 and 60 percent of the total system volume (Annan, 1998).

As part of this study, samples of compost were tested for FAS content by three direct-measurement techniques: the water pycnometer, a water saturation and draining method, and the air pycnometer. These results were statistically compared to each other and to two formulaic methods for calculating FAS found in the literature: an equation proposed by Schulze (1962) and a fundamental air filled porosity equation common to soil science and promoted for composting applications by Haug (1993).

The results produced by the water pycnometer and air pycnometer were similar, though not statistically identical, and compared well with values generated by the air porosity formula promoted by Haug (1993). The water saturation and draining method and the formula first proposed by Schulze (1962) followed another trend, generally producing disparately lower values of FAS for almost all the mixtures examined.

Based on derivation of weight-volume relationships, the air porosity equation suggested by Schulze (1962) is incorrectly derived, and was found to produce dubious results. Study results also indicate that as a technique for measuring total air-filled pore space in composts, the water saturation and draining procedure is fundamentally flawed and should not be used as a best practice. Based on study results, the air pycnometer, water pycnometer, and the air porosity equation promoted by Haug (1993) are recommended as best practice techniques for measuring compost air porosity. The air pycnometer is proposed to be the method of choice because; 1) it is a simple, repeatable, and quick method, and 2) it more accurately measures the numerous small pore spaces found in any compost sample.

INTRODUCTION

Air filled porosity, or free air space (FAS), is defined as the ratio of gas filled pore volume to total sample volume. Adequate air spaces are needed to provide oxygen to aerobic bacteria, and insufficient FAS can prolong the composting period and may lead to anaerobic conditions. Air spaces and channels also allow mixtures a degree of cooling. As air diffuses through open voids within a compost pile, it carries away excess heat to the open atmosphere.

The presence of air voids in a compost mixture helps explain why optimum moisture levels may not be constant for all substrates. Bulky materials may have considerable FAS, lending themselves to excessive air flow which causes cooling and drying. For such materials, higher moisture levels can be tolerated. For finer materials,

the small air spaces between solid particles are easily clogged with excessive moisture or compaction. Moisture and FAS are interdependent. Increased moisture levels correspond to decreases in the volume of air filled pores. Research has indicated that the optimum level of FAS is between 30% and 60% of compost sample volume, while optimum moisture content falls in the range of 50-60% of total sample mass. Bulky materials, known as bulking agents, create air voids in a compost mixture. Wood chips are a common bulking agent. Bulking agents can account for up to 60% of the total cost of a composting system, and their use should be rationed to a level that provides optimum FAS and structural support (Shea, *et* al., 1981).

There are two procedures found in the literature for measuring FAS in a compost: the water pycnometer, explained in detail by Singley, *et* al (1981), and a water saturation and draining procedure written by the U.S. Compost Council and proposed by that organization as a standard test method (U.S. Compost Council, 1997). Both techniques use water to fill in air voids. In addition, there are two mass-volume equations that can be used to predict compost FAS content based on sample bulk density, specific gravity, and moisture content. This study also proposes a FAS measuring fifth technique, the air pycnometer. The air pycnometer uses pressurized air to measure air pore volume. These techniques have not been compared to one another, and a comparison of the methods would benefit industry and researchers. This study will also identify the detractions, if any, particular to each test.

LITERATURE REVIEW

Compost, like soil, is comprised of portions of air, water, and solid particles. Each occupies a fraction of a total sample volume. The total volume is described as

$$V_t = V_a + V_w + V_s \tag{1}$$

where

V_t = total sample volume,
V_a = volume occupied by air,
V_w = volume occupied by water,
V_s = volume occupied by solid matter.

Air-filled porosity is defined as

$$f = \frac{V_a}{V_t} \tag{2}$$

where

f = air filled porosity.

Rather than air filled porosity, Schulze (1962) first coined the term "free air space" for compost applications, which he defined identically, in a verbal sense, to air filled porosity. Hereafter, air filled porosity (f) and FAS will be considered identical.

A detailed derivation of the FAS phase equation (equation 3) is presented in Annan (1998) and is not repeated here. Based on fundamental parameters of soil science, FAS can be expressed as

$$FAS = \left(1 - \frac{\rho_t(dm)}{G_s \rho_w}\right) - (1 - dm)\left(\frac{\rho_t}{\rho_w}\right). \tag{3}$$

where

ρ_t = total (wet) bulk density (M_t/V_t) (g/cm^3),
dm = dry mass (M_s/M_t),
G_s = absolute specific gravity of the compost particles (dimensionless),
ρ_w = density of water (g/cm^3) (usually taken to be 1 g/cm^3),

Schulze (1962) originated the concept of FAS for compost applications and developed the expression

$$FAS = \left(1 - \frac{\rho_t(dm)}{G_s \rho_w}\right)(dm). \tag{4}$$

Note that the two FAS equations (equations 3 and 4) are not equivalent. A dimensional analysis of equation 4, presented in detail by Annan (1998), shows that Schulze's equation is not correctly derived.

Instead of using the equations derived above, FAS may be found experimentally. Two techniques are found in the compost literature: a water pycnometer procedure and a saturation and draining procedure referred to in this thesis as the U. S. Compost Council "standard". A "standard" procedure for FAS evaluation is found in section 07.01-A of *Test Methods for the Examination of Composting and Compost* (*TMECC*), draft 3.9.4, currently being developed by the U. S. Compost Council, a professional organization.

In the water pycnometer test, a compost sample is submerged in a known volume of water. The volume of water needed to fill in air spaces within the material is equal to the FAS volume. Water pycnometry has been used for a variety of materials, including soil, coal, and grain. A water pycnometer procedure for compost applications is described in Singley, *et* al., (1982).

In the Compost Council test, a compost sample is first saturated with water. The water is then allowed to drain from the bottom of the cylinder. The weight difference between the saturated and drained states is equal to the volume of water needed to fill all open spaces. This standard method is procedurally very similar to the weight-differences method first developed by Lèamer and Shaw (1941) for soils.

An air pycnometer could be used for composting applications. Torstensson and Eriksson (1936) first developed the air pycnometer for measuring soil porosity. The air pycnometer used in this investigation consisted of a reservoir chamber containing air at a known pressure and a sample chamber filled with a known volume of material, yet initially open to atmospheric pressure. An air valve connects the two chambers. After sealing the system, compressed air from the reservoir is released to the sample chamber by opening the connecting valve. A gauge registers the pressure in the reservoir chamber before and after the connecting valve is opened. Boyle's law can be applied to the pycnometer system by writing the relationship

Pressure x Volume = Constant and constant temperature.

This relationship can be expanded to

$$P_o(V_s + V_r) = P_s V_s + P_r V_r. \tag{5}$$

where

P_o = equilibrium pressure in the entire system,
V_o = gas volume of overall system,
P_s = pressure in sample chamber,
V_s = gas volume of sample chamber,
P_r = pressure in reservoir chamber,
V_r = gas volume of reservoir chamber.

Assuming that P_s is initially zero (since the sample chamber is open to the atmosphere prior to testing) equation 5 can be solved for V_s, the volume of gas in the sample chamber, producing the result of

$$V_s = \frac{(P_r - P_o)V_r}{(P_o)}. \tag{6}$$

In equation 7, P_r represents the initial gauge pressure reading (with compressed air contained only in the reservoir). The final gauge reading is recorded as P_o, the pressure in the entire system. As V_s is the measure of gas volume in the sample chamber (either with or without sample), FAS may be calculated by

$$FAS = \frac{V_s}{V_m} \tag{7}$$

where

V_m = volume of sample in sample chamber.

Often, the sample chamber is equipped with a cup to hold material. If the sample cup is filled completely, the material volume equals the volume of the cup. This is a convenient way to ensure a constant sample size over a range of tests.

PROCEDURES

Samples of sewage sludge (87% moisture) were mixed with air-dried hardwood wood chips (10-12% moisture) in volumetric proportions of: 0.5:1, 0.75:1, 1:1, and 1.25:1 wood chips to sludge. Two batches of each mixture were prepared at different times. Five samples from each mixture-batch combination were tested for FAS content by each test method. After these tests, a batch of 1.75:1 and 2:1 wood chips to sludge mixtures were prepared and tested.

The procedure for the water pycnometer test is described in Singley, *et* al., (1982). In this study, a four liter, graduated plastic cylinder was filled with 1800 cubic centimeters (cm^3) of compost. The material was compacted by dropping the cylinder from a height of six inches onto a 0.5 inch foam mat. Once filled to the 1800 cubic centimeter mark, the cylinder was weighed to the nearest 0.1 gram, and the material bulk density was calculated. A wire mesh screen was placed atop the compost to prevent material from floating once submerged in water. One thousand mL of deionized water was slowly poured over the compost sample. Additional water, in 500 mL increments, was added if the water level failed to rise above the top of the compost. After the water addition, the cylinder was gently rocked from side to side five to ten times to free trapped air bubbles before recording the final water level. Water levels were recorded to the nearest 10 mL. The cylinder was emptied and cleaned thoroughly after each test.

Sample FAS was calculated by subtracting the final water level reading (in mL) from the zero FAS mark. The zero FAS mark is equal to the sample volume (1800 mL) plus the volume of water added to the sample (1000 mL in most cases). This difference represents the volume of water needed to fill air-pores within the compost.

The procedures for the Compost Council "standard" are presented in Tests 07-01 A in *Test Methods for the Examination of Composting and Compost* (*TMECC*). Per the test procedures, 1800 cm^3 of compost were added to a clear cylinder. The sample is compacted by dropping the cylinder from a height of six inches onto a foam mat. The compacted sample was weighed to the nearest 0.1 gram and the sample bulk density was calculated. The sample was saturated with deionized water (saturation is when the water level was even with the top of the compost). Water was then allowed to drain for at least 15 minutes through four 1/8 inch holes drilled in the bottom of the cylinder. The saturation and draining steps were repeated three times. For a final time, the compost sample was saturated, and the saturated weight of the sample was measured to the nearest 0.1 gram. Water was allowed to drain from the sample through the bottom of the cylinder for four hours. After this time, the compost-filled cylinder was weighed and the weight recorded to the nearest 0.1 gram. As defined by the Compost Council procedures, the difference in weight between the saturated compost and the compost after the four hour drain period is equal to the FAS volume.

The air pycnometer used in this investigation is shown in Figure 1. Prior to conducting tests, the air pycnometer was tested for leaks by pressurizing the entire system and monitoring the pressure gauge for drops. The

pycnometer was calibrated using precision steel ball bearings, which allowed for very exact solids volumes to be placed in the sample chamber. Once a given number of ball bearings were placed into the sample chamber, the volume of air space in the cup was found by subtracting the solids volume from the total volume of the sample cup (91.5 cubic inches). A calibration curve was generated, plotting final gauge pressure readings versus FAS content of the sample cup containing different numbers of ball bearings. The curve is shown in Figure 2. This curve was generated using an initial reservoir pressure of 7.50 psi, and is valid for only those tests run at that initial pressure. Using Microsoft Excel's regression programs, a straight line was fitted to the points on the calibration curve. The linear regression equation was used to compute sample FAS from the final gauge pressure reading.

The sample chamber holding cup was filled with compost (about 1500 cm^3). After adding each layer, the cup was dropped from a height of six inches onto concrete. After compacting the third layer by this method, compost was added in excess, without compaction, then smoothed to the top of the sample cup. The filled sample cup was then weighed to the nearest 0.1 gram, and the bulk density of material was calculated.

Once the sample cup had been prepared, it was placed into the sample chamber of the pycnometer. The chamber lid was then secured. The connecting valve (valve E on Figure 1) was closed, while the air release valve (valve F on Figure 1) was opened. The reservoir chamber was filled with pressurized air to a gauge pressure of about 8.5 pounds per square inch (psi). The air entrance valve (valve C on Figure 1) was then shut. The pressure in the reservoir was reduced to exactly 7.50 psi by opening the connecting valve and allowing air to slowly escape through the air release valve. While open, the air release valve prevents pressurized air from entering the sample chamber. Once the reservoir pressure was set, the air release valve was shut, and then the connecting valve was opened. This allowed pressurized air to move from the reservoir into the sample chamber, filling air spaces within the sample. The system was allowed to equilibrate for about one minute, and the final gauge pressure was recorded to the nearest 0.025 psi. The sample FAS was found using the calibration curve (Figure 2). After recording the final pressure, the air release valve was opened, and the sample cup was emptied and cleaned. The average of the three pressure readings was taken as the final pressure reading for the sample.

The equations of Haug (1993) and Schulze (1962) (equations 3 and 4, respectively) were used to determine the FAS for each sample using the bulk density values found from each test method and using the average moisture content and specific gravity for the mixture under study.

RESULTS

Sample compaction affects FAS content, as more compacted samples will have less air voids, and bulk density is a reflection of sample compaction. Initial statistical testing of measured bulk densities revealed that samples were prepared to the same degree of compaction from test to test (see Annan, 1998). With this established, FAS testing techniques were compared.

The next series of tests analyzed the measured FAS values. The objective of this analysis was to determine which measuring techniques were similar. As variations in sludge were found to have statistically insignificant effects on bulk weight, samples were compared across batches for each mixture ratio. A plot of mean FAS percentage as a function of mixture ratio (expressed as percentage wood chips) is shown in Figure 3. Ninety-five percent confidence intervals were ascribed to each mean, as shown on Figure 3.

Two trends are present in the data: an "upper range" of FAS registered by the air pycnometer, water pycnometer, and Haug's equation; and a "lower range" established by Schulze's equation and the Compost Council standard. More advanced statistical testing, presented in Annan (1998) demonstrate that for the most part, the tests did not produce statistically identical results. However, the trends shown in Figure 3 demonstrate relative relationships between test results.

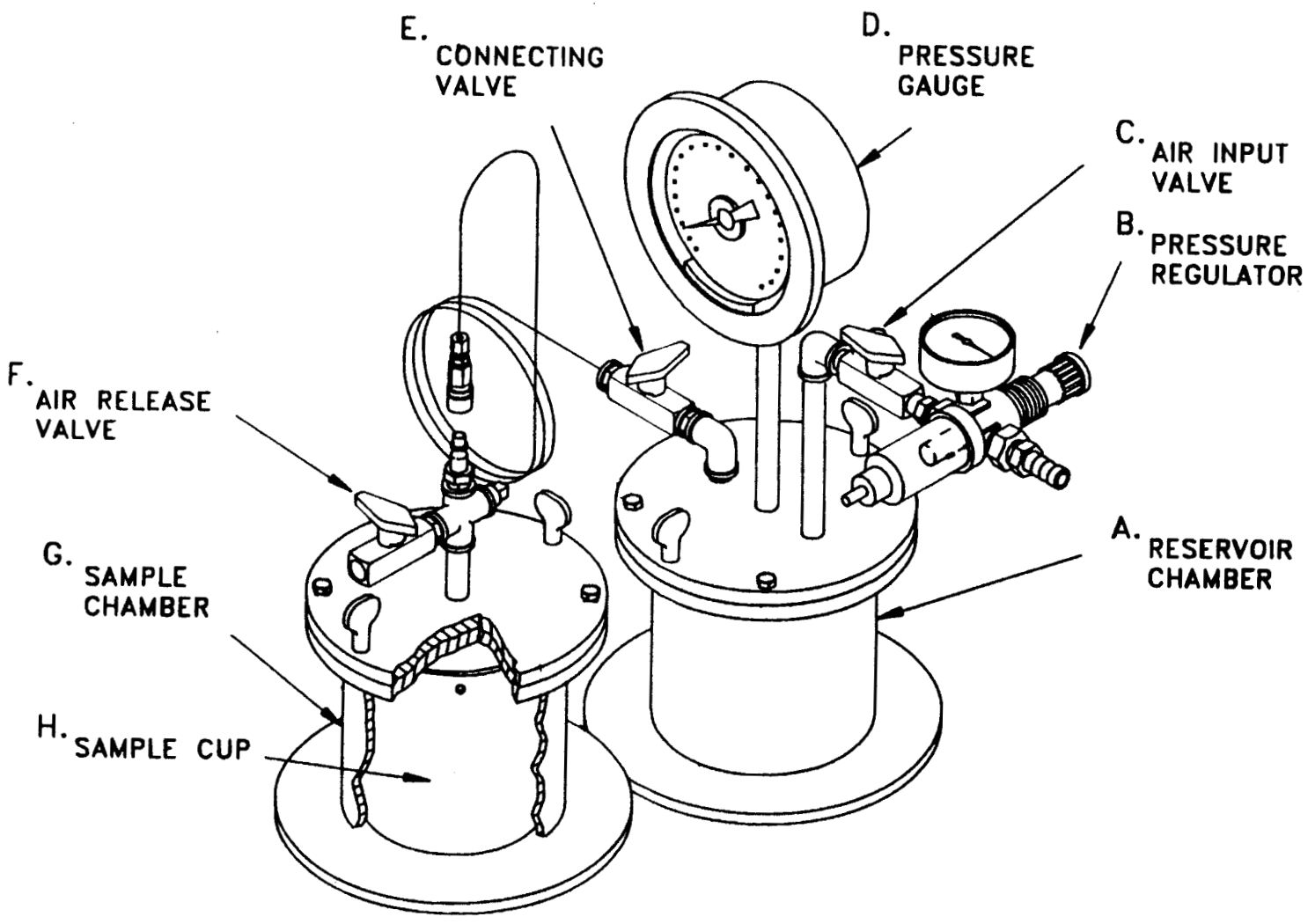

Figure 1. Air Pycnometer

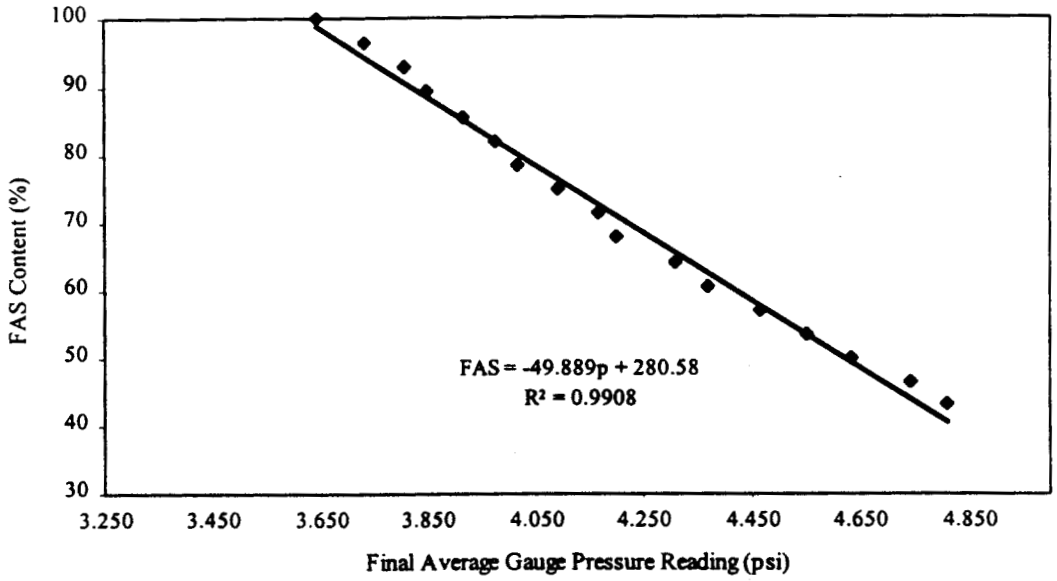

Figure 2. Calibration Curve for Air Pycnometer.

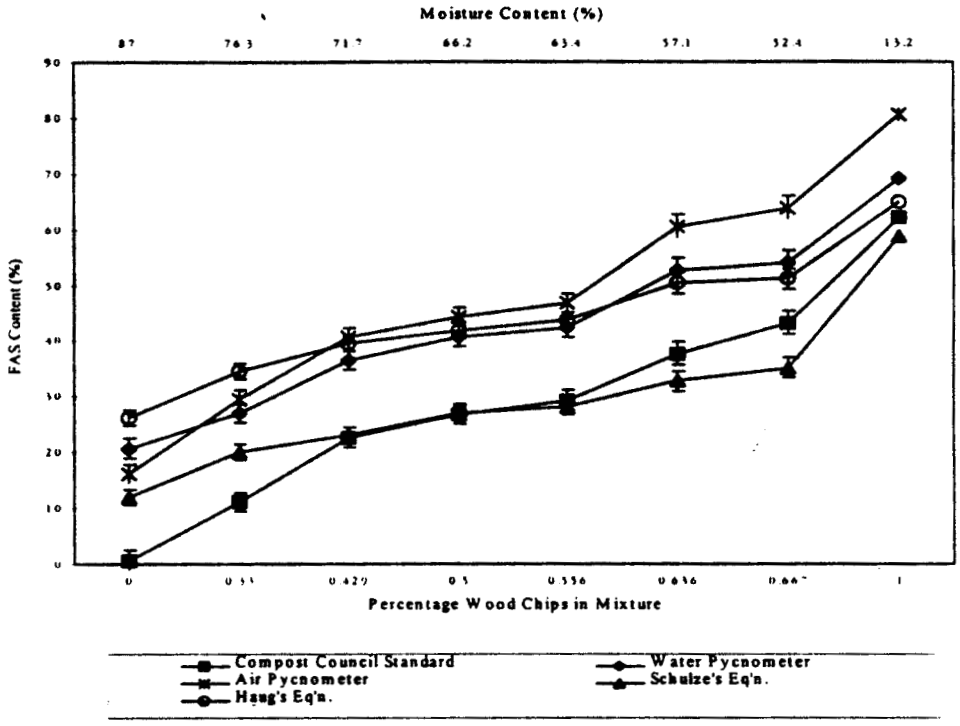

Figure 3. Plot of FAS Content Versus Mixture Wood Chip Content with 95% Confidence Intervals Around Means

Across all mixtures, the water pycnometer differed from the results from Haug's equation by only about 9.5%. Likewise, the results from the air pycnometer differed from those from the water pycnometer by 12.4%, and

from Haug's equation by 15%. The pooled results from Schulze's equation differed from the Compost Council standard by 25.4 %.

As observed in Figure 3, there is considerable scatter in the results for the pure sludge (0% wood chips) and 0.5:1 (33% wood chips) mixtures. These mixtures were very wet and compacted easily. There was considerable occlusion of pores in the middle and bottom of the samples. Neither water nor air was able to reach the occluded pores in the bottom of the material. Likewise, the results from the Compost Council standard are suspect. Blocked by compacted material, water was unable to drain from the bottom of the test apparatus as intended, giving an FAS content of essentially zero.

CONCLUSIONS

Water Pycnometer. In general the water pycnometer was a found to be a procedurally simple test that provided adequate measures of FAS content. This test requires only the simplest equipment and is a good "quick and dirty" assessment, taking only about 10-15 minutes to prepare a test a sample.

While testing compost samples with the water pycnometer, air bubbles became trapped within the compost material. These bubbles were plainly visible, yet they could not be dislodged by gentle movement. The presence of bubbles caused a lower than actual recording of FAS content. Cylinders used for the water pycnometer test should be wide enough to allow compost material to "settle naturally", without binding on the container walls. Singley (1981) recommends using a cylinder with a diameter at least twice as large as the largest compost particle being tested.

Air Pycnometer. The air pycnometer produced results that followed the trends of the water pycnometer and Haug's equation. However, the air pycnometer did produce consistently higher values for FAS content, especially for mixtures containing the greatest amounts of wood chips. This result is explained by the fact that air is a much less viscous fluid than water, and is able to enter the smaller pores that water cannot. In "drier" mixtures (those with higher wood chip content) air was able to enter wood chip pores not sealed with moisture, thus causing the pycnometer to register relatively higher measured values of sample FAS content.

In principle, the air pycnometer produces the most reliable measures of FAS. The air pycnometer does not have the problems of trapped bubbles that plagued the water pycnometer and Compost Council tests. The device is operationally simple and easy to use. After preparing the calibration curve, it required but five minutes to prepare and test a compost sample. No specialized parts are needed to construct the pycnometer. High precision air pycnometers are commercially available, though the sample sizes they are capable of handling are generally too small for compost applications.

Compost Council "standard". The Compost Council standard produced very different results from the air pycnometer, water pycnometer, and Haug's equation. The primary reason for this difference is because the Compost Council procedure, as it is currently written, only measures non-capillary air porosity, or the "larger" air voids that readily release water during draining. Another significant part of total air porosity is capillary porosity—smaller pores that retain water even after prolonged draining. A test of complete FAS should measure both capillary and non-capillary porosity (see Annan, 1998).

The Compost Council procedure does have one other flaw. It is very difficult prepare a saturated sample so that the water level is exactly equal to the level of compost in the container. This is even more a problem when testing raw composts containing large particles, like wood chips. More often than not, some ponding on the compost surface will occur.

The Compost Council test took approximately five to six hours to complete. Material often clogged the drain holes in the bottom of the cylinder preventing water from draining from the sample. Based on the results of this study, the Compost Council standard should be abandoned as a best practice technique for measuring FAS.

The Equations. Haug's equation provided a very good estimate of FAS content for most mixtures, and tracked the water pycnometer and air pycnometer results especially well. The use of this fundamental equation from soil science requires one to know sample moisture content, bulk density, and specific gravity. Of these properties, specific gravity may be the most difficult to measure. A comparison of tests for measuring specific gravity is presented by Annan (1998).

Schulze's equation was found to be incorrectly derived and its use should be abandoned. Unfortunately, this equation has been used by many researchers to establish the ranges of FAS that afford the optimum composting conditions (Jeris and Regan, 1973).

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BIOFILTER TESTING USING COMPOSTING FOR STYRENE AND METHYL ETHYL KETONE EMISSIONS

By

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ABSTRACT

This project is a technology demonstration to establish the biofilter technique as a cost-effective method to remove airborne volatile organic compounds (VOCs). The system was designed to remove mainly styrene from the airstream from the Pipe Assembly Building at Augusta Fiberglass Coatings in Blackville, South Carolina. The biofilter was also proved capable of removing methyl ethyl ketone (MEK). Results from the demonstration have shown that the effluent generally remaining below 7 ppm of styrene. The average styrene influent is 200 ppm. The project has demonstrated a reliable and inexpensive method for removing low levels of VOCs. Chicken compost was used as a source of nutrients and microbial growth.

INTRODUCTION

Several technologies are currently being used to reduce VOC emissions. These technologies include vapor scrubbing, thermal oxidation, catalytic oxidation, carbon adsorption, UV oxidation, corona destruction reactors, plasma technologies devices, and biofiltration. The first four are the mature technologies that have been proven effective at reducing VOC air emissions. The latter are newer technologies that are still being tested as to their effectiveness. The technique described and discussed here is a field-pilot biofiltration demonstration used to reduce styrene, methylene chloride and MEK air emissions. Compost matrix was used as a source of nutrients and bacterial growth.

Biofiltration can be widely applied to control VOC emissions from industrial and commercial sources, wastewater treatment plants and soil and groundwater remediation operations. Biofiltration is an air pollution control technology that cleans contaminated air as it passes through one or more beds of a selected medium. VOCs are transported from the gas phase to the biofilm on the compost matrix and degraded to CO_2 and H_2O by the microorganisms in the biofilm. Cost analyses have shown that biotreatment of industrial waste gases containing VOCs is potentially 2 to 10 times less expensive than thermal oxidation or catalytic oxidation, 10 to 40 times less expensive than adsorption to activated carbon and 4 times less expensive than traditional scrubbing (Salemink, R., 1991 and Dharmovaram, S., 1991). Furthermore, vapor scrubbing and carbon adsorption techniques require further processing of volatile organic carbons to oxidize them to CO_2 and water.

The objectives of the pilot demonstration described here are:

- To measure the biodegradation rate of compost microorganisms stimulated by styrene to determine the efficiency of the process.
- To determine the major parameters that effect the biofiltration system and the consequences of long-term shut down of the fiberglass manufacturing process.

FIGURE 1: Biofilter at Augusta Fiberglass Coatings site.

- To determine the efficiency of the biofilter process when it is compared with other air emission reduction technologies.

SITE DESCRIPTION

Augusta Fiberglass Coatings (AFC) is a commercial fiberglass production facility located in an industrial zone outside the city of Blackville, South Carolina. The site is comprised of approximately 168 acres of land and includes 15 production buildings, an administrative structure, and several storage buildings. The biofilter, Figure 1, has been constructed alongside the Pipe Assembling Building (PAB), a 60 ft. by 100 ft. (18m x 30m) building used to complete the construction of smaller specialty fiberglass items. AFC has complied with air emissions regulations, and mass balance calculations show styrene, methylene chloride and methyl ethyl ketone emissions at the PAB of 1.142 lb/hr (518 g/hr), 0.347 lb/hr (157 g/hr), and 0.095 lb/hr (43 g/hr), respectively.

TREATABILITY STUDY: SET-UP AND RESULTS

A treatability study was conducted to optimize biofilter medium composition and styrene removal efficiency. Samples of the PAB exhaust were collected for VOC analyses using hand-held portable pumps and absorbent tubes; laboratory analyses of these samples show that styrene is the major VOC emission from the PAB. Based on these results, the biofilter treatability study was configured using only styrene as the VOC influent.

The dimensions of the treatability bioreactor were 6 inches (15.2 cm) diameter with a 4-foot (121.9-cm) bed height. The styrene inlet flow rate varied from 0.5 to 2 scfm. The selected medium that presented best removal efficiency was chicken compost and granular activated carbon (GAC) in a 2:1 ratio. Removal efficiencies using flow rate of 2 scfm are listed in Table 1. Different loading methods were used for each run in order to check percentage removal of varying influent styrene concentrations.

Table 1: Styrene Removal Pilot Experiment, 8/19/96 to 9/17/96

Influent (Relative ppb)	Effluent (Relative ppb)	% Removal
125200	4400	96.46
421250	1192	99.72
913520	50	99.99
203000	1700	99.16
130000	174	99.92
147700	0	100.00
2700	127	95.30
1141100	16840	98.52
354400	58870	83.39
410400	52240	87.27
877600	121800	86.12
1194000	214720	82.02

PROJECT DESIGN AND DESCRIPTION

The process flow diagram for the biofiltration system in operation at AFC is illustrated in Figure 2. The biofiltration system consists of the following major sub-systems / equipment and components:

1. Blower System (B);
2. Steam Generating Boiler (S) and Humidifier(H);
3. Bio-Filter Vessel (F);
4. Utility Supply System;
5. Instrumentation and Control System, and
6. Influent and Effluent Gas Analyzer System.

The biofilter system was placed on a reinforced concrete foundation and was connected to the PAB with poly vinyl chloride (PVC) piping. The air pump (B) is a positive displacement

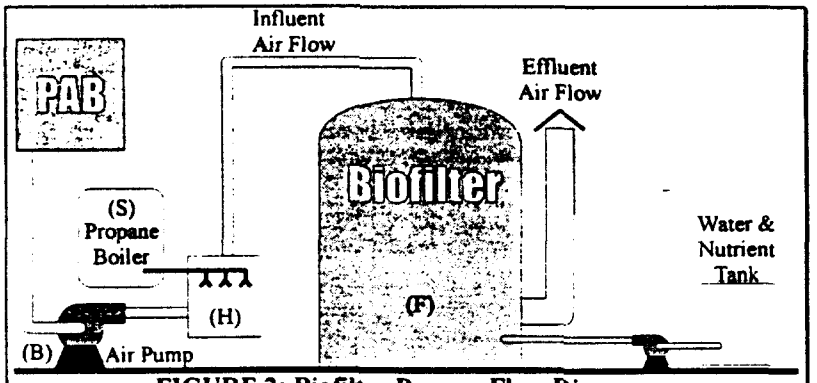

FIGURE 2: Biofilter Process Flow Diagram

blower that, with silencers, exhausts the building air stream through the biofilter tank. The blower system operates at approximately 1,000 scfm, resulting in a water column pressure drop across the biofilter bed in the range of 20" to 30". The biofilter system includes a propane fired boiler (S) providing steam to heat and humidify the influent air stream, and an automatic moisture system providing water and/or nutrients to the compost biofilter medium via a series of spray nozzles in the tank. The average relative humidities (RH) of the air entering the biofilter bed is 38% and averages 85% leaving the biofilter.

The biofilter vessel is a fiberglass tank, 18 ft. high by 9 ft. diameter (5.5 m x 2.7 m), that was designed and manufactured by AFC. Analyses of the compost indicated a high percentage of nitrogen and phosphorus and a neutral pH. The selected GAC is a particle size of 5 to 10 mesh and, once mixed with the compost, is in two layers 4-feet (1.22 m) thick in the biofilter. The Instrumentation and Control System provides data on humidity and temperature. The system controls the steam and water injection into the biofilter, and measures the humidity and temperature of the influent and effluent air flow.

A Bruel and Kjaer Model 1302 Infrared Photoacoustic Spectrometer (IRS) gas analyzer was used to analyze the influent and effluent concentrations of VOCs. The IRS was calibrated for styrene, methylene chloride, MEK, carbon dioxide, and water vapor, with a full set of measurements recorded every 30 minutes. Analyses of the effluent carbon dioxide concentrations provided the aerobic respiration rate of the microbial population. The biofilter system was totally automated to the point that trips to the site were made primarily to download data from the gas analyzer. The IRS was used to monitor styrene, MEK, and methylene chloride oxidation.

RESULTS

Figure 3 is a chart of the IRS analyzer data showing styrene levels in and out of the biofilter for a normal week of operations at AFC. This chart shows styrene levels peaking at 200 ppm on the biofilter inlet and an outlet concentration that generally remains below 7 ppm. Styrene levels in the influent vary considerably due to the variations in the amount of work being performed in the building, but the effluent styrene levels remain consistently low.

The inlet concentrations of methylene chloride and MEK have been negligible and the performance of the biofilter has been addressed only in terms of styrene removal efficiency.

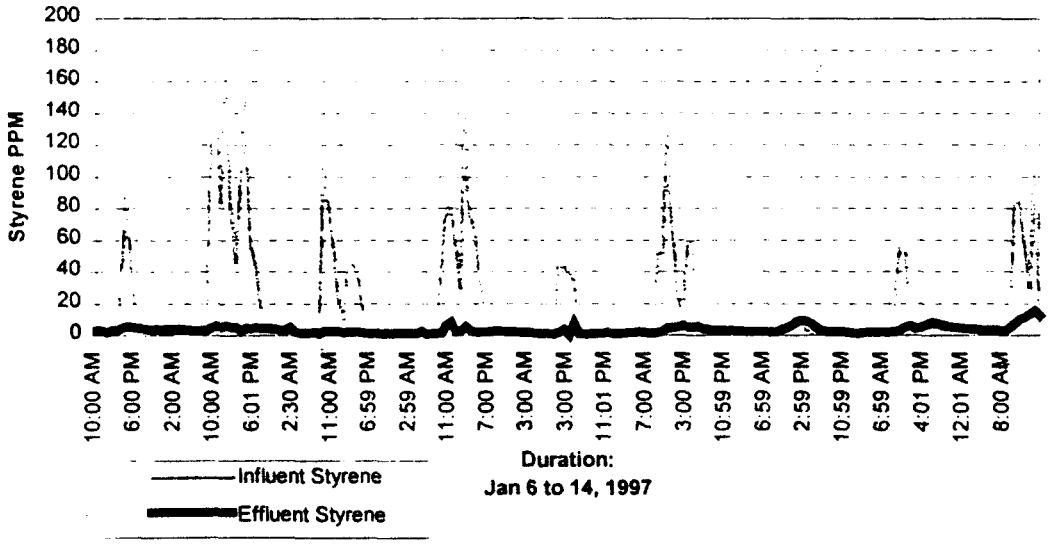

FIGURE 3: Styrene Levels Recorded over a Standard Week at AFC

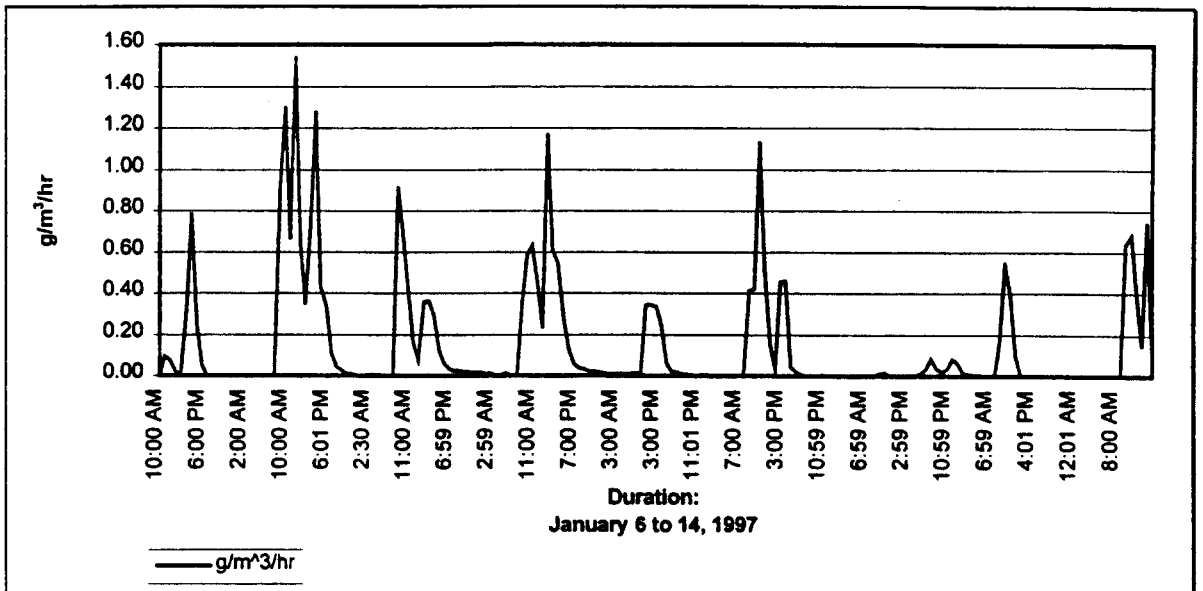

FIGURE 4: Styrene Elimination Rates over the Sample Test Period

Figure 4 reflects the elimination rates of the biofilter bed for styrene using the data plotted in Figure 3. The elimination rates are calculated using the following equation:

$$E_R = (C_{in} - C_{out}) \cdot Q/V$$

Where E_R = elimination rate, $g/m^3/hr$
Q = flow rate, m^3/hr
C_{in} = influent gas phase pollutant concentration, g/m^3
C_{out} = effluent gas phase pollutant concentration, g/m^3
V = volume of the bed material, m^3

CONCLUSIONS AND RECOMMENDATIONS

The results of this field-pilot biofilter demonstration provide strong support for the use of biofilters to treat industrial styrene emissions. The project commenced with contract award in June of 1996, construction was completed in August, and startup of operations in October of 1996. As of mid January 1997, bed acclimation has been accomplished, and significant performance data have been acquired.

Data from the treatability study and the CO_2 effluent concentrations recorded by the IRS for the pilot technology demonstration support the biodegradability of styrene in this demonstration. The efficiency of the process in terms of a calculated biodegradation rate was not determined. Styrene biodegradability has been well documented; intrinsic biodegradation rates from bench-scale biofilter for styrene has been in the range of 9 to 35 μg styrene per hour per mg dry weight (Togna, et al., 1992)

Figures 3 & 4 show that a steady-state effluent concentration was obtained and that acclimation of the bed was reached. It seems that the large fluctuations in the VOC mass loading due to changes in the manufacturing process is not adversely affecting the biofilter performance.

The efficiency of the biofilter process when compared with other air emission reduction technologies was demonstrated in this project. Traditional air pollution control technologies have been known to be too costly and, in some cases, not capable of treating low concentration VOCs. Conversely, biofiltration is both cost-effective and provides treatment of low concentration VOCs.

The demonstration project has proven itself so well that AFC has requested that the biofilter remain in operation at the completion of the demonstration and become a permanent addition to their continuing program of environmental responsibility.

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THE EFFECT OF SYNTHETIC BULKING AGENTS ON PRESSURE DROP THROUGH FOOD WASTE COMPOST

By

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SUMMARY

Pressure drop was measured through a column of lettuce and onion food processing waste containing synthetic bulking agents from chemical separations processes. Six different polypropylene bulking agents were compared against the more traditional bulking agent pine bark. The bulking agents were used at various different fractions, or bulking agent densities. The results consistently showed that the synthetic bulking agents caused a pressure drop three to five times lower than pine bark. Pressure drop models suggested by Shedd, Hukill and Ergun were used to fit these data. A parameter in Ergun's equation was used to quantify the fraction of bulking agent necessary to implement 50% viscous energy pressure drop losses.

INTRODUCTION

Vegetable wastes have several characteristics which have made composting problematic, these include high moisture content, low carbon to nitrogen ratio, and often high concentrations of odor causing chemicals such as sulfur. Bulking agents may mitigate problems associated with vegetable waste composting. An ideal bulking agent would contribute pore space throughout the compost pile and process (Haug, 1993). Low-cost synthetic bulking agents might indeed be designed to provide optimal support and void space integrity. Similar criteria have been used for the design of numerous packing materials for gas absorption used in the chemical manufacturing industries. Indeed, low pressure drop is a principal concern in the selection of these inert packing materials (Coker, 1991).

The high moisture content of vegetable waste results in considerable deformation and compaction during the degradation process, causing significant reduction of pore space through which air may flow (Haug, 1993). As pore space is reduced, pressure drop across the compost pile will increase, necessitating higher energy input to the blowers to maintain the air flow (Keener, 1993). These problems may be partially circumvented with bulking materials that provide a relatively constant pore matrix in the compost.

The low C:N ratio of lettuce and onion wastes may cause incomplete microbial digestion. Therefore, these wastes should be augmented with a substrate containing a high C:N ratio. In addition, the high sulfur content of the vegetables (particularly onions) increases the likelihood of odor formation, particularly if an aerobic environment is not maintained (Haug, 1993). Sulfur caused odors may be reduced by augmenting vegetable waste with low sulfur substrates to provide a chemical balance, or by insuring adequate aeration during the entire compost process. Adequate aeration is also facilitated with bulking agents and high pore space.

CORRELATIONS FOR PRESSURE DROP

Numerous correlations are available for predicting pressure drop encountered by fluids flowing through a matrix of porous material such as compost. In general, pressure drop per depth of material (ΔP) is a function of superficial fluid velocity (U). Shedd (1951, 1953) proposed the following equation for airflow through seed and grain:

$$\Delta P = AU^B \quad (1)$$

The superficial air velocity (units of cfm/ft^2, or ft/min) is equal to the volumetric flow rate (Q) divided by the cross-sectional area of the porous material, tangential to the direction of flow. The two terms A and B in Equation 1 are empirically determined. Hukill (1953) modified Equation 1 to account for nonlinearities in the results of Shedd:

$$\Delta P = \frac{CU^2}{\ln(1+DU)} \quad (2)$$

In Equation 2, C and D are empirically determined. Although the pressure drop is normalized by material height, Equations 1 and 2 do not account for the effects of compressible materials such as vegetable wastes. The simplest correlation (Chen, 1980; Higgins et al., 1982; Haug, 1993) for quantifying air flow through a column of compressible materials is:

$$\Delta P = KU^n h^j \quad (3)$$

In Equation 3, the value of K and the exponents n and j are empirically determined. The values of these exponents approach one for laminar flow. The value of j becomes one for non-compressible materials, and Higgins (1982) suggested that j will be one for a depth less than 2.4 meters. Since flow through porous media is turbulent (Schedegger, 1957) values of the exponents are generally not equal to one. More recently Das and Keener (1997) demonstrates the effect of moisture content and compaction on pressure drop. Reynolds (1900) formulated an alternate approach to describe pressure drop as a function of superficial velocity:

$$\Delta P = aU + bU^2 \quad (4)$$

Ergun (1952) is often credited with the application of this equation, as he provided an extensive demonstration of its utility in describing the behavior of oven coke. As in previous equations, Equation 4 has empirical constants which must be determined for the specific material. The first term in Equation 4 represents the viscous energy losses, and is essentially a simplification of Darcy's Law, which regards inertial effects as negligible. Viscous energy losses are caused by the contact of a fluid with the surface over which it is traveling. The second term represents the kinetic energy losses, caused by rapid lateral movement of the fluid as it flows through pore spaces. In completely turbulent flow at high air velocities, kinetic energy losses constitute the principal resistance to flow. Thus the coefficients in Ergun's equation indicate the relative importance of viscous and kinetic energy losses.

An important parameter in composting with bulking agents is the ratio of bulking agent to compostable material, or the bulking agent density (ϕ). One would anticipate that at a given air flowrate increasing the bulking agent density would in general decrease the pressure drop. Increasing the value of ϕ would change the empirical constants in any of the above correlations (Equations 1 - 4). An optimal bulking agent would be one which provides low pressure drop (and associated costs) while maximizing the quantity and quality of the composted material.

The goal of this study was to compare quantitatively several bulking agents for the composting of lettuce and onion waste. The two measures of bulking agent effectiveness are the pressure drop in a column of compost, and the compostability of the mixtures.

COMPOSTING VEGETABLE WASTES

The U.S. 1997 fresh-cut vegetable production was estimated at 830 million pounds (Raynes, 1997). At one processor near Atlanta GA, 83% of total production consists of lettuce and 8% of onions (Raynes, 1997). The industry is very sensitive to vegetable quality, and therefore waste generation almost equals wholesale production. The U.S. annual projected fresh-cut vegetable waste by-products are 790 million pounds (Raynes, 1997), essentially all of which will go directly to landfills. With increasing public

pressure to reduce solid waste disposal reduction or recycle of these vegetable wastes is of growing importance. Composting may provide one alternative to landfilling there highly biodegradable materials. In addition to causing a significant volume reduction, composting can yield a useful soil amendment. However, unlike traditional compost materials such as animal and municipal waste, vegetable waste has several characteristics that may present difficulties to the process (Haug, 1993). Specifically, lettuce and onions are high in moisture, have a low C:N ratio, and can generate odor while composting due to their high sulfur content.

MATERIALS

The organic compostable mixture used in this study consisted of lettuce, onions, poultry litter, and pine sawdust. Lettuce and onions were both obtained as fresh waste from a local vegetable processing plant, the poultry litter from a local farm, and the sawdust from a sawmill (Curl Pack, Suwanee, GA). For size uniformity, the vegetables were manually chopped and screened (2" x 2"). The volume of material was measured to the nearest 0.003 m^3 and routinely stored in 45 gallon covered containers in a cold room (4 °C).

Non-organic bulking materials consisted of random packing materials commonly used in chemical manufacturing industries. Three polypropylene packing materials (shown in Figure 1) were studied: Telpack (Telpack Tower Packing, Boston, MA), Tripac, and Saddles (Jaeger Products, Inc., El Dorado, KS). For each packing material two nominal sizes (1" and 2") were studied. Pine bark (Craven Pottery, Commerce, GA) was also used studied. Table 1 shows pertinent parameters on these seven bulking materials.

Table 1 - Physical properties of the bulking materials

	Nominal Size	Void space (%)	Bulk Density (lb/ft^3)
Tripac	1"	90	6.20
Tripac	2"	93	4.20
Telpack	1"	90	4.30
Telpack	2"	94	3.50
Saddle	1"	91	5.00
Saddle	2"	94	3.25
Pine Bark	0.5-3"	78	10.00

The experimental setup to study the pressure drop consisted of three major components: a column, blowers and associated piping, and two manometers (Figure 2). The column (155 cm by 61 cm diameter) was made of reinforced fiberglass (U.S. Plastics, Lima, OH). The concave column floor averaged 23 cm above the base, yielding an effective depth of 132 cm. Over 40% of this floor was open and covered with an expanded metal and a fine mesh screen to permit airflow and to support the compost material. The top of the column was open to the atmosphere. Two blowers (Dayton Electric Mfg. Co., Niles, IL) attached in parallel via 5 cm diameter PVC piping provided air flow to the column. A single ball valve controlled the combined air flow. Two incline manometers (Dwyer Instruments Inc., Michigan City, IN) were used in this study. A manometer of 0.25 kPa maximum water pressure, calibrated with air flow covering the experimental range, was used to estimate the air flow rate. A 0.12 kPa water pressure manometer allowed measurement of the column pressure. Both manometers had a 0.0012 kPa precision.

METHODS

The compost mixture consisted of organic materials in a mass ratio of 19:23:10:1(lettuce: onions: poultry litter: sawdust) wet basis. In order to achieve this mixture, 0.091 m^3 of lettuce, 0.091 m^3 of onions, 0.04 m^3 of poultry litter and 0.005 m^3 of sawdust were mixed. A selected volume of bulking material was then mixed into the organic material, beginning with the lowest density to be tested. The resulting mixture was carefully placed in the column to avoid packing. Starting with the highest flow rate, the air flow valve

was set to each of five nominal flow rates (0.0075, 0.0107, 0.183, 0.0274, and 0.0366 $m^3/s/m^2$) and corresponding pressure drops across the material were recorded.

After a set of pressure/air flow measurements, the material was taken out of the column, mixed gently and replaced into the column for a subsequent set of measurement. After three replicate measurements were made for a given bulking agent density, additional bulking agent was added to provide the next density.

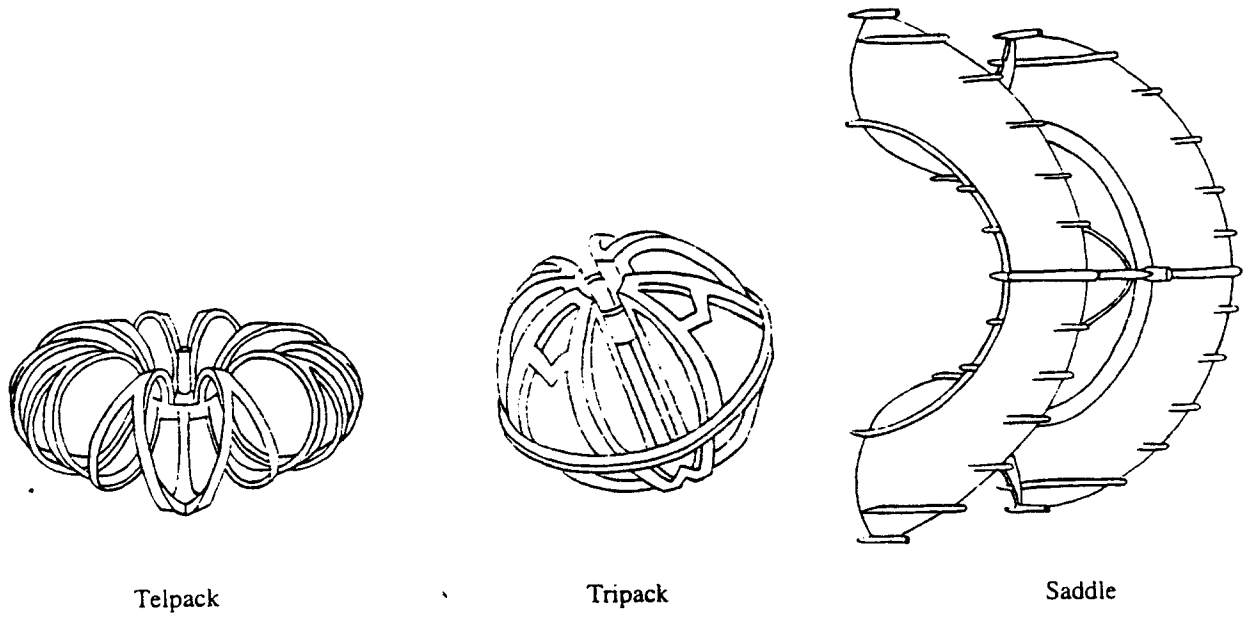

Figure 1: Synthetic Bulking Agent Shapes

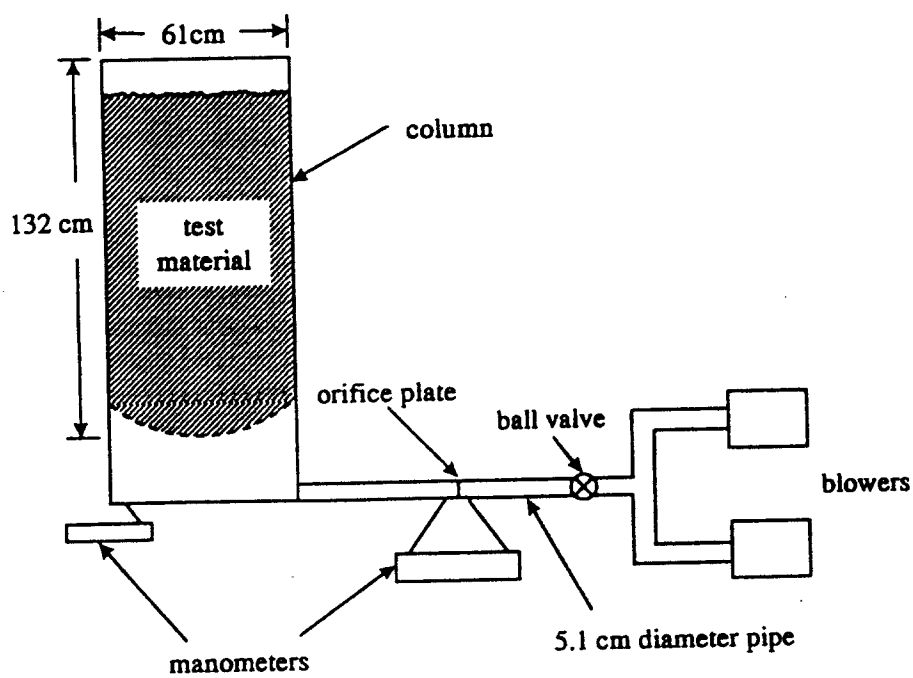

Figure 2: Experimental Setup for Pressure Drop Tests

RESULTS AND DISCUSSION

Table 2 shows the chemical and physical parameters for the four organic substrates. The lettuce and onions were above 90% moisture content and below a C:N ratio of 15.

Table 2: Chemical and physical parameters for substrates

Parameter	Lettuce	Onions	Poultry Litter	Sawdust
Moisture (wet basis)	96.17	91.10	22.70	11.33
Carbon (dry basis)	42.50	43.30	31.90	40.40
Nitrogen (dry basis)	4.13	3.76	3.71	0.05
Sulfur (dry basis)	0.20	0.69	0.68	0.36
C:N ratio	10	12	9	792
Bulk density (kg/m^3)	99.667	421.667	383.380	118.000
Particle density (kg/m^3)	679.333	963.667	1023.550	660.000
Pore space	0.853	0.521	0.623	0.824

Figures 3, 4 and 5 show the pressure drop in the compost column as a function of the superficial air velocity for three selected bulking agents. As expected, increasing the air flow increased the measured pressure drop. Moreover, for each of the bulking agents an increase in the bulking agent density resulted in a significantly reduced pressure drop. Significant differences are also observed between different bulking materials. For example, the measured pressure drop for a compost with 0.00062 m^3/kg of 1" Telpack was approximately 0.018 kPa/m at an air flow of 0.0274 m/s. In contrast, the measured pressure drop at an identical flow and bulking agent density was 0.025 kPa/m for 2" Saddles and 0.040 kPa/m for pine bark. The compost without bulking agent yielded a pressure drop of about 0.070 inches kPa/m at this flow rate. These differences were validated in a statistical analysis which showed a significant difference (at $p < 0.025$) between the trial with no bulking agent and the trials with other bulking agents, and between the trials with pine bark and those with synthetic bulking agents. However, there was no significant difference when comparing the 1" bulking agents to the 2" bulking agents, or when comparing any of the bulking agents of the same size.

Figure 6 shows another way to present the pressure drop measurements for 1" Telpack. For each air flow, increasing the bulking agent density reduced the pressure drop. The differences in pressure drop between the five bulking agent densities was statistically significant (at $p < 0.025$); the only exception to this was between $\phi = 0.00025$ and $\phi = 0.00045$ for the 1" bulking agents for which the hypothesis of equal means was accepted ($p > 0.025$).

A regression was performed to Equation 4 on the pressure drop measurements for each of the seven bulking agents and the material without bulking agent, resulting in correlation coefficients above 95%. The predicted pressure drops resulting from these equations are shown in Figures 3, 4 and 5 for selected bulking agents. As expected, an increase in the bulking agent density resulted in a decrease in the linear coefficient of Ergun's equation. Demonstrating that the linear coefficient, a, is directly related to pressure drop. Therefore, the effect that the bulking agent density, ϕ, has on the value of a indicates the effectiveness of the bulking agent in reducing the pressure drop. Figure 7 shows the relationship between the bulking agent density and the linear coefficient for five of the bulking agents. In each case this coefficient decreased with increasing bulking agent density. Moreover, the synthetic bulking agents were more effective than pine bark at reducing the value of a at any given density.

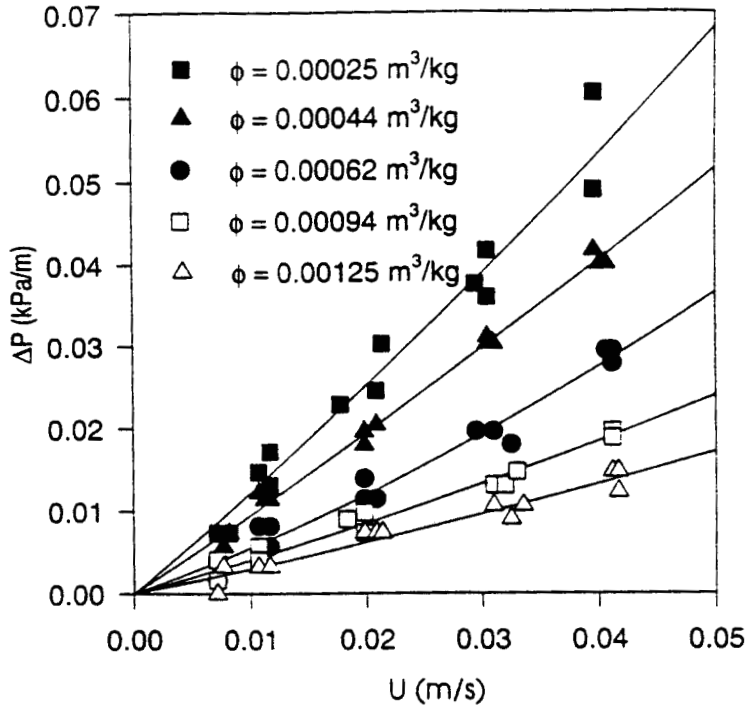

Figure 3: Measured pressure drop across column per unit material height (ΔP) as a function of superficial air velocity (U) for 1" Telpack. Solid curves represent regressions of data to Equation 4 in text.

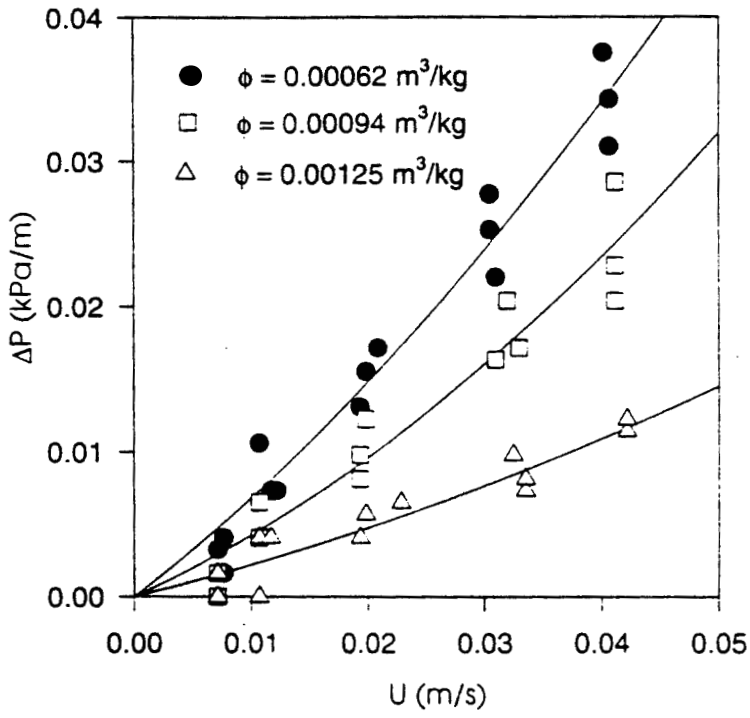

Figure 4: Measured pressure drop across column per unit material height (ΔP) as a function of superficial air velocity (U) for 2" Saddles. Solid curves represent regressions of data to Equation 4 in text.

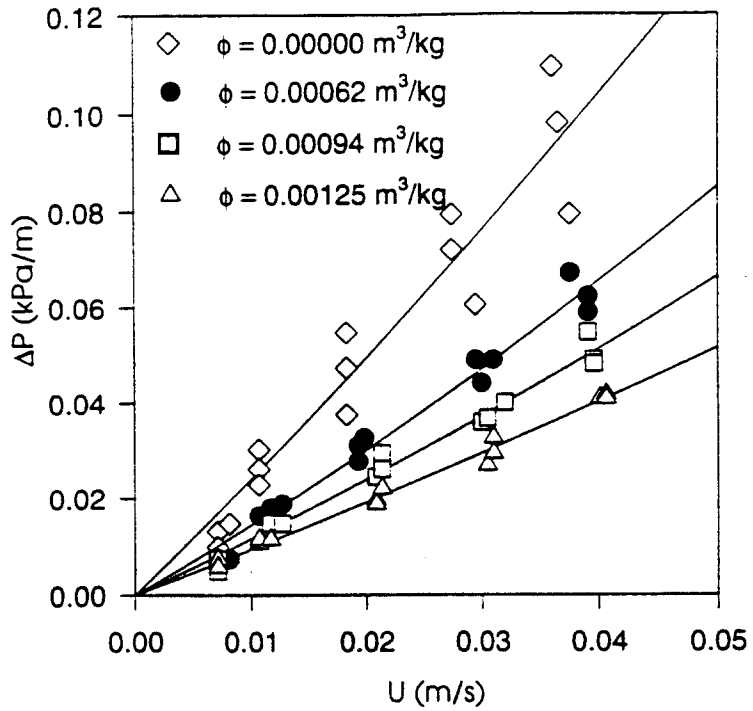

Figure 5: Measured pressure drop across column per unit material height (ΔP) as a function of superficial air velocity (U) for pine bark and without bulking agent. Solid curves represent regressions of data to Equation 4.

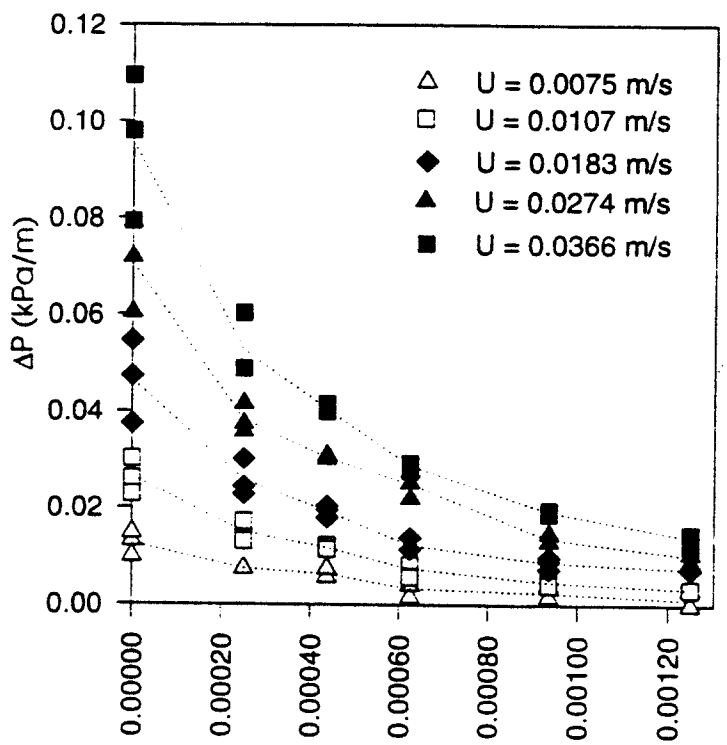

Figure 6: Measured pressure drop across column per unit material height (ΔP) as a function of bulking agent density (Φ) for 1" Telpack.

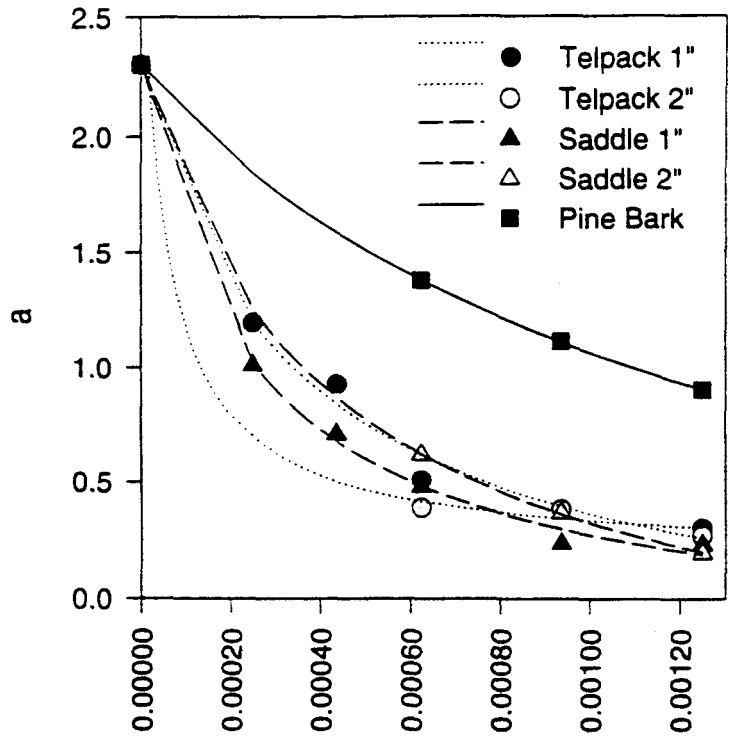

Figure 7: Linear coefficient a versus bulking agent density (Φ).

The relationship between ϕ and a was modeled with the following empirical relationship:

$$\frac{a_0 - a}{a_0} = \frac{C_1\phi}{C_2 + \phi} \tag{5}$$

In Equation 5, C_1 and C_2 are fitted parameters and a_0 is the linear coefficient in Ergun's equation for the case of no bulking agent. Thus, the dimensionless ratio $(a_0 - a)/a_0$ is a measure of the fractional improvement in pressure drop: for a bulking agent which provides no improvement in the linear coefficient over the case of no bulking agent this ratio will be equal to zero, while for a bulking agent which essentially removes pressure drop this ratio will approach one. If the bulking agent density approaches zero ($\phi \leq 0$) then the term $C_1\phi/(C_2 + \phi)$ approaches a value of C_1 for any type of bulking agent. For this case the fractional improvement in pressure drop should approach 1, so that the value of C_1 determined by fitting the data in Table 3 should be close to 1. When $\phi = C_2$, the fractional improvement in pressure drop given by Equation 5 becomes equal to $C_1/2$. If $C_1 \approx 1$, then the fractional improvement in pressure drop is 0.50 when $\phi = C_2$. Thus, this second empirical constant, C_2, is a measure of the bulking agent density required to decrease the linear form of Ergun's equation by 50%. The greater the value of C_2 calculated, the higher the bulking agent density necessary to affect a change in pressure drop. Table 3 shows the resulting best-fit values for the empirical constants (C_1 and C_2) in Equation 5. The resulting equations are also shown in Figure 7 for these selected bulking agents. As Table 3 shows, the value for the constant C_1 for each bulking agent was indeed approximately equal to 1. Of the bulking agents tested, the pine bark had the highest value of C_2, while 2" Telpack (lowest r^2 and three data points) and 1" Saddles (five data points) had the lowest value of C_2. These results demonstrate and quantify the reduction in pressure drop afforded by the synthetic bulking agents over pine bark.

Table 3: Results of Regressing the Linear Coefficient in Ergun's Equation to Equation 5

Bulking Agent	C_1	C_2	r^2
Telpack 1"	1.129	0.000340	0.981
Tripack 1"	1.191	0.000394	0.965
Saddle 1"	1.097	0.000242	0.992
Telpack 2"	0.922	0.000074	0.793
Tripac 2"	1.155	0.000447	0.937
Saddle 2"	1.223	0.000421	1.000
Pine Bark	1.250	0.001322	1.000

For the pine bark and each of the three 2" synthetic bulking agents, the value of this second-order coefficient decreased with increasing bulking agent density. In other words, for these four bulking agents as their density increased, the pressure drop became more linear with superficial air velocity. As expected, the addition of any of these bulking agents serves to reduce the kinetic energy losses.

CONCLUSIONS

The pressure drop data across a column of compost shows a high correlation to Ergun's equation. For all bulking agents an increase in the bulking agent density (ϕ) resulted in an almost linear decrease in pressure drop. The synthetic bulking agents resulted in a significantly lower pressure drop than the pine bark. The 2" synthetic bulking agents resulted in lower pressure drop than the 1" agents. No one particular synthetic bulking agent shape stood out as better than the others across the 1" and 2" sizes.

The synthetic bulking agents provide an advantage over the pine bark by reducing the head differential across a compost reactor. The reduced head differential results in decreased fan power requirements, and thus decreased costs. Synthetic bulking agents cannot provide the nutrient and absorbent advantages of biodegradable agents; however, the synthetic bulking agents can be recovered after composting whereas the pine bark will deteriorate over time. Additional testing should be conducted to determine the suitability of Ergun's model for other compost materials and bulking agents, and to determine if parameter C_2 varies with compost material.

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List of Symbols Used

a, b, A, B, C, D, j, k, n = empirically determined parameters in pressure drop correlations (Eqs. 1-4)

ΔP = pressure drop per foot depth of grain (inches H_2O/ft)

ϕ = bulking agent density (ft^3/lb)

U = superficial air velocity (ft/min)

BIODEGREDABILITY AND NUTRIENT ANALYSIS DURING CRAWFISH PROCESSING BY-PRODUCTS AND RICE HULL COMPOSTING

By

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ABSTRACT

Disposal of crawfish processing by-products poses a challenging problem to the rapidly expanding crawfish industry. Degradation of mass and nutrient content was determined during co-composting of different mixtures of rice hulls and crawfish by-products. This experiment was also undertaken to assess the suitability of recycling compost product with additional crawfish by-products. Mixtures containing high percentage of crawfish by-products had the highest degradability and nutrient content. The reuse of the recycled product induced higher degradation in the recycled product as well as complete degradation of the crawfish by-products.

INTRODUCTION

Crawfish processing by-products are highly organic and are typically rich in nitrogen (N) and readily-degradable organic carbon (C) compounds. These materials begin to decompose very soon after processing. Consequently, they become highly putrescent and could potentially create environmental problems if not handled and disposed of properly. By contrast, certain agro-industrial by-products are rich in less-readily-degradable C compounds. Examples are rice hulls, bagasse, bark, and yard wastes. These materials degrade slowly under normal conditions (Crawford, 1976).

By combining the N-rich crawfish by-products with materials high in C, such as rice hulls, the combination C:N ratio can be adjusted to within an acceptable range (20-40) to enhance composting without the associated odor problems. Earlier, Minkara et al. (1998) demonstrated that when composting crawfish by-products and rice hulls, most, if not all, of composting was attributed to the degradation of the crawfish by-products. It is because rice hulls contain more than 60 % lignocellulose and 20 % silica on a dry weight basis (Mizuki et al., 1993). These properties make rice hulls less susceptible to attack by microbes and consequently degrade very slowly. The slow degradation rate of rice hulls allows them to be reused as bulking material by simply adding raw crawfish by-products to the previously composted rice hull-crawfish by-products compost. A cost saving in bulk materials is thus realized by reusing the rice hulls.

When designing any compost process, knowledge of compost feedstock degradability is essential (Haug, 1993). In this study, dry mass and organic matter losses during composting were estimated in order to assess the degradability of different rice hull and crawfish by-products compost mixtures. Nitrogen losses and compost nutrient concentration were also analyzed to assess the nutrient value of the completed compost product.

The objectives of this research work were to characterize and compare the degradation rates and nutrient values of rice hull-crawfish by-products compost mixtures and to examine the efficacy of adding raw crawfish by-products to partially composted rice hulls. More specifically, the objectives were to 1) determine dry mass and organic matter losses, 2) measure N loss, and 3) estimate nutrient value of the final compost.

MATERIALS AND METHODS

Experimental Setup

Crawfish by-products were composted with rice hulls in 3-L beakers containing about 600 g of mixed material. Crawfish by-products were ground (5 mm) before mixing with rice hulls to facilitate sampling. Three replicates of four different mixing ratios of crawfish by-products and rice hulls, were used to obtain initial C:N ratios

of 14:1, 17:1, 25:1 and 42:1. The initial C: N ratio is used as the treatment in a 3x4 factorial experimental design. The 12 reactors were placed in an environmental chamber (Lab-Line Instruments, Melrose Park, IL) having the capacity to control temperature between 25 and 70 °C.

Three separate runs were performed. A new batch of crawfish by-products was added to the finished product of the first run identified as phase I. This second compost process was identified as phase II. As the degradation rate of phase II slowed, raw crawfish by-products were again added to begin phase III.

Sampling and Measurement Procedure

Samples were taken once weekly from each reactor to determine moisture, volatile solids, organic-C, and total-N concentrations. Water was added when necessary to maintain optimum moisture conditions in all reactors (40-65% wet basis). The compost was turned manually 3-4 times weekly to homogenize the mixture. Compost percent oxygen concentrations were measured four times weekly to confirm aerobic conditions.

Moisture content was determined gravimetricly at 60°C (APHA et al., 1992). After drying, samples were ground to 150-mesh size, thoroughly mixed and stored in air-tight containers for further analysis. Approximately 3 g sub-samples were combusted at 550 °C to determine volatile solids content. About 20 mg subsamples were used for organic C and total N determination using a Heraeus model CHN-O Rapid Analyzer. Elemental analysis of compost extract was determined for the initial mixture and the final product of each phase by the Inductively Coupled Plasma (ICP) method (APHA et al., 1992). Percent oxygen in the compost air space was measured using a model OT-21 oxygen probe (Demista Instruments, Wheeling, IL).

Determination of Organic Mass, Dry Mass, and N Losses

Degradation of organic matter is generally determined by a mass balance of the input and output materials. The mass lost during the process represents the total degradation. Dry mass degradability was determined to compare the degradability of rice hull-crawfish by-products compost during the three different phases of the experiment. Measuring total mass during the composting process is not always practical and cost-effective due to handling of different feedstock and the large volume produced. However, measurement of volatile solids concentration is feasible and a common practice, since aerobic biological activity decreases the volatile solids content by converting organic C to CO_2. Volatile solids concentration during composting is then used to estimate organic matter degradation.

Organic matter degradation, K_{OM} (%), was stated by Haug (1993) according to the conservation of ash. Total dry mass degradation, K_{dm} (%), is then calculated as a function of K_{OM} and initial volatile solids concentration (Minkara, 1998). Also, knowing the initial dry mass and K_{dm} at any time (t), the dry mass can be estimated at any time (t) during the composting period (Minkara, 1998).

Nitrogen mass balance is used to determine N loss during and after the composting process. Total N losses is estimated from the N concentration and dry mass after a time t of composting (Minkara, 1998).

RESULTS AND DISCUSSION

Changes in Organic Matter (Volatile Solids) and Total Dry Mass

During all three phases of the experiment, volatile solids content was reduced with the advancement of the biochemical reaction. Initial mixtures having higher C:N ratio tended to have higher volatile solids content as well. Initial volatile solids contents of 68.4, 72.6, 76.2, and 80.9 %, were obtained from mixtures having initial C:N ratios of 14, 17, 25, and 42, respectively. Raw rice hulls and crawfish by-products have volatile solids content of 81.3 and 62.1 %, respectively. During phase I, volatile solids content decreased to values of 63.0, 69.3, 73.5, and 79.3 % for the CN 14, CN 17, CN 25, and CN 42 treatments, respectively, by the end of the 40-day period (Figure 1).

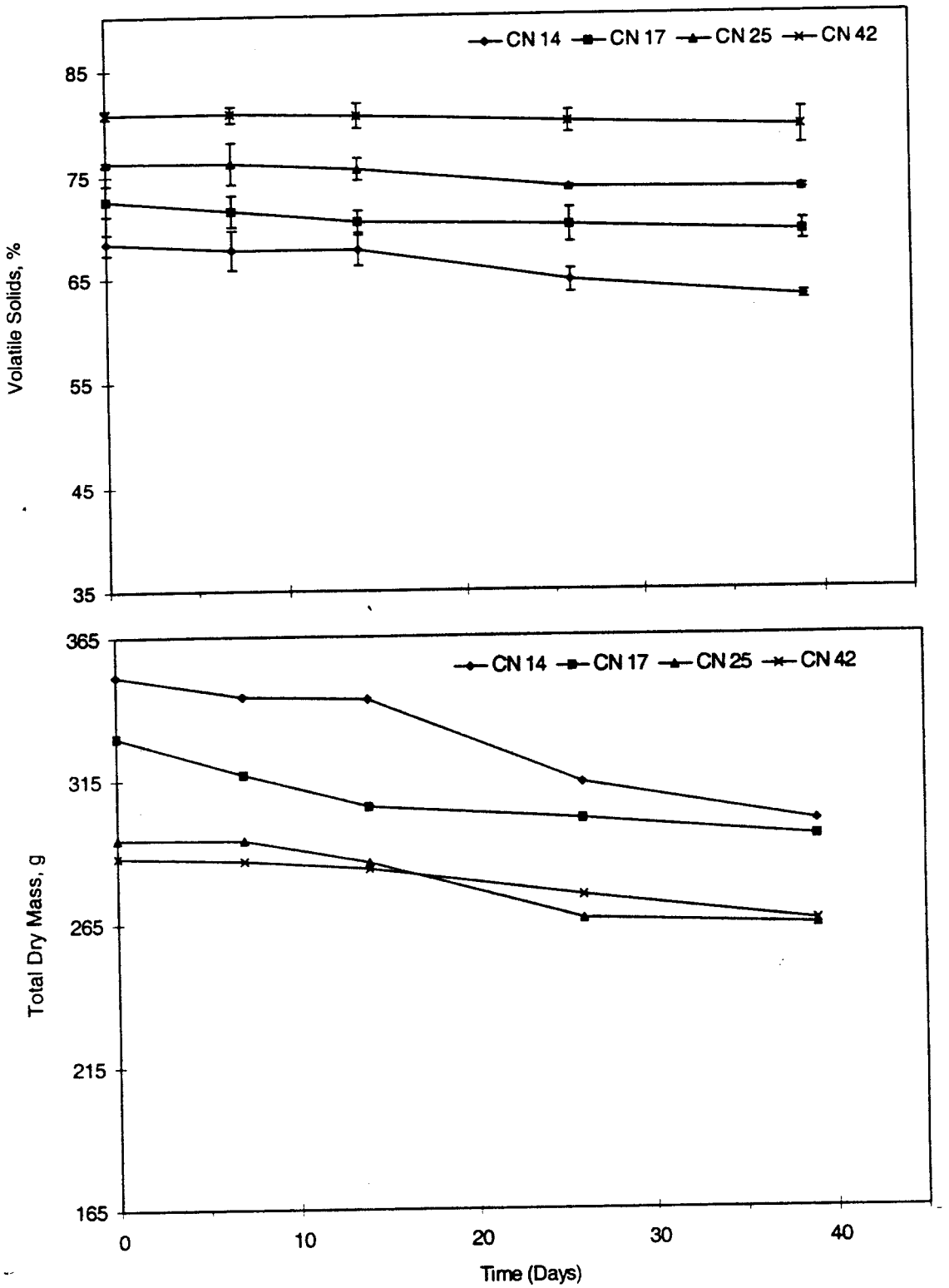

Figure 1. Volatile solids concentration (%) and total dry mass (g) versus time (Days) for the four treatments during phase I. Data are means of triplicate samples.

Phase II was initiated by recycling the product of phase I with a batch of crawfish by-products. Crawfish by-products were added at different amounts to each of the earlier treatments to obtain C:N ratios of : 11, 13, 15, and 20 and initial volatile solids content of 60.3, 64.1, 70.4, and 72.9 %, respectively. During phase II, volatile solids in the reactors were continuously decreasing to values of 50.2, 55.5, 65.7 and 67.9 %, for CN 11, CN 13, CN 15, and CN 20 treatments, respectively, at the end of the 40-day period (Figure 2).

Phase III was initiated by recycling the product of phase II with a new batch of crawfish by-products. Initial C:N ratios became as follow: 10, 12, 13, and 14 and initial volatile solids contents were 52.9, 55.2, 59.9, and 62.1 %, respectively. In this phase, although all four treatments had relatively similar initial C:N ratios, their initial volatile solids contents were significantly different. Volatile solids in the reactors continuously decreased and they reached values of 38.7, 40.0, 49.5 and 51.2 %, for CN 10, CN 12, CN 13, and CN 14 treatments, respectively, at the end of the experiment (Figure 3).

Total dry mass for phase I had a different trend than for phase II and III (figures 1, 2, and 3). In phase II and III, total dry mass experienced a sharp decline as commonly observed during the early stages of composting. This decline meant that substrate was readily available for microbial consumption. For phase I, acclimation of microbial population to the newly mixed feedstock delayed this phenomena. Total dry mass reached a steady state toward the end of each phase implying the exhaustion of the substrate.

The total dry mass loss and organic matter degradation for each treatment during each phase are shown in Table 1. In general, treatments with the lowest percentage of initial volatile solids had the highest loss of dry mass and organic matter. Although the percentage of crawfish by-products added was about the same at the beginning of phases I, II, and III, for treatment 1 (CN 14, CN 11, and CN 10) and for treatment 2 (CN 17, CN 13, and CN 12), the yield was higher for phase III than phase II or phase I (Table 1). Also, for treatments 3 (CN 25, CN 15, and CN 13) and 4 (CN 42, CN 20, and CN 14), the yield was higher during phase III than phase II, although a similar percentage of crawfish by-products was added. This implies that the degradability during phases II and III is not contributed to the added crawfish by-products alone, but also to the recycled materials. So the addition of crawfish by-products has provided an extra means for further degradation of the recycled product. In his model, Haug (1993) has considered that recycle product does not contribute any biodegradable fraction of volatile solids by assuming that the entire biodegradable fraction was consumed during the earlier cycle of composting. The results of this study seem to contradict his findings.

Changes in Total N

Initial N concentration varied in each mixture according to the ratio of crawfish by-products added to the amount of rice hulls or recycled compost. The initial N concentrations, for phase I were 28.7, 23.2, 16.4, and 10.1 mg/g (dry mass basis) for CN 14, CN 17, CN 25, and CN 42 treatments. During phase I, nitrogen concentration in all mixtures was continuously decreasing over the 40-day incubation period to final values of 10.5, 10.1, 8.2, and 6.7 mg/g, respectively (Figure 4). When the product of phase I was recycled with more crawfish by-products, N concentration became 28.0, 26.9, 23.7, and 19.5 mg/g corresponding to new C:N ratios of 11, 13, 15, and 20, respectively. Also, in phase II, N concentration for all treatments dropped simultaneously to final values of 12.0, 11.5, 10.1, and 8.5 g/kg for CN 11, CN 13, CN 15, and CN 20 treatments, respectively (Figure 5). The treatments in phase III having initial N concentrations of 29.4, 25.8, 26.0, and 25.0 mg/g corresponded to initial C:N ratios of 10, 12, 13, and 14, respectively. Final N concentration (dry mass basis) was observed for all treatments in phase III to be between 13.5 and 14.5 mg/g (Figure 6). Final N concentrations were the highest in phase III for treatment having similar initial N concentration.

Nitrogen content in each reactor was continuously decreasing through out the composting period (figures 4, 5, and 6 and tables 2, 3, and 4). Treatments with the highest N content observed the highest drop. This drop occured during the first 10 days due to high NH_3 volatilization. After the second week, N content tended to level off between 2 and 4 g N/reactor or a N concentration between 6 and 14 mg/g.

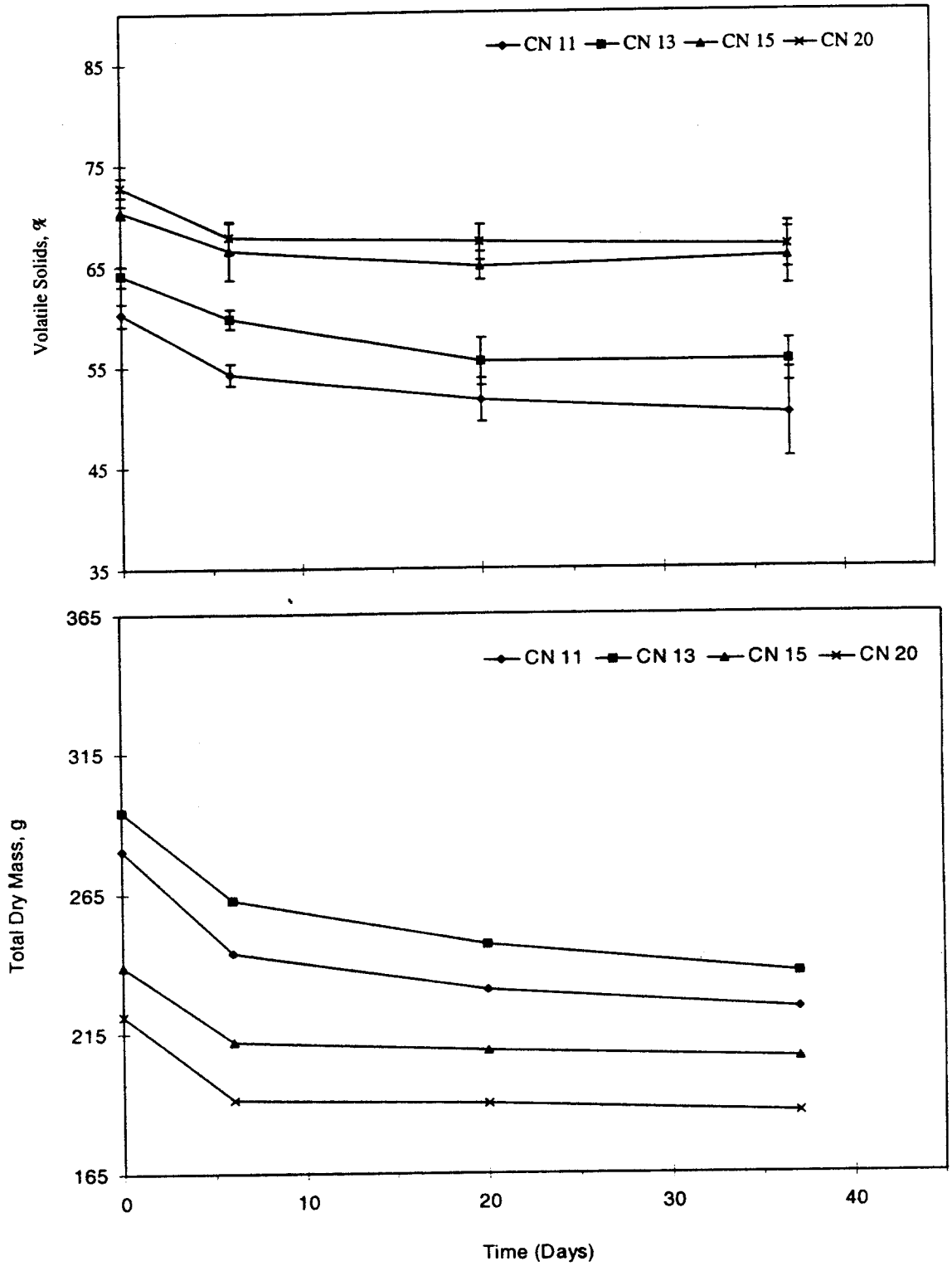

Figure 2. Volatile solids concentration (%) and total dry mass (g) versus time (Days) for the four treatments during phase II. Data are means of triplicate samples.

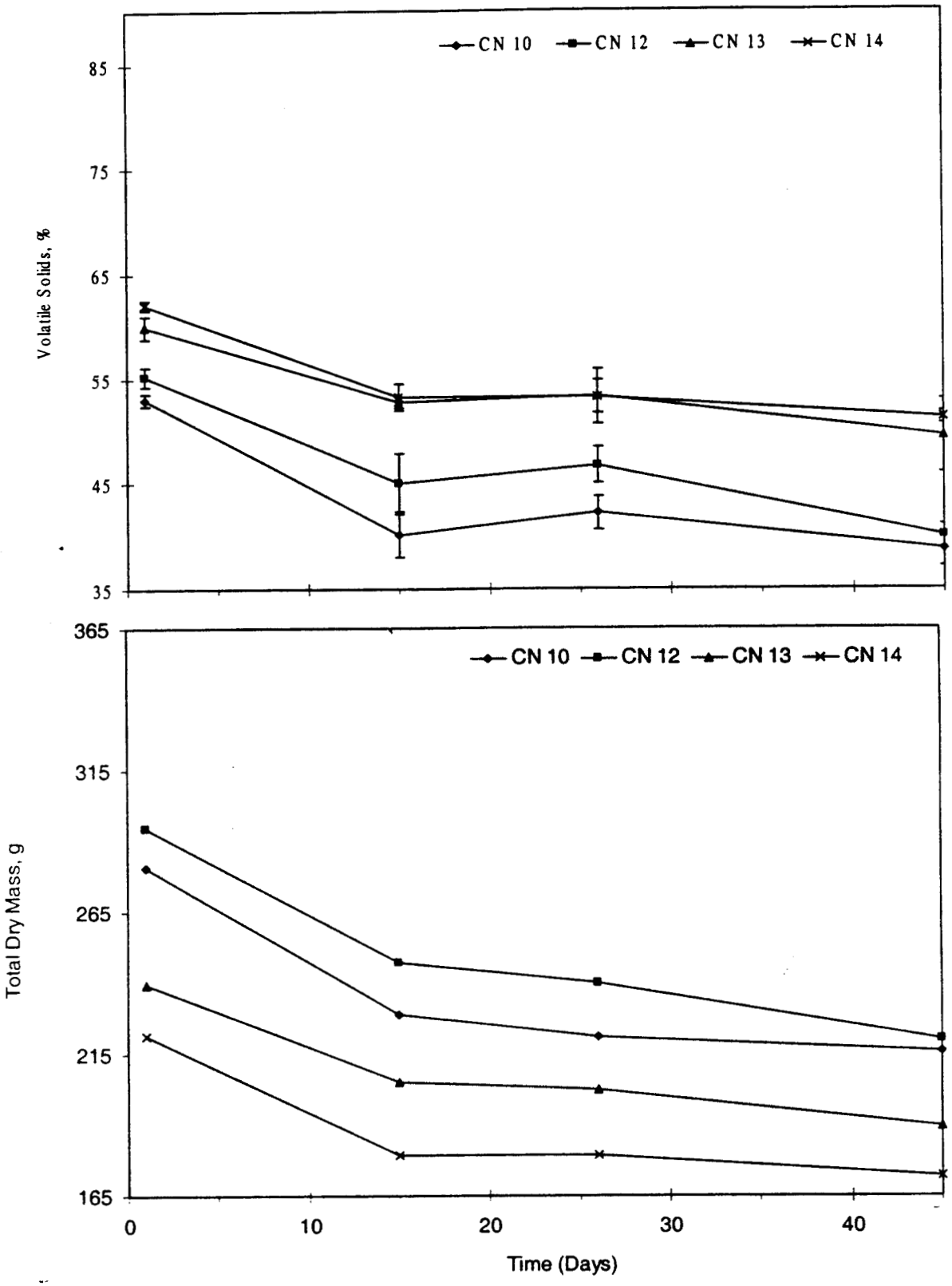

Figure 3. Volatile solids concentration (%) and total dry mass (g) versus time (Days) for the four treatments during phase III. Data are means of triplicate samples.

Table 1. Final organic matter degradation (K_{OM},%), dry mass loss (K_{dm}%), and percent distribution (dry mass basis) of crawfish by-products, rice hulls or recycled compost in feedstock having initial volatile solids, VS_i (%), for phases I, II, and III. Values are means of triplicate samples.

Phase I					
Treatment	VS (%)	Rice Hulls (%)	Crawfish By-Products (%)	K_{OM}(%)	K_{dm}(%)
CN 14	68.4	47	53	21.3	14.6
CN 17	72.6	57	43	14.8	10.8
CN 25	76.2	73	27	13.6	10.3
CN 42	80.9	84	16	9.6	7.8
Phase II					
Treatment	VS (%)	Recycled Compost (%)	Crawfish By-Products (%)	K_{OM} (%)	K_{dm} (%)
CN 11	60.3	50	50	33.4	20.2
CN 13	64.1	56	45	30.4	19.5
CN 15	70.4	57	43	19.5	13.7
CN 20	72.9	62	38	21.5	15.7
Phase III					
Treatment	VS (%)	Recycled Compost (%)	Crawfish By-Products (%)	K_{OM}(%)	K_{dm} (%)
CN 10	52.9	53	47	43.8	23.2
CN 12	55.2	59	41	46.0	25.4
CN 13	59.9	60	40	34.5	20.7
CN 14	62.1	63	37	35.9	22.3

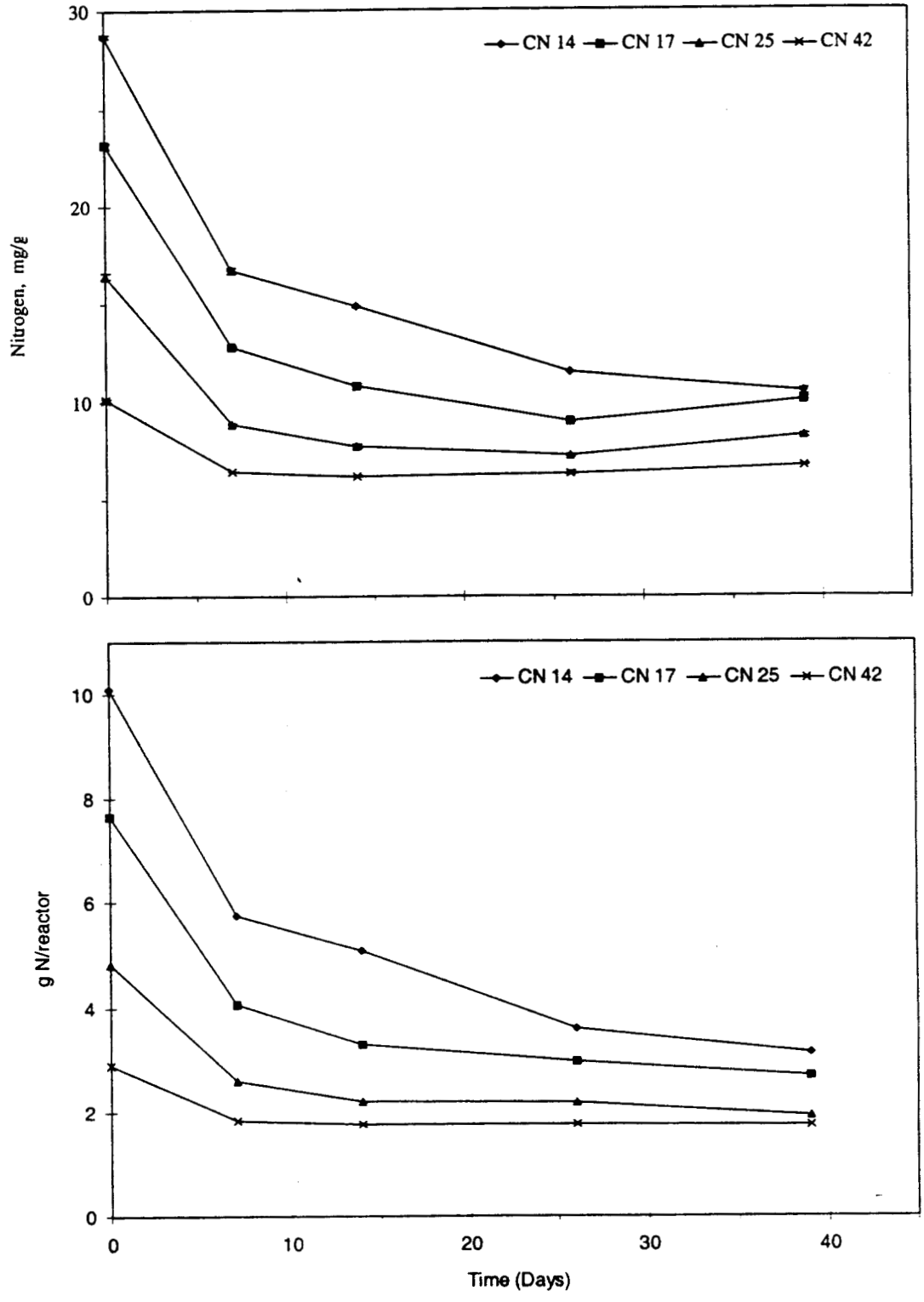

Figure 4. Mean total N concentration (mg/g) and content (g N) per reactor versus time for the four treatments during phase I.

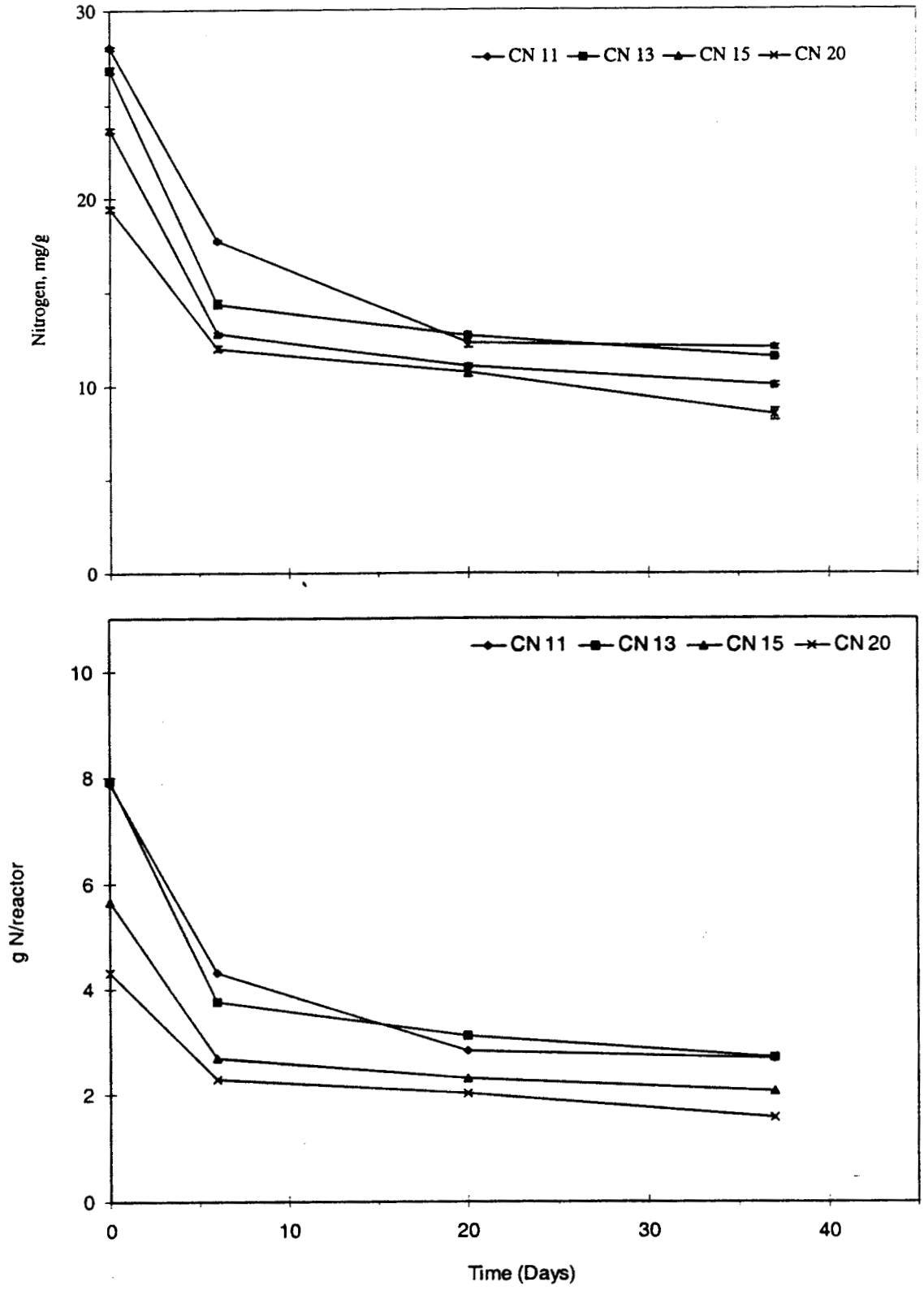

Figure 5. Mean total N concentration (mg/g) and content (g N) per reactor versus time for the four treatments during phase II.

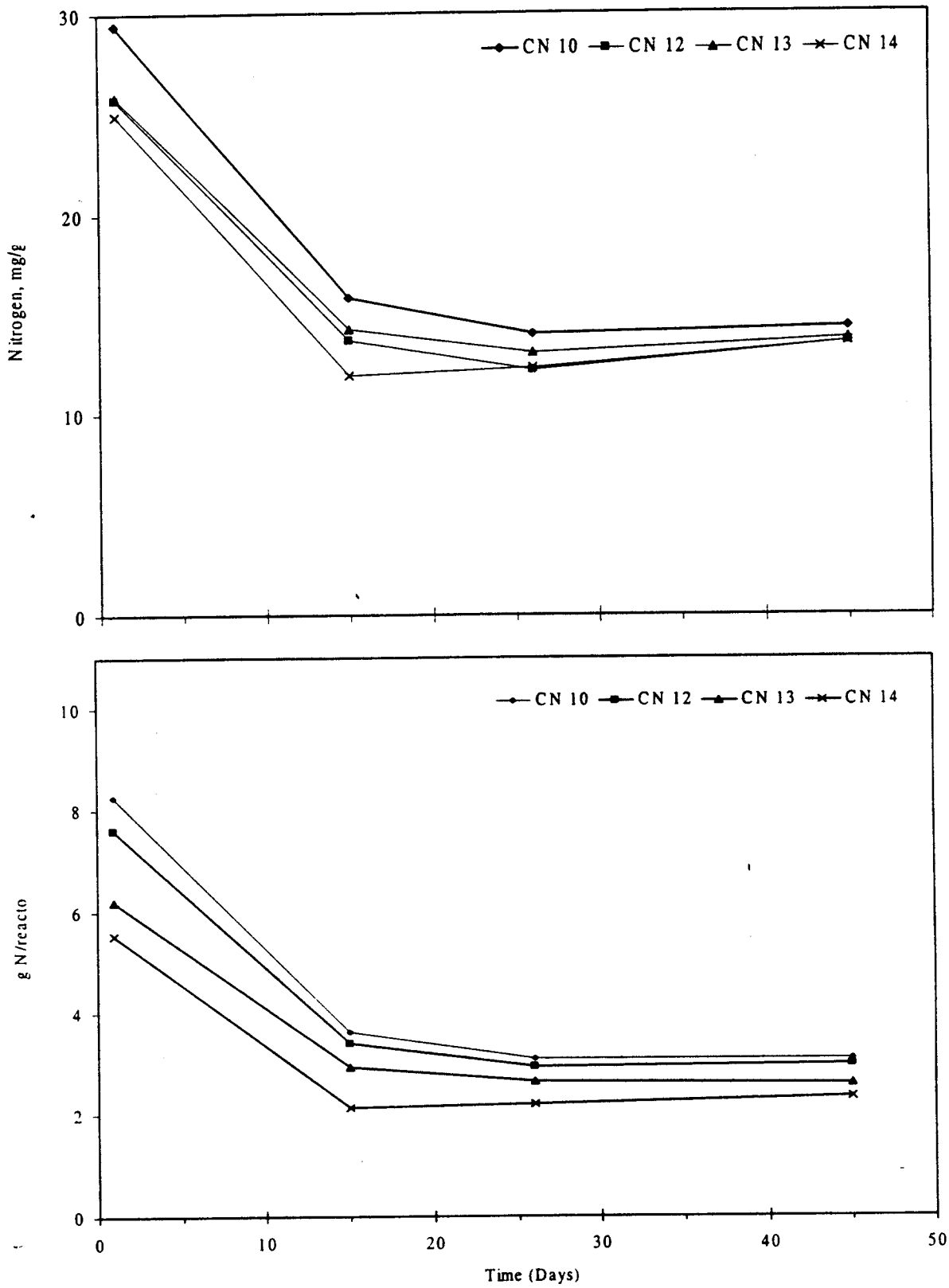

Figure 6. Mean total N concentration (mg/g) and content (g N) per reactor versus time for the four treatments during phase III.

Table 2. Average N loss from each treatment, for phase I, expressed as the cumulative mass loss and percentage loss from initial amount.

Time (Days)	CN 14 g N Lost per Reactor	CN 14 % N Lost of Initial Amount	CN 17 g N Lost per Reactor	CN 17 % N Lost Initial Amount	CN 25 g N Lost per Reactor	CN 25 % N Lost Initial Amount	CN 42 g N Lost per Reactor	CN 42 % N Lost Initial Amount
0	0	0	0	0	0	0	0	0
7	4.35	43.1	3.60	47.0	2.22	46.0	1.56	36.7
14	5.00	49.6	4.35	56.8	2.62	54.2	1.14	39.1
26	6.49	64.3	4.68	61.2	2.66	55.1	1.15	39.5
39	6.96	68.9	4.95	64.7	2.91	60.2	1.18	40.5

Table 3. Average N loss from each treatment, for phase II, expressed as the cumulative mass loss and percentage loss from initial amount.

Time (Days)	CN 11 g N Lost per Reactor	CN 11 % N Lost of Initial Amount	CN 13 g N Lost per Reactor	CN 13 % N Lost Initial Amount	CN 15 g N Lost per Reactor	CN 15 % N Lost Initial Amount	CN 20 g N Lost per Reactor	CN 20 % N Lost Initial Amount
0	0	0	0	0	0	0	0	0
6	3.55	45.1	4.14	52.3	2.96	52.2	2.01	46.7
20	5.03	63.9	4.79	60.5	3.35	59.2	2.27	52.7
37	5.18	65.7	5.19	65.5	3.59	63.4	2.73	63.3

Table 4. Average N loss from each treatment, for phase III, expressed as the cumulative mass loss and percentage loss from initial amount.

Time (Days)	CN 10 g N Lost per Reactor	CN 10 % N Lost of Initial Amount	CN 12 g N Lost per Reactor	CN 12 % N Lost Initial Amount	CN 13 g N Lost per Reactor	CN 13 % N Lost Initial Amount	CN 14 g N Lost per Reactor	CN 14 % N Lost Initial Amount
0	0	0	0	0	0	0	0	0
15	4.64	56.2	4.20	55.3	3.28	52.9	3.38	61.2
26	5.16	62.5	4.66	61.4	3.55	57.2	3.32	60.1
45	5.16	62.6	4.61	60.7	3.59	58.0	3.19	57.8

Characterization of Final Product

Nutrient analysis of compost samples showed that repetitive addition of crawfish by-products increases the concentration of important nutrients like P, K, Mg, Mn, S, and Ca (tables 5 and 6). These high concentrations provide plant nutrients and improve soil quality. Although high concentration of Na may cause damage to crop, the concentration of Na in crawfish compost remains lower than poultry litter compost (Lu et al., 1997). It was noted earlier that multiple addition of crawfish by-products reduces the volatile solids concentration (i.e. increases ash concentration). Since Ca is a major constituent of ash, the increase of ash concentration led to an increase in Ca concentration as well. This is why final Ca concentration ranged between 110-150 mg/g. At the end of the experiment, the treatments receiving the highest amount of crawfish by-products have the highest final nutrient concentration. The concentration of Si did not vary significantly among treatments

CONCLUSIONS

Biodegradability analysis conducted in this experiment showed that rice hulls and crawfish by-products can be composted when initial C:N ratio is within 10-42; however, mixtures containing a higher percentage of crawfish by-products to rice hulls or recycled product, tend to degrade at a faster rate. The results also showed that the initial

Table 5.

Table 5. Selected properties of initial compost mixture for all treatments (mg/g).

Treatment	K	P	Na	Mg	Mn	Ca	S	Si
CN 10	3.3	3.6	2.6	0.88	0.17	50.5	1.9	0.09
CN 12	3.1	3.0	2.1	0.78	0.17	41.3	1.5	0.11
CN 13	2.7	2.1	1.6	0.64	0.18	26.6	1.2	0.12
CN 14	2.1	1.2	0.9	0.49	0.18	12.8	0.9	0.13
$LSD_{0.05}$*	0.1	0.5	0.2	0.08	0.01	7.9	0.3	0.02

* Least significance difference

Table 6. Selected properties of final compost product for all treatments (mg/g).

Treatment	K	P	Na	Mg	Mn	Ca	S	Si
CN 21	6.3	10.2	5.5	2.4	0.34	150.6	3.6	0.068
CN 20	5.9	9.4	5.0	2.3	0.33	138.9	3.4	0.075
CN 17	5.6	8.0	4.5	2.0	0.32	118.4	3.0	0.064
CN 18	5.3	7.5	4.1	1.9	0.30	111.0	2.9	0.065
$LSD_{0.05}$*	0.3	0.4	0.2	0.1	0.01	6.1	0.1	0.02

* Least significance difference

C:N ratio is not a good indicator of the subsequent composting of feedstock. In addition to N availability, the extent of C degradability must also be taken into account. The addition of a nitrogenous feedstock, such as crawfish by-products, to recycled compost had a positive effect in improving the degradability of the recycled compost and the nutrient concentration of the final compost product. Rice hulls, having good structural property (i.e. high porosity, low bulking density), proved to be an excellent bulking agent for composting crawfish by-products which in turn provided readily available substrate for microorganisms. Further research is needed to quantify the degradation of different lignocellulotic materials during repetitive composting with nitrogenous feedstock.

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THE BENEFICIAL USE OF COMPOSTED PAPER MILL SLUDGE AND ANIMAL WASTE FOR AN INDUSTRIAL LANDFILL CLOSURE

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INTRODUCTION

A 28-year old paper mill landfill in western Massachusetts was closed in 1997 using the mill's own wastes as final cover materials. This final cover design incorporates a soil-like paper mill primary clarifier sludge in lieu of compacted clay as the side slope infiltration barrier. A conventional PVC flexible membrane and synthetic drainage media were used to limit infiltration on the flatter landfill cap, but this covers a relatively small surface area. A relatively thick (30 cm) vegetative support layer consisting of composted blend of primary clarifier sludge, food wastes and animal manure was substituted for topsoil over the entire landfill. Water balance concepts were used to demonstrate that these permeability values, higher than typically required for compacted clay barriers in many jurisdictions, are sufficient to limit post-closure side slope infiltration to less than 3 percent of the total precipitation.

This project turned several unique waste products into viable landfill final cover material, which has long reaching implications for closure of industrial and municipal landfills, as well as generators of soil-like industrial wastes and agribusiness concerns. Paper mill wastes have been demonstrated through various studies to serve as a suitable soil substitute, in addition to a soil enhancement. This project conserved both land and material resources, but the project owner estimates that the unique final cover design saved his company over $2M in final closure costs, relative to a traditional cover. Cooperation with agribusiness provides this mill with a long-term alternative to land filling, which reduces future disposal costs and creates new outlets for beneficial use of the waste.

FINAL COVER MATERIAL PROPERTIES

Paper Mill Waste. Paper mill primary clarifier sludge, when partially dewatered, can be engineered and worked much like a soil. This specialty paper waste is a non-hazardous 3:1 blend of mineral filler (kaolin and titanium-dioxide) and short pulp fiber. The material is belt-filter pressed to achieve roughly a 50% solids content. The high mineral content enhances the soil-like characteristics, at once lowering the hydraulic conductivity (permeability) but limiting shear strength when wet. The combined effects of the mineral and fiber contents caused high moisture retention, which was a significant factor in engineering a closure for this landfill.

Geotechnical laboratory tests indicate that the waste exhibits a liquid limit of 256 and a plasticity index of 133. These values confirm a strong affinity for water. Tested field-moist unit weights were 1.26 gm/cm^3 (80 pcf), with dry unit-weight based moisture contents of 270 percent. Dry unit weights were estimated at 0.34 gm/cm^3 (20 pcf). The moisture-density properties and high sensitivity are typical of a low-strength material. Undrained triaxial shear strength testing resulted in an internal friction angle of 43° and cohesion of about 0.116 kg/cm^3 (200 psf). The laboratory shear strength values are misleading, though, because the waste is soft and heavy when wet, resulting in difficult access and requiring specialized handling and placement.

Agricultural Compost. A composted mixture of the paper mill sludge and other byproducts was developed (with the mill's participation) by a third party agribusiness. The compost consists of 30% high mineral-fill paper sludge, 30% institutional organic food waste, 30% chipped wood and yard wastes and 10% chicken manure. At the composting facility, the blended materials are placed in windrows, turned after 30 days, then allowed to stabilize for an additional 30 days, prior to screening. The resulting product is exhibits a topsoil-like texture and a rich, earthy color, with no objectionable odor or runoff. The paper mill sludge serves as a bulking agent and is the key agent to laboratory permeability tests results on the order of 10^{-5} to 10^{-6} cm/sec.

Normally, each of these waste products would require disposal space. The compost was placed over the compacted sludge to serve as the vegetative support layer for the entire landfill, in lieu of imported topsoil. The compost exhibited easy handling characteristics, contrary to the non-composted wastes, and is not susceptible to erosion.

Vegetation is an essential part of the water balance cover design. The composted blend did not require fertilizer. Grass seed germinated in just a few days and healthy vegetation was established in a matter of weeks. The only apparent drawback was some isolated pockets of vegetative distress, believed to be caused by methanogenesis within relatively fresh sludge placed on-slope prior to the final cover, but not due to the compost itself.

WATER BALANCE DESIGN CONCEPTS

Final Cover Infiltration - The purpose of a final cover is to reduce surface water infiltration to the waste. The final cover for the paper mill landfill was modeled with water balance calculations, which consider long-term climatic effects and specific conditions, e.g. slope geometry, vegetation, permeability, porosity. These calculations are based on relatively simple concepts that borrow from hydrogeology, soil mechanics and agricultural engineering. A simple water balance model for a single layer soil system is shown in Figure 1.

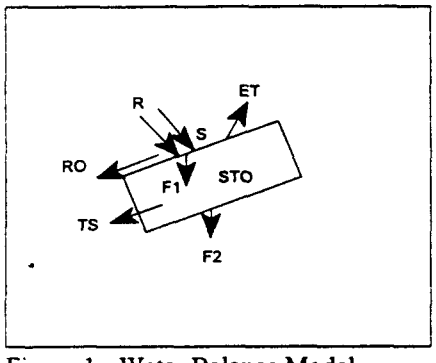

Figure 1 - Water Balance Model

The mass balance equation for the soil surface is:

$$R = F + ET + RO$$

Where:

$$R = \int_0^t r\,dt,\ r = \text{steady rainfall rate}$$

$$F = \int_0^t f\,dt = F_1,\ f = \text{infiltration rate}$$

$$\left.\begin{array}{l} S = \text{Surface Storage} \\ ET = \text{Evapotranspiration} \end{array}\right\} = 0$$

$$RO = \text{Direct Runoff}$$

The terms R and F can be considered as flux rates with units of [L/T]. Consider a steady rainfall associated with a 24-hour, 25-year storm, which might total 6 inches. The equivalent flux rate impinging on the ground is 0.25 inches/hour. Now consider a soil layer with a saturated hydraulic conductivity, K_s, of 10^{-4} cm/sec, or an equivalent flux of 0.142 inches/hour. At the onset of rain, the infiltration capacity, f_c, or boundary flux is governed by the capillary suction forces within the pore space but cannot exceed the rainfall rate, as shown in Figure 2.

The infiltration capacity, hence the boundary flux, decreases with time due to the reduction of the capillary forces as the pores near the surface fill with water. At time, t_p, when the surface pore space becomes saturated, runoff begins and the infiltration rate across the top boundary is limited saturated hydraulic conductivity. For a design storm event, t_p is relatively short compared to the duration of the rain, t, so the variation is typically neglected infiltration rate, f, is assumed to equal K_s. The cumulative infiltration, F, is calculated as K_s multiplied by time, t.

The fate of the water once it enters the soil system is of interest for completing the water balance calculation. The surface soil has a porosity that may vary up to 50%, that is, the potential volumetric pore water storage capacity is 0.5. This varies with soil type, compaction effort and root penetration. The available volumetric water content, θ, contained within the pore space can vary from near zero (in extreme drought conditions) to the full porosity value (completely saturated) depending on prevailing climatic conditions.

As the available pore space becomes saturated, a 'wetting front' moves downward through the soil, more from the influence of capillary suction forces than from gravity. The available storage in the surface layer of a soil cover system is expressed as the difference between the total porosity and the initial volumetric water content, multiplied by the average layer thickness.

During a seasonal or climatic wetting and drying cycle, the stored pore water at any given time is likely somewhere between dry and completely saturated, and the remaining pore space is available for storage of infiltrated water. In periods of drought or high potential evaporation conditions, the stored pore water is radiated back to the atmosphere, assisted by plant uptake. During wet spells or low evaporation conditions, pore water may migrate within the surface layer either as lateral seepage (parallel to slope) or as vertical seepage. The availability of water to migrate through the bottom of the surface layer is described by the mass balance equation:

$F_1 = STO + TS + F_2$

Where: STO = Soil Storage, $\theta_s - \theta_i$

θ_s = Saturated Volumetric Water Content

θ_i = Initial Water Content

TS = Tangential Seepage
May require drainage in surface layer

F_2 = Infiltration Below Surface Layer
(becomes leachate in a single-layer system

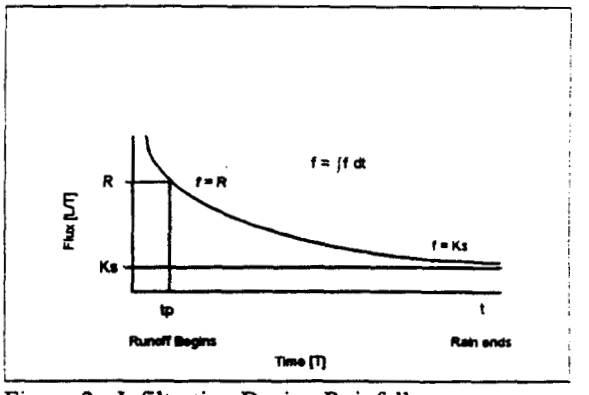

Figure 2 - Infiltration During Rainfall

In a landfill side slope cover, compacted soil layers offer anisotropic conditions that provide preferential pathways to seepage movement. The lateral or tangential seepage can be modeled as a confined porous layer, with the seepage rate governed by the horizontal saturated hydraulic conductivity, K_h. The vertical seepage, e.g. percolation into a deeper soil layer or into the waste, is controlled by the vertical saturated hydraulic conductivity, K_v. Typically, K_h is 2 to 4 times K_v in a compacted embankment or similar earth structure.

The vertical seepage or flux at the bottom of a given soil layer is limited by the lesser hydraulic conductivity on either side of the soil boundary. This is the 'path of lesser resistance' concept that forms the basis for the compacted barrier layer. Ostensibly, if the lateral conductivity of the surface layer is greater than the vertical conductivity of the barrier layer by at least an order of magnitude, the water in the surface layer is 10 times more likely to migrate as tangential seepage within the surface layer, rather than migrating down into the barrier layer. This concept is useful for modeling the removal of water from within the final cover system, and can be put into practice in the field by careful selection of cover soils. The tangential seepage component can be substantial, possibly requiring drainage to prevent excess pore pressures within the cover layer.

Tangential seepage, along with direct runoff and evapotranspiration, are the primary mechanisms that remove water from the final cover system, thus limiting infiltration to the waste. The process of water removal from the cover soil, i.e. 'infiltration recovery,' is enhanced by a well developed vegetative root system, which functions to

1. increase the soil porosity and pore water storage capacity,
2. provide a preferential lateral seepage pathway, and
3. enhance evaporation of pore water through root uptake.

Computerized modeling of final cover system balances precipitation and temperature and vegetation dependent evapotranspiration, e.g. Thornthwaite's equation, with estimated soil moisture levels. On a yearly basis with typical climatic conditions, PET can usually be shown to far exceed precipitation even in the wettest of regions. In other words, the annual water balance is negative, so provided that pore water storage within the surface layer is adequate, i.e. there is sufficient layer thickness and healthy surface vegetation, the calculated infiltration is relatively low. In practice, conventional final cover construction techniques result in built-in secondary porosity, e.g. clodding and/or inconsistent compaction. Conventional final covers lose long-term effectiveness due inherent drawbacks, described below, or due to loss of vegetation is that leaves the surface susceptible to erosion and dessication cracking.

CONVENTIONAL FINAL COVER DESIGN DRAWBACKS

Many regulatory jurisdictions require a maximum permeability of 1.0×10^{-7} cm/sec within the compacted clay layer over the entire landfill surface. This requirement is unrealistic for many industrial landfills, because the covers are constructed mainly on slopes, not level ground. The soft, highly compressible wastes yield under the weight of construction equipment, making the surface inaccessible to construction equipment. Compaction of clay over the yielding waste to meet the permeability requirements would have been difficult to achieve, if not impossible.

The biggest drawback to compacted clay covers is the tendency for cracking, typically through desiccation, which leads to increased surface water infiltration and promotes instability or ground water contamination. In colder climates, cracking and increases in permeability can be brought on by cyclical freezing and thawing. Nearly all wastes, including paper mill wastes and MSW, undergo long-term settlement, which induces cracking and loss of positive surface drainage. Cracking renders a conventional clay cover ineffective in a just a few seasons.

Compacted clay barriers typically add $20,000 to $40,000 *per acre* to the cost of the final cover. In areas where suitable clay is scarce, e.g. western Massachusetts, estimates for imported clay may run as much as $25 per cubic yard, which can add $100K *per acre* to the estimated landfill closure costs. Surface stabilization techniques required for construction of a conventional clay cover would have further added to the cover construction costs.

Many final cover designs incorporate flexible membranes with other geosynthetic components as the infiltration barrier. Such designs are accepted in nearly all regulatory jurisdictions and are in wide use. Though not as sensitive to settlement, synthetic membrane covers are not without drawbacks. Besides the initial capital costs, similar to that of a compacted clay barrier, side slope stability is a big concern. Numerous landfill cover failures have been attributed to veneer sliding of the cover soil above a flexible membrane, typically destroying the membrane itself.

More times than not, veneer failures are caused (or exacerbated) by inadequate internal drainage, i.e. build up of excess pore water pressure in the cover soils above the membrane. Pore pressure buildup can be prevented through the use of synthetic drain layers, but this can easily double the cost of a synthetic cover. In addition, the placement of geosynthetic components in contact on side slopes steeper than 4H:1V has been shown to create a potential low-friction interface boundary that can also promote veneer instability.

A problem inherent to both compacted clay barriers and synthetic covers is the tendency to trap the inherent moisture in the waste through the prevention of upflux. This can be a contributing factor to excess pore pressure buildup in side slopes constructed of paper mill wastes. The high initial moisture contents can persist indefinitely if drainage is inadequate and upflux is limited. An often overlooked problem is that the lack of upflux cuts off sustaining moisture to the vegetative cover during periods of drought. This condition promotes erosion and contributes to higher vegetation maintenance costs - in some cases, irrigation is required.

CONCLUSIONS

This project is a showcase of innovative technologies that turned several waste disposal liabilities into several economic and environmental benefits. The water balance cover design, with its less stringent permeability requirements, and the use of select industrial wastes and composted waste blends in lieu of soils, offer reduced construction cost relative to conventional landfill final cover designs. The composted paper mill and animal/food waste required no fertilizer, nor is the compost susceptible to erosion. The composted blend offers resistance to dessication with year-round support of vegetation. These key requirements for stability and final cover performance ultimately translate into reduced long-term cover maintenance costs. All of the waste products used to make this cover would normally require disposal space elsewhere. This effort conserves land and other resources.

Composting can provide select industries with a long-term waste disposal method that is less costly than traditional landfill disposal. Throughout the United States, emphasis is being placed on waste reduction, natural resource conservation, and the beneficial reuse of waste products in lieu of raw materials. The innovative use of paper mill residuals and other industrial byproducts as a component of "manufactured topsoil" or, even more simply, as daily cover for municipal landfills, can be used to solve difficult and expensive solid waste disposal problems. Mining and minerals processing, paper/pulp and other heavy industries annually produce thousands of tons of soil-like waste materials that can be composted with agribusiness wastes for beneficial use. These alternative disposal means require a certain degree of regulatory "buy in," thus more effort is required on waste generator's part than simply signing a contract with a waste hauler. However, the potential cost benefits far outweigh the effort.

This unique landfill closure met with strong regulatory support and required relatively minimal permitting effort. Landfill airspace is finite, and as future permitting and landfill construction, i.e. disposal costs, for new landfills inevitably becomes more expensive, alternative uses of industrial waste products, including composting and soil substitutes, becomes a sensible solid waste solution for both public and private sectors. Through beneficial use demonstrations, alternative waste disposal concepts will gain wider acceptance, alleviating permitting concerns.

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COMPOSTING PULP AND PAPER INDUSTRY SOLID WASTES : PROCESS DESIGN AND PRODUCT EVALUATION

By

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INTRODUCTION

Over 70% of the recyclable organic solid wastes produced by the U.S. pulp and paper industry are presently landfilled. A single mill in Georgia produces about 100,000 dry tons of solid wastes a year. At moisture contents of 50-90%, disposal of these materials costs the company about a million dollars each year. Interest in reducing cost and exploring more sustainable solutions through reuse, has lead to the identification of four compostable waste streams, namely, sludge, bark (wood yard debris), grit and ash. Research literature suggests that composting can be a suitable treatment that eliminates the usual problems of solid waste by (1)improving handling characteristics of sludges and ash, (2)reducing weight, moisture content and volume, and (3)removing nuisance due to odors. The resulting product has increased storability and improved physical characteristics and a balanced nutrient base suitable for high rate application in agriculture, forestry, landscaping and related industries.

Sludges from pulp and paper mills are mainly cellulose fiber generated at the end of the pulping process prior to entering the paper machines. They are composed essentially of fibrous fines and some inorganics such as kaolin clay, calcium carbonate, titanium dioxide and other chemicals used in the specific manufacturing process. The fibrous fines are 59-72 % (dry basis) cellulose, 6-16 % lignin and 7-10 % hemicellulose (Sosulski and Swerhone, 1993). Ash contents in the sludges range from 10 to 70 %. The high cellulose, lignin and ash contents make the material rather slowly degradable by microorganism. Hence, providing an environment that enhances growth of cellulolytic organisms such as *Trichoderma* spp. (Lynch and Wood, 1985) will be key to accelerating stabilization.

Carter (1983) reported the successful full scale composting of primary and secondary sludges bulked with bark. Comparing the product with other commercial composts and peat, Fitzpartick (1989) reported that Dwarf oleander growth was significantly better in this compost than in peat and at least one other commercial compost blend. Cellulose degradation from an initial 40% (dry basis) to a final 19% was observed during composting primary sludge, bark and nitrogen fertilizers as amendment (Valente et al., 1987). The process of accelerated windrow with forced aeration took a minimum of 60 days and in some cases 90 days. Higher degradation rates were found when the material was inoculated with bovine manure which could have introduced a population of cellulose degrading microorganisms, thus accelerating the process. A 3:1 v/v mixture of refiner mechanical pulp (RMP) and chemimechanical pulp (CMP) was composted by Campbell et al. (1991). The material composted just as well with urea amendment as without. The mixture heated to 60°C within 2 days and stayed above 45°C for over 14 days. Moisture reduced from 55% to 33% over a 6 week period. No significant loss in dry matter was noticed in that study. In another study, Campbell et al., (1995) reported composting a blend of bleached kraft/NSSC primary sludges, ash and paunch (cattle stomach contents as nitrogen source) from a slaughterhouse. They report significant reduction in dry matter, up to 50 % of the initial. The nutrient balance stabilized from an initial C:N of 270 to a final of 14-67. Increased fraction of ash in the blend produced a more agronomically valuable compost.

In this project, our objective was to quantify the operational steps in the composting of typical pulp and paper mill solid wastes, namely, sludge, bark (wood yard debris) and ash. Rapid composting of these high carbon solids requires a blend with optimal moisture, porosity and nutrients (C/N ratio). The evaluation of mixes and

nitrogen supplement both as mineral fertilizers and organic forms (chicken litter) were the overall objectives of this project. The specific objectives were :

1. Determine the best blend of primary sludge, grit, bark, ash and a nitrogen source that maximizes degradation and stabilization during composting,
2. Compare ammonium nitrate and poultry litter as the two nitrogen amendments,
3. Determine the minimum amount of amendment required for composting,
4. Characterize the stability and nutrient values of the final compost product,

MATERIALS AND METHODS

Primary sludge, bark (wood yard debris), grit and wood ash were collected from the Weyerhaeuser pulp mill located in Oglethorpe, Georgia, USA. Poultry litter was obtained from the Poultry research center of the University of Georgia in Athens, Georgia. Ammonium nitrate was purchased as bags of fertilizers from a local farm supply store.

Initial physical and chemical properties testing were measured on six samples from each feedstock obtained at different sampling times ranging over six months. Moisture content was evaluated by drying about 200g of sample in an oven at 105°C for 24 hours. After complete drying, the sample was finely ground and incinerated at 550°C for 6 hours to estimate the volatile solids and ash content. A portion of the ground sample, about 50g was used for chemical and nutrient analysis. Total carbon and total nitrogen contents were evaluated using a Leco CNS analyzer. Mineral contents were measured by first preparing the sample by incinerating in a muffle furnace for four hours at 500°C (to remove organics) and dissolving the residual ash in aqua regia. The extract was analyzed using an inductively coupled plasma atomic emission spectrometer. A known standard material (apple leaves) was simultaneously analyzed to ensure measurement accuracy. If measurement error based on the apple leaves were greater than 15% the readings were discarded.

Germination index (phytotoxicity) was evaluated using the cress seed germination test described in the Washington State Interim Guidelines (1994). A 0.45μ filtered water extract of the compost was produced and water cress seeds were added to 2mL of the extract placed in a petri dish and allowed to incubate at 30°C for four days. At the end of four days, the percentage of seeds germinated and root length of the germinated seeds were measured and expressed as percentages of a control (distilled water) germination plate. The germination index was calculated as the product of the percentage germination and the root length. The pH of the material was measured after dissolving 25 mL of the compost sample in 50 mL of distilled water and placing in a shaker for 15 minutes. The extract was filtered through a coarse filter and pH was measured on the filtrate.

Pilot composting was done in stainless steel vessels with a diameter of 38.1cm, depth of 49.5cm and a volume of 56.8L. The vessels were insulated with 7.6cm of foam insulation to minimizes conductive heat loss thereby simulating an environment within a large compost pile. Temperature of the material in the vessel was monitored using T-type thermocouples at two locations, 25.0 and 37.0cms from the surface. Vessels were aerated using a temperature feedback control with an adjustable set point that was set at a predefined temperature, e.g. 55°C. When the compost temperature exceeded the set point, air was continuously introduced to the vessel at a rate of 40.8 m^3/day. When the temperature of the compost was below the set point, air was introduced intermittently based on a timer providing aeration for 30 seconds in every 20 minutes. The resulting effective aeration of 1.02 m^3/day was designed to provide sufficient oxygen (>6% residual oxygen) to maintain aerobic microbial growth. Solenoid valves activated the airflows into the vessels and every event of valve opening and closing was recorded to a datalogger. Hence, the total airflow into each vessel was accurately calculated. An automatic sequencer extracted headspace gas from each vessel successively at a rate of 1 L/min for a period of 210 seconds every hour. After clearing sampling lines for 180 seconds, the gas stream was passed through gas analyzers to measure residual oxygen and carbon dioxide concentrations. Gas analyzers were calibrated using standard gas once a day. Compost temperature, gas analyzer data, airflows and measured ambient air temperature and humidity were written to a data logger once every hour.

At the start of each composting trial, weighed quantities of materials at known moisture content were placed in the test vessels. At each "turn" (approximately one a week), test vessels were weighed and contents emptied. The contents of each vessel were homogenized in a large plastic drum and water was added to the material to adjust the

moisture content when required. Several sub-samples were taken and combined to form one representative composite of approximately 250g for moisture, volatiles and nutrient analysis. A similar sample was used for pH and germination index (phytotoxicity) measurement. Two sets of experiments were performed, namely, preliminary trials and replicated trials. In the preliminary trials, different blends of the four feed stocks were evaluated with the two nitrogen amendments at different rates. One mix was selected at the end of the preliminary trials and this was evaluated with different rates of nitrogen amendments in replicated trials.

RESULTS AND DISCUSSION

The variability in properties among feed stocks and over time was significant. Average moisture content (Table 1) of the four paper mill feedstocks ranged from 50-70% with standard deviations as high as 8.0%. The volatile solids percentage indicating biodegradable matter were low in ash and high in grit and bark. The wastes being largely from woody sources are high in cellulosic carbon and low in nitrogen as indicated by the high C/N ratio (Table 1).

The objective of creating a blend was to include as much primary sludge as possible without losing optimal bulk density and moisture contents. Bark was included largely to provide bulking and grit was included to provide the volatiles that accelerate degradation. The initial base mix (WM_0) of Sludge 45%, grit 28% and bark 27% (by dry weight) resulted in a C/N ratio of 245.4 and a moisture content of 59.1%. The high C/N and low C/N treatments were developed by adding more (1.35 kg/kg of WM_0) and less (0.40 kg/kg of WM_0) of chicken litter (see Table 2). From a total dry matter loss the two treatments show no difference (Table 2). The volatile solids loss over the period of composting were different, however, the amount of mill solid waste base mix (WM_o) was 71% of the mix (i.e. only 29% chicken litter) in the first treatment and only 42% (i.e. 58% chicken litter) in the second which could account for the higher (5.7 %) volatile solids loss in the second mix.

Other base mixes (WM_1 and WM_2) were developed by adding ash to the other three streams as shown in Table 2. WM_1 and WM_2 behavior were very similar in the poultry litter amended treatments. The total dry matter loss (8.6 and 9.1%) and the total volatile solids loss (7.0 and 6.9%) were similar for each of the treatments. Several ammonium nitrate dosages were evaluated ranging from 20.1 to 86.4 g/kg (dry basis) corresponding to a nutrient balance of 12.5 to 47.9 C/N ratio. Surprisingly, both dry matter loss and volatile solids loss reduced with increasing nitrogen levels. This suggests that a lower dosage would be appropriate and the high corresponding C/N ratio is caused by the portion of the total carbon being unavailable to microbial metabolism.

The important results from the replicated trials are tabulated in table 3. Increasing the amount of poultry litter added to the wood mix (WM_3) from 0.18 kg/kg to 0.44 kg/kg resulted in an increase in dry matter loss from 14.8 to 20.1 % of initial mix. An increase in the stability of the final product compost was also seen with increasing poultry litter content. A value of stability index of 0.5 mg/g/hr or less indicates stability. Except the first and sixth treatment, all others treatments produced composts that had stable values. Increasing rates of ammonium nitrate addition did not show any clear increase in degradation. Similar to the preliminary trials, although the total dry matter loss ranged between 12.2 to 16.7%, there was not consistent increase or decrease in degradation with increasing nitrogen levels. Figure 1 shows the temperature profile of two levels (8.7 and 15.9 g/kg) of ammonium nitrate dosage along with the temperature profile in a chicken litter amended treatment. The increase in ammonium nitrate shows a delay in temperature increase, possibly due to a mild ammonia toxicity. The chicken litter amended materials were very active within 24 hours and completed most of the biological activity within the first ten days.

The compost was cured for over 60 days after removal from the bioreactors and then tested for physical and chemical properties. The final properties are shown in Table 2. It is clearly evident that the compost with poultry litter as the amendment has a higher level and diversity of micronutrients. This makes the compost more attractive to horticulturists than the ammonium nitrate amended material. This material also had a lower final C/N ratio of 37.4 (initial C/N of 80.9) compared to the ammonium nitrate amended which had a C/N of 97.9 (compared to initial of 136). The low C/N ratio is an important property of final compost as this indicates how much of a nitrogen tie up would result if the compost was applied to the soil. The level of phosphorus (an essential macronutrient) in the ammonium nitrate amended compost was very low (0.04%) compared to 0.29% in the chicken litter amended mix. The ratio between N, P and K is critical in judging the compost to be of balanced nutrient value. In this regard the chicken litter amended compost was far superior to the other.

CONCLUSIONS

The compostability of a mix of primary sludge, bark, grit and ash was evaluated. It was found that the mix could be composted to a stable and agronomically useful product. The following are some key findings :

1. The best mix from a degradation stand point was 57% (dry weight basis) sludge, 25% grit, 6% bark and 12% ash. The mix (WM_0)had an initial moisture content of 54% and a C/N ratio of 412.7,
2. Addition of nitrogen amendments decreased C/N ratio and increased total degradation. It was sufficient to use no greater than 0.18 kg(chicken litter)/kg(WM_0) on a dry basis resulting in an initial C/N of 80.9,
3. Adding ammonium nitrate at 5.42g/kg(WM_0) resulting in a C/N ratio of 136 was sufficient to provide about 15% dry matter degradation and a final compost with a stability of 0.078 mg(oxygen)/g(VS)/hr.
4. From a product quality standpoint, chicken litter amended compost was superior. It provided higher and a wider variety of nutrients.
5. From a degradation standpoint the ammonium nitrate amended mixes result in greater amount of pulp mill solids being processed within a given time period.
6. At the end of 30 days of composting the stability ranged between 0.14 to 0.88 mg(oxygen)/g(VS)/hr. After sufficient curing the composts are extremely stable at 0.078-0.096 mg(oxygen)/g(VS)/hr.

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TABLE 1. Initial properties of the feedstock materials used in composting trials[1].

	Sludge[2]	Bark[2]	Grit[2]	Ash[2]	Poultry Litter[3]
Moisture content, % wb	50.4 (4.6)	70.0 (0.9)	56.2 (5.8)	52.6 (8.0)	19.2 (4.3)
Volatile solids, % db	57.0 (3.5)	90.8 (2.8)	90.8 (8.3)	34.2 (12.8)	87.6 (3.4)
Carbon content, % db	35.0 (5.4)	45.3 (1.6)	48.9 (3.3)	20.8 (4.0)	43.4 (0.9)
Nitrogen content, % db	0.05 (0.03)	0.39 (0.07)	0.15 (0.06)	0.01 (0.01)	2.6 (0.8)
C/N Ratio	700	116	326	2080	16.7
pH	8.0 (0.6)	5.9 (0.1)	5.5 (0.8)	10.0 (1.4)	8.1 (1.1)
Germination index, %	63.2	59.5	27.2	71.1	0

[1]Numbers are average of 6 measurements over 3 sampling times. Numbers in parenthesis are standard deviations.
[2]Sludge, bark, grit and ash were obtained from Weyerhaeuser's Flint River Facility, Oglethorpe, Ga.
[3]Poultry litter was obtained from the University of Georgia poultry research center, Athens, Ga.

TABLE 2. Preliminary composting trials mix ratios, degradation and product stability.

Materials in compost mix	Composition (weight, db)	Initial C:N -	Total Dry matter loss, % (of initial)	Total Volatile solids loss, % (of initial)
WM_0 = 45% Sludge, 28 % Grit, 27 % Bark (dry weight basis)				
WM_0+ Poultry Litter	1:0.40	48.2	13.7	1.2
WM_0+ Poultry Litter	1:1.35	26.7	14.8	5.7
WM_1 = 38% Sludge, 24 % Grit, 10 % Bark, 28 % Ash (dry weight basis)				
WM_1+ Poultry Litter	1:0.16	84.0	8.6	7.0
WM_2 = 45% Sludge, 29 % Grit, 11 % Bark, 15 % Ash (dry weight basis)				
WM_2+ Poultry Litter	1:0.19	76.6	9.1	6.9
WM_2 + Amm. Nitrate	20.1 g/kg (db)	47..9	16.9	13.4
WM_2 + Amm. Nitrate	42.1 g/kg (db)	24.7	15.9	8.0
WM_2+ Amm. Nitrate	47.1 g/kg (db)	22.2	15.7	7.9
WM_2+ Amm. Nitrate	86.4 g/kg (db)	12.5	14.4	3.3

1. Target moisture content in all preliminary trials was 60% (wb). Actual measured moisture contents during the 30 days of composting averaged 61.8% (Std Dev. 4.8%) with a range of 67.7 to 54.2 %
2. Ammonium nitrate (fertilizer grade, 34 %N) were applied at rates measured in g(of ammonium salt)/kg(dry matter of compost material).

TABLE 3. Summary of replicated composting trials.

Materials in compost mix	Mix Ratio (weight, db)	Initial C:N	Total Dry matter loss % (of initial)	Total Volatile solids loss, % (of initial)	Final Stability Index, mg(O2)/g(VS)/hr
WM_3 = 57% Sludge, 25 % Grit, 6 % Bark, 12 % Ash (dry weight basis)					
WM_3+Poultry Litter	1:0.18	80.9	14.8	9.0	0.880
WM_3+Poultry Litter	1:0.26	63.5	16.4	10.7	0.491
WM_3+Poultry Litter	1:0.44	45.8	20.1	-	0.140
WM_3+Amm. Nitrate	5.42 g/kg	136.0	15.2	-	0.202
WM_3+Amm. Nitrate	8.70 g/kg	96.8	12.6	15.3	0.494
WM_3+Amm. Nitrate	10.9 g/kg	81.1	16.3	12.5	0.792
WM_3+Amm. Nitrate	15.9 g/kg	59.2	12.2	5.9	0.347
WM_3+Amm. Nitrate	67.2 g/kg	15.7	16.7	-	0.179

1. Target moisture content in all preliminary trials was 60% (wb). Actual measured moisture contents averaged 61.8% (Std Dev. 4.8%) with a range of 67.7 to 54.2 %
2. Ammonium sulfate (laboratory grade, 21 %N) and ammonium nitrate (fertilizer grade, 34 %N) were applied at rates measured in g(of ammonium salt)/kg(dry matter of compost material).

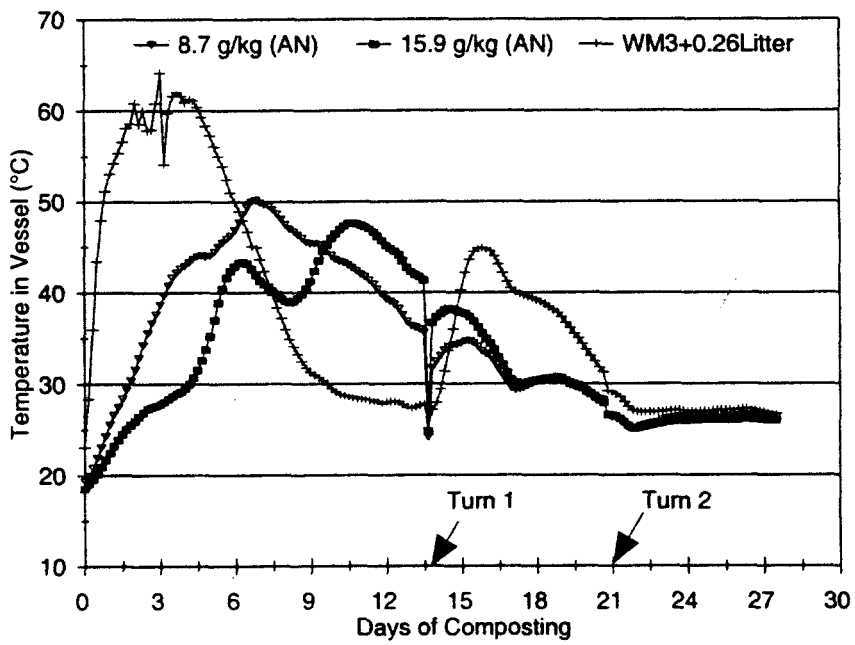

Figure 1. Temperature profile during a composting trial with low and high rates of ammonium nitrate (AN) amendment compared with chicken litter amendment. WM3 is a mix of the four feedstock as shown in Table 3. Temperature profiles are average of temperatures in three bioreactors under identical conditions.

TABLE 4. Final composted and cured sample chemical characteristics and stability.

	Ammonium Nitrate Amended mix Rate = 5.42 g/kg (Table 3)	Poultry Litter Amended mix Rate = 1:0.18 (Table 3)
C, %	13.7	14.2
TKN, %	0.14	0.38
C/N Ratio	97.9	37.4
P, %	0.04	0.29
K, %	0.09	0.27
Ca, %	2.74	2.41
Mg, %	0.08	0.15
S, %	0.06	0.12
Mn, %	0.03	0.04
Fe, %	0.15	0.12
Al, %	0.22	0.20
B, ppm	<0.6	5.65
Cu, ppm	6.32	159.20
Zn, ppm	46.3	122.4
Na, ppm	556	1059
Pb, ppm	4.28	4.66
Çd, ppm	0.53	0.45
Cr, ppm	4.02	3.59
Ni, ppm	3.34	3.14
Mo, ppm	<0.5	0.61
As, ppm	0.24	0.62
Se, ppm	<0.3	<0.3
Stability Index, mg-O_2/g-Volatiles/hr	0.078	0.096

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SUMTER COUNTY SOLUTIONS: INNOVATIVE, INTEGRATED MSW COMPOSTING AND RECYCLING

By

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FINDING AN INNOVATIVE SOLUTION

Faced with rising landfill costs and more demanding State-mandated recycling goals, communities in Florida and elsewhere are struggling to divert a larger portion of the municipal waste stream from landfills by recovering more of that waste stream through recycling and composting. Sumter County, Florida has developed a "state-of-the-art" system to do what communities everywhere want to do: recover more of the waste stream. This high-tech system takes full advantage of integrated solid waste management technology to consolidate recycling and composting activities at one location. The system, which evolved gradually as County officials worked to develop a solid waste management system to best serve the needs of the Sumter County community, represents a model for communities everywhere.

In 1975, Sumter County permitted a landfill to dispose of the municipal solid waste (MSW) generated by the residents of this small rural county in central Florida. As the County's landfill neared capacity and the State of Florida passed laws requiring more extensive recovery of material for recycling, Sumter County began to explore alternative solid waste disposal methods.

Energized by the 1988 Florida Solid Waste Management Act, the County evaluated existing options for treating solid waste and selected MSW composting supplemented with a drop-off recycling program. This combination of recycling and composting, one of the first of its kind in the United States, was selected for its ability to maximize the recovery of material and for its compatibility with the County's rural demographics. Sumter County began processing and composting MSW at the Sumter County Solid Waste Facility in 1988.

In 1995, in an effort to improve materials recovery and composting operations, the County appointed a solid waste steering committee to develop the most effective and efficient integrated recycling-composting system possible. The result of the this committee's efforts was development of a MSW materials recovery facility (MRF) and a compost digester system specifically designed to achieve the County's solid waste management objectives.

The County's state-of-the-art MRF and compost digester system offers maximum up-front recovery of materials for recycling, enables the County to produce top quality compost, and has the capacity to process 100 tons per day of municipal solid waste. It is the only MSW processing and composting facility of its kind, not only in Florida, but in the United States. The facility's innovative design has already gained widespread attention in the industry both because its design combines recycling and composting processes and because of its projected high materials recovery rates.

COMBINING RECYCLING AND COMPOSTING

During initial up-front processing, recyclable materials are both mechanically and manually removed from the waste stream and recovered for recycling. The MRF is equipped with the latest processing and recycling technologies, including an automated debagging system, a residue disc screen, and an eddy current separator. Recovered materials are baled on-site and marketed by the County. Materials remaining after processing in the recycling system are used for compost feedstock.

The materials remaining in the waste stream after MRF processing are introduced into an aerobic digester for composting. The digester is an impressive metal cylinder approximately 13 feet in diameter and 185 feet long. This giant rotating barrel provides a favorable environment for the natural biological breakdown of organic waste into compost. The digester's controlled environment produces a higher quality compost in less time than under natural conditions. The County's digester system is equipped with an air filter and drainage system to eliminate odors and leachate.

The County's compost digester system also offers an effective alternative for managing animal wastes and biosolids. The digester system is designed to handle 50 tons of MSW compost feedstock per day, and for every 50 tons of MSW feedstock, 25 tons of nitrogen source materials are added to support the composting process. Thus, the County processes 25 tons per day of biosolids or other nitrogen sources in the production of high quality compost.

PRODUCING HIGH QUALITY COMPOST

After processing in the digester for approximately three days, material is discharged and screened. Material leaving the digester is partially composted but needs additional "curing" to become high quality finished compost the County can market. This curing process is most efficient when moisture and oxygen levels can be controlled. To protect compost from excessive moisture and drying, screened material is deposited in windrows in the County's compost finishing building, a pre-engineered metal building where turning machines periodically aerate the material to complete the composting process and produce high-quality Class A compost.

After curing in windrows for approximately thirty days, compost is processed through a final screening to ensure consistency of texture and particle size. Finished compost produced by the County's system can be marketed for a variety of agricultural and horticultural applications.

High quality compost serves as a valuable soil amendment to improve moisture retention, conserve waster, and increase resistance to pests and diseases.

SERVING AS A MODEL

Sumter County's integrated system, which incorporates lessons learned from the County's pioneering experience in solid waste management and composting, represents a unique approach to solid waste management planning. Rather than rely on any one technology or company—none of which have successfully implemented all the necessary design, siting, technology, and financial components—the Sumter system uses the best elements available from several suppliers of solid waste and composting equipment and systems. Customizing facility design in response to local operating experience, rather than accepting the usual turnkey package approach, is exactly what is necessary to make mixed waste composting succeed.

Successful operation of the Sumter system will also demonstrate that mixed waste composting is a technology that, if properly designed, can substantially enhance solid waste management and produce a valuable soil amendment. Moreover, mixed waste composting may be the key element in keeping recycling and resource recovery options viable for small rural counties, which increasingly must either haul their waste to distant landfills or overcome the difficult challenges of siting and operating their own landfills.

Because Sumter County's integrated recycling and composting system offers an innovative solution to common solid waste management challenges, other communities are looking to Sumter County for leadership in this rapidly developing technology. The Sumter system has been the focus of articles in leading trade publications, and the facility was a featured tour site for the NRC conference in Orlando in September 1997. Sumter County's solution serves as an important model for other communities seeking cost effective systems to maximize materials recovery and achieve sound solid waste management.

CHARACTERIZATION OF LANDFILLED MUNICIPAL SOLID WASTE FOLLOWING *IN SITU* AEROBIC BIOREDUCTION

By

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INTRODUCTION

In January 1997, a pilot-scale project to assess the feasibility of *in situ* aerobic bioreduction of municipal solid waste was initiated at the Live Oak Landfill, located near Atlanta, Georgia. The high costs (money, regulatory hurdles, societal objections) of developing new landfills are making recovery and reuse of existing landfill space an increasingly attractive alternative. One of the first examples of landfill mining in the U.S. was the Collier County, FL landfill that began mining operations in 1986 (von Stein and Savage, 1993). The Collier County demonstration did not include aerobic bioreduction before mining. Some benefits of aerobic bioreduction of municipal solid waste (MSW) landfills include: reduced emissions of methane and reduced methane recovery costs; extended life of currently operating landfills; potential minimization of leachate and landfill gas contamination of ground water; stabilization and/or complete removal of old, unlined landfills.

This pilot-scale project was carried out in a lined cell containing approximately 70,000 yd^3 of MSW. The cell had been constructed using conventional techniques for the landfill and was approximately 30 feet in depth. The materials in the cell had been placed no more than three years before beginning this project. They were not segregated, or specially selected in advance, for this project, and the materials contained a significant portion of biosolids from waste water treatment plants.

To stimulate aerobic decomposition of the MSW, air and water (recycled leachate and additional fresh water) was injected into the fill material through wells. Routine monitoring of the process included temperature measurement; landfill gas composition; water volumes pumped and leachate generation; and physical, chemical, and biological chacterization of leachate. The details of the aerobic bioreduction process will be presented in future publications.

The purpose of this paper is to present a brief introduction to the project and to discuss initial results from analyses of the characteristics of the aerobically treated MSW.

AEROBIC BIOREDUCTION PROCESS

Water additions to the cell were initiated in mid-January 1997. Water additions were continued for approximately four weeks before initiating air injection to increase the moisture content of the MSW and reduce chances for fire. Average temperatures within the cell began to increase within three weeks of introducing air. Average temperatures within the cell during the process were approximately 120 °F. There were large variations in temperature throughout the mass, and some areas reached temperatures exceeding 160 °F. At about the same time

as temperatures increased, landfill gas composition changed from greater than 40 percent methane and 0 percent oxygen to less than 10 percent methane and 1-5 percent oxygen. Microbial counts in the leachate increased at about the same time as shown in Figure 1. These factors suggested significant increases in biological activity within the cell.

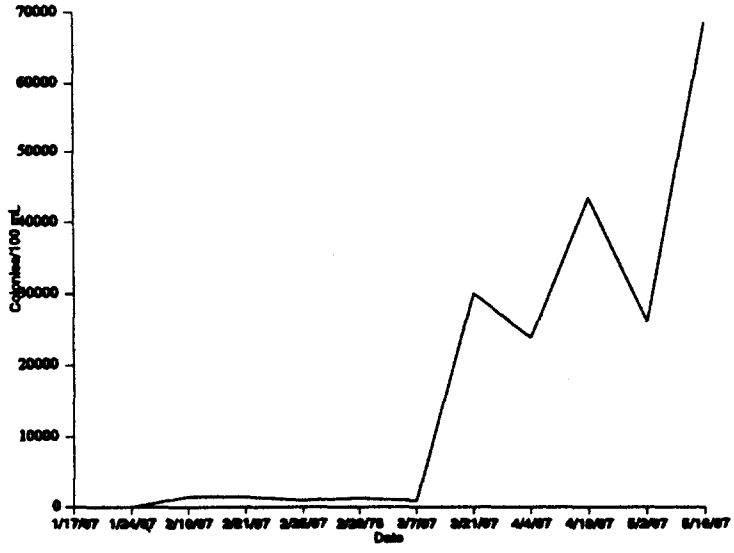

Figure 1. Microbial counts in leachate from Cell 3.

In May, the landfill mass was sampled by drilling in seven locations. Samples of the cuttings were collected during each five-foot progression of the drill bit. These were analyzed for, among other things, moisture content. The results showed that water content increased with depth, and that near the surface, the landfill mass was not much wetter than what would be expected in a normal landfill, *i.e.* water additions were not affecting moisture contents in the top of the fill. The results of these measurements are shown in Table 1. Visual observations during the drilling operation showed that the drier materials were the least decomposed and that the wetter areas were where the most degradation had occurred. These observations resulted in the redesign of the water distribution system to deliver water to the upper layers of the landfill mass. Figure 2 shows microbial counts as a function of depth in the augured samples.

Table 1. Average moisture content of bulk fill material as a function of depth from seven test holes

Depth, feet	Moisture Content, % wet weight basis
0-5	24.3
5-10	26.5
10-15	29.3
15-20	39.5
20-25	54.5

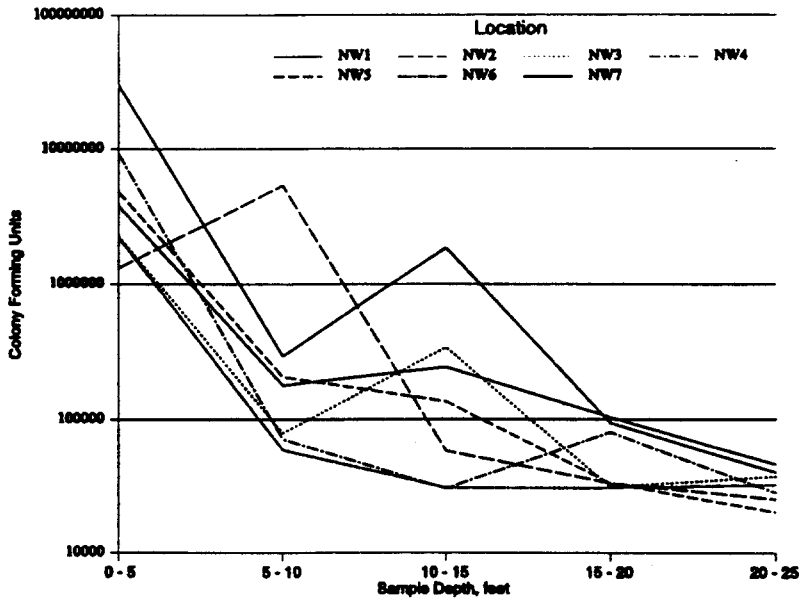

Figure 2. Microbial counts as a function of depth in drilled samples.

Accurate values of the amounts of water pumped into the cell are not available due to intermittent problems with flowmeters, particularly the meter on the leachate sump. The flowrates in the system were often low enough to allow flow through the meter without overcoming the inertia of the impeller, thus the meter failed to record all of the water pumped through it. From early January through mid October, at least 1,766,200 gallons of water were pumped into the cell. This is an average of 47,735 gallons per week or 6,819 gallons/day. The measured flow from the leachate sump totaled 703,920 gallons over the same period or 19,024 gallons per week (2,717 gallons per day.) The difference between total water pumped and leachate pumped represents makeup water provided from several sources - primarily city water and water from a nearby sediment pond.

There are at least two major conclusions to note related to water additions in Cell 3A. The first is that the aerobic bioreduction process requires tremendous quantities of water. Through the period of water additions discussed above, an average of approximately 25 gallons of water was added per cubic yard of fill. Even with these additions, there was no noticeable increase in the quantity of leachate produced by the cell. It is believed that much of the water was lost due to vapor diffusion through the boundaries of the cell and some water merely raised the moisture content of the fill without exceeding its water holding capacity. The second observation is that the quantity of leachate produced within a cell is entirely inadequate to supply the water requirements of the aerobic bioreduction process. Additional water from other sources is required.

CHARACTERIZATION OF BIOREDUCED LANDFILL MATERIALS

Beginning in October 1997 and continuing into 1998, small sections of cell 3A were mined and separated to assess procedures, equipment needs, and to characterize the materials recovered. To date, no attempt has been made to optimize the separation processes. The typical separation process used so far has been to pass the material through a trommel with a two-inch screen to remove the large fractions. The material that passes through the trommel screen is then conveyed into a second screen with 3/8 to 3/4 inch screens. The material passing through the second screen is generally a mixture of soil, composted organics and small bits of glass and metal. The materials that do not pass the second screen are generally large pieces of paper, plastic, wood, rock, *etc.*

Samples collected from each hole drilled in May were collected, screened (<0.5 inch), and composited to produce one sample for each depth increment. These samples were analyzed for oxygen uptake to determine whether

they were essentially fully composted, *i.e.*, whether they were stable. These results showed that none of the materials were completely stabilized at the time of drilling.

Three samples were randomly collected from the small fraction (< 3/4 inch) obtained during the first dig and separation in October. These samples were again tested for stability and were stable with oxygen uptake rates ranging from 0.167 to 0.351 mg of oxygen per gram of volatile solids per hour. Respirometry measures of this type performed on compost have determined that oxygen uptake rates of less than 0.5 mg of oxygen per gram of volatile solids per hour indicate stable compost. Besides respirometry, these samples were analyzed for composition in terms of the fractions of recyclable materials. The results showed that the small fraction contained between four and 8 percent plastic, less than 1 percent metal, and less than 8 percent glass. The rest of the sample contained degraded organic materials, soil, and paper. Laboratory analyses of the metals content of the humus fraction showed that all of the metals were well within limits set for high quality compost.

Samples from several different excavations and combinations of separation equipment have been analyzed. Results of analyses of the smallest fraction (passing a 3/8 - 3/4 inch screen) obtained during separations in February 1998 are shown in Table 2. It is clear from Table 2 that additional processing of the fine fraction obtained during the initial separation will be required to remove inert materials such as glass, plastic, and metals from any material destined to be taken off site as compost.

Approximately 10 yd^3 of the materials that did not pass through the trommel screen were hand sorted to determine the composition. The results of this separation are presented in Table 3. This material probably contained more soil than it did coming out of the trommel due to scraping up soil with the sample as it was loaded for transport. As it was, paper and plastic accounted for 15.6 and 12.1 percent of the material, respectively, by weight. If we remove the soil and other small fractions, the fractions for paper and plastic would change to 35 and 27 percent by weight, respectively.

SUMMARY AND CONCLUSIONS

The demonstration of aerobic bioreduction of Cell 3A has achieved the initial goals set for the project. We have shown that we can convert the cell to aerobic metabolism. We can control the aerobic process within safe limits. We learned many things during the demonstration that will allow improved operation and performance of the process during full-scale operations.

The organic materials in the small fractions are stable, indicating that they were substantially degraded. The high percentage of paper in the large fraction, however, indicates that large paper objects such as magazines have not degraded well in Cell 3A. This may be due to insufficient water, or insufficient time. In any case, if we cannot modify the bioreduction process enough to increase degradation of these products, it might be necessary to consider some post processing to separate the paper products, chop them and recompost them along with the already degraded organics. This will serve to reduce the amount of nondegraded paper that must be disposed of and provide an opportunity to cure, further stabilize, and deodorize the final compost. This process might also be where we aim to achieve the minimum temperature-time combination necessary to prove significant pathogen reduction.

If the soil and degraded organic material fraction is going to be used off-site, it will be necessary to significantly improve removal of the small glass and metal fragments that are currently present in this fraction. Such separation effort might not be justified, however, and on-site use as intermediate cover might be a better use of this material. Samples of the fractions generated during this pilot-scale study are being evaluated for their potential for off-site use/recycling. These efforts are continuing and no final dispositions for the mined materials have been determined. The more these materials that can be used off-site, the more landfill air space will be recovered, and the more economically attractive this process becomes. It is possible, however, that the in situ bioreduction of MSW landfills can be economically justified on other grounds such as environmental impacts.

Many remaining questions will be answered as proceed with a full-scale test of the aerobic bioreduction process. In this test, we will be applying these techniques to a cell containing approximately 1,000,000 yd^3 of MSW. Results from this test should be available during the next two years.

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Table 2. Characteristics of smallest fraction after separation.

Characteristic	Average	Std. Deviation
Physical/Chemical		
Moisture Content, % dwb	38.2	6.1
Volatile Solids, %	18.2	3.7
Respiration Index, mg O_2/g-VS/hr	0.552	0.296
Germination Index, %	68.2	10.1
pH	7.64	0.55
Electrical Conductivity, dS/m	1.97	0.52
Water Holding Capacity, %	82.0	11.2
Bulk Density, kg/m^3	1134.2	86.9
Avg. Particle Size, cm	0.53	0.08
Inerts, % of dry wt.	9.0	3.7
Sharps, % of dry wt.	0	0
Nutrients		
C, %	6.36	3.07
N, %	0.33	0.15
P, %	0.12	0.03
K, %	0.13	0.03
Ca, %	0.79	0.37
Mg, %	0.57	0.07
Mn, %	0.08	0.01
Trace Elements/Metals		
As (EPA Limit 41 mg/kg)	3.24	1.63
Cd (39)	1.19	0.72
Cr (1,200)	315.06	155.38
Cu (1,500)	97.68	13.77
Pb (300)	61.32	23.64
Mo (18)	0.78	0.35
Ni (420)	110.36	17.76
Se (36)	0.33	0.35
Zn (2,800)	252.73	139.95

Table 3. Composition of materials rejected by the trommel (> 2 inch).

Fraction	Weight, lbs	Percent by Weight
Wood	355.6	3.7
Plastics	1,155.4	12.1
Paper	1,484.8	15.6
Metal	415.6	4.4
Textiles	487.5	5.1
Rocks & Misc.	311.9	3.3
Soil & Other		
Inerts	3,242.6	34.1
Volatiles	1,121.6	11.8
Water	945.0	9.9
Total Soil & Other	5,309.2	55.8
Overall Total	9,520.0	100.0

In-Situ Municipal Solid Waste Composting Using an Aerobic Landfill System

by
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Abstract

Municipal solid waste (MSW) landfills worldwide are experiencing the consequences of conventional landfilling techniques, whereby anaerobic conditions are created within the landfill waste. Under anaerobic conditions, slow stabilization of the waste mass occurs, producing methane, (an explosive, "green house" gas) and toxic leachate over long periods of time. In attempts to reduce the production of this leachate, composite soil cap systems are constructed over landfilled waste. To reduce the release of leachate into the environment, many landfills use sophisticated subsurface liner and leachate collection systems. However, these cap, liner, and collection systems ultimately fail, potentially releasing methane gas and leachate to air and groundwater. As a result, this design approach only postpones the inevitable risks associated with landfills.

As a solution, it was demonstrated that aerobically degrading MSW within a landfill can significantly increase the rate of waste decomposition and settlement, decrease the production of methane gas, reduce the level of toxic organics in the leachate, and decrease quantities of landfill leachate that need treatment. Through a technology transfer initiative supported by the U.S. Department of Energy (DOE), an aerobic landfill system (ALS) was installed and operated within a 16-acre Subtitle D MSW landfill near Augusta, Georgia (USA). Readily integrated into the landfill infrastructure, an ALS can safely and cost-effectively convert a MSW landfill from anaerobic to aerobic degradation processes, thereby composting much of the organic portions of the waste. As a result of increased waste decomposition, stabilization, and settlement, not only are landfill operating costs reduced, but the life of the landfill can be extended, potentially increasing revenues. It was also shown that by properly controlling the injection of air and leachate into the waste mass, waste mass temperatures remained stable between 40 and 60 degrees C. Through the continued development of this technology, the ALS will foster a new perspective on landfilling waste, and, at the same time, reduce the cost burdens of landfill operations and/or site remediation.

I. Introduction

A. The Consequences of Anaerobic Waste Decomposition

Many of the world's landfills are becoming significant risks to the environment. Past and present day landfill designs include soil and/or plastic barriers above and below the waste in an attempt to reduce the infiltration of moisture into the waste mass and thus into the environment. This design approach creates a "dry-tomb" environment within the landfill and induces anaerobic degradation of the waste. Over time, anaerobic decomposition of sanitary wastes can have effects on landfill operations which actually increase the potential for risks to human health and the environment. These risks include:

- the potential for an increase in leachate strength, as well as organic and metals compounds concentrations in the leachate;
- possible formation of toxic daughter compounds in the leachate, such as vinyl chloride; and,
- slow stabilization of waste mass, increasing the potential for leachate releases through the landfill's liner systems.

In addition, anaerobic conditions within a landfill result in the production of methane, an explosive, odorless gas, and vapor-phase VOCs. Considered a "greenhouse gas" under the Clean Air Act, methane generated in landfills is typically in excess of 40% of the total landfill gases. In some cases, VOCs present in the landfill gas have been identified as a source of groundwater contamination. At many landfills, these gases are required to be collected, controlled (flare or other end use), and monitored to minimize the risks of gas build up and/or fires as well as to comply with environmental regulations.

Although the "dry-tomb" approach is an attempt at reducing toxic releases from a landfill, this approach is a temporary solution. According to the EPA, "liner and leachate collection [systems] ultimately fail due to natural decomposition..."[1] (EPA, 1988). In 40 CFR 258, EPA recognizes that "Once the unit is closed, the bottom layer of

the landfill will deteriorate over time and consequently, will not prevent leachate transport out of the unit." As a result, leachate collection systems and impermeable caps do not decrease the risk that toxic constituents, typically found in aging landfill leachate, will reach local groundwater. To prepare for this, landfill owners are required to set aside funds for their own cleanups. Once the landfill begins releasing leachate, remediation must be initiated, and the waste mass is "managed" once again. The net effects of this "dry-tomb" approach can be costly, even beyond the landfill's closure.

Ironically, landfills are required to be designed using the "dry-tomb" approach. As a result, landfill owners find themselves using a solid waste management approach that will most likely fail, and only postpone high landfill costs and long-term liabilities. Although there are relatively a few landfills where waste-to-energy (WTE) is cost-effective (discussed below), the anaerobic, "dry-tomb" approach to landfills appears to be the wrong answer to long-term solid waste planning.

B. Aerobic Degradation of MSW

Active aerobic biodegradation processes, such as composting, have demonstrated for years that the biodegradable portion of MSW can be stabilized in a significantly shorter time frame (than under anaerobic conditions) by adding the proper proportions of air and moisture to the waste mass. In addition, the recirculating of the waste's own leachate through the waste mass improves degradation, whereby the recycling of moisture, and nutrients are continually made available to the respiring microorganisms indigenous to the waste.

In a landfill environment, this concept of *in-situ* aerobic biodegradation of MSW is being evaluated worldwide. Laboratory experiments, such as those conducted at the University of South Florida, have demonstrated that, in an aerobic environment, respiring bacteria convert the biodegradable mass of the waste and other organic compounds to mostly carbon dioxide and water, instead of methane, with a stabilized humus remaining[2]. Reportedly, several European and Asian countries are evaluating this approach and have begun their own aerobic landfill studies. In these cases, the landfill itself serves a large closed vessel or bioreactor, is operated as a cell, and is managed to control leachate, landfill gas (LFG), and waste recycling.

As many wastewater treatment facility operators know, aerobic treatment processes reduce concentrations of organic compounds typically found in wastewater. Compounds such as toluene, MEK, vinyl chloride, as well as many odor-causing compounds (e.g. ammonia) can be treated in aerobic lagoons, rotating beds, and fixed media systems. Using the landfill waste as a treatment bed, the ALS also promotes the aerobic treatment of the leachate in a similar manner, whereby air, moisture, and nutrients are combined together. Since the concentrations of these compounds are reduced, the need for subsequent leachate treatment could also be reduced, depending on applicable regulations. As an additional benefit, there is an increase in the rate of waste stabilization (the point at which risks associated with the waste are minimized) as well an increase in the rate of waste subsidence. This creation of landfill "air space" can maximize the useful life of a landfill.

C. Demonstration of the ALS at a Subtitle D Landfill

Through a technology transfer initiative funded by the U.S. Department of Energy (DOE), American Technologies Inc. (ATI) demonstrated the effectiveness of this concept by implementing an Aerobic Landfill System (ALS) within an active 16-acre portion of the Columbia County Baker Place Road Landfill (CCBPRL) near Augusta, Georgia (USA). Based on aerobic studies conducted to date, ATI designed, installed, and presently operates an 8-acre ALS. Since January 1997, the ALS demonstrated that this municipal sanitary landfill could cost-effectively be converted from anaerobic to aerobic degradation processes, and that aerobic degradation of the MSW can provide short- and long-term benefits for landfill operators.

With a minor modification of the landfill's operating permit, the ALS was approved by the Georgia Environmental Protection Division (EPD) within a relatively short timeframe (30 days). The system was then installed in approximately two weeks and has been operational since. Presently, designs are being developed for expansion of the system in the 16-acre landfill and discussions are currently being held with EPD for implementation of a second ALS within the 60-acre unlined landfill which lies adjacent to the Subtitle D area.

D. How the ALS Process Works

The ALS is a natural process via the addition of air (providing oxygen to the waste mass) and the recirculation leachate (providing moisture and nutrients for the indigenous, respiring microorganisms). A reliable, flexible system for adding air and leachate was designed based on several leachate recirculation studies conducted to date as well as on practical environmental remediation systems that treat soils and groundwater *in-situ*. Using readily available materials and equipment, the system was readily integrated into the existing CCBPRL infrastructure. The key to the ALS effectiveness is the proper control of aerobic conditions, whereby waste mass temperatures and moisture are maintained within optimal ranges. This is accomplished by balancing airflow and leachate recirculation into the waste mass in a manner that effectively stabilizes the waste in a much shorter time frame than under conventional anaerobic conditions.

The air injection system is comprised of electric blowers and PVC piping, connected to the existing landfill infrastructure. For landfills with an existing leachate collection system (LCS) (e.g. such as in the floor of the CCBPRL Subtitle D cell), the ALS incorporates the LCS to provide oxygen to the waste mass (it was demonstrated that the LCS could still collect leachate during air injection). Where needed, vertical air injection wells were also installed directly into the waste to provide additional oxygen. Landfills with no leachate collection systems, can be readily retrofitted with horizontal and/or vertical air injection wells.

Leachate, collected in the landfill's holding tank was pumped into the system through a PVC and flexible hose leachate recirculation system to the top of the waste. The system then injects leachate through the intermediate clay cap (which covers the waste) and into the waste mass. The leachate then percolates downward contercurrent to air that has been forced into the waste by the blowers. Leachate that is not utilized during aerobic decomposition migrates downward to the landfill's leachate collection system or recovery wells, is pumped to the tank, and recirculated through the waste mass. Landfills with no leachate collection systems, can be retrofitted with horizontal and/or vertical leachate recovery wells at locations where leachate is likely to collect. This "closed-loop" configuration reduces the potential for operator exposure to leachate and minimizes operator involvement. A schematic of a typical ALS is shown in Figure 1.

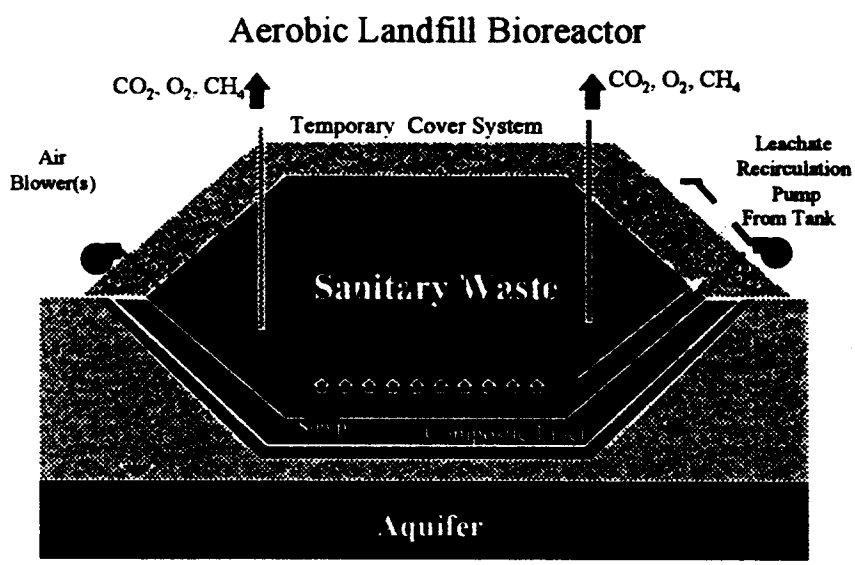
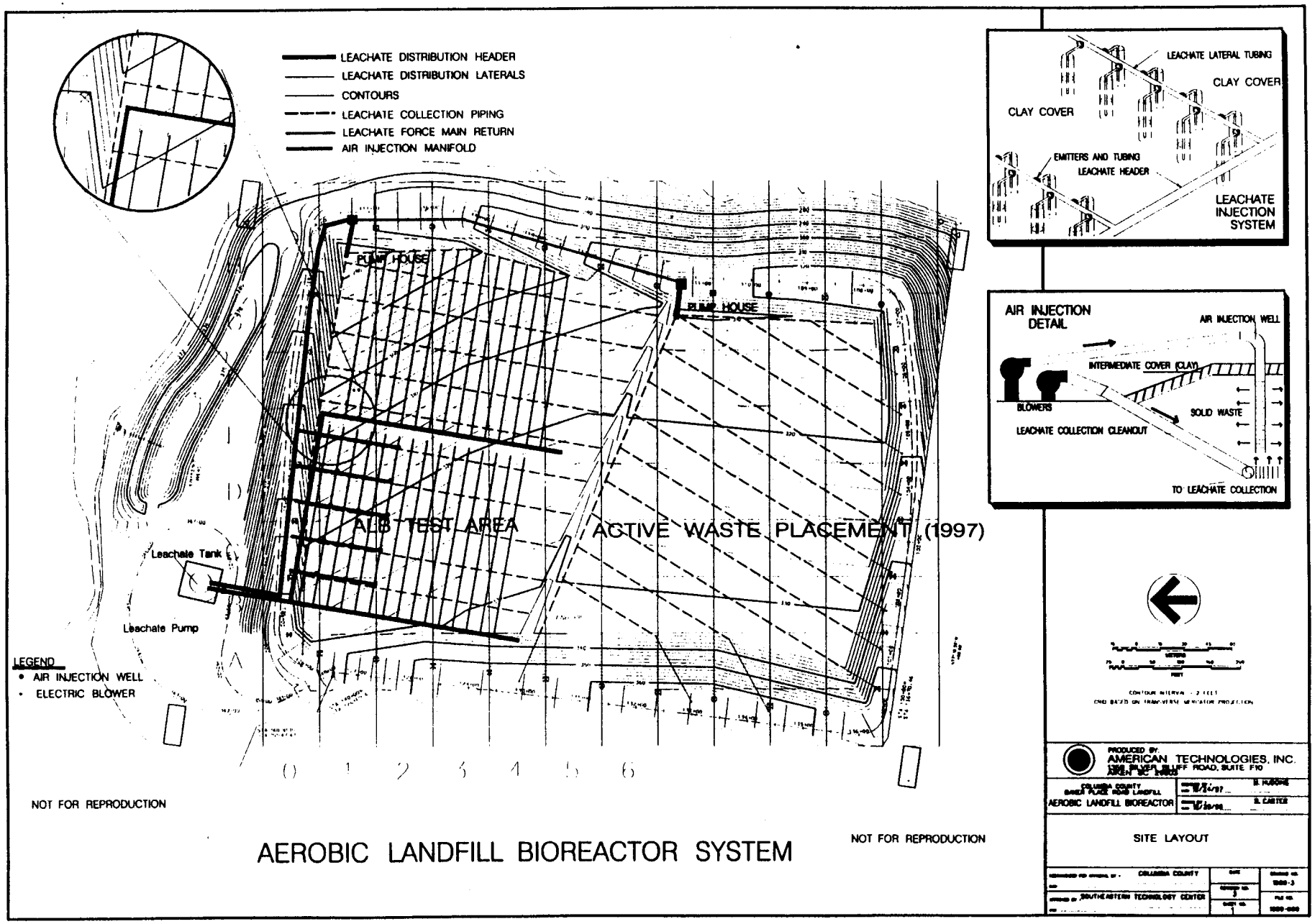


Figure 1: Typical ALS Construction

The ALS was divided into three areas, as shown in Figure 2: 1) air injection and leachate recirculation, 2) leachate recirculation only, and 3) active waste placement (no air or leachate injection). LFG data and waste samples were collected in these areas for comparisons.



AEROBIC LANDFILL BIOREACTOR SYSTEM

NOT FOR REPRODUCTION

Aerobic conditions were balanced in the landfill by properly adjusting leachate flow and air delivery into the waste mass to keep the waste mass moisturized and aerated. Improper balancing of air and leachate can lead to poor ALS performance and, possibly, elevated waste mass temperatures. Technicians closely monitored the ALS during the startup period (2 to 5 months) to ensure safe, effective operating conditions were established. Adjustments to the system were made based on key data, as described below. Afterwards, monitoring of the system was readily accomplished by site personnel. Automation of system components can be implemented to further minimize the time requirements for landfill operators.

During ALS operation, waste mass moisture content, temperature and off-gas concentrations (VOCs, CO_2, O_2, and CH_4) were measured in the field to ensure safe, efficient aerobic operations. Using moisture probes, thermocouples, and vapor points that were installed directly into the waste, key operational data were collected from portable monitoring instruments. Leachate analyses includes, at a minimum, pH, TKN, TSS, specific conductivity, BOD, COD, metals, and VOCs. Other data includes an inventory of leachate production/use for mass balance calculations, and measurement of the moisture content of the landfill gas.

The primary goal of the ALS is to achieve optimum waste stabilization. This is defined in terms of decreased concentrations of leachate constituents, reduced methane production, and waste mass subsidence. Laboratory analyses provided the data needed to determine the ALS's effectiveness on the leachate. Direct measurements of landfill gases were used to determine the amounts of methane production. The subsidence of the landfill waste mass was monitored by physical survey. Although, the biodegradation rate of this process can be determined in various manners, for this application, the biodegradation rate was determined based on oxygen uptake rates, and waste mass temperature measurements. The results of the CCBPRL ALS are provided below.

Upon complete stabilization of the waste, the ALS will be removed, the temporary soil cover stripped back and stockpiled, and replaced on a new lift of waste, thereby minimizing material costs.

II. Bioreactor System Results

Overall, the ALS demonstrated that aerobic decomposition of MSW *in-situ* could safely and successfully be accomplished. The analyses of vapor samples, leachate chemistry, biological activity, and inspection of waste samples confirmed that the ALS was extremely effective at stabilizing the waste. Moreover, the ALS can functions as an *in-situ* leachate treatment system, whereby leachate volumes as well as toxic contaminant concentrations are reduced.

Specifically, the ALS demonstrated: 1) a significant increase in the biodegradation rate of the MSW over anaerobic processes, 2) a reduction in the volume of leachate as well as organic concentrations in leachate, and 3) significantly reduced methane generation. In addition, waste settlement was observed as the ALS stabilized the organic portions of the waste mass. These benefits were obtained while maintaining an optimum moisture content of the waste mass and stabilized waste mass temperatures. Table 1 provides a summary of the results:

Parameter	Results (11/97)	Notes
Biodegradation Rate	Increased > 50% (1)	(1) Based on CO_2 production, O_2 uptake, and waste mass temperatures
Leachate BOD_5	Reduced by 70%	
Metals & VOC concentration in leachate	Reduced by 75 - 99% (2), (3)	(2) Iron reduced by 75% to 90%; Lead was reduced to BDL. (3) e.g. MEK, toluene, acetone
Leachate Volume	Reduced by 86%	
MSW Settlement (ft/ft)	Greatest: 12% (4) Average: 4.5%	(4) Based on physical survey, future overburden not considered
Methane Generation	Reduced by 50 - 90% (5)	(5) Methane reduced by 50 to 90% for 80% of the points: 70 to 90% for the row of points closest to air injection.

Table 1 Summary of Results

A. Landfill Gas Measurements

At system startup, O_2 initially increased in many of the vapor points inserted in the waste mass. In conjuncture with this, CO_2 fell initially and then rose in close correlation with O_2 consumption. When observed with the methane levels, these gas readings indicated a transformation from anaerobic to at least partial aerobic metabolism: CO_2 rises as O_2 is consumed and CH_4 production falls off. Based on direct measurements from thermocouples inserted in the waste, waste mass temperatures remained stable between 40° C and 60° C after aerobic conditions had been reached. Waste mass moisture was above 50% (w/w) in the most active areas. Overall, these data indicated that aerobic conditions within the waste were attained. Typical landfill gas and waste mass temperature data is presented in Figure 3.

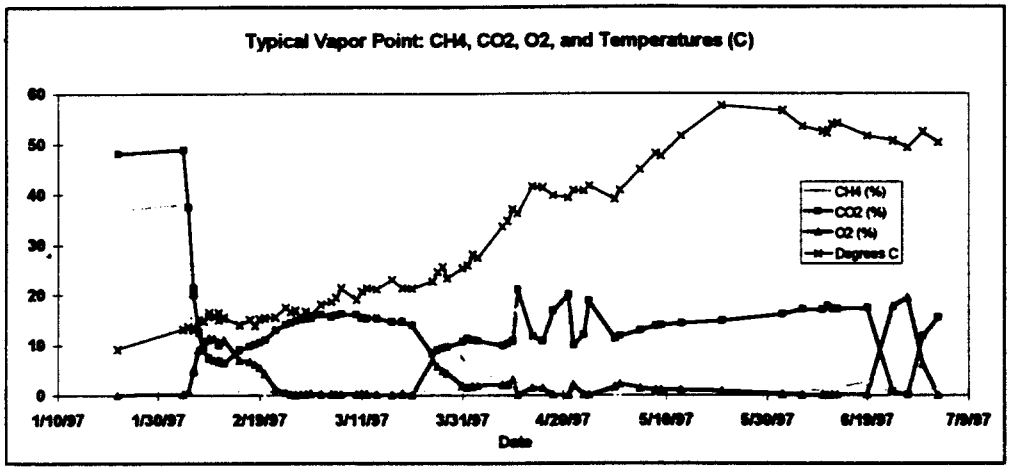


Figure 3: Typical Vapor Point/Thermocouple Measurements

B. Leachate Quality

Laboratory analyses of Biochemical Oxygen Demand (BOD) and Volatile Organic Compound (VOC) concentrations in the leachate indicated significant reduction by the aerobic process, as shown in Figures 4 and 5. BOD in the "Sump One" samples were reduced by at least 70%. Organics such as methyl-ethyl ketone (MEK) and acetone were reduced significantly; also fecal coliform was eliminated from the leachate. Total VOC concentrations in the many of the vapor samples collected were less than 1 ppm.

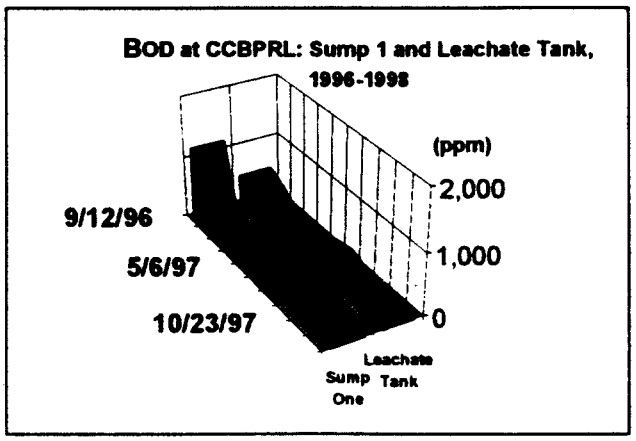


Figure 4. BOD Analyses

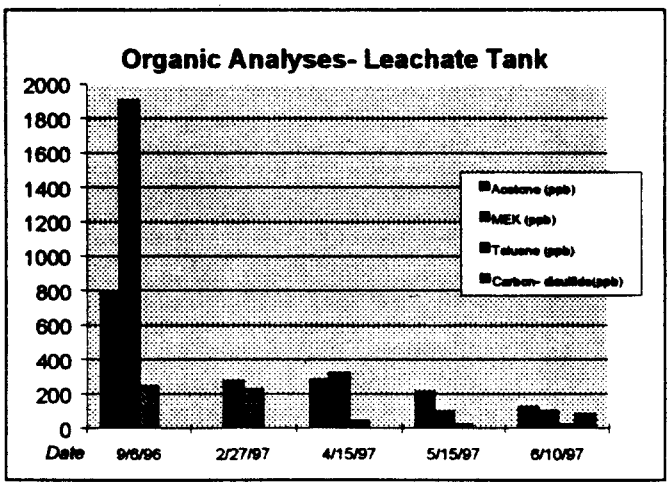


Figure 5. VOC Analyses

C. Leachate Volume Reduction

Prior to ASL startup in January 1997, the CCBPRL sent approximately 120,000 gallons of leachate each month to the local treatment plant. This leachate was pumped through the landfill's new lift station (a capital investment of approximately $100,000) with no pre-treatment.

During the first six months after ALS startup, the County did not pump any leachate to the treatment plant. As of March, 1998 (14 months since startup), the County has only pumped a total of 250,000 gallons to the treatment plant. If a leachate production rate of 120,000 gallons per month were maintained, approximately 1.68 million gallons (120,000 gallons x 14 months) would have required treatment. As a result, the County's leachate treatment needs were reduced by over 85%.

It is estimated that this reduction of leachate is caused, in part, by the evaporative effects of the higher waste mass temperatures and the effects of air drying out the waste. Additional studies associated to this effect are ongoing, including evaluations of waste mass field capacity.

D. Waste Excavation Results

In November, 1997, "aerobic" and "anaerobic" areas of the landfill were excavated to examine the results of the ALS. In most of the areas excavated, the waste appeared to be MSW typical of this region of the country, bagged and unbagged food, paper, plastic, and miscellaneous wastes. However, an abundant percentage of large, inert and recalcitrant materials such as C&D wastes, treated lumber, wood wastes, and thick plastics were observed in the waste excavations. This had not been anticipated, for waste surveys conducted prior to this project, reported that the CCBPRL had been accepting MSW with a high organic content (over 60%). Despite the presence of these recalcitrant materials, however, inspection of the various types of organic wastes collected the "aerobic" areas confirmed that the ALS rapidly degraded these organic fractions of MSW (see photos below), similar to other aerobic composting operations.

The waste inspections indicated that the readily degradable materials, such as food wastes, vegetation, and paper products, had been significantly composted to a brown, rich humic material. In comparison, inspection of the waste samples collected from the excavations in the "anaerobic" areas confirmed little to no degradation of the organic wastes present. Also, odors from the excavations in the "anaerobic" areas had significant ammonia and sulfur components. MSW examined in these two areas had been placed into the landfill at approximately the same time.

In addition, it was noted during the excavations that the large, recalcitrant landfill materials were arranged in a matrix, containing large void spaces that were filled with organic materials, as described above. It is likely that although the aerobic process did little to reduce the structural strength of the matrix materials (attributable to the minor settlement of intermediate clay cap), this matrix still allowed the injected air and leachate to be introduced to the more easily degradable organic matter.

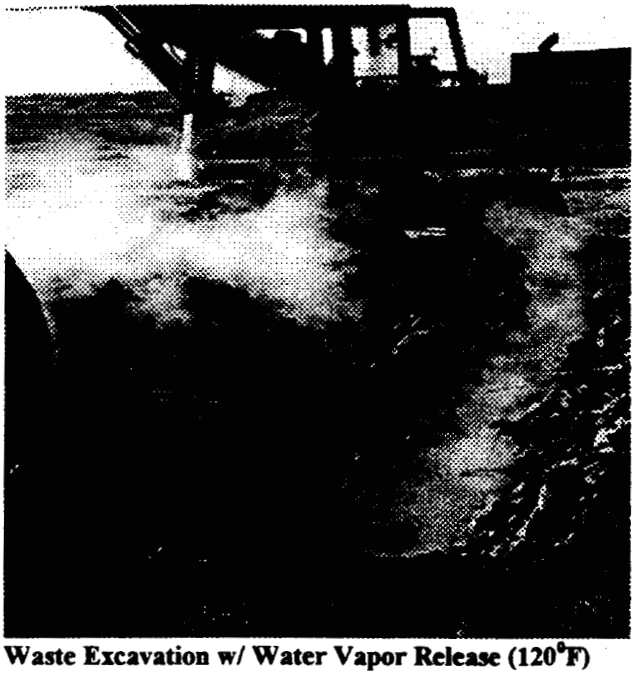
As a result, the ALS data presented indicates the composting of, mostly, the readily degradable materials. Over a longer period, however, it is estimated that the ASL will ultimately degrade much of these recalcitrant woody materials, further reducing their structural strength.

E. Waste Settlement

Waste settlement is a function of waste types, compaction density, moisture, landfill heights, and time. Despite the "bridging" effect described above, the 11 months of operation, the types of recalcitrant waste encountered, and that the waste was, on average, only 10 feet deep (approx.), physical waste surveys, taken before and during the project, indicated cover settlement at several locations in the aerobic test area. (Table 1) Although it is apparent that the ALS can compost readily degradable landfill wastes despite these limitations, it is recommended that inert and recalcitrant materials such as treated lumber, concrete, wood wastes, and thick plastics be placed into C&D-type landfills or

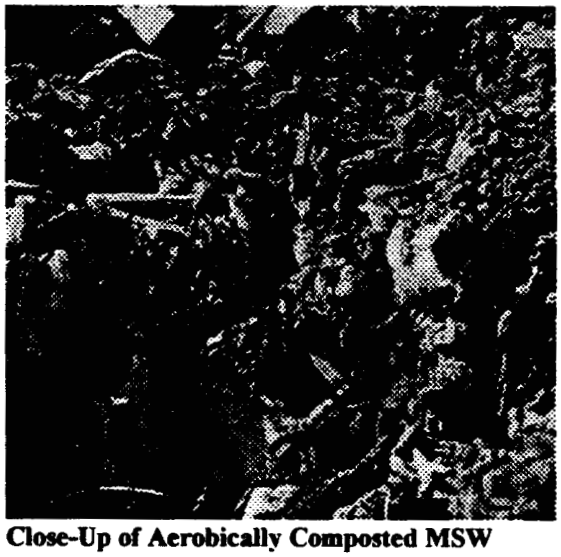
recycled, where appropriate. This would allow the ALS to compost a larger percentage of landfill materials in a more efficient manner.

Based on other composting studies, it is estimated that the ALS will increase the predicted landfill waste settlement as a result of the overburden from future waste lifts. Meanwhile, the ALS continues to aerobically degrade and reduce the strength of the waste, as shown below:



Waste Excavation w/ Water Vapor Release (120°F)

Stockpile of Aerobically Composted MSW (120° F)



Close-Up of Aerobically Composted MSW

III. Benefits of the ALS

While the ALS depends upon complex biological mechanisms, this technology can easily be incorporated into new and existing landfills in such a manner as to minimize its impact on the landfill operations. Since the degraded waste at CCBPRL is similar in nature to the waste in many other landfills, the benefits realized by Columbia County using the ALS can repeated worldwide. As this technology develops, additional system data can be evaluated to optimize performance of future ALS systems .

The potential cost benefits of the ALS include: 1) increased revenues through airspace recovery, 2) reduction in leachate contaminants and volumes, 3) reduction in methane gas generation, 4) reduced closure and post-closure costs, and 5) reduced environmental liabilities. In addition, this design incorporates a practical, cost-effective approach to providing air and moisture to the waste mass.

A. Projected Cost Benefits Using the ALS

1. Recapturing of Air Space/ Extension of Landfill Life

In previous laboratory and bench-scale studies, MSW settlement by aerobic degradation has been observed to be 30% and greater[2]. Assuming a waste mass settlement of 15% is achieved at the CCBPRL, the remaining fill capacity of 720,000 cubic yards could potentially be extended by 107,000 cubic yards. Using a net tipping fee of $24.50 per ton ($32.50/ton gross fee minus $8/ton O&M costs) and a compacted waste density of 0.65 tons per cubic yard, additional revenues to the landfill could be up to $1.7 million. This amount does not account for future value of the revenues which could yield a much higher net value. Additionally, this 15% increase in air space could extend the life of this landfill by almost a year. Waste is accepted at the CCBPRL at a rate of approximately 250 tons per day.

2. Reduced Landfill Leachate Management Costs

With an ALS in place, concentrations of organic compounds typically found in aging leachate streams, such as toluene, methylene chloride, and methyl-ethyl ketone (MEK), as well as BOD (a measurement of leachate strength), can be more rapidly reduced (as compared to under anaerobic conditions) as the result of the ALS.

In addition, the overall volume of landfill leachate can be reduced. As presented earlier, the ALS at the CCBPRL reduced approximately 120,000 gallons of leachate from the entire landfill each month. Based on this benefit, a landfill with leachate generation of 120,000 gallons per month and a treatment cost of 3 cents per gallon could save at least $21,600 per year (1997 dollars) assuming the ALS reduced leachate by only 50%. At a 6% interest rate, future value savings would be over $222,000 over 40 years (10 years of landfill operations plus 30 years of post-closure leachate treatment).

3. Methane Gas Management Cost Savings

There has been much focus on the earth's environment since the 1980's, including extensive studies on its atmosphere. Fueled by discussions on "global warming" and the possible effects of "greenhouse gases" on the earth and human population, many governments are setting reduction goals, and encouraging the development of new methods for reducing these gases. In the U.S., recent changes to the Clean Air Act (CAA) regulations require specific controls and monitoring provisions be implemented for methane production from landfills, also a "greenhouse-gas."

One methane management approach is landfill gas (LFG) for energy recovery, otherwise known as "waste-to-energy" (WTE). At several landfills, the LFG is produced under mostly anaerobic conditions and the methane captured, cleaned, and used for combustion and/or supplemental fuel. However, although WTE is feasible, this methane management approach does not offer attractive economic advantages for many other landfills. The EPA's Methane Outreach Program (1997) estimates that of the approximately 3,700 landfills in the nation, only 750 are considered candidate WTE landfills. This leaves approximately 3,000 non-candidate landfills, many of which may face methane gas compliance with few low-cost LFG management options. This assessment is based on factors such as the size of U.S. landfills, their location and proximity to a potential LFG user, and potential market conditions.

In an attempt to increase the production of LFG to make WTE possibly more economically attractive, a number of studies have been conducted using leachate recirculation technologies under anaerobic conditions to increase the production of methane and other gases. In these cases, increased LFG is produced, captured, cleaned, and used for combustion and/or supplemental fuel.

Despite the limited success of WTE projects as well as demonstrations that optimize LFG production, there are several issues of potential concern.

- Increased production of methane could increase, if not create, new CAA regulatory compliance requirements for certain landfills. Not only would capital and O&M costs increase but regulatory compliance cost may as well;

- The size of the landfill, its location, and proximity to a potential LFG user, and market conditions could still not offer an attractive economic advantages even with an increase in electricity/usable gas production;

- At many landfills, there can be significant gas recovery inefficiencies with respect to the capture of landfill methane landfill (i.e. fugitive methane emissions). If there is an increased methane gas production via enhanced-WTE with no improvements in gas recovery efficiency, there would most likely be a high potential for increases in fugitive methane emissions from the landfill. This could have significant regulatory impacts and/or increase gas collection/recovery capital costs; and,

- WTE and enhanced-WTE projects still operate under anaerobic conditions. Although certain organic compounds can be degraded under anaerobic conditions, there remains the potential, over the long term, to increase the overall toxicity of landfill leachate under anaerobic conditions. As a result, the costs, environmental risks, and liabilities associated with anaerobic waste conditions within a landfill, as described earlier, could be issues for WTE landfills.

In contrast, by minimizing the production of methane gas from landfills, the ALS provides an alternative, natural, approach to reducing "greenhouse gases" that may be more cost-effective. As presented above, the ALS at the CCBPRL demonstrated that methane gas was reduced up to 90% in many of the "aerobic" areas. At many landfills, one of the short-term cost savings associated with this benefit could be the costs that would, otherwise, be directed to methane gas collection, treatment, and management options. (This is provided that carbon dioxide recovery is not required.)

The long-term cost savings of reduced methane production (where WTE is not economical) may be significant where reductions in regulatory monitoring and compliance efforts are allowed. This would lower methane management costs and associated methane-related risks. Columbia County, for example, plans to seek regulatory relief of certain landfill monitoring requirements, based on this benefit.

In this light, the EPA has recognized the ALS as an emerging Tier II methane control technology and that this approach "is expected to become a prime candidate technology for landfills in the U.S. and elsewhere that can not generate LFG in sufficient quality or quantity to economically recover the associated energy."[3] As this technology develops further, additional performance data will be available to measure the impact of the ALS on reducing "greenhouse" gases. Discussions are continuing with other state and federal regulatory agencies on possible relief under the CAA using the ALS. Other cost benefits are being evaluated with respect to: 1) possible impacts to landfill insurance premiums, 2) relief of certain financial responsibility requirements, 3) emission "shares", and 4) the impact of meeting "greenhouse gas" reduction goals. Overall, this natural approach to methane control could be very beneficial to landfills.

4. The ALS As A Remediation Option

There are many landfills world-wide that pose threats to local groundwater and surface water resources. At many landfills, it is predicted that toxic compounds typically found in aging leachate streams will ultimately leak through

cracks that will develop in the landfill's protective liner systems and be released into nearby water resources at elevated concentrations. Once released, these contaminants can migrate through the subsurface and into groundwater and surface water, causing severe health effects. This is evident due to the increasing number of landfills that have (and are planning) to initiate remediation activities associated with landfill leachate releases. Of the numerous groundwater remediation technologies available, many leaking landfills with related groundwater problems look toward conventional "pump-and-treat" or *ex-situ* systems as a solution. These type systems recover the contaminated ground and/or surface water through a series of pumping wells or surface intakes, and treat the influent using a variety of physical, chemical, and/or biological systems.

However, these type of treatment approaches are initiated only *after* the release has been identified. In addition, they can be expensive, and require extensive laboratory analyses, monitoring, and regulatory compliance. Furthermore, using only a "pump-and-treat" approach for groundwater remediation can add years to a landfill cleanup. These type systems, once installed, rely on subsurface hydrogeology to transport impacted groundwater to well intakes. Assuming there is a high-efficiency recovery of impacted groundwater, this approach still could take many years to meet groundwater quality standards. Overall, this is an indirect response to leaking landfills that will inevitably extend the cost of site remediation. A more pro-active approach is needed, one that not only addresses present groundwater impacts at landfills, but one that also address the landfill waste mass, *before* it becomes a source of groundwater contamination.

By treating the waste aerobically with an ALS, the leachate is *directly* treated, before it can be released through any cracks in the landfill liner. At landfills undergoing (or preparing for) groundwater remediation, this method of directly treating the waste (and leachate) would lessen the toxicity of the escaping leachate, thereby lessen the toxicity of the impacted groundwater and reduce "downstream" groundwater remediation efforts, saving potentially significant system operating and monitoring costs.

Furthermore, the ALS was shown to reduce vapor-phase VOCs. Since many of these compounds can migrate through the subsurface and impact groundwater, early deployment of ALSs at landfills that could potentially impact the environment (e.g. off-site VOC migration) would minimize the production of these gases, thereby reducing risks and associated remediation costs.

5. *Odor Control*

In the "aerobic areas" of the CCBPRL, strong NH_3- and H_2S odors associated with conventional landfill operations were minimal throughout ALS operations. Instead, less pungent, organic odors indicative of composted waste were detected. From a public acceptance perspective, this benefit can be important to solid waste planners during the siting of new landfills or to address odor complaints at existing ones.

6. *Reduced Closure and Post-Closure Costs*

Potential cost savings could also be realized with respect to site closure. A recent study conducted by the University of Ohio found that the mean cost of closing a sanitary landfill (in Ohio) was $67,112 per acre. Post-closure care for landfills include, at a minimum, groundwater, surface water and methane monitoring, as well as maintenance of the landfill cap. For many landfills, closure and post-closure costs are in the millions of dollars.

Upon waste stabilization and reaching full landfill capacity, the ALS provides the opportunity for landfills to seek regulatory relief of closure and post-closure monitoring requirements. Since the a portion of waste at the CCBPRL has been stabilized and leachate quality improved via the ALS, the potential for groundwater impact by the leachate as well as the production of VOCs and methane has been reduced. As the system is to be expanded, operated, and monitored, the potential to stabilize more of the waste will exists. There is now an opportunity to demonstrate further reductions in risks to the environment based on future LFG, leachate, and groundwater analyses. In this light, ATI has begun discussions with the Georgia EPD regarding regulatory relief with respect to the County's closure and post-closure requirements, starting with a request for a reduced monitoring program.

Additionally, landfills can consider the option of landfill mining as part of an ALS strategy. In these cases, the waste is rapidly stabilized in a more timely manner and the humis removed, analyzed, and possibly used for agricultural

purposes or as landfill daily cover. The remaining non-degraded matter (plastics, glass, and metal) could have some market value, providing additional income for the landfill and reducing "up-front" recycling efforts (costs). This approach lends itself to a continuous landfill, precluding the need for a costly permanent cap and the siting of new landfills, altogether saving millions of dollars. It is cautioned, however, that markets should be first established and that the composted materials could be sold or re-used at a cost less than the efforts to mine and process the stabilized waste.

Moreover, a less-expensive, temporary cap would be used instead to cover the waste while it degrades, then removed to allow mining activities. New waste would be placed back into the landfill and the previously mined humis reused as a cover, prior to re-starting of the aerobic process. Under this option, a significant portion of the costs associated with the cover, closure and post-closure, as described earlier, as well as siting new landfills could be avoided.

B. ALS Costs

Overall costs for an ALS can be significantly lower than the costs owners and operators will face during the operation and maintenance of a landfill. Although, there are many landfill design and operational factors to consider as part of the implementation of an ALS at a particular landfill, it is estimated that an ALS would provide an attractive return on investment for many landfills. The design of an ALS should, at a minimum, consider the landfill's current design and waste operations, waste height and placement, environmental regulations, and site conditions. As presented in this paper, three possible ALS approaches have been identified: 1) ALS applications on successive lifts of waste landfills (landfills under construction); 2) ALS applications on existing landfills; and 3) ALS applications with cell mining.

The approximate capital cost for an ALS in these cases would be similar to the costs for a methane gas collection system ($25,000 to $30,000 per acre). Since the ALS may preclude the need for gas collection system (due to reduce methane production) and that the ALS could re-use much of its original air and lecjate injection equipment (less buried PVC piping and plastic hoses), the net increased capital cost would be minimal. Gas monitoring system(s) would still be required in with or without the ALS. Any capital investment in gas filter/combustion would be significantly reduced.

An ALS application in a cell approach whereby the waste is mined could provide significant savings. Once the waste is degraded and stabilized, the ALS equipment is then moved to an adjacent cell and this process repeated. The previously degraded wastes are then mined and recovered for market or for re-use. It is estimated that only a few cell areas would be required to perform this cycle of waste placement, aerobic degradation, mining, and cell re-use, rather than an entire landfill. This approach could significantly reduce landfill construction/capital costs.

In each of the three cases (or modifications thereof), operational and monitoring costs would be moderate for each ALS cell start-up (2 to 6 months) and would include monthly leachate and landfill gas analyses as well as daily system monitoring by a technician. After the start-up period, monitoring requirements (and costs) would be reduced, and the system possibly turned over to landfill personnel. Depending on the type of landfills (under construction, existing), its construction, and regulatory requirements, O&M costs would most likely vary from site to site.

However, compared to the costs of expensive site cleanups, methane gas and leachate management, closure and post-closure O&M, and the risks associated with landfill operations, it is estimated that the ALS approach provides potentially significant savings for many landfills. For example, based on waste settlement alone, the CCBPRL stands to benefit from an estimated two-year return on investment. Additional cost savings could be realized as the leachate and methane gas management costs are reduced, as discussed above.

IV. Summary

For landfills worldwide, the ALS promotes a change in the overall management of solid waste disposal. In many cases, the ALS serves as means to operate landfills more efficiently. Additionally, the ALS serves as a cost-effective, aerobic remediation solution for landfills which are adversely impacting the environment. Through the continued development of this technology, the ALS will foster a new perspective on landfilling waste, and, at the same time, reduce the cost burdens of landfill operations and/or site remediation. In addition, the long-term liability and costs associated with landfill operation and closure will be greatly reduced.

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Mr. Hudgins serves as the Project Manager for the ALS Project and all of ATI's landfill biotechnology programs. Mr. Hudgins' professional career has primarily been involved with assessment and remediation of hazardous wastes, specifically the development and implementation of biotreatment systems. He is a 1985 graduate of the Citadel, holds a Bachelor of Science in Civil Engineering. Mr. Hudgins has led numerous treatment system design programs, including hazardous waste remediation systems, bioremediation, and biofiltration and odor control systems, as well as groundwater assessment and treatment programs.

Mr. March, a Biological Engineering Degree graduate from The University of Georgia, is the ALS project's field engineer. Mr. March's work experience includes an extensive research background, including work with treatment of landfill wastes, treating hazardous waste with plants (phytoremediation), and enzyme studies. He has also served as an investigator for a state funded fire ant research program and helped develop a hypothesis for fire ant control. Mr. March has also designed experiments and wrote software modeling phytoremediation of heavy metals. He is also pursing a Master's Degree in Biological Engineering at The University of Georgia.

COMPOST FACILITY ODOR CONTROL USING BIOFILTRATION: COMPARISON OF APPROACH AND PERFORMANCE AT AN OPEN FACILITY AND A TOTALLY ENCLOSED FACILITY

By

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INTRODUCTION

Odor control is one of the major issues affecting design and operation of compost facilities. Several facilities have been shut down because of odors. Often, these shut downs are a result of poorly designed or operated compost facilities with little or no odor control. Biofiltration systems are effective at treating and reducing odorous emissions. The effectiveness of the biofilter system is often times a function of the odorous air collection system. There are two general alternatives for collection of odorous air from aerated composting systems. The first alternative is collection of all of the air inside a totally enclosed compost facility. Makeup air is normally brought into the building from outside to provide fresh air for worker comfort or for heat and moisture removal. This approach results in collection and treatment of large volumes of air with diluted odorous compound concentrations. The second alternative is collection of the compost process exhaust. A blower is operated in the negative mode whereby air is drawn through the compost pile and then conveyed to a common odor collection header. This approach results in collection and treatment of smaller volumes of air that is typically hot and has high odor compound concentrations. This paper presents information at two facilities that utilize these different odor collection alternatives.

Davenport Compost Facility

Basis of Design

The City of Davenport, Iowa (the City) owns and operates a 28 dry ton per day (DTPD) aerated static pile biosolids and yard waste compost facility. The biosolids are anaerobically digested and then dewatered to between 13% and 20% total solids (TS) using belt filter presses. The dewatered biosolids are hauled via dump truck from the wastewater treatment plant to one of two biosolids receiving bins located in the mixing area of the compost facility. In addition, clean yard waste is delivered by private and public vehicles to a paved outside storage area where it is ground through a horizontal grinder. The ground yard waste is supplemented by wood chips and rubber tire chips for use as a bulking agent. The bulking agents are mixed with the biosolids through either of two continuous feed pugmill mixers. The flow of bulking agents and biosolids is controlled to achieve a target mix solids content of 40% TS. Composting occurs in a 66,000 square foot (SF) building which is totally enclosed and insulated. Pre-cast polymerized concrete trenches are placed in the concrete compost floor and provide aeration to the compost pile. Twenty-four blowers are automatically controlled (on/off) by a temperature feedback system to control the aeration rate to the 24 individual aeration zones. Following three weeks of composting, the material is screened through a trommel screen. The overs are recycled as bulking agent, and the compost is cured for an additional 30 days prior to marketing.

During the planning stages of the project, one of the primary objectives of the City was to effectively manage odors so there would be no off site odor impacts. To accomplish this primary objective, the mixing and composting areas were totally enclosed in an insulated pre-engineered building. The exhaust air from the mixing area is utilized as make-up air to the compost building to reduce the total volume of air to be treated. Exhaust gas from the entire compost building is treated through a biofiltration system. The exhaust system ventilates a total of 210,000 cubic feet per minute (CFM) and provides ~12 air changes per hour. The biofilter consists of eight independently controlled blowers and biofilter cells. The odor collection system consists of 12 intakes spaced equally along the wall on the east and west sides of the composting building. The ductwork is aluminum and conveys the exhaust air to the blowers and to the biofilter cells. A series of manually operated dampers allows an individual cell or blower to be isolated for maintenance. The biofilter is 42,000 SF and was designed at a loading rate of five CFM/SF. The exhaust air is conveyed through a series of polyethylene laterals with a

custom hole pattern to evenly distribute the air into an 18 inch deep aeration plenum. The aeration plenum consists of washed round stone and serves to evenly distribute the air through the biofilter media. The media is four feet deep which provides a nominal open bed residence time of 48 seconds. The media consists of yard waste compost and wood chips. An automated irrigation system provides surface moisture addition to the media.

Operating Experience

The biofilter system began operating in July 1995. Performance testing was conducted in October 1995 using odor panel analysis according to ASTM E679-91, and an average odor removal efficiency of 86% was achieved. Two of the eight cells had media removed and replaced in October 1996 to correct drainage problems resulting from improper pipe installation between cells. The originally installed geotextile fabric was also removed to enhance air distribution in these cells. The geotextile fabric in the remaining six cells was removed in May 1997. The biofilter system was initially designed to operate with spray nozzles in the duct ahead of the biofilter for dust removal. The spray nozzles were utilized sporadically during the initial two months of operation and have not been used since. As a result, dust accumulated in the air distribution laterals beneath the biofilter media. The laterals have been retrofitted to include an extension and end cap which allows for periodic cleaning. The biofilter system has operated efficiently, and no odor complaints have been received from neighbors since the facility began operation.

Cape May County Municipal Utilities Authority (CMCMUA)

Basis of Design

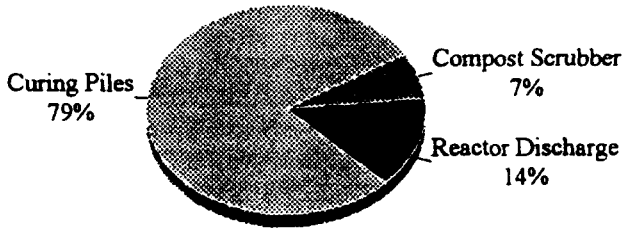
The CMCMUA owns and operates a 20 DTPD in-vessel biosolids composting system to manage dewatered raw solids from four secondary wastewater treatment plants. The biosolids compost facility began operation in 1985. The facility consists of two Purac reactor (vertical) vessels, which are totally enclosed in buildings. Originally, the facility was designed to function with the two reactors in series. However, increased loading to the plant prompted the CMCMUA to modify the facility so that both reactors operate in parallel. During peak summertime loading conditions, the reactors process 20 DTPD. The sludge cake is approximately 28% solids and is mixed with bulking agents such as shredded pallets and recycled material. Prior to placement in the reactors, the shredded pallets are typically mixed on a two to one ratio with the recycled material from the reactors and then blended with the biosolids in an automated pugmill mixer to achieve a target mix solids content between 38% and 40%. Material is then loaded into one of the two reactors where it is maintained for a two week period. After the two week period, the material is discharged from the reactors into a dump truck and then transported to the adjacent curing pad where front end loaders place the material over aeration pipes. The pipes are connected to blowers in an extended aerated static pile fashion. Prior to the biofilter project, the blowers operated either on or off as controlled by the operator with a cycling timer.

Odor control at the compost facility has improved over the years to the point now where all fugitive emissions from the solids and bulking agent storage areas, buildings, the solids receiving building, mixing building, and the composting reactors are being contained and collected for treatment in a three stage chemical scrubbing system which then discharges exhaust gases through a 100 foot high stack. While such an approach provided significant improvement in odor control at the facility, odor complaints persisted during peak loading conditions in the summertime months. It was determined by observations of operations personnel that off site odor impacts remain primarily from the untreated curing process odors rather than the scrubber exhaust. It was this area where fugitive odor emissions were identified as potential problems off site and where an odor study was focussed.

At the beginning of the odor study, some CMCMUA staff thought that enclosing the curing area and treating all of the building air was the only method to reduce odors from the curing process. The odor study verified that the majority of the odors were emanating from the curing piles and that the majority of the odors were generated in the first 14 days of curing. Figure 1 summarizes the percentage of odorous emissions from the major sources. Furthermore, the odor study determined that 90% of the curing odors appeared to be released when blowers were in the "on" mode. In a subsequent composting bin study, the amount of odors generated were reduced by providing air continuously rather than intermittently (on/off cycle). Based on this information, it was determined that odorous emissions from the facility could be substantially reduced by installing an aeration system that could operate in the negative mode, thereby pulling air through the compost piles, and collecting this odorous process air for treatment through a biofilter system.

FIGURE 1
CMCMUA COMPOSTING ODOR EMISSIONS

% Contribution of Sources During Reactor Discharge



The odor control portion of the curing process involved the first 14 days, and the new biofilter odor control system was designed to consist of the following:

- Ten variable speed curing blowers with a capacity of between 200 and 800 CFM.
- Central odor collection ductwork to convey exhaust gases from the curing piles to the biofilter system.
- Two biofilter booster blowers, each rated at a capacity of 1,200 CFM.
- Two cooling chambers designed to reduce curing pile exhaust temperature to less than 40°C.
- Two biofilter cells with an effective treatment area of 300 SF each.

The modified process description is as follows:

Compost discharged from the reactors is placed in an extended aerated curing pile for the first 14 days out of the reactor. The curing pile aeration blowers are connected to four inch diameter high density polyethylene (HDPE) perforated aeration pipes. This aeration pipe has a customized hole pattern for even air distribution and is reused after each curing cycle. The variable speed blowers are operated at the higher aeration rate initially as the material is discharged from the reactor. The system is sized such that two of the aeration blowers can operate at the maximum aeration capacity of 600 CFM, and six of the aeration blowers can operate at a lower aeration rate of 200 CFM with two fans in stand-by. The curing aeration blowers are operated utilizing a temperature feedback control system which is controlled by temperature sensors in the cure pile blower exhaust airstream.

Exhaust gas is discharged from these blowers into one of two chlorinated polyvinyl chloride (CPVC) collection ducts which are used to convey the odorous gases to the biofiltration system. The biofilter blowers are operated at a constant speed to provide 1,200 CFM of capacity through the system. During periods when inadequate flows are being provided by the curing blowers, outside air is automatically introduced into the ductwork to maintain a constant flow rate to the biofilter system. Two cooling chambers were constructed out of surplus aluminum storage tanks with coarse spray nozzles at a water flow rate of between 15 and 20 gallons per minute. These cooling chambers provide a nominal gas residence time of 3.75 seconds to allow for cooling of the curing pile exhaust gas. The gas then passes through the biofilter blowers and is distributed to two independently operated biofilter cells. Each cell is an open bed design consisting of a main distribution header and six air distribution laterals (six inch diameter) beneath the biofilters. The cells include a PVC liner to collect any excess irrigation water which is drained back to the wastewater plant for treatment. The distribution laterals are placed in an 18 inch deep bed of washed, round stone above which is a four feet deep layer of media consisting of a uniform mixture of wood chips and stabilized yard waste compost. The gas loading rate to the biofilters is four CFM/SF, providing a nominal gas residence time of 60 seconds. Moisture control in the biofilter cells is provided through surface irrigation during summertime months. During the wintertime, the filter is operating in a condensing mode, and surface irrigation is not necessary.

Operating Experience

The biofiltration system has been on-line since July 1996. Odors from the curing portion of the compost facility decreased markedly since the facility was placed on-line. Pressures and temperatures to the system are measured on a regular basis by operations personnel. The addition of the automatic temperature feedback control system has reduced the level of effort required to monitor the curing operation. Once a curing pile has been constructed, the blowers are placed in automatic mode. The PLC based control system adjusts the variable speed blowers to maintain pre-determined set points. The status of all equipment is graphically displayed in the control room. The performance trends of each blower is also recorded by the computer.

Two operational problems surfaced during the initial operation of the facility. The first problem was with regards to scaling of the cooling chamber. The original design called for the use of non-potable water (effluent) from the neighboring wastewater treatment facility to cool the curing gases and remove some of the ammonia. The high seasonal temperature (approximately 27°C) of this water did not provide a great enough temperature difference for adequate cooling, so a well was drilled to obtain lower temperature water. The well water was extremely hard and had a near neutral pH. The high level of ammonia within the curing process offgas resulted in a slight increase in the spray water pH due to the high solubility of ammonia. As a result, precipitation of salts occurred, creating a heavy scale formation on the packing and the inside walls of the cooling chamber. A small acid feed system was installed to add sulfuric acid to the system to lower the pH level, thereby minimizing scale formation and maximizing ammonia removal. The second problem which occurred during initial stages of the operation was that of increased backpressure and decreased flows. Initially, the cells were constructed with a geotextile fabric between the stone layer and the media. This fabric fouled within eight months of start-up resulting in a decreased airflow to the biofilters. Subsequent removal of the geotextile fabric and replacement with a six inch layer of wood chips in the spring of 1997 resulted in normal operations at the facility. Flows and pressures within the system are at or above the design levels.

Performance testing of the biofilter system was conducted in July 1997 during peak loading conditions. The biofilter achieved 98% odor removal as measured by ASTM E679-91. Ammonia concentrations to the system were between 225 and 275 ppm. The spray chamber reduced the ammonia concentration by approximately 58%, and the overall biofilter system achieved a 99.9% ammonia removal efficiency. In the spring of 1998, new cooling chambers and a mist eliminator were installed to further enhance cooling and ammonia removal prior to the biofilter. In an effort to optimize biofilter performance during peak odor conditions, the CMCMUA has replaced the media each year of operation.

COSTS

Capital costs for the Davenport Compost Facility biofilter were approximately $490,000 or $2.33 per CFM of air treated. Capital costs for the CMCMUA Compost Facility biofilter (not including curing costs) were approximately $135,000 or $56.25 per CFM of air treated. The higher cost per CFM at the CMCMUA facility can be attributed to the following factors:

- Economies of scale
- Use of spray chambers for cooling and ammonia removal
- Use of PVC liner
- Use of concrete retaining wall for media

The largest portion of the operating cost for a biofilter system is typically electricity to operate the blowers. The second largest operating cost is generally media replacement. Other costs include labor for periodic inspections and testing associated with monitoring the biofilter system and equipment maintenance. The operating costs for the Davenport biofilter are approximately $235,000 per year, or $1.10 per CFM per year. This is based on media replacement every two years. The operating costs for the CMCMUA biofilter (not including compost curing costs) are approximately $15,100, or $6.30 per CFM per year. This is based on replacing media each year.

BIOFILTER DESIGN CONSIDERATIONS

The Davenport Compost Facility and the CMCMUA Compost Facility illustrate unique methods of control and treatment of odorous emissions utilizing biofiltration. Table 1 summarizes each of the exhaust gas streams treated.

TABLE 1

Exhaust Gas Source	City of Davenport Compost Building	CMCMUA Compost Curing Blowers
Airflow, CFM	210,000	2,400
Temperature, °F	40 - 80	130
Dust	High	Low
Inlet NH_3 Concentration, ppm	0 - 35	225 - 275
Inlet Odor Concentration, D/T	350 - 640	4,825 - 5,790
Loading Rate, CFM/SF	5	4

The exhaust gas flow rate is much higher when an entire building is ventilated as compared to only the exhaust gas from the process blowers. The smaller flow rate from the process blowers yields a hotter exhaust gas with higher ammonia and higher odor concentrations. High exhaust gas temperatures require cooling prior to treatment through a biofilter. Biofilters operate more efficiently with gas temperatures below 105°F. The higher ammonia levels necessitate the use of an ammonia removal pre-treatment system to optimize biofilter performance. The higher odor levels dictate a lower biofilter loading rate in order to achieve high odor removal efficiencies. The high levels of dust associated with ventilating the entire building require dust removal pre-treatment or the ability to clean the dust out of the aeration system.

CONCLUSIONS

Two distinct alternatives for the capture of odors at aerated compost facilities exist. These two alternatives are complete enclosure and capture of all exhaust air and collection of only compost exhaust air. The decision must be based on objectives of the owner/operator as well as financial limitations.

The City of Davenport Compost Facility illustrates the odor control effectiveness of completely enclosing the composting operation and treating all of the exhaust through a biofilter system. The CMCMUA Compost Facility illustrates that substantial odor reduction can be achieved through a biofilter system treating only compost process exhaust. Different design factors including the level of dust, ammonia concentration, and temperature of the odorous air must be considered when designing and operating a biofilter system. In addition, an odor study can help identify odor sources and prioritize the use of odor capture and treatment equipment.

MONITORING WATER QUALITY AT A FOOD WASTE COMPOSTING SITE

By

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INTRODUCTION

In 1993, the Georgia Diagnostic and Classification Prison (located near Jackson, GA) initiated an on-site composting operation to convert food waste into a useable by-product. Each week, inmates compost about 20 tons of food waste, which are mixed with ground cardboard, hay, yard leaves, or wood products. The operation takes place on a 1.2-ha site (3 acres) that drains towards a small, perennial stream. Because of the potential for contaminating surface and ground waters with nutrients derived from the compost, we initiated a study in 1997 to monitor the quality of surface runoff and groundwater at the site.

MATERIALS AND METHODS

The composting pad was properly graded and bermed so that most of the surface runoff would drain towards one end of the pad (Allen, 1994; Block, 1997). During the study, all composting windrows were placed perpendicularly to the slope of the pad to slow surface runoff. A 45-cm (1.5-ft) H-flume and an ISCO 2100 sampler (ISCO, Inc., Lincoln, NE) were installed at the lower end of the composting pad to monitor surface runoff. The height of water in the flume was continuously measured with a pressure transducer, with average water heights recorded every 5 minutes in a Campbell Scientific CR10 datalogger (Campbell Scientific Inc., Logan, UT). Rain data were collected with a tipping bucket rain gauge connected to the same datalogger. The ISCO sampler was activated every time water in the flume reached a height of 17 mm (0.7 inches). When activated, the sampler took a 500-mL sample every 20 minutes, storing each sample in a separate bottle. Surface runoff from the site was monitored from December 2, 1997, through May 4, 1998.

To monitor groundwater at the site, we installed a 5-cm diameter (2 in), 5.4-m deep (18 ft) well downslope from the pad, at a surface elevation of about 3 m (10 ft) below the surface of the composting pad. The bottom 1.5 m (5ft) of the well was screened. Since water in the well was found at a depth of 3.6 m (12 ft), the groundwater was at approximately 6.6 m (22 ft) below the surface of the composting pad. Before taking a monthly 1-L sample, the well was purged 10 times with a submersible, electrical pump. Groundwater was monitored from October 2, 1997 through June 22, 1998.

Groundwater and surface runoff samples were brought to the laboratory and kept refrigerated at 4°C (40° F) until analyzed. Groundwater samples were analyzed as collected, but surface runoff samples were filtered through 0.45 µm membranes. All samples were analyzed for inorganic N and phosphorus with colorimetric procedures implemented on an Alpkem RFA-300 Autoanalyzer (O-I- Analytical, Wilsonville, OR). Ammonium-N was determined by the salicylate-hypochlorite method (Crooke and Simpson, 1971, and (nitrite+nitrate-N) by the Griess-Ilosvay procedure, after reduction of nitrate to nitrite with a Cd column (Keeney and Nelson, 1982). Orthophosphate-P was determined with the molybdate-blue method of Murphy and Riley (1962).

The 5-minute averages of water height in the flume were used to calculate flow, which was integrated with time to estimate the cumulative volume of surface runoff at which each sample was taken. The measured concentrations of ammonium-N, (nitrate+nitrite)-N, and orthophosphate-P were in turn integrated with cumulative volume to

calculate the total mass of each species lost in each runoff event. To calculate the flow- weighted concentration of each chemical species, we divided the total mass loss by the total volume of surface runoff.

RESULTS AND DISCUSSION

Between December 2, 1997, and May 4, 1998, there were 54 rain events that provided 871 mm of rain and caused 36 runoff events totalling 429 mm of runoff (Fig. 1). The volume of surface runoff, expressed as a percentage of the rain, ranged from 7 to 76% for the individual runoff events, with an overall average of 49%. As expected, the large runoff events were observed with large rains that fell on a wet composting pad. The difference between rain and surface runoff in each event was either retained by the composting windrows or infiltrated into the soil.

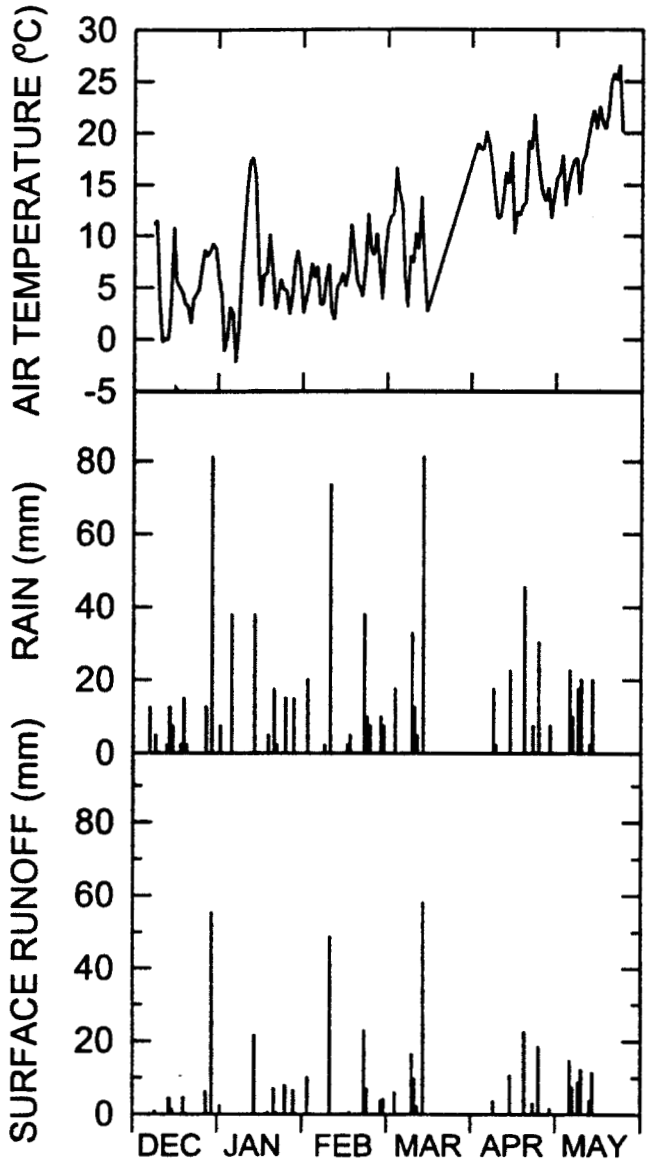

Figure 1. Average daily temperature, rain, and surface runoff from December 1997 through May 1998.

Table 1. Date, rain, runoff, and flow-weighted concentrations of ammonium, nitrite+nitrate, and orthophosphate.

DATE	RAIN	RUNOFF	NH_4-N	(NO_2+NO_3)-N	PO_4-P
	-- mm --	% of rain	---------- mg/L ----------		
3 December 1997	5.1	14.6	3.22	0.00	0.09
8 December 1997	6.9	6.7	5.72	0.00	0.10
22 December 1997	7.6	21.4	6.42	0.00	0.20
7 January 1998	12.7	26.0	4.32	0.00	0.13
13 January 1998	5.1	15.3	1.63	0.00	0.08
14 January 1998	10.2	27.8	9.45	0.06	0.33
11 February 1998	5.1	9.3	0.83	0.28	0.06
16 February 1998	12.7	40.2	6.66	0.12	0.11
22 February 1998	10.2	28.4	0.43	0.06	0.06
11 April 1998	23.0	44.9	7.68	0.01	0.11
14 April 1998	46.0	44.4	3.22	0.17	0.05

We collected and analyzed runoff samples in 11 of the 36 runoff events observed. In general, the concentrations measured were low at the beginning of a runoff event, and increased with cumulative runoff (Fig. 2). The range of nutrient concentrations in the individual samples was 0.17 to 24.85 mg N L^{-1} for ammonium, 0.00 to 4.82 mg N L^{-1} for nitrate+nitrite, and 0.02 to 1.22 mg P L^{-1} for orthophosphate.

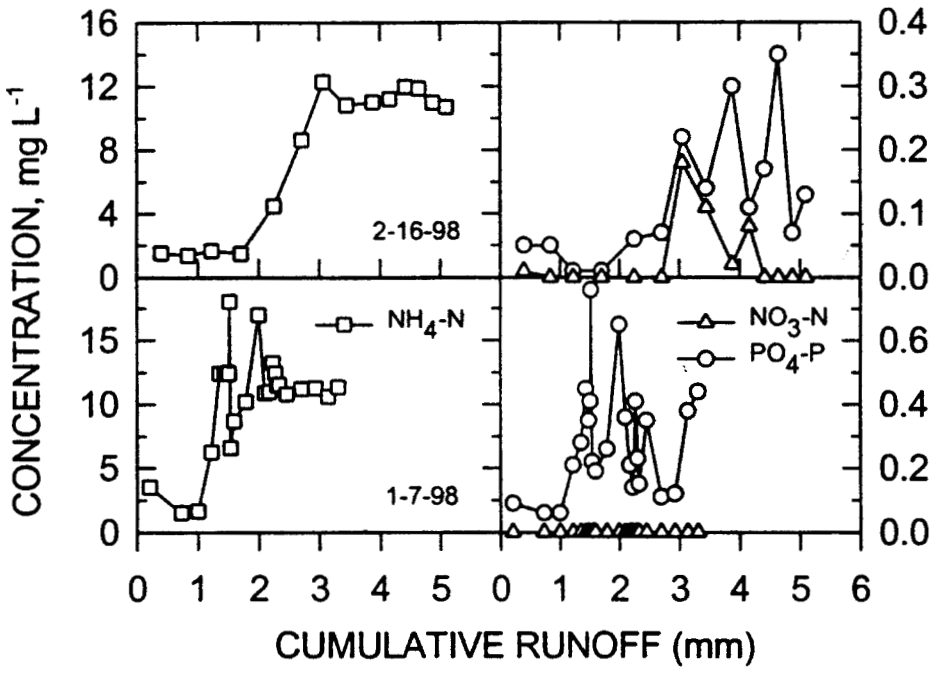

Figure 2. Concentrations of ammonium-N, (nitrite+nitrate)-N, and orthophosphate-P as a function of cumulative runoff in runoff events of January 7 and February 16, 1998.

The flow-weighted concentrations in individual runoff events ranged from 0.43 to 9.45 mg N L^{-1} for ammonium, from 0.00 to 0.28 mg N L^{-1} for nitrite+nitrate, and from 0.05 to 0.33 mg P L^{-1} for orthophosphate (Table 1). In most cases, the concentrations of nitrite+nitrate were low, with the exception of a runoff event on April 14, 1998, in which the values were relatively high (Fig. 3). The low concentrations of nitrite+nitrate in most runoff events were probably due to the average temperature being below 10°C, which is considered to be the threshold temperature for nitrification. At the beginning of April, daily temperatures increased to about 15°C, favoring nitrification (Fig. 1) and resulting in higher nitrite+nitrate concentrations in the runoff of April 14.

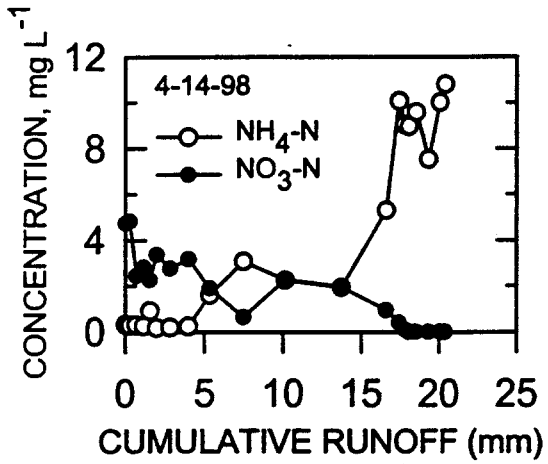

Figure 3. Concentrations of ammonium-N and nitrite+nitrate-N in the runoff event of April 14, 1998.

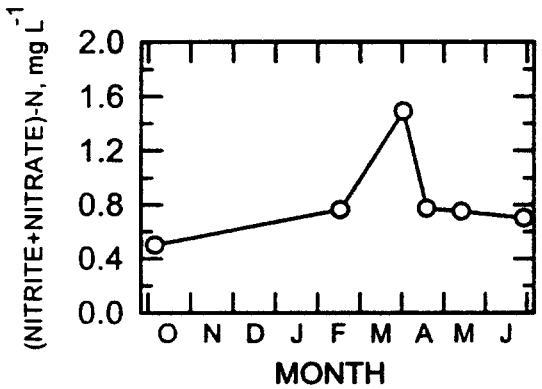

Figure 4. (Nitrite+nitrate)-N concentration in groundwater samples taken from October 1997 through June 1998.

The overall flow-weighted concentrations for the 11 runoff events were 4.87 mg N L^{-1} for ammonium, 0.09 mg N L^{-1} for nitrite+nitrate, and 0.10 mg P L^{-1} for orthophosphate. These concentrations of nitrite+nitrate and orthophosphate are low and not likely to cause environmental problems in surface waters. In contrast, the concentration of ammonium is rather high and may lead to eutrophication problems in surface waters in which N is the limiting nutrient. It should be noted, however, that the significance of a high concentration of ammonium at the edge of the composting pad depends on the dilution that may occur from the edge of the pad till the point where the surface runoff enters the nearby stream. If the watershed contributing to the nearby stream is relatively large, there may be enough dilution of the ammonium concentrations to decrease or eliminate the potential for eutrophication. Thus, the next step in the evaluation of the potential of this site for contamination of surface waters would be to conduct a study in which the quality of surface runoff from the composting pad is monitored simultaneously with the quality of water in the nearby stream.

Nitrite+nitrate concentrations in groundwater ranged from 0.50 to 1.49 mg N L^{-1} during the measurement period (Fig. 4). A peak observed on March 27, 1998, may have been due to nitrate leaching from the composting pad. Nevertheless, the concentrations were at all times well below the 10 mg N L^{-1} drinking water standard established by the USEPA. Considering that this site has been in operation since November 1993, these results suggest that nitrate leaching from the composting pad does not appear to be contaminating groundwater.

CONCLUSIONS

The flow-weighted concentrations of (nitrite+nitrate)-N and orthophosphate-P in surface runoff from the composting pad were relatively low and not likely to cause environmental problems. In contrast, ammonium-N concentrations were rather high, suggesting the need for additional studies to determine the amount of dilution that occurs before runoff water from the composting pad enters the nearby stream. Groundwater (nitrite+nitrate)-N concentrations were at all times well below 10 mg N L^{-1}, suggesting that nitrate leaching from the composting pad does not pose a threat to groundwater quality.

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A CASE STUDY OF THE GREENVILLE COUNTY MULCHING PROGRAM

By

Marcia Papin
Greenville County Solid Waste Division
Greenville, South Carolina

Program: Yard Waste/Mulch Program

Operations Manager: Marcia Papin, Solid Waste Manager

Program Start-up: July 1, 1995

BACKGROUND:

Yard waste was banned from landfill disposal on May 27, 1993. An intergovernmental agreement was enacted between the City of Greenville, the Greater Greenville Sanitation (GGS) and Greenville County to jointly compost yard waste at the City of Greenville Landfill. This agreement lasted until July 1, 1995. All yard waste within the County was transported to GGS where it was processed through an in-line grinder and discharged directly into a 75-yard transfer trailer and transported the material to the City of Greenville's landfill. The material (in theory) was then fed into a tub grinder, placed in a windrow, and used for daily cover on the landfill. In reality, most of the material was piled into static piles directly from the transfer trailers, covered with soil and remains there to this day. In July 1995, the City of Greenville closed their landfill and Greenville County became the only lined Sub Title D landfill within the County.

PROJECTION DESCRIPTION:

In July of 1995, our yard waste program began much like the City's program. Yard waste came into our facility lose or in large chips after being initially processed at the GGS facility. We in turn processed that material through the W.H.O. grinder we received from the City and attempted to windrow the material. We soon realized that it was impossible to grind and compost the amount of yard waste we were receiving with one employee, a small windrow turner and one tub grinder. We readdressed the plan and determined that grinding the yard waste into mulch and giving it away to citizens would be more economical, required no additional employees and provided some much needed goodwill.

Greenville County receives an average of 123 tons/day (TPD) on a 6-day work week with an average of 181 TPD during leaf season. To address this volume of yard waste we purchased a 1260 Diamond Z tub grinder and a grapple attachment for our rubber tire loader. The grapple attachment enhanced the productivity of our loader significantly. The Diamond Z tub grinder easily handles 40 tons per hour. These improvements meant that one operator can keep up with the waste stream, perform all maintenance and load mulch customers.

Yard waste received between March 1 and November 30 is ground into mulch and given away to citizens (with marginal plastic contamination). We provide complementary loading on Thursday, Friday and Saturday from 9:00 - 12:00 and 1:00 - 3:00. We load an average of 200 customers each day. However, during the winter months (and when plastic bag contamination increases) we continue to grind and stockpile the mulch as the demand for mulch drops off. The stockpile consists of 2' layers of mulch sandwiched between 1' layers of soil. When the season is over, we cap the entire stockpile. When needed, the pile will be excavated mixed with a kiln dried sludge (1:1 ratio) and used for daily cover on the landfill. We receive 200 tons/day of kiln dried sludge from Wester Carolina Regional Sewer Authority at no charge to augment our supply of daily cover material.

PROJECT UPDATE:

- The total amount of yard waste processed between July 1, 1995 and July 1, 1998 equals 116,184 tons.
- The total amount of mulch given away to citizens equals approximately 40,000 tons.
- Total amounts used to mix with kiln dried sludge for daily cover equals 30,000 tons.
- Total amount stockpiled, for future use as landfill cover, equals 45,000 tons.

RECENT EXPANSIONS AND EXPECTATIONS:

We improved the loading and unloading area with the addition of a 150' x 150' concrete pad. This improvement has reduced tip wear, reduced the staff hours dedicated to replenishing stone and improved customer relations. We also began an aggressive campaign to advertize our free mulch program. Landfill cover was the primary user in FY96. However, during the last two years, outgoing mulch tonnages have kept pace with incoming tonnages between March 1 and November 30. In an effort to improve the quality of our product, we implemented mandatory debagging for all yard waste received between March 1 and November 30.

YARD WASTE REDUCTION:

Our incoming yard waste tonnages increase every year because Greenville County is a high growth area. The Solid Waste Division is continually working to educate its citizens about the benefits of composting. We have established a compost garden at the Roper Mountain Science Center. The facility is maintained by Master Gardeners and school children routinely tour the garden. Classes in composting are periodically provided and compost bins are sold annually at a reduced price to citizens.

GEORGIA STATE-WIDE HOME COMPOSTING PROJECT

Dr. Wayne McLaurin - Professor, University of Georgia
Dr. Gary Wade - Professor, University of Georgia
Dr. Horace Hudson - Professor, University of Georgia
Mr. Leamon Scott - Georgia Department of Community Affairs
Ms. Lynn Cobb - Georgia Department of Community Affairs

Landscape trimming constitutes 20% of Georgia's waste stream each year, amounting to 1 million tons of material and costing the taxpayers $90,000,000 for disposal. The 1990 Georgia Solid Waste Management Law mandated a 25% reduction in all materials going into Georgia landfills by 1996. Moreover, landscape trimmings were banned from all Georgia landfills in 1996. Public officials and consumers needed an efficient and economical means for dealing with the escalating environmental problem and for meeting the requirements of the new state law which mandated

1. The separation of yard trimmings and solid waste.
2. A ban on the disposal of yard trimmings at waste facilities.
3. The sorting and composting of yard trimmings.

The Georgia Cooperative Extension Service had long been an advocate of waste reduction through composting and had developed educational composting materials. In response to the passage of the bill and to the national CES Waste Management initiative these materials were expanded. As a result of these materials, we obtained a grant from the Georgia Department of Community Affairs (DCA) and the Environmental Protection Division (EPD). With this grant we wrote The Georgia Home Composter Handbook and along with the DCA developed the first statewide home composting training program in the United States.

Due to the tremendous amount of yard waste being generated and the need to keep the yard trash off the curb, the Department of Community Affairs initiated the statewide Home Composting Program. A grant from the EPA was the kickoff for conducting the statewide program and for providing educational materials for each participant. The University of Georgia became involved in putting together educational materials for the workshops.

PERSONNEL

This project involved three state specialists from the Cooperative Extension Service, who provided educational implementation and scientific support; personnel from the state Georgia Department of Community Affairs, who sponsored the program and selected the demonstration sites; state and local members of the Georgia Clean and Beautiful Commission, who assisted in site selection and coordination, and the Environmental Protection Agency, which provided funding. Meeting participants were community leaders, interested citizens, and city and county officials.

MATERIALS

The Home Composter Handbook, a comprehensive 152-page reference manual on the science of composting provided a key component of this statewide educational program. The Home Composter Handbook was published in 1992 and, due to demand, the second and third editions were published in 1993. The Handbook was designed so that each chapter stood alone and sections could be easily removed for reprinting and newspaper publication as well as for Master Composter presentations. The handbook has been adopted by the Department of Community Affairs as the official composting guide for local governments in Georgia.

Another informational bulletin used was Composting and Mulching - A Guide to Managing Organic Landscape Refuse, Circular 816, University of Georgia Cooperative Extension Service Publication.

Also, each site selected received a set of laminated posters titled *What's In Our Garbage?*, *Best Ever Compost*, and *How Does Composting Work?*. Small scale models of three composting structures were given each site (barrel composter, wire bin, and turning unit). The Home Composting Handbook was available for each participant and was sent to each county Extension office in the state. A slide set *Recycling Organic Landscape Refuse* was also given each site, as well as copies of the following one-page, three-fold handouts:

Composting - Feed Your Landscape - Not the Landfill, U of Ga CES MP426 Mulching - Feed Your Landscape - Not the Landfill, U of Ga CES MP438
Grasscycling-Feed Your Landscape - Not the Landfill, U of Ga CES MP427

Each site received camera-ready copies of these three handouts for duplication purposes. The handouts were designed to permit application of local logos. To date over 300,000 of these handouts have been printed.

PROGRAM

In 1992, the Cooperative Extension Service and the Georgia Department of Community Affairs (DCA) teamed up to develop a statewide train-the-trainer program on horticultural waste recycling and curbside waste reduction.

The Extension/DCA team established three goals for the program:

1. To educate residents about the problems associated with solid waste disposal.

2. To encourage individual actions to reduce curbside waste.

3. To establish a network of community-based education programs on horticultural waste recycling.

As part of the CES response to its national mandate and to the state Solid Waste Act, training meetings were originally conducted at 10 locations throughout Georgia and expanded to more sites later. In conjunction with these meetings permanent Home Composting Demonstration Sites were constructed that still serve as visual displays to aid composting efforts in these communities. The Department of Community Affairs gave each composting site a grant of $2,000.00 and encouraged the recipients to design the site to the best advantage for educational use. The only stipulation was that it be a walk through display with sufficient bins and appropriate signage for maximum educational effect.

The training program was conducted through workshops designed to give home composting instruction to selected community residents who would in turn train others with the knowledge they received.

METHODS

These meetings were held at designated locations throughout the state. At each of these locations a permanent outdoor composting demonstration display had been set up; each display included various types of bins and compostable materials and offered a self-guided tour with the appropriate signage at each stop.
The instructional effort involved using these outdoor displays as well as handouts, slide sets, videos, posters, hands-on demonstrations, and lectures. The demonstration team gave presentations designed to acquaint participants with the amount of organically-generated compostable waste that currently goes into the landfills and the simple, "fail-safe" procedures they could use to turn this waste into an effective mulch/soil amendment for personal and community use.

During the full day's training program attendees learned about training volunteers, involving the community, selling the idea to and obtaining support from community officials, mulching, grasscycling, planning and implementing composting systems, buying or building compost structures, selecting waste materials (what and what not to compost), identifying basic biological composting processes in both aerobic and anaerobic composting, and acquiring

further composting information. In addition, time was spent visiting and becoming familiar with the composting site.

During the meetings the demonstration team discussed with those present composting techniques developed for home owners. Team members also covered the basic biological processes in both aerobic and anaerobic composting including bacterial, fungal, and other organisms involved in the decomposition of organic materials, the effect of moisture and temperature, and the selection of waste materials that can be incorporated into home composting. Also, the demonstration team offered participants information on ways to involve the community and individuals within the community in the implementation of home composting.

Directed especially to city/county officials present was information about the impact on waste reduction that could be made by full-scale participation in a home composting initiative.

RESULTS

In total, the program created ninety-four permanent composting demonstration sites throughout Georgia. These demonstration sites are now being used by the surrounding communities as teaching sites for the training of additional composting volunteers. To date, over 900 persons have been trained in home composting, as well as techniques and systems for relaying this information to others. Government officials have quickly endorsed this program because it is simple, cost effective, and sound. Mr. Jim Higdon, Commissioner, Georgia Department of Community Affairs, said "With your help, we have laid the foundation for a program which is sure to have a significant and positive impact on Georgia's solid waste stream".

USE

The Georgia Home Composting Program is currently being used as a model in 22 states that have requested the program, materials, and information. Additionally, the home composting program was awarded a Certificate of Environmental Achievement by The National Environmental Awards Council citing it "as a model of environmental excellence". The Program was recognized in the fourth edition of the Renew America Environmental Success Index as an outstanding educational program. The Georgia Home Composting Program has been recognized by Biocycle, Resource Recycling, Solid Waste and Power, Alternatives, and Composting News magazines as the first state-wide home composting program in the nation. According to Leamon Scott, Director of the Governmental Management Division, Georgia Department of Community Affairs, "National publicity generated by the program has led to the distribution of information and materials to a multitude of agencies and individuals in other states".

According to Robin Mitchell, Solid Waste Officer of the United States Environmental Protection Agency, The Home Composter Handbook has been adopted by the EPA for use in its programs and has been made a reference in the Solid Waste Information Clearinghouse as well as EPA Headquarters in Washington, D. C. In addition, it is listed in EPA's Grant Output Directory as exemplary of current materials on home composting.

There is a continuing effort to meet the needs of the counties and municipalities concerning their composting projects. Since the project was completed, there has been over 75 additional composting meetings held in various counties and towns throughout Georgia. In addition, 11 training sessions for county agents and school personnel and 57 invited lectures have been requested of the Extension staff. The Extension staff will be working with the county agents and the Department of Community Affairs to continue conducting compost informational meetings as needed.

ENCOURAGING HOME COMPOSTING THE HANDS-ON WAY: LESSONS FROM CHARLOTTE-MECKLENBURG

By

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ABSTRACT

Since 1993, Charlotte-Mecklenburg (North Carolina) Solid Waste Management's popular home composting program has reached over 1500 households. The program offers hands-on workshops, free bin distributions, a compost demonstration garden and a how-to brochure and compost guidebook. Charlotte's hands-on home composting workshops teach a simple, inexpensive and effective method of making compost at home using a wire bin. Charlotte emphasizes teaching a specific composting method (a 'model' approach) in its home compost program, rather than using a 'museum' approach of displaying many types of home compost units. Home composting is less energy intensive than large-scale centralized compost processing. Estimated cost of Charlotte's home composting program ranges from $21 to $57 per tonne ($19 to $51 per ton) over 5 years. In Charlotte, 'macro' and 'micro' composters work together to implement community composting and to encourage public acceptance of composting as a resident-friendly and environmentally sound technology.

INTRODUCTION

Much like economists, composters split into two camps, the 'macros' and the 'micros'. 'Macro' composters, working on a scale of truckloads, tonnes and hectares (tons and acres), approach composting as a way to manage the mountains of organic solid waste generated by modern cities, industries and agriculture. Meanwhile, measuring in wheelbarrows, buckets and shovelfuls, 'micro' composters see composting as a way to grow bigger tomatoes and healthier zinnias, and to help the environment by transforming banana peels and autumn leaves into 'black gold' for their gardens.

The biological processes in a well-managed backyard compost pile are fundamentally the same as those in a carefully monitored aerobic windrow at a municipal composting site. Nevertheless, 'micros' and 'macros' speak different languages. 'Macro' composters discuss aerated static piles and process kinetics; 'micro' composters talk about the ratio of 'browns' to 'greens' and whether or not to add coffee grounds or eggshells. Sometimes, it is hard to see what the two have in common.

In truth, both approaches transform 'wastes' into resources for building soil fertility and safeguarding the environment. Working together, 'macro' and 'micro' composters can help increase public acceptance of composting as a community-friendly and environmentally sound technology, and, at the same time, advance the science and art of composting.

Community-sponsored home composting programs help build a synergistic relationship between 'macro' and 'micro' composting. In 1994, Johnson found and surveyed 539 community home compost education programs around the United States and Canada (Johnson, 1995). Since 1993, Charlotte-Mecklenburg Solid Waste Management has sponsored a home composting program. Lessons from Charlotte can be useful for other communities interested in encouraging home composting, especially in the southeastern US.

CHARLOTTE-MECKLENBURG'S HOME COMPOSTING PROGRAM

Charlotte-Mecklenburg Solid Waste Management, a county agency, converts yard debris to mulch and compost, using a windrow system, at two large sites. Yard wastes may not be landfilled in North Carolina. The city and

county collect yard waste from the curbside weekly throughout the year. Charlotte launched its home composting program, in part, as a way to cut the amount of yard waste put out for collection, to reduce pressure on its 'macro' facilities so they can run more efficiently.

Charlotte-Mecklenburg's composting operations offer mulch and compost for sale, both on site and through a contract with a private firm that markets the compost under the 'Eco' brand. Home composting workshops and displays at 'The Compost Garden', located at Compost Central, the county's 25 acre yard waste composting facility, offer a way to publicize and market the mulch and compost, and increase positive public awareness of the county's yard waste operations.

Key elements: Charlotte-Mecklenburg's home composting program features four key components; hands-on workshops, free bin distributions, a compost demonstration garden and a how-to brochure and compost guidebook. Workshops teach residents a simple, inexpensive and reliable method of home composting. Over 1000 people have attended hands-on home composting workshops since 1994. In addition, the county has distributed almost 500 free bins at locations throughout the city. The Compost Garden is attractively landscaped with low maintenance plants well adapted to the Piedmont, and features informational signs on composting and examples of home compost bins. County residents can obtain a composting guidebook and brochure specifically designed to accompany workshops.

A brief history: The roots of Mecklenburg County's home composting program go back to January 1990, when Charlotte environmental activist Martin Webster contacted the county on behalf of the 'Pile-it Project', a citizen-based home composting initiative. Brenda Barger began working on the program in 1992, when Cary Saul of Solid Waste Management named her to a newly organized Backyard Composting Education Team.

Cooperative Extension Master Gardeners joined the effort in 1993, working with Steve Elliot, Compost Central's site manager, to create a 'vision' for a home composting demonstration garden at Compost Central. Early in 1993, representatives from Mecklenburg County Waste Management and Cooperative Extension visited the National Horticulture Society (NHS) National Home Compost Park in Alexandria, Virginia, set up by Joe Keyser, as well as home compost demonstration sites in North Carolina. After these visits, Cooperative Extension Agent Ted Caudell and Master Gardeners designed a 0.3 ha (3/4 acre) Compost Garden for Compost Central.

The Compost Garden opened in July 1993, with more than a dozen models of commercial and homemade backyard composting bins on display. Landscaping featured drip irrigation and well-adapted native plants, herbs and perennials. The front section of the garden was designed for workshops, with benches made from recycled plastic.

Martin Webster taught Charlotte-Mecklenburg's first two home composting classes in August and September of 1993 at the Cooperative Extension Auditorium in the Hal Marshall Center in downtown Charlotte. Following a 1 hour indoor lecture-demonstration, participants took an optional field trip to the Compost Garden.

After Webster relocated to the Asheville (NC) area, Don Boekelheide was hired in early 1994 to work with the county's Susan Richards to write a composting guidebook and to organize and teach a series of workshops. Boekelheide, a returned Peace Corps volunteer with an agriculture background, suggested changing the composting workshops to 'Peace Corps-style' hands-on activities held outdoors in the Compost Garden. These workshops proved popular, and have been offered annually spring and fall since April 1994.

In fall 1996, building on the success of the home compost program, the county sponsored a free bin distribution and gave away over 150 bins in an hour. The following year, Boekelheide teamed with the county's Bobbie Campbell to write a $10,000 North Carolina state grant to fund four 'neighborhood compost fairs' in Charlotte. Over 300 people received bins and saw a composting demonstration at these fairs. The grant also provided funding for revising the 'how-to' compost brochure and for a survey of bin recipients. The survey found that over 80% of free bin recipients continue to compost after six months

METHODS USED IN CHARLOTTE'S HOME COMPOSTING PROGRAM

Best practices: Charlotte actively seeks out and researches home composting programs in other communities. Before preparing printed materials, staff carefully reviewed pamphlets and documents from other programs, including those from the Pacific Northwest (Seattle, 97; VanMiert, 91) and the National Horticultural Association (Keyser, 93). The World Wide Web, especially the Cornell University Compost Site (Cornell, 98) and the Home Composing Listserv (Home Compost, 98), has provided invaluable information and feedback.

Hands-on extension-style workshops: For a $5 workshop registration fee, participants receive a wire compost bin and a guidebook on composting which covers the method taught in the workshop. Workshop participants learn a specific compost making method that is inexpensive, efficient and predictable in Charlotte's climate. Even composting novices leave ready to set up a bin at home and succeed in composting.

Composting workshops are taught outdoors, hands-on. In classes of 8 - 20 (12 - 16 is ideal), participants build a bin just as they will in their backyard, using fallen leaves. Each workshop also 'turns' (remixes) a compost pile built by the previous week's workshop, and adds kitchen scraps to a pile. Workshop members also see finished and actively decomposing compost in bins built by earlier workshops.

Compost workshops are offered on Saturdays during a 5 to 6 week period in the fall, beginning with the leaf drop in October; and again in the spring, beginning in mid-March. Each workshop lasts 2 hours. Two sessions are held each Saturday, one in the morning, one in the afternoon.

Inexpensive large-capacity bins: Workshops use a simple bin, a cylinder formed from a length of 5 cm x 10 cm (2 in x 4 in) welded wire fencing 90 cm (3 ft) tall and 3.8 m (12 ft 6 in) in length. This cylinder holds slightly over 1 m^3 (roughly 1.4 yd^3) of materials.

Charlotte chooses to keep home composting simple and low cost, requiring no mechanical shredding or special equipment. The low cost of the wire bins ($4.50 per unit) keeps workshops and free bin distributions affordable. The large bin is ideally suited to yard waste composting under local conditions. (An accompanying paper, entitled *Charlotte-Mecklenburg's Hands-on Composting Workshops and Home Composting Method: A Technical Description* (Boekelheide, 98) details technical aspects of Charlotte's home composting system.)

Free bin distributions: Mecklenburg County has sponsored 5 free bin distributions, each with a live demonstration of the composting method. The first was held at the Compost Garden in the fall of 1996; the others as grant-funded 'Neighborhood Compost Fairs' at school and community garden sites in Charlotte in the fall of 1997. The county has distributed over 500 bins through these events.

On-going evaluation and research: Workshops, free bin distributions, and the compost method itself are the subjects of continuous evaluation and on-going research. The bins set up during hands-on workshops are a valuable source of information on the composting process, and have helped fine-tune the compost method we teach.

All workshop participants fill out an evaluation form after each workshop. Both the workshop instructor and Solid Waste Management staff review these evaluations. Staff recently conducted a well-designed survey of all recipients of free bins during the 'Compost Fairs', with assistance in procedure and data analysis from Dr. Diane Zablotsky of the University of North Carolina, Charlotte Department of Anthropology and Sociology.

Future activities: Solid Waste Management is considering a new compost demonstration site closer to downtown Charlotte, in cooperation with Mecklenburg County Park and Recreation; a 'Master Composter/Recycler' program modeled on the Cooperative Extension 'Master Gardener' program; offering more information and possibly workshops on natural landscaping, grasscycling, compost use in gardens, and vermiculture; and creating school materials for science education based on composting and vermiculture. Ann Gill has joined the Waste Reduction staff to manage and expand the home composting program, under the direction of Waste Reduction Program Manager Loret Hall.

DISCUSSION

The importance of home composting: Although the amount of compost processed in a home bin is tiny compared to that processed in large composting operations, there are nonetheless unique strong points for a backyard approach. As Chiras points out:

> 'Leaves, grass clippings, branches, and organic kitchen wastes can be deposited in small backyard bins where they decompose over time. Far less energy intensive than municipal composting programs, which often require weekly pickups and massive machinery to process the compost, a backyard compost bin takes very little effort on the part of the homeowner. Bacterial and other microorganisms do most of the work. An occasional application of water and a periodic turning of the pile is about all a homeowner need do to produce a rich organic soil supplement' (Chiras, 92).

Home composters also play a role in shaping the public perception of composting. Home composters can be persuasive 'good will ambassadors' for composting, both 'macro' and 'micro', able to explain the benefits of composting across the back fence to neighbors who have little knowledge and sometime negative stereotypes about composting.

'Museum' or 'Model'? Home composters can choose among scores of compost-making devices available for purchase, some sturdy and effective, others less so. Reflecting the marketplace, some home composting programs present would-be home composters with a host of choices. Many home compost demonstration areas, notably The NHS National Home Compost Park, are organized as 'compost bin museums', featuring everything from wooden three unit compost bins to rotating compost tumblers.

Charlotte's Compost Garden used the 'museum' approach when it first opened. Over time, however, Charlotte's program has changed direction. Instead of offering a 'museum', the Compost Garden and workshops now emphasize a 'model', a single inexpensive reliable method of composting that is easy to master.

Which approach is better? Each has advantages and disadvantages, and the two are not mutually exclusive.

A 'museum'-style composting demonstration site is relatively easy to set up if funds are available, and requires little home composting expertise. Building a garden is the type of project that attracts volunteers and favorable press coverage. However, once the site is completed, someone must continue to work on a regular basis to keep it in good condition, especially if bins are used to make compost as a demonstration. This has proven difficult logistically in Charlotte. A poorly maintained site may hurt home composting's public image more than it helps.

A 'model' approach does not even require a permanent site, although one is helpful. Classes to teach or demonstrate the model can be held at community or school gardens, in backyards, or wherever materials and space are available. However, designing a model system and teaching hands-on compost classes requires staff skilled in both home composting and teaching or extension. (Influential and effective home composting teachers, such as Jim McNelly or Richard Merrill, make and use compost in their own gardens, and have years of experience doing so.) In Charlotte, community members with the needed expertise are hired on a contract basis, which requires county staff time for working with and managing contracts. A good working relationship among all parties is essential. Some communities draw on Master Gardeners or specially trained Master Composter volunteers as teachers, but this also requires staff time to train, organize and support the volunteers.

Compost utilization in the backyard: Many enthusiastic novice composters are also enthusiastic but novice gardeners, with little idea of how to use compost most effectively in their gardens. Home composting classes must teach how to use compost. An obvious ally in this effort is Cooperative Extension, particularly Master Gardeners. A handout or brochure illustrating compost use and listing optimum amounts for different purposes (for instance, initial vegetable bed preparation, topdressing shrubs, and so on) makes a helpful addition to workshop materials.

Estimated amount of diversion and cost-per-tonne: Estimating the cost-per-tonne of home composting programs is difficult, since much depends on the behavior of the composter (for instance - How many piles do they makeper year? Do they compost kitchen scraps as well as leaves?). Further research in this area, especially following up with workshop participants to assess their composting patterns, would be of great value. For this paper, the cost-per-tonne estimate uses reasonable assumptions based on personal experience with home composting, discussions with workshop participants, and the recently completed survey of Compost Fair participants.

Since 1994, approximately 840 tonnes (924 tons) of waste have been diverted by the home composting program. The waste is mostly leaf drop, with some garden debris and kitchen scraps. The estimated cost per tonne $21.43/tonne ($19.48/ton), comparing favorably with the cost of large scale MSW composting at $50 per ton (Renkow, 96). The cost per ton for the home composting program will continue to drop each year the program is in operation. Alameda County estimates the cost of their home composting program to be $18/ton ($19.80/tonne) (Alameda, 1997). This does not consider the value of compost to residents. Using assumptions based on the survey, home composters have produced over 275 tonnes of compost for home use. At the retail price of $3.75 per bag (1.5 ft^3 (~40 lb, or ~18 kg)), home composters would have paid over $160,000 for an equal amount of Charlotte's municipal yard wastecompost purchased bagged at the garden store.

CONCLUSION

Charlotte's home composting program has made a positive contribution to waste reduction and a healthier environment since its beginnings in 1993. This cooperative effort has been lead by Mecklenburg County Solid Waste Management, in partnership with NC State Cooperative Extension and citizen environmental groups.

Charlotte-Mecklenburg's popular program has supplied over 1500 families with the materials and know-how they need to compost successfully at home, by teaching them a simple composting method that works. These successful home composters reduce the amount of material which large public composting facilities must process, act as 'good will ambassadors' for composting with their neighbors and friends, and make a personal contribution to waste reduction and the environment while improving their own garden soil.

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CHARLOTTE-MECKLENBURG'S HANDS-ON COMPOSTING WORKSHOPS AND HOME COMPOSTING METHOD: A TECHNICAL DESCRIPTION

By

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Charlotte, North Carolina

ABSTRACT

Mecklenburg County Solid Waste Management (Charlotte, North Carolina) offers two hour hands-on compost making workshops for residents. The workshop's objective is to enable participants to compost successfully at home. Charlotte's method of home composting using an inexpensive wire bin is easy to learn and tailored to local conditions. Autumn leaf drop is the main feedstock; supplemental nitrogen is added to bring the C:N ratio to 30:1. Bins have a capacity of 1 m^3, and produce about 0.3 m^3 of compost per batch. This paper includes a description of workshop activities, and discussion of technical issues in home composting such as layering, turning, managing grassclippings, adding kitchen scraps, 'organic' versus 'budget' nitrogen sources, tools, materials and costs.

INTRODUCTION

The modern history of composting dates from Sir Albert Howard's development of the Indore composting method in India during the early 1900s. J.I. Rodale, who brought Howard's ideas to America, popularized home composting through *Organic Gardening and Farming* magazine, launched in 1942 (Haug, 1993; Rodale, 1960). Home composting today remains a fundamental garden activity, indispensable for organic gardeners who avoid synthetic fertilizers, and highly beneficial for those who rely on 10-10-10 or '*Miracle-Gro*'.

Cooperative Extension 'how-to' pamphlets on home composting date back at least to the late-1940s, and composting books by Rodale and others have long been a familiar sight on gardening bookshelves. Home gardeners today can access home composting information on the World Wide Web (Cornell, 1998). An ever-increasing number of companies offer home compost bins, composting tools, compost inoculants and chipper-shredders for sale.

Home composting is also an effective way to transform organic 'wastes' such as yard trimmings and kitchen scraps into an environmentally beneficial resource, without the need for collection, centralized processing and distribution. For more than a decade, municipalities interested in boosting home composting have sponsored education programs, free or subsidized bin distributions, home compost demonstration gardens and composting workshops. Initiatives in Seattle, Washington, and Alameda County, California, have been especially successful (Alameda, 1997).

Since 1994, Charlotte-Mecklenburg, North Carolina, Solid Waste Management Waste Reduction has sponsored a home composting program. Over 1000 residents have attended hands-on home composting workshops, where they learn an easy-to-master and inexpensive method of home composting tailored to the Piedmont region of the southeastern USA. (For more information on the historical and organizational aspects of Charlotte's home composting program, please see the accompanying paper, *Encouraging Home Composting the Hands-On Way: Lessons From Charlotte-Mecklenburg* (Boekelheide and Barger, 1998).)

Defining composting and compost: Classic definitions of *composting* such as Golueke's (1977) and Haug's (1993) apply in a general sense to home composting, although home composting refers not to a single composting method but to a variety of techniques (Johnson, 1995). Home composting transforms organic wastes produced in the house and yard into compost or mulch on site. Typically, such systems are small, often with a capacity of 1m^3 or less. Ideally, backyard composting systems are low cost, easy to use, free from problems such as offensive odors, and able to generate a useful amount of compost for the home garden.

Similarly, a macro definition of *compost*, emphasizing factors like stability, homogeneity and absence of pathogens and weed seeds, provides a list of worthy goals for home compost rather than a workable definition.

CHARLOTTE'S HAND'S-ON HOME COMPOSTING WORKSHOPS	
OBJECTIVE	• Participants will be able to make compost at home successfully
ACTIVITIES	• Examine good quality finished home compost (made by a class the previous season)
	• Build a 1 m^3 compost pile using a wire bin, with leaves as the primary feedstock and supplemental N (either a 'budget' source or an 'organic' source), paying attention to moisture level and good aeration
	• Turn (remix) a compost pile built by a previous class
	• Add kitchen scraps to a working pile, cover 30 cm deep
	• Discuss grasscycling, mulching and 'eco-landscaping' as ways to reduce and manage grass clippings. Discuss vermiculture.
	• Distribute bin and guidebook to participants
	• Questions, discussion and evaluation
WORKSHOP ORGANIZATION	• 2 hours • 16 participants • Offered spring and fall • Active outdoor activities (old clothes and gloves recommended) • Information presented during activity rather than lecture format

Table 1: *Charlotte's home composting workshop - objective, activities and organization*

Home composting takes place largely under mesophilic conditions (~10° - 43° C), and is not confined to the compost pile, but also occurs 'in situ' as the gardener uses partly decomposed compost in various ways around the yard. Home composters and gardeners often define the quality of backyard compost using something closer to aesthetic criteria than precisely measurable factors: 'Finished' home compost is typically dark colored, easy to move with a shovel or fork, and easily mixed with soil using hand tools. The composted feedstock has transformed into a black crumbly material with a sweet earthy smell.

HANDS-ON COMPOSTING WORKSHOPS

The objective of Charlotte's home composting workshops is to enable participants to compost successfully at home. Workshops are 'hands-on' active learning activities, where participants build a compost pile similar to the one they will make in their own yard. The composting method is based on familiar home composting techniques, adapted to conditions in Charlotte and the Piedmont.

Workshops: Home composting workshops are open to all county residents, and charge a $5 registration fee. Participants receive a wire compost bin and a compost guidebook (Boekelheide, 1994). A second bin is available for an additional $5. Over 1000 people have taken a workshop since the program started in April 1994. (In addition to the workshops, approximately 500 residents have taken advantage of one of the free compost bin give-aways sponsored by Mecklenburg County five times since 1996. At each give-away, the workshop instructor demonstrated the composting method taught at workshops, using a lecture-demonstration format.)

Workshop activities: The organization of Charlotte's compost workshops owes much to Peace Corps training philosophy and practice (Peace Corps, 1984). Lecturing is kept to an absolute minimum; instead, information is presented 'just in time' as needed in class, or in response to participant questions as they come up.

Before beginning the bin building activity, the instructor welcomes the group and invites participants to 'put on their gloves, roll up their sleeves and join in'. Since the guidebook includes all information presented in class, there is no need to take notes. The first stop for each group is a pile of finished compost made by a class during the previous season. Viewing the black rich compost invariably raises group interest and motivation.

Each group then selects a location and forms the bin. Participants learn the 'campsite method' for siting a pile: Water readily available, a level spot, a convenient site (and, preferably, out of sight of the neighbors). The class then fills the bin in layers. The instructor builds the first layer as a demonstration; the class builds the second with a good deal of instructor input, then completes the third relying on themselves.

After completing a new pile, participants 'turn' a pile built by an earlier class. Feeling the heat of the decomposing compost and measuring the temperature is another activity that generates intense participant interest. The instructor then demonstrates how to add kitchen scraps, using the class's newly built pile.

At the close of class, the group holds a brief question and answer period and the instructor distributes bins and a 17 page guidebook on composting and grasscycling.

Workshop scheduling: Charlotte offers workshops in the fall and in the spring. The fall series runs from the time of leaf drop in mid-to-late October through late November. The spring series is offered from late March through early May, a period when gardeners clean up yards after the winter and countless bags of leaves are set out for curbside collection.

Workshops are held on Saturdays, with one class in the morning from 10 AM - noon and a second from 1-3 PM, at the Compost Garden at Compost Central, Charlotte's large yard waste composting facility. Workshop enrollment is limited in theory to 16 people, an ideal number for a hands-on class. However, no one is turned away, and classes have been larger than 20 at times. If fewer than five people pre-register for a class, that class is generally canceled the preceding Friday and the registrants informed by phone. The Compost Central location has a great advantage in providing plenty of leaves for hands-on classes (> 24 m^3 per year).

CHARLOTTE'S HOME COMPOSTING METHOD

Background, climate and ecology: Charlotte is located in the central part of the American Piedmont (Godfrey, 1997). Soil organic matter in the Piedmont is naturally maintained through autumn leaf drop. Mecklenburg is an urbanized and rapidly growing county, with few if any undisturbed natural areas. Charlotte is nicknamed 'The City of Trees' - majestic oaks line major streets, and autumn leaf drop is a major waste management problem.

Mecklenburg County is on the border between USDA zones 7B and 8A. The climate is temperate, with four distinct seasons, though winters are mild, rarely falling below 0° for more than a few days at a time. Charlotte has a long, warm and humid growing season between April and October, with average summer temperatures in the upper 20s C. Between 100-120 cm rain falls annually, distributed more-or-less evenly throughout the year.

In Charlotte, composting follows seasonal variations. Home compost piles built in the spring are ready within three months, for fall or even late summer use. Those built in the autumn are usually not ready for six to eight months, for late spring or (more usually) summer use.

Bin materials: The compost bin used in Charlotte's classes is made of welded wire fencing. Several other public home composting programs around the US have used wire bins successfully (Composting Council, 1996). The relatively low cost of wire bins ($4.50 per unit) keeps workshops and free bin distributions affordable. The fencing is medium gage steel wire welded in rectangles 5 cm by 10 cm (2 in x 4 in). The fencing is 90 cm (3 ft) high (taller fencing (120 cm (4 ft) and higher) is very inconvenient to work with for people of average height).

Composters make a bin by cutting a 3.75 m (12 ft 6 in) length of wire and forming it into a cylinder. The ends of cut wire are bent back to keep the cylinder from unrolling. Each cylinder bin holds ~1 m^3 (~1.4 yd^3) of material.

The ample capacity of the bin is ideal for leaf composting. Rolls of wire 15 m (50 foot) long retail for $18 each; each roll makes four bins.

Location and land preparation: The workshop suggests leveling soil under the bin and removing grass and weeds. Leveling is important, since wire bins have the disadvantage of 'slumping' when placed on a slope. In Charlotte's climate, bins work in either sun or shade. Roots sometimes invade bins under trees. Building piles on a layer of black plastic mulch covered with 7-15 cm (3-6 in) of inexpensive organic mulch or dry leaves solves this problem.

Composting method: Composters learn to build a 'batch' of compost (filling the bin to capacity) using a layering technique. Each layer contains 30 cm of leaves, a nitrogen source, and a shovelful or two of working compost or topsoil. Classes select a 'budget' N source (cow manure plus 30-2-2 fertilizer or equivalent) or an 'organic' N source (inexpensive rabbit food) (Tables 2 and 3). Using a manure fork, composters mix the ingredients of each layer while adding water to 50% by volume (the moisture of a squeezed-out sponge). After finishing the bottom layer, the composter uses the same process to make the middle layer, and then the top layer.

Workshops do not recommend the traditional technique putting a layer of coarse materials such as sticks or brush at the bottom of piles, since that interferes with easy turning using a manure fork.

Turning: Workshops recommend four turns for the compost, the first and most important turning within the first week. Subsequent turns are at roughly three week intervals.

Tools: Recommended tools include a five pronged manure fork or a D-handled garden fork; a container for gathering leaves, such as an old plastic garbage can; a wheelbarrow and shovel for moving finished compost to sites in the yard; and a garden hose or watering can to water the pile. I strongly recommend a piece of 'rebar' ~1.2 m (48 in) long. For people wishing to compost kitchen scraps, I suggest a 2-4 quart plastic container for the kitchen counter, and a simple 'poking' device made from a 5 cm x 10 cm (2x4) board 1.2 m long cut at a 45° angle on one end. This composting method requires no mechanized equipment, such as a shredder.

Compost production: Each bin, filled according to instructions to capacity (1 m^3), produces about 0.3 m^3 of finished compost (~10.6 ft^3). This is enough to amend 3 m^2 (32 ft^2) of garden bed (at 7.5 cm (~3 in) coverage), or topdress an area of 9 m^2 (97 ft^2) (at 2.5 cm (1 in) coverage). Purchased commercially in bags, 0.3 m^3 of Charlotte's municipal yard waste compost sells for about $26.50.

Materials not recommended for composting: The instructor warns participants against adding dog or cat droppings; large amounts of meat, fish or dairy wastes; oils and fats; pesticides, herbicides or other household chemicals; or sick plants and weeds that have set seed to their home compost. These materials can become a danger or a nuisance, and their safe composting requires more carefully controlled conditions than those in most backyard compost bins.

DISCUSSION

Charlotte's workshops teach a managed biological process approach (Golueke 1977) to building and maintaining the bin. By Golueke's taxonomy of composting methods, the Charlotte composting technique is an aerobic mesophilic non-mechanized system. Although a wire bin holds materials in place, the design is best described as a self-insulating 'contained' windrow. To design the system, I drew on personal experience, composting techniques used by Peace Corps and other well-established garden and horticultural programs, a literature review, experimentation at Compost Central and in Charlotte backyards, and suggestions from experienced composters.

Passive piles: Workshop participants learn that 'passive' leaf piles, without additional N, are a viable option for those who do not want a faster composting method. A 'passive' leaf pile gives 'leaf mold compost' in 12-24 months, and a passive pile is far preferable to dragging bags of leaves to the curb for collection (Table 2).

TECHNIQUES

Layering: Layering is an easy way to arrive at the right approximate proportions of C:N. Some excellent home composting instructors, however, do not recommend layering and strongly prefer to pre-mix ingredients before

CHARLOTTE HOME COMPOST MATERIALS, CHARACTERISTICS AND YIELD

Feedstock	Mass (kg)	Moisture %	N %	C:N	Yield (kg)	Soil application area (m^2/ft^2) bed prep (7.5cm)	top dress (2.5 cm)	Cost $	Retail value $
Home leaf compost without N ('passive pile')									
leaves	150	35	0.625	80					
water	46	100	0	0					
total	*196*	*50*	*0.6*	*80*	*98*	*2.2/24*	*6.6/71*	*$0*	*$20*
Home leaf compost with 'budget' N supplement									
leaves	150	35	0.625	80					
manure	54.6	50	0.5	50					
30-2-2	3.5	0	30	0					
compost	12	50	2	25					
water	47	100	0	0					
total	*267*	*50*	*1.5*	*32*	*134*	*3/32*	*9/97*	*$4*	*$28*
Home leaf compost with 'organic' N supplement									
leaves	150	35	0.625	80					
rabbit food	22.5	15	2.56	16.6					
compost	12	50	2	25					
water	60	100	0	0					
total	*244*	*50*	*1.1*	*47*	*122*	*2.8/30*	*8.3/89*	*$10*	*$25***
Home leaf compost with 'budget' N supplement plus kitchen scraps									
leaves	150	35	0.625	80					
manure	54.6	50	0.5	50					
30-2-2	3	0.5	30	0					
compost	12	50	2	25					
scraps	91.3	80	3	16.7					
water*	0	100	0	0					
total	*311*	*51*	*1.6*	*31*	*155*	*3.5/38*	*10.5/113*	*$4*	*$32*
Home leaf compost with 'organic' N supplement plus kitchen scraps									
leaves	150	35	0.625	80					
rabbit food	22.5	15	2.56	16.6					
compost	12	50	2	25					
scraps	91.3	80	3	16.7					
water*	5	100	0	0					
total	*281*	*50*	*1.3*	*38*	*140.4*	*3.2/34*	*9.5/102*	*$10*	*$29***

Table 2: *Charlotte home compost materials, characteristics and yield.*

Reference: Cornell University Compost Website [T.Richard, N. Trautmann, M. Krasny, S. Fredenburg and C. Stuart] (Cornell, 1998). Notes: *Water: Although kitchen scraps contribute ample moisture, they are added in relatively small amounts on an on-going basis. In a practical sense, the amount of water added when a pile is first made is more accurately reflected in the calculations without kitchen scraps (above). **Value of 'organic' compost: Certified 'organic' compost is not available in Charlotte. Using the price of the closest locally-available product, an 'organic vermicompost' sold at Talley's Market natural food store for ~$5/kg, the value of one batch of organic home compost might be on the order of $500! Justifiably or not, the designation 'organic' can clearly have a powerful influence on the public.)

adding them to the bin. After trying both pre-mixing and layering at different workshops, I found layering was more popular and readily understood by workshop participants. In trials, layering also has (unexpectedly) given higher quality finished compost than pre-mixing, given that layered piles are turned and thoroughly remixed within the first week. However, I did not shred materials before or during pre-mixing, a technique often used by composters who prefer pre-mixing.

Turning: The wire bin makes turning a very simple operation, a fact much easier to demonstrate than to explain in words. The composter unhooks the wire to open the cylinder; removes it from the pile; sets it up (now empty) next to the pile and refastens it; then tosses the working compost back into the wire cylinder, breaking up and mixing the materials and adding water as needed.

The first turn, ideally within a week of when the pile is built, is a remixing process that allows the composter to blend and break up materials that are packed together and to water dry spots. Three additional turns at roughly three week intervals thereafter (at four weeks, seven weeks, and ten weeks) gave the best results in trials, perhaps in part because the pause between turnings allows actinomycetes and fungi populations to become well established. Additional or more frequent turnings made no difference in either speed of composting or quality of end-product.

Unturned piles take longer to break down and have large areas within the pile with minimum decomposition. The first turn yields the greatest benefits.

Shredding: I do not suggest that composters shred material. The cost of a shredder might discourage many home composters, especially low-income families, and inexpensive shredders can be noisy and inconvenient to use.

In Charlotte, a home composter can produce nicely finished compost from leaves in a reasonable time without shredding. Surprisingly, trials have shown no clear evidence that shredding Charlotte's autumn leaves speeds up or improves the composting process. Instead, shredded leaves tend to mat together in hydrophobic clumps, similar to peat moss, which remain dry and resist breakdown.

Experienced home composters report excellent results composting with leaves and grassclippings shredded and mixed using a lawn mower (Webster, personal communication; Alameda, 1997). Although this mix has not worked well in trials without shredding, using a 'lawnmower as shredder/mixer' as an inexpensive and convenient way to mix leaves and grassclippings for home composting merits further testing.

FEEDSTOCKS: LEAVES AND KITCHEN SCRAPS

Leaves: The basic compost feedstock: The most important feedstock for home composting in Charlotte is autumn leaf drop from hardwoods such as pin oak (*Quercus palustris*), willow oak (*Q. phellos*), sweet gum (*Liquidambar styraciflua*), hickories (*Carya spp.*) and maples (*Acer spp.*). The home compost bin used in Charlotte's system holds approximately 150 kg (~330 lbs) of leaves per batch (equivalent to approximately 15 average sized plastic 'lawn waste' bags of leaves, at 10 kg each (~22 lbs).

I encourage incorporation of other yard wastes in home compost, the exception being grassclippings. Workshops advocate grasscycling as the preferred way to deal with grassclippings. Kitchen scraps,with certain precautions, are an optional ingredient.

Kitchen scraps: Kitchen scraps increase chances for odor and insect problems in home compost piles, and some well established programs (Seattle, 1996) offer bins especially designed for kitchen scraps at discount prices, and discourage residents from composting yard waste and kitchen scraps together. Kitchen scraps are typically high in moisture (>70%) and food wastes that attract flies. On the other hand, kitchen scraps are a traditional ingredient in home compost piles which contribute valuable nutrients and divert a troublesome source of organics from garbage destined for the landfill.

Charlotte workshops take a 'middle of the road' approach. Experienced composters are encouraged to add kitchen scraps in small quantities (~ 4 liters) to their working compost, and to bury them at least 30 cm deep. Scraps can be added for no more than 12-14 weeks to a single pile. This approach treats the compost pile as simple backyard 'microbial digester' for the easily decomposed kitchen wastes, and can be easily managed without odor or pest problems. Vermicomposting offers another option for kitchen scraps for dedicated home composters

At the same time, workshops stress that kitchen scraps are not necessary for composting. I encourage beginners to try a simple leaf pile enriched with N first, especially if they live in densely populated urban areas, or if they have had problems in the past with rodents, dogs, raccoons or opossums.

GRASS CLIPPINGS:

Grass clippings can be a major headache for both waste managers and backyard composters in Charlotte. Grass clippings are difficult to work with even for large- scale composting operations (Steve Elliot [Compost Central manager], personal communication). Haug (1993) gets it 100% right when he observes that 'Grass and leaves are sometimes collected and composted together, but the two substrates could not be more different. Leaves...make a good structural mix, (while) ...grass is often anaerobic and malodorous....' As Tom Richard demonstrates, the high moisture content of grass clippings makes using them as a nitrogen source a very tricky process, since the added water can turn a pile into an anaerobic 'mess' (Cornell, 1998). Grass clippings have been the source of the majority of public complaints and questions about backyard compost piles in the past in this area.

The backyard composting method taught in workshop is excellent for fallen leaves and workable for kitchen scraps, but does not work especially well with grass clippings from the tall fescue (*Festuca elatior*) lawns predominant in the area. Grass clippings mixed manually with leaves did not compost well in trials at Compost Central. The grass clippings tended to mat together and desiccate or putrefy (creating strong odors and fly problems) without contributing much N to the decomposing leaf mass, which decayed as slowly as piles without any supplemental N.

In view of these observations, Charlotte's composting workshops stress the importance and desirability of grasscycling and use of grass trimmings as mulch, rather than composting grass clippings. The best home composting option for grass clippings may well be passive leaf piles in shady areas on the edges of yards large enough to place the compost well away from areas where people gather. When grass clippings are stirred into these piles on an on-going basis during the growing season, the piles over time attract very healthy worm populations. After approximately two years, the home gardeners can harvest 'finished' compost from the middle of the pile.

The most promising way to cut down the amount of grass clippings, however, may be to encourage a new approach to landscaping using native plants, perennials, shrubs and trees to create beds and natural areas in place of vast lawns. Workshops encourage re-landscaping huge lawns, customary here, with a mix of grass and garden beds planted with the many desirable perennials that thrive in the Carolina Piedmont.

In spite of problems and lack of success thus far, trials of grass clippings in home compost continue, seeking ways to harness the N in the clippings. Shredding leaves and grass clippings with a lawnmower may be the best option for this (see shredding).

NITROGEN SUPPLEMENT-'BUDGET' AND 'ORGANIC'

Local trials confirm the axiom that leaf piles do not heat significantly above ambient and compost slowly without supplemental N. Since the objective of workshops is to teach a composting method that works reliably under local conditions (heats readily to thermophylic temperatures, causes no odor problems, gives a nicely finished compost in a reasonable amount of time), participants learn how to make home compost using an N supplement.

The main feedstock, autumn leaves, has a C:N ratio of approximately 80:1. A full bin of leaves contains approximately 40 kg of actual C. The Charlotte method adds supplemental nitrogen to bring the C:N ratio of each batch to approximately 30:1. Approximately 1.3 kg actual N is needed per pile to reach a 30:1 C:N ratio. The leaves contain about 0.5 kg N; thus, approximately 0.8-1 kg. N is needed to reach a 30:1 ratio.

Charlotte's home composting system uses a purchased N supplement. Charlotte, an urban area, has few readily available sources of 'scroungable' N, such as farm manure. While garden 'greens' (spent bedding plants, prunings, weeds, and so on) theoretically can provide N, locally sufficient quantities of 'greens' are not available for most urban composters (including most gardeners), particularly at the time of leaf drop in the fall. Grass clippings are difficult to home compost without problems, as discussed above.

Classes offer two choices for adding N: A 'budget' option and an 'organic gardening' option. Each workshop selects the type of N they wish to use in their model pile by majority vote (so far, the split has been about 50/50).

NITROGEN SOURCES FOR BACKYARD COMPOST			
N source	N %	$/kg N*	Amount required (kg)[1]
'Budget' N supplements			
30-2-2 (lawn fertilizer)	30	$1.29	3.3
48-0-0 (urea)	48	$0.77	2.1
Organic' N supplements			
5-2-2 (Espoma Plant-tone)	5	$15.84	20
Rabbit food ($7/bag)[2]	2.6	$11.85	38.6[2]
Rabbit food ($10/bag)[2]	2.6	$16.92	38.6[2]
Blood meal	12	$24.75	8.3
Charlotte compost[3]	2	$10.30	50
Chicken manure[4]	3	$18.33	33.3
Cottonseed meal	6	$26.40	16.7
Cow manure[5]	0.5	$11.00	200
'Recycled' N supplements[6]			
Coffee grounds	2	$0	71.4
'Greens'[7]	2.5	$0	114.3
Kitchen scraps	3.3	$0	150
Grass clippings	2.6	$0	152

TABLE 3: *Nitrogen sources for backyard compost*

Notes: * $/kg N: Since a 1m^3 leaf bin requires ~1 kg actual N to reach 30:1, the amounts shown in this column also represent the cost per pile of supplementing N using a given method. 1. Amount required: This column shows the amount of listed materail needed to bring a 1 m^3 leaf pile to 30:1 C:N. 2. Rabbit food: As explained in the text, inexpensive rabbit food in the least expensive way locally to buy alfalfa. Prices range widely, this shows a low and high cost. Though 38.6 kg is theoretically needed to reach 30:1, 22.5 kg (1 bag) appears to be ample based on trials. 3. Charlotte compost: Charlotte-Mecklenburg yard waste compost, bagged ("Eco" brand). 4. Chicken manure: 'Black Hen' brand, bagged. 5. Cow manure: Bagged. 6. 'Recycled' N supplements: These materials are available wiithout charge. Amount required reflects moisture content of the materials.

With either technique, the temperature of the interior of the composting mass reaches at least 20° C above ambient, (50° C (122° F), ± 5° C) within a week. For a summary of Charlotte's home composting 'recipes' and N sources, please see Tables 2 and 3.

Alternative N sources: Though workshops demonstrate making a pile using purchased N, the instructor discusses alternative free sources of N available locally to motivated and enterprising home composters, including horse or poultry manure, coffee grounds from coffeehouses like Starbucks and 'green' wastes from large gardens, produce sellers or juicers. If used in sufficient quantities, these all can be as effective as purchased N.

'BUDGET' NITROGEN SUPPLEMENT

For each batch of compost, 'the budget' option uses twelve cup measures (2.7 kg (6 lb)) of inexpensive lawn fertilizer (roughly 30-2-2 or the equivalent), along with three bags (54.6 kg) of inexpensive cow manure (0.5-0.5-0.5), adding four cups of fertilizer and 1 bag of manure per layer.

Rather than simply add N in the form of synthetic fertilizer, such as urea ($CO(NH_2)_2$) (48-0-0) or NH_4NO_3 (34-0-0, no longer readily available), I decided to 'enrich' bagged cow manure by adding enough synthetic fertilizer to reach the level needed for a 30:1 C:N ratio in the pile. I hoped to simulate farm manure, an ideal N source for

home composting but hard to find in Charlotte. In contrast, bagged cow manure is widely available locally for less than $1 for a 18.2 kg (40 lb) bag, with a cost of $11.00/kgN. Alternatives were to use bagged chicken manure (~3% N) or to gather manure from farms. The latter was logistically impossible; the bagged chicken manure was relatively expensive ($18.33/kgN, as 'Black Hen' brand), not readily available, and malodorous.

The fertilizer N carrier workshops use is inexpensive 'lawn green' fertilizer (~30-2-2), frequently on sale locally for ~$3 for a 7.7 kg (17 lb) bag, enough for three bins using 'the Charlotte method'. This is more convenient for the typical resident than buying large (22.7 kg (50 lb)) bags of N fertilizer. The price per kg N is $1.29/kgN, compared to $0.77/kgN for urea.

To my surprise, I observed that piles made with the 'supplemented' manure decomposed more rapidly and completely than those made with mineral N alone, though the amount of N in the two treatments was the same. Perhaps mineral N leaches from the pile readily in the absence of a material like manure, or the microbes (many heterotrophic) prefer amino N or N in an organic complex (urea seems to behave like mineral N, although it is a small organic molecule containing amino N). There is no guarantee, however, that this observation would hold up under more careful experimental conditions.

'ORGANIC' NITROGEN SUPPLEMENT

Many home composters garden organically, and are reluctant to use synthetic fertilizer in composting. Our first 'organic' recipe used cow manure as described for the 'budget' method, supplemented with an 'organic' fertilizer. Espoma 'Plant Tone' (5-2-2) with N carriers including dried manure and food processing wastes. This, however, was relatively costly (a 22.7 kg (50 lb) bag of Plant Tone cost $18, and provided N for roughly three piles, at a cost per kg N of $15.84). Other 'organic' N fertilizers, such as bagged chicken manure, cottonseed meal ($26.40/kgN) and bloodmeal ($24.75/ kgN), were even more expensive per unit N, and faced numerous objections from gardeners concerned about pesticide use (in cotton), sustainability and humane treatment of livestock.

I decided to research legume-based material as an 'organic' and 'sustainable' N supplement. Ground alfalfa was not readily available locally, but inexpensive rabbit food, largely alfalfa, was. Initial experiments were very promising, and workshops now use rabbit food as the 'organic' N source. In many ways, it is ideal for backyard composting; easy to handle, no unpleasant odor, relatively easy to obtain, with N fixed by bacterial action rather than industrial processes. Subsequent inquiries have revealed that rabbit food is a popular N source for composting experimentation. The only drawback is a relatively high price per kg N (between $13.75 and $17.19).

The 'organic' recipe for compost uses 22.7 kg (50 lbs) of inexpensive rabbit food (the least expensive local source of ground or pelleted alfalfa) as an N source, per batch of compost. Cow manure is not necessary in the 'organic' recipe using rabbit food.

The 'organic' method provides about 0.6 kg actual N, which when added to the 0.5 kg of leaf N gives a total of about 1.1 kg actual N for the pile. This provides a C:N ratio of about 42:1 for the pile. Curiously, in spite of the 'higher than optimal' C:N ratio, piles made with the rabbit pellets consistently heat more rapidly and to higher temperatures than those made using the budget method, and as little as 11.3 kg (25 lb, or a half bag) of rabbit food is sufficient to heat piles made May through September. During the coming season, I plan to test to find the smallest amount of rabbit food needed to obtain pile heating.

One caution: When using straw as a feedstock and 22.7 kg of rabbit food, and an overly-heavy watering of the pile, a marked odor nuisance from ammonia can occur, a problem I have not noted in piles made with leaves. The cause is uncertain - perhaps the higher pH of the straw and high moisture level contribute to NH_3 formation.

INOCULA

Charlotte's method does not use purchased inoculum. I teach composters to introduce beneficial microbes by adding about 24 liters (3 bucketfuls or 6 shovelfuls) of old or working compost to their pile as they build it. An equal amount of 'sweet smelling dark topsoil' can replace the compost. Although this traditional practice may not be necessary given the ubiquity of microbial life on Earth, it does no harm. Large scale composting operations often remix finished or partially-finished compost with new feedstock (Haug, 1993).

Adding large amounts of soil makes the compost very heavy and inconvenient to turn. Some Coop Extension pamphlets still call for 1/3 soil in compost piles, a recommendation I cannot support.

HOME COMPOST PRODUCED AND WASTE DIVERTED

In Charlotte, home composters typically compost between 1-4 m^3 (1-4 bins, or 1.4 to 5.6 yd^3) of 'feedstock' (mostly leaves) per year, or 150 - 600 kg of yard waste. Home composters who compost kitchen scraps can divert up to an additional ~365 kg (803 lbs) per year for a family of four. An 'active' composting family of four that makes four piles per year and composts all food scraps can divert as much as 965 kg (2123 lbs) of material from 'waste' to resource per year in their backyard.

Output from a home compost pile of the type used in Charlotte is about 0.3 m^3 (Table 2). The 'active' composting family of four can generate enough compost to dramatically improve five large flower or vegetable beds (2.7 m^2 (30 ft^2) each), or topdress 42 m^2 (440 ft^2) of garden or lawn annually. '(Improvement' assumes a 7.5 cm (~3 in) application of compost; topdressing assumes a 2.5 cm (~1 in) application.)

Using Charlotte's system, the start-up cost of materials and tools for the home composter is not high, from $0 (for those who already own needed tools and receive free bins) to < $50. The cost of purchased N is between $4 ('budget') and $10 ('organic') per pile. For the novice making a single bin using the 'budget' system who takes a workshop, the ~$26 retail value of 0.3 m^3 of compost (purchased by the bag) offsets the $5 class plus $4 cost of N.

WHY TEACH A SPECIFIC METHOD OF COMPOSTING HANDS-ON?

Communities face a dilemma in selecting the best strategy for encouraging home composting. One option is to demonstrate a wide variety of composting options, reflecting the myriad successful ways home gardeners make compost. The other approach, selected by Charlotte, is to focus on teaching a single composting method that works well.

Our experience is that beginning composters are hungry for clear guidelines, and are looking for a successful way to make compost, rather than 'a few simple rules' or long list of possibilities. At the same time, there are countless ways to compost successfully, and it is important not to discourage those who want to experiment or who have developed their own methods of composting. I do not present the workshop composting method as 'the only way to compost', but as simply a straightforward method that works, which individual composters can easily modify or adapt to suit their needs.

Workshops work best with minimum of technical jargon, lots of hands-on activities, and as much relaxed banter as possible. Technical aspects of composting discussed in this paper are an important part of designing and improving a composting method. Such topics may be appropriate for Master Composter training. But detailed discourses on C:N ratios and other technical questions are neither necessary nor recommended for general classes, especially with beginners.

TRIALS AND DISCARDED IDEAS

The author systematically observed compost piles made by classes and set up a number of trials using different composting techniques, though as yet no formal controlled formal experiments. These observations have been very useful in devising the composting method discussed in this paper. It is worth mentioning that some trials lead to the rejection of a number of compost-making ideas. These included covering or wrapping bins with plastic sheeting, using a 'breather pipe' of 20 cm (4 in) pvc in the center of the pile, and using clips to hold the wire in a cylinder. In sum, 'the simpler, the better' seems the best policy for home compost design.

IDEAS FOR THE FUTURE:

-- **Experimentation:** Formal experiments at the Compost Garden can yield valuable data. Ideal partners in this work would be faculty from area colleges and universities, science teachers, and Cooperative Extension agents. Diane Zablotsky of UNCC's Department of Anthropology and Sociology has already made outstanding contributions to a 'farming systems'-style ('composting systems'?) approach to gathering information on human factors and home composting behaviors.

Grass clippings: Although the bin taught in workshops is ideal for leaves, problems remain with grass clippings. Grass clippings are a major source of problems for the macro yard waste composting operation in Charlotte. This issue clearly highlights the fact that even well-designed home compost bins and workshops only address part of the need for yard waste reduction. Perhaps waste managers, Cooperative Extension Agents, and environmental groups can work together to design 'eco-landscaping' and 'eco-neighborhood' programs, where home composting is but one technique among many a resident uses to cut waste while improving soil, plant health and habitat. Reducing grass clippings may involve finding a better way to compost them at home, but programs may also want to consider teaching about grasscycling, mulching and lawn alternatives including ground covers, natural areas, and use of perennial and native plants in the landscape.

Kitchen scraps: Charlotte continues to look for an inexpensive, durable and rodent-proof kitchen waste composter for urban situations, especially for households where little dry C-rich material (such as autumn leaves) is available. Mecklenburg County is field testing the 'Green Cone' style micro-digester for this application, but Charlotte's difficult-to-dig red clay soils with poor drainage may hamper its effectiveness.

Schools and worms: The home composting system makes an ideal school science project. The author has used the method with great success with fifth graders. Developing a teaching guide and activities aligned with the North Carolina curriculum (and reflecting the current emphasis on literacy) merits a high priority because of its potentially high payoff (school children can be excellent 'motivators' for home composting and recycling). Vermiculture attracts a good deal of interest from schools and the public, and Charlotte is considering worm composting workshops for the future. Children find worms fascinating, but experience suggests that people with high enthusiasm, an active interest in worms, and sufficient time are most likely to succeed with vermiculture projects.

CONCLUSION

Charlotte-Mecklenburg's home composting workshops offer a model for other communities, especially those in the Piedmont region of the southeastern USA. By teaching residents 'hands-on' how to make compost successfully, using a simple, inexpensive and well-designed composting system, Charlotte has reduced wastes and helped gardeners enrich their soils and manage their yards in a more environmentally sound and sustainable way.

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COMPOSTED MUNICIPAL WASTES INCREASE GROWTH, YIELD AND DISEASE TOLERANCE OF CITRUS

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SUMMARY

Most citrus grove soils in Florida are infested with *Phytophthora nicotianae*, which causes Phytophthora trunk and root rot resulting in decline of tree condition and fruit production. The potential for composted municipal solid waste (CMW) as a soil amendment to provide long-lasting suppression of *P. nicotianae* and enhance root health and tree yield was evaluated. CMWs were applied to newly planted young trees and bearing citrus groves in central ridge and east coast flatwoods locations. Young trees were planted on typical citrus soils, while bearing trees in decline were located on marginal soils. Two sources of CMW were applied as 5- to 10-cm-thick mulch layers under the tree canopy. Rhizosphere population densities of *P. nicotianae* were not reduced, but in some cases were increased by CMW. Root density response was site-dependent. Trees treated with CMW were more densely foliated probably due to improved soil moisture availability. Young trees responded immediately to CMW treatment with 20-30% increases in stem caliper and root mass. Yields and fruit size of bearing trees were increased in the second and third seasons after application. CMW did not suppress the root pathogen, *P. nicotianae*, but CMW increased water and nutrient availability in soils low in organic matter which enhanced root health and uptake efficiency, and thereby reduced the impact of fibrous root disease and probably other soil stresses.

INTRODUCTION

Citrus is the most economically important and widely planted crop in Florida covering about 273,000 ha in central and south Florida. The center of the citrus industry is within a 100-mile radius of over 7 million people producing 5 kg of solid waste per person per day. Between 1992 and 1994, over 10.3 million new trees were planted on sandy soils, mostly low in organic matter, and poor in nutrient exchange and water holding capacity.

In citrus nurseries and groves, *Phytophthora nicotianae* Breda de Haan (synonym = *P. parasitica* Dastur) is often an endemic root pathogen that causes girdling of the trunk due to bark infection and slow decline in canopy vigor and fruit production due to rot of fibrous roots (Graham and Timmer, 1992). Applications of the fungicides control fungal infection of bark and roots and increase fibrous root density (Timmer et al, 1989). Although fungicides increase yields and fruit size of orange and grapefruit trees on Phytophthora-susceptible rootstocks, yield response is often variable. Therefore, fungicides are not recommended unless populations of *P. nicotianae* exceed a threshold of 10 to 15 propagules per cm^3 of soil. Fungicides are usually applied to the soil through the irrigation system two to three times over several seasons to be effective and economical for application. However, soil-applied pesticides are prone to loss of efficacy after prolonged usage and, since they are water soluble, have the potential to leach into the groundwater after excessive irrigation or rainfall (Kookna et al., 1995). Fungal resistance to the metalaxyl has been found in Florida nurseries, raising concerns about the long-term usage of this fungicide in citrus groves (Timmer et al., 1998).

An alternative strategy to fungicides for sustained control of soilborne diseases is to periodically apply composted organic materials as amendments to suppress fungal root pathogens. Composted bark, when incorporated into potting media, suppresses soilborne diseases of ornamental plants (Hoitink and Grebus, 1994). In Australian avocado groves, root rot caused by *P. cinnamomi* was effectively controlled by intensive mulching with organic amendments and applications of gypsum (Broadbent and Baker, 1974).

In our studies of citrus, CMW from different sources reduced the incidence of root infection of citrus seedlings through direct suppression of *P. nicotianae* in soil (Widmer et al., 1998a). Thus, the principal objective of field studies was to examine the potential for CMW, from different sources applied as a mulch layer on the soil surface, to suppress *P. nicotianae* and improve root health. Growth of young trees and yield of bearing citrus trees was evaluated in typical and marginal soil types with damaging soil populations of the pathogen.

RESPONSES OF YOUNG TREES TO CMW

Three trials from 1991-1996 demonstrated that mulch treatments of composted municipal wastes (CMW) are highly effective for growth stimulation of young citrus trees in newly established groves (Widmer et al., 1996,1998b). Responses were seen for soils typical of both the ridge and flatwoods production areas. While greenhouse bioassays predicted that CMW might suppress the pathogen (Widmer et al., 1998a), populations of *P. nicotianae* were either not affected or even increased by CMW. Despite inoculation with the pathogen, stem diameter and root mass of young trees increased 20-30% in response to post plant treatments with surface mulches as well as incorporation treatments at planting. Thus, CMW can be applied to existing groves without incorporation of the material into the root zone. Operationally, the CMW is effectively and efficiently applied with a New Holland 3000 side-discharge spreader as a 5-10 cm thick mulch layer within the tree row to cover about 80% of the root system. The rates are quite high, ranging from 150-170 metric tons per hectare, but last up to 2 years before reapplication is necessary. Reduction of mulch layers to 2-5 cm thick decreases the tree response and may require yearly re-application to be effective.

Current trials are to designed to establish the optimum rate of CMW and the mechanism for the growth enhancement of young citrus in low organic matter sandy soils. Although CMW increased growth of trees in the presence of *P. nicotianae*, the fungus was not suppressed by the CMW (Widmer et al., 1996,1998b). Despite pathogen activity in CMW-amended soils, the trees performed nearly as well as those in noninfested soils and significantly better than those in nonamended soils. The growth response is best explained by increased tolerance to the disease rather than pathogen suppression. Tolerance is attributed to improvement of conditions in the root zone for more efficient water and nutrient uptake. Young trees received adequate fertilizer and scheduled irrigation so CMW did not substantially increase their nutrient status. Soil water holding capacity was elevated at the interface between the mulch and the mineral soil, as was soil temperature. The proposed major benefit of CMW, increased soil water availability to tree roots, will be substantiated by further measurements of soil and plant water relations.

RESPONSES OF BEARING TREES TO CMW

CMW applied as 5- to 10-cm-thick mulch layers increased the yield and fruit size of Marsh grapefruit and fruit size of Valencia orange 2 and 3 years after application (Widmer et al., 1997). The responses occurred in groves with marginal soils and ill-adapted rootstocks that were predisposed to damaging populations of *P. nicotianae*. The effect of CMW on root density was site specific. CMW increased root density of the Valencia sweet orange trees on Carrizo citrange rootstock in a high pH, calcareous soil, whereas, CMW decreased root density of the Marsh grapefruit trees on sour orange rootstock in a low organic matter sand soil (depressional sand soak) at two sites. The roots in the organic mulch layer were usually lighter in color and healthier in appearance than those in the mineral soil below. The mulch layer apparently provided a zone of favorable conditions for growth and function of fibrous roots.

The increase in yield of trees in very sandy, slightly acid soils versus the non response in calcareous, alkaline soils may be related to the effect of CMW on root density at the different sites. Trees in the very well drained sand soak soil treated with CMW were more densely foliated and showed little sign of water stress compared to the stressed, nontreated trees. CMWs have slow mineralization rates, due to their moderate to high C/N ratios (Eichelberger, 1994), so mulches did not increase N status of the tree (Widmer et al., 1997). The mulches substantially improved moisture holding capacity of the soil as demonstrated for CMW applications to other Florida crops in similar soils (Obreza and Reeder, 1994; Turner et al., 1994). Under more favorable conditions for water uptake, apparently fewer roots were required to take up water and water mobile nutrients (e.g. N and K) bringing about a 30% decrease in root density after CMW application in well-drained sand soak soil. Hence, trees were able to produce more and larger fruit instead of supporting the high density of roots required by a tree in the low water and nutrient holding capacity sand. In finer textured, high pH calcareous sand, where root density was 25-35% of that in the sandy soil, CMW apparently exacerbated the soil conditions (high calcium and somewhat alkaline pH) that normally limit performance of certain

rootstocks like Carrizo citrange (Castle et al., 1993). Although the mulch layer provided a favorable site for root growth in calcareous soil, yield of trees was not increased even after 3 year.

Thus, as for young trees, the principal effect of the CMW was improvement of soil water holding capacity. This condition enhanced pathogen reproduction in the mulches because *P. nicotianae* was favored by elevated soil moisture (Duncan et al., 1993). However, CMW appeared to increase tolerance to Phytophthora root rot. The benefits of CMW for increasing water and nutrient availability in soils low in organic matter enhanced root health and uptake efficiency, and thereby reduced the impact of fibrous root disease and probably other soil stresses as well.

CURRENT STATUS OF RESEARCH ON CITRUS

Some limitations in the use of CMW have been encountered. Foremost is the availability of high quality sources of CMW near the citrus industry that can be supplied with minimal delivery cost. Most of the research has been conducted with a co-composted municipal solid waste (approx. 90%) with waste water residuals (10%) from Sevierville, TN supplied by Bedminster Bioconversion. Co-composted CMW has a favorable C/N ratio for microbial activity (19:1) and slow soil mineralization of nitrogen (Eichelberger 1994) so nitrogen leaching is not a concern.

The local CMW tested in the early 1990s is no longer available (Reuter) and evaluation of CMW from Palm Beach County has only recently been initiated. A grower/cooperator conducted a preliminary trial with Palm Beach CMW in 1996 and reported that the material was very fibrous containing palm branch wastes and other coarse woody residuals that made spreading difficult. The Palm Beach material may also have been high in salts, but thus far, residual salts in the Bedminister CMW have not been a problem for citrus in contrast to the experience for vegetables where growth of the first crop is reduced initially (Obreza 1995). Very sandy soils facilitate rapid leaching of salts and thus, no effect on perennial citrus trees have been observed over the longer term (at least one year to detect growth responses). The Palm Beach material spread in 1997 did not share the problems experienced with the 1996 material, but this points out the requirement for CMWs to be consistent in quality through time if they are to be used commercially.

Another major limitation to proceeding with further trials is the availability of a commercial applicator with the New Holland or equivalent spreader in south-central Florida. Two cooperators representing about 25,000 acres of commercial grove land are at present unable to use CMW due to the lack of the appropriate application equipment. These companies are unwilling to purchase a spreader given the high capital cost (approx. $10,000-14,000) and the uncertain availability of high quality CMW. Nevertheless, our results have stimulated their interest in further trials of local CMW sources, especially in low organic matter, sandy soils. Current evaluation of the benefits of CMW mulches is focused on both young and old groves in depressional sand soils, where citrus trees have not responded to extra water and nutrient inputs and, thus, are probably not manageable without soil amendments. Reduced rates of CMW sources produced by local munipalities in close proximity to the citrus industry are now under evaluation to further quantify the benefits and costs of CMW applications. Although the responses are positive, it is unlikely that the horticultural benefits will offset the high cost of production and transport of CMW. However, as land fill space disappears, the cost of production and transport of CMW will eventually be borne by the municipalities surrounding the citrus industry. For example, Los Angeles County is now paying citrus growers to accept yard wastes for disposal in their citrus groves (J. A. Menge, University of California, Riverside, personal communication).

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COMPOSTED MUNICIPAL SOLID WASTE APPLICATION IMPACTS ON COTTON YIELD AND SOIL PROPERTIES

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INTRODUCTION

Municipalities are facing a growing problem of how to safely dispose of their solid waste. A possible solution to this problem is composting the organic fraction of municipal solid waste (MSW). Biosolids are entering composting facilities to turn a waste byproduct into a valuable resource. Industry is looking to expand towards composting of the organic fraction of the municipal solid waste stream as evidenced by the development of Bedminster BioConversion Corporation in Sieverville, Tennessee and Cobb County Georgia. The largest potential user of MSW compost is the agricultural industry (Parr and Hornick, 1992; Slivka et al., 1992). Application of MSW compost usually increases yields of agronomic and horticultural crops, under both field and greenhouse conditions. Agricultural uses of composted MSW have shown promise for a variety of field crops (sorghum, maize, forage grasses) and vegetables sold for human consumption (lettuce, cabbage, beans, potatoes). Responses by plant systems have ranged from none to over twofold increases in yield (Shiralipour et al., 1992). According to research at Louisiana State University (Hallmark et al., 1994) application of 22.4 Mg/ha of composted MSW to opened sugarcane rows prior to planting resulted in an 808 kg/ha increase in sugarcane yields. Addition of 25 Mg/ha compost increased ryegrass yields compared to untreated plots but did not excessively increase the trace metal concentration in the soil (Bauduin et al., 1987). In other studies application of 8, 16, 32, or 64 Mg/ha compost to a sandy soil increased heights and weights of two successive sorghum crops (Hortenstine and Rothwell, 1973).

Soil hard pans can reduce crop yields and are a significant problem in many soils in the Southeast. A high-energy input is required via in-row subsoiling to break up the compaction to promote improved root development and subsequent nutrient and water utilization. Composted MSW has the potential to increase organic matter content of sandy coastal plain soils. Under laboratory conditions values of bulk density, penetration resistance and peak shear strength decreased with increasing organic matter contents in sandy loam and clay soils (Ekwue and Stone, 1995).

Seedling cotton (cotyledon - 4 true leaves) is attacked by various thrips species, western flower thrips (Frankliniella occidentalis), tobacco thrips (F. fusca) and eastern flower thrips (F. tritici) with the first two being most prevalent in South Carolina. Over 99% of South Carolina cotton acreage is treated with an at-planting, in-furrow insecticide to control early season thrips. The effects of different rates and application methods of municipal compost on early season thrips populations needs to be determined. Plant-parasitic nematodes cause over $250,000,000 in yield losses on cotton in the United States each year (Blasingame, 1996). Yield losses in individual fields may reach 30-50%. At the present, nematode management relies heavily on the use of nematicides, such as aldicarb applied in-furrow at-planting at a cost of approximately $52.00/ha. Higher organic matter content tends to increase the populations of many soil microorganisms, including those that are naturally antagonistic or pathogenic to plant-parasitic nematodes.

Research is needed to determine whether compost can be used economically to replace or supplement commercial fertilizers for cotton production. Quantitative data on the effects of compost on soil and plant characteristics are needed as a means of understanding benefits and problems associated with utilization of composted municipal solid waste in coastal plain soils. Determination of the best methods of applying MSW composts to land (broadcast, banded, etc.) is needed. In addition, the effects of compost on pest management decisions needs to be determined.

OBJECTIVES

The objectives of this project were to develop and test equipment for broadcast, banded or injection applications of composted municipal solid waste at selected rates to agricultural lands for cotton production; and determine the effects of compost on soil parameters (organic matter, soil compaction, soil fertility and additive effects over years), plant responses (yield, nutrition) and pest management.

METHODS AND MATERIALS

Tests were conducted at the Edisto Research and Education Center near Blackville, SC on a Faceville loamy sand soil. A randomized complete block design with four replications was the statistical model selected for comparing different treatments. Two application methods (broadcast and banded), three application rates 11.2, 22.4, and 33.6 Mg/ha (5, 10, and 15 tons/acre), and a control (no compost) were used in 1995. The same treatments were used in 1996 and 97, except the broadcast application plots were split in half to determine the additive effects of compost over the years. No additional compost was applied to one half while the other half received the same rate as in 1995. Cotton was planted and carried to yield using recommended practices for seedbed preparations, seeding, fertilization, insect and weed control. Plots consisted of 12 30-m rows on 96-cm centers. The two middle rows of each plot were machine harvested for yield determinations.

A commercially available spreader (Knight Pro Twin Slinger, model 8024) was used for broadcast application of compost in 1995. The spreader was adjusted to apply different rates of compost. With this system, swinging hammers deliver the material to the side resulting in a uniform coverage over 7.5-m width of the test plots. A 4-shank subsoiler-bedder was used to disrupt the hardpan and incorporate the composted material. Drift was a problem with this spreader under windy conditions. In 1996 and 97, a conventional flatbed, chain conveyer type manure spreader was used for broadcast application to eliminate drift problems associated with the side delivering system. An adjustable gate was added to the spreader to control the application rates.

A 4-row device for band application of the MSW compost was developed and mounted behind a John Deere MaxEmerge2 cotton planter. The unit consisted of a hopper with four fluted-wheel-metering devices at the bottom of the hopper. A hydraulic motor was used to run the metering system. Compost application rates were adjusted by changing speed of the motor using a flow control valve. This system dispensed the material, 20-cm wide, behind the cotton planter.

To determine the effects of compost on soil compaction, a tractor-mounted, hydraulically-operated, microcomputer-based, digital recording penetrometer system was used to quantify soil resistance to penetration. Soil cone index values were calculated from the measured force required to push a 3.2 cm^2 base area, 30° cone into the soil at a constant velocity. Penetrometer data (four probes per plot) was taken before compost application and immediately after cotton harvest in 1996. Penetrometer readings were taken to a depth of 45 cm from crop rows and row middles).

Each plot was sampled for Columbia lance nematodes, soil organic matter, ammonium and nitrate contents at planting, 6-weeks-after planting and 14-weeks-after planting. Twelve cores 20-cm deep and 2.5-cm in diameter were taken from each plot on each date. Plant tissue samples (35 leaves/plot) were collected and analyzed for nitrogen.

INJECTION TEST, 1997

The trials were expanded for the 1997 season by including a site with subsurface application. Equipment was

constructed for injecting MSW compost under the seed row at sufficient depth to place it in the compacted subsoil layer at different application rates. Tests were conducted on a Varina sandy loam soil. Two application methods (injection and broadcast), three application rates 9, 18 and 27 Mg/ha (4, 8, and 12 tons/acre), and a control (no compost) were used in a randomized complete block design. Briefly, the equipment was configured for two rows and consisted of subsoiler shanks which had been modified by attaching a 10-cm x 20-cm thin-wall rectangular tubing to the back of each subsoiler shank. These extended from the lower end of the shank to a position above the soil surface. The trailing edge of the rectangular tubing was cut away from the lower end of the tubing to allow the MSW compost to be deposited into the slot created by the subsoiler shank. Compost was funneled into the top of the rectangular tubing and fell by gravity flow to the bottom, filling the tube. As the tool moved through the soil, the MSW compost was placed into the bottom of the subsoil.

For preparing the test plots, the MSW was carried on the subsoiler. A hopper was constructed and attached to the subsoiler frame. This hopper was fitted with a drag chain which pulled the MSW material toward a drop point above the injection tubes. Material dropped by gravity from the hopper floor and was directed into the top of the injection tubes with transitions constructed from sheet metal.

RESULTS AND DISCUSSION

Cone index values before tillage and compost application indicated that the field had a hardpan in the E horizon at a depth of 17 to 25 cm. All rates of compost significantly reduced formation of the hardpan in the top 30-cm of soil for cotton rows compared to no compost application (Table 1). In addition, all rates of broadcast application significantly reduced soil compaction in the top 30 cm of the row middles compared to no compost application (Table 2). Banded application did not affect the compaction in the row middles. Similar results were obtained in 1997.

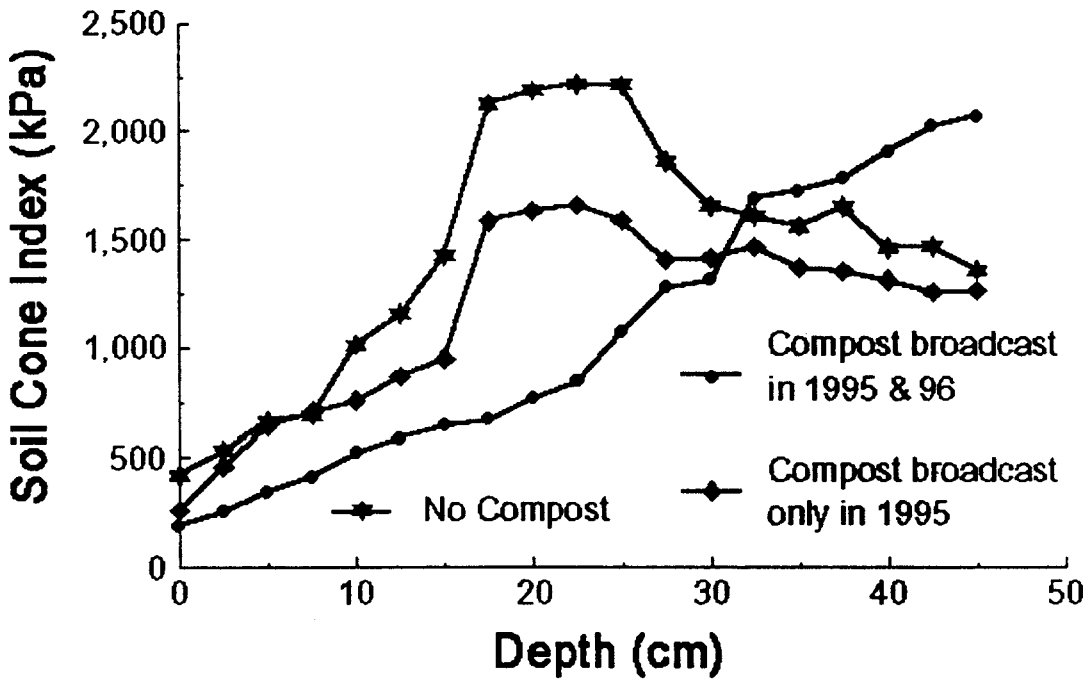

Figure 1. Effects of multiple compost application on formation of hardpan from crop rows after cotton harvest in 1996 (33.6 Mg/ha).

Table 1. Effect of compost application methods and rate on formation of hardpan under cotton rows at harvest, 1996. Clemson University, Edisto Research and Education Center, Blackville, SC.

Compost (Mg/ha)	Application Method	Cone index (kPa)			
		0-7.5 cm Depth	7.5-15 cm Depth	15-22.5 cm Depth	22.5-30 cm Depth
11.2	Broadcast	409 bc	605 b	706 b	1253 bc
22.4	Broadcast	302 c	549 b	754 b	808 c
33.6	Broadcast	301 c	586 b	760 b	1286 b
11.2	Band	536 ab	644 b	1146 b	1236 bc
22.4	Band	495 ab	691 b	1097 b	1155 bc
33.6	Band	510 ab	675 b	1030 b	1218 bc
None	-------	578 a	1198 a	2176 a	1909 a

Means within a column followed with a letter in common are not significantly different (Duncan's Multiple Range Test, $\alpha = 0.05$).

Multiple broadcast applications of compost (1995 and 96) significantly reduced formation of the hardpan in the top 30 cm of cotton row compared to no compost application (Figure 1). Also, there were significant differences in cone index values between no compost application and one year application of compost. In row middles both one-year application and multiple applications of compost significantly reduced soil compaction in the top 22.5-cm of soil compared to no compost application. Also, there was a significant difference in cone index values in the 7.5 to 15 cm depth of soil between compost applied only in 1995 versus 1995 and 1996 applications (Figure 2).

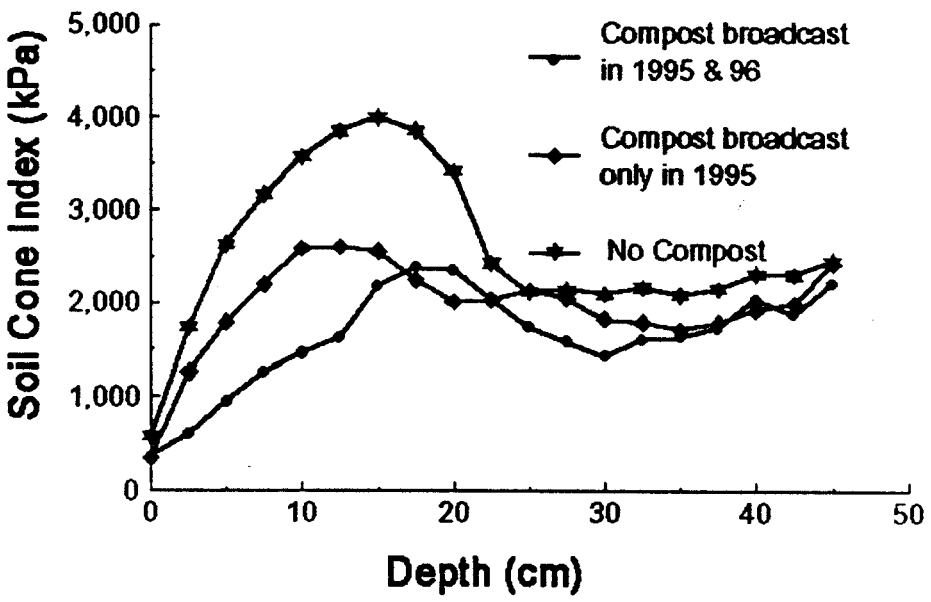

Figure 2. Effects of multiple compost application on soil compaction from row middles after cotton harvestin 1996.(33.6 Mg/ha)

All application rates of banded municipal compost reduced early season thrips populations in 1995 and 1996. However, it showed no effect on thrips in 1997. Recovery of Columbia lance nematodes (*Hoplolaimus columbus*) prior to planting in 1995 was minimal. By midseason reproduction in the untreated check plots was more than double that in all treatments except the 22.4 Mg/ha (10 tons/acre) broadcast application (Table 3). Columbia lance nematode levels decreased in all treatments between harvest in 1995 and planting in 1996. By harvest in 1996, nematode population densities had again increased significantly, especially in the check that had almost triple the density of any of the other treatments. Several of the compost treatments had nematode densities comparable to those found in the Temik 15G treatment. Temik 15G was applied at the rate of 1.18 kg a.i./ha. At midseason in 1997, only the broadcast applications provided level of control comparable to that provided by Temik 15G.

Table 2. Effect of compost application methods and rate on soil compaction for row middles at harvest, 1996. Clemson University, Edisto Research and Education Center, Blackville, SC.

Compost (Mg/ha)	Application Method	Cone index (kPa)			
		0-7.5 cm Depth	7.5-15 cm Depth	15-22.5 cm Depth	22.5-30 cm Depth
11.2	Broadcast	1017 b	1870 b	2374 b	1757 c
22.4	Broadcast	858 b	2010 b	2331 b	1859 bc
33.6	Broadcast	791 b	1752 b	2292 b	1580 c
11.2	Band	1884 a	3143 a	3264 a	2214 a
22.4	Band	2019 a	3337 a	2631 ab	2086 ab
33.6	Band	1544 a	3073 a	2664 a	1897 ab
None	-------	2024 a	3807 a	3234 a	2121 a

Means within a column followed with a letter in common are not significantly different (Duncan's Multiple Range Test, $\alpha = 0.05$).

Figure 3 shows soil organic matter content averaged over top 20 cm of the soil for 1996. Application of MSW compost significantly increased the soil organic matter content and soil nitrogen content (Figure 4) 6-weeks-after planting proportional to compost application rate. However, these differences did not affect the leaf nitrogen content of cotton plants during the same sampling period (Figure 5). Similar results were obtained in 1995 and 1997.

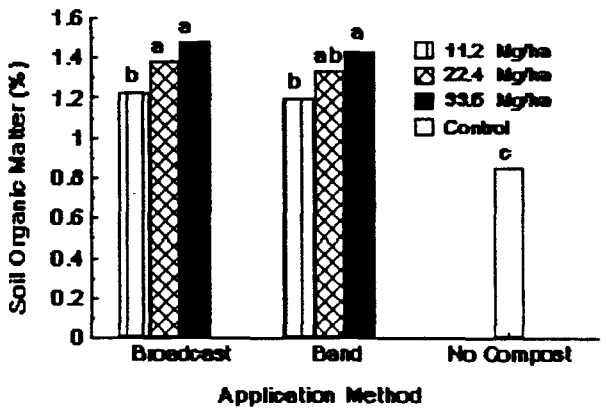

Figure 3. % Soil Organic Matter 6 Weeks after planting

Table 3. Effects of compost on recovery of Columbia lance nematodes from soil.

Compost (Mg/ha)	Application Method	Columbia lance nematodes/100 cm^3 soil			
		1995 Midseason	1996 Preplant	1996 Harvest	1997 Midseason
11.2	Broadcast	31	11	24	11
22.4	Broadcast	22	5	13	8
33.6	Broadcast	3	5	0	24
11.2	Band	13	1	5	52
22.4	Band	71	15	13	41
33.6	Band	52	8	16	66
None	------	125	18	61	61
Temik 15G	In-furrow	19	19	13	39

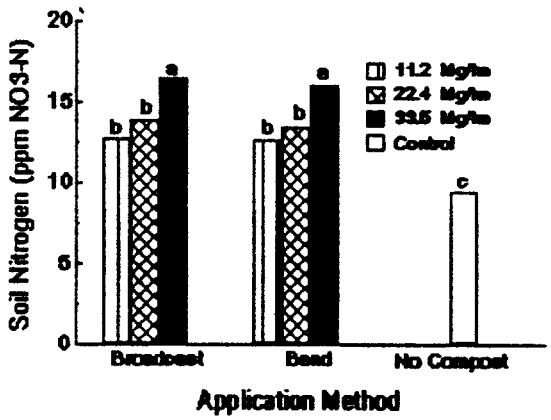

Figure 4. Soil Nitrogen Content 6 Weeks after planting

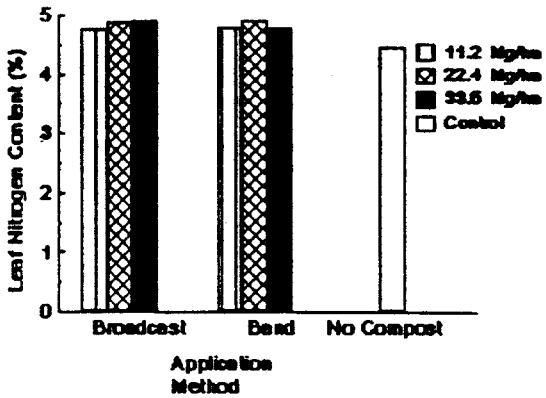

Figure 5. Leaf Nitrogen Content 6 Weeks after planting

Table 4. Effects of compost on seed cotton yield.

Trt. No.	Compost (Mg/ha)	Application Method	Yield (kg/ha) 1995	1996	1997
1	11.2	Broadcast	2063 b	2323 c	2814 c
2	22.4	Broadcast	2213 b	2400 bc	3093 b
3	33.6	Broadcast	2375 a	2633 a	3406 a
4	11.2	Band	2084 b	2306 c	2831 c
5	22.4	Band	2216 b	2353 bc	3064 b
6	33.6	Band	2396 a	2495 ab	3361 a
7	None	-------	2208 b	2135 d	2617 d

Means within a column followed with a letter in common are not significantly different (Duncan's Multiple Range Test, $\alpha = 0.05$).

- Figure 6 shows soil organic matter content 14-weeks-after planting. Except for 11.2 Mg/ha (5 tons/acre) banded application rate, MSW compost significantly increased soil organic matter compared to no compost application. Only application of 33.6 Mg/ha (15/acre) compost (broadcast or banded) statistically increased soil nitrogen content averaged over the top 20 cm of the soil (Figure 7).

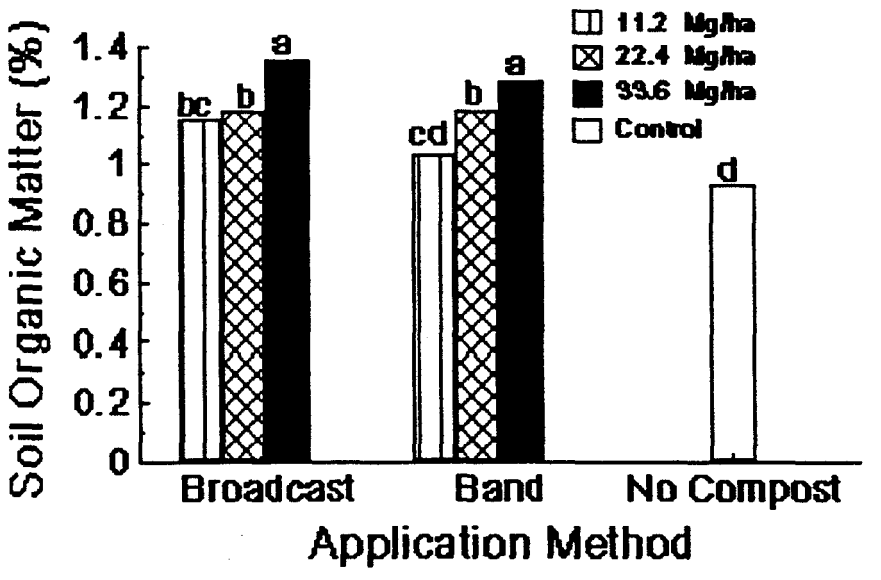

Figure 6. Soil Organic matter content 14 weeks after planting

Table 5. Carryover and additive effects of compost on soil nitrogen and organic matter contents and seed cotton yield 1996.

Trt. No.	Compost (Mg/ha) 1995	Compost (Mg/ha) 1996	No3-N (ppm) 6 W*	No3-N (ppm) 14 W	Organic Matter (%) 6 W	Organic Matter (%) 14 W	Yield (Mg/ha)
1a	11.2	11.2	12.7b	2.1ab	1.23b	1.15b	2323 b
1b	11.2	None	8.4c	1.6 b	0.95cd	0.95c	2131 c
2a	22.4	22.4	13.8b	2.4ab	1.38b	1.18b	2400 b
2b	22.4	None	7.2c	1.6 b	1.0cd	0.88c	2143 c
3a	33.6	33.6	16.4a	3.0 a	1.48a	1.35a	2633 a
3b	33.6	None	9.5c	2.0ab	1.05c	0.98c	2057 c
7	None (control)		7.7c	1.5 b	0.90d	0.93c	2137 c

- . 6 W and 14 W = 6- and 14-weeks after planting.
- Means within a column followed with a letter in common are not significantly different (Duncan's Multiple Range Test, $\alpha = 0.05$).

Table 4 shows seed cotton yields for the 1995, 96, and 97 tests. Application of 33.6 Mg/ha (15 tons/acre) of MSW compost (broadcast or banded) significantly increased seed cotton yield (187 kg/ha) compared to no compost application in 1995. There were no significant differences in yield among the rest of the treatments. In 1996 and 97, all rates of MSW compost significantly increased seed cotton yield. Yield increase was proportional to application rate. In 1996, for 33.6 Mg/ha broadcast application treatment, the yield increase was 498 kg/ha or 23% more compared to no compost application. In 1997, yield increase at this level of application rate was 30% higher than no compost application. Similar results were obtained for the compost injection test in 1997. Yield increases were proportional to the application rates. Application of 27.0 Mg/ha increased seed cotton yield by 23% compared to no compost application.

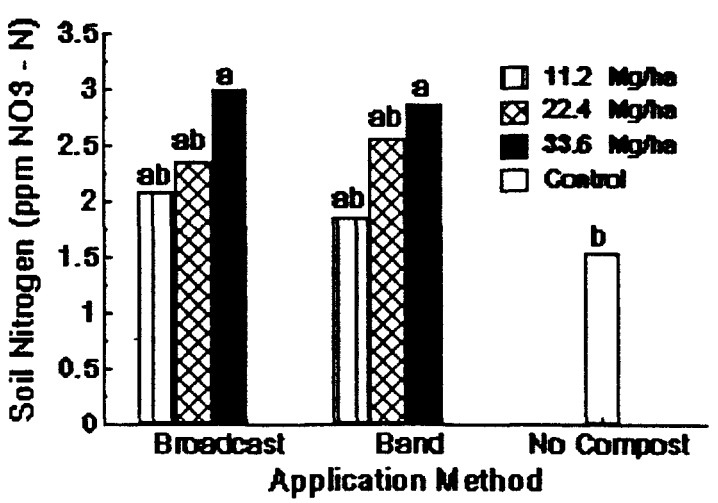

Figure 7. Soil nitrogen content 14 weeks after planting

Table 5 shows carryover and additive effects of compost on soil organic matter and soil nitrogen for both 6- and 14-weeks-after planting and seed cotton yield. There were very few carryover effects with all of these parameters except for soil organic matter contents 6-weeks-after planting at the 33.6 Mg/ha (15 tons/acre) application rate (treatment 3b, Table 5). Additive effects of compost were significant on soil organic matter, nitrogen content and seed cotton yield (treatments 1a, 2a and 3a as compared to 1b, 2b and 3b). Increased soil organic matter and nitrogen content combined with the potential increase in soil water-holding capacity and decreases in soil density associated with MSW compost, could be the contributing factors to yield increase.

Table 6. Effects of compost on seed cotton yield for compost injection test.

Compost (Mg/ha)	Application Method	Yield (kg/ha) 1997
9.0	Injected	3426 b
18.0	Injected	3624 ab
27.0	Injected	3787 a
9.0	Broadcast	3440 b
18.0	Broadcast	3592 ab
27.0	Broadcast	3763 a
None	-------	3091 c

Means within a column followed with a letter in common are not significantly different (Duncan's Multiple Range Test, $\alpha = 0.05$).

SUMMARY

Equipment was developed and tested for broadcast, band and injection application of MSW compost at selected rates to agricultural land for cotton production. Replicated tests were conducted to determine the effects of compost on soil parameters (organic matter, soil compaction, soil fertility and additive effects over years), plant growth, and pest population.

All rates of compost (broadcast application) significantly reduced soil compaction in the top 30 cm of soil for cotton rows and row middles compared to no compost application. Banded application did not affect the compaction in the row middles.

Multiple applications of compost (broadcast, 1995 and 96) significantly decreased soil compaction in the top 30 cm of cotton row and the top 22.5 cm of row middles compared to no compost application.

All rates of banded applications of compost reduced early season thrips populations in 1995 and 1996. However, it showed no effect on thrips in 1997. By midseason 1995, Columbia lance nematode density in the untreated check plots was more than double that in all treatments except the 22.4 Mg/ha (10 ton/acre) broadcast application. Columbia lance nematode levels decreased in all treatments between harvest in 1995 and planting in 1996. By harvest in 1996, nematode population densities had again increased significantly, especially in the check that had almost triple the density of any of the other treatments. Several of the compost treatments had nematode densities comparable to those found in the Temik 15G treatment.

All rates of compost significantly increased the soil organic matter content and soil nitrogen content 6-weeks-after planting. The increase was proportional to application rate. However, compost did not affect the leaf nitrogen content of the cotton plant during the same sampling period.

Except for the11.2 Mg/ha (5 tons/acre) banded application rate, MSW compost significantly increased soil organic matter 14-weeks-after planting. Only application of 33.6 Mg/ha (15 tons/acre) compost (broadcast or banded) statistically increased soil nitrogen content during this period.

In 1996 and 97, all rates of MSW compost significantly increased seed cotton yield. Yield increase was proportional to application rate. For the33.6 Mg/ha broadcast application treatment, yield increase was 23% and 30% more compared to no compost application respectively. There were very few carryover effects from previous year on soil organic matter, soil nitrogen and seed cotton yield.

ACKNOWLEDGMENTS

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BLENDS OF COMPOSTED BIOSOLIDS AND BOTTOM ASH AS POTTING MEDIA TO GROW ORNAMENTALS

By

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ABSTRACT

The experimental data confirmed that blending and class *A* biosolids and bottom ash from power plants produces material that meets the EPA's definition for an exceptional quality product and has properties suitable to grow ornamental plants. The tested blends had sufficient concentrations of major nutrients (NPK), low soluble salts content (EC), pH in range of 6.0 to 7.0, and the level of regulated metals (As, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Se, Zn) well below current environmental limits. These blends were successful in supporting growth of petunias, geraniums, marigolds in a research greenhouse as well as poinsettias under normal production conditions in a commercial greenhouse. Comparing to control plants geraniums, petunias, and marigolds grown in biosolids/ash mixtures had darker leaves and showed no symptoms of nutrient deficiency. Besides looking healthier, marigolds grown in the tested blends produced much bigger biomass than the control. The poinsettia plants looked healthy, visually attractive, and were not significantly different from the plants grown in commercial mixes. Therefore, biosolids/ash blends are at least as effective as commercial mixes in supporting plant growth. Cost estimates reveled that the bottom ash/biosolids blends are cheaper than the commercial potting mixes and they can offer extra savings to a greenhouse (nursery) operators by decreasing fertilizer requirements.

INTRODUCTION

Compost produced form municipal sewage sludge (biosolids) can be successfully used as a component in container media (Chen et al., 1988). Compost used for this purpose must be of a consistent quality and fully mature (Inbar et al., 1993). The most important physical properties are high porosity and a pore size distribution to facilitate optimal air to water ratios. The desired pore size distribution can be achieved by establishing an appropriate particle size during blend formulation (Inbar et al., 1993). In addition, container media should have low level of soluble salts (EC), slightly acidic or neutral pH, high cation exchange capacity (CEC), maintain stable

volume, and have sufficient level of major nutrients (Inbar et al., 1993). Biosolids compost used by itself usually has too high level of soluble salts, too much available nitrogen, and may undergo volume reduction over time. Blending of biosolids compost with other materials (e.g., bottom ash from electrical power utilities) can produce mixes with low level of EC, sufficient concentrations of nutrient, and physical properties suitable to grow plants in containers.

The objective of this research was to evaluate performance of blends of class *A* biosolids (composted sewage sludge) and bottom ash from power plants and as potting mixes in an experimental setting and in a commercial greenhouse under normal production conditions. We tested a hypothesis that the experimental blends will be as effective as commercial potting mixes in growing various ornamentals (geraniums, petunias, marigolds, and poinsettias).

MATERIALS AND METHODS

Experiments in a research greenhouse: Composted biosolids from sewage treatment plants and bottom ashes from power plants in the Southeast US were blended to formulate mixes with biosolids to ash ratios of 1:1 (50% of compost), 1:2 (33%), and 1:3 (25% of compost). The resulting blends were used in a greenhouse to grow geraniums (*Pelargonium* spp.) and petunias (*Petunia x hybrida*). Seedlings of geraniums and petunias (3-5 inches tall) were obtained from a local garden center. A commercially available potting mix (blend of milled pine bark, sphagnum moss peat, perlite, and charcoal) was used as a reference potting medium. All treatments were watered every day with deionized water. No fertilizer was used during the first three weeks of the experiment. At the forth week, the control treatments received the first fertilizer dressing (a commercial plant feed) as recommended by the producer of the control potting mix. Plants grown in biosolids/ash blends were not fertilized. The experiment was conducted for five weeks and then pictures were taken and plant growth observations were made. In addition, the biosolids/ash blends with the ratios (by volume) of and biosolids to bottom ash 1:1 and 1:2 were used to grow marigolds (*Tagetes erecta* L) from seeds. The commercial potting mix was again used as a control. All treatments were watered every day with deionized water. No fertilizer was used during the first three weeks of the experiment. At the forth week, the control treatments received the first fertilizer dressing of 100 ml of 1% solution of commercial plant feed (N 15%, P 30%, K 15%, traces of B, Cu, Fe, Mn, Mo, Zn). The same amount of fertilizer was applied every week till the end of experiment. The control plants received jointly about 1 g of N, 2 g of P and 1 g of K per pot. The treated plants were fertilized twice during the last three weeks of the experiment, receiving about 0.5 g of N, 1 g of P and 0.5 g of K per pot. Marigolds were grown for about six weeks and then harvested to measure the biomass produced.

Experiment in a commercial greenhouse: A pot experiment was conducted in the greenhouse of Greenhost Incorporated in King George, VA. Poinsettia cuttings (*Euphorbia pulcherrima* Willd. Ex Klotsch) were planted in 6" standard round pots on August 22, 1997. The experiment was ended on December 11, 1997— pots were removed from the greenhouse and pictures and measurements of plants were taken. The experimental design included various blends of composted biosolids from sewage water treatment facilities in the Southeast US and a bottom ash . The inclusion rate of biosolids in the blends was either 25% or 33% by volume. The blends were screened to a 1/4" particle size diameter before filling the pots. The treatments were replicated eight times in a completely randomized design.

Table 1. Concentrations of regulated elements (mg/kg, dry wt.) in blends of bottom ash and biosolids

Sample	As	Cd	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn
Control	0.1	0.9	0.6	4.0	0.05	0.2	1.8	3.0	<0.01	43
BA+B1 (1:1)	0.6	3.1	15	43	0.19	0.8	18	13	0.4	126
BA+B1 (2:1)	1.4	3.2	17	58	0.38	2.0	20	20	1.3	282
BA+B1 (3:1)	1.2	2.8	29	151	0.26	4.5	20	47	1.2	530
BA+B2 (2:1)	2.6	2.8	37	301	0.17	6.1	23	64	1.4	894
BA+B2 (3:1)	2.1	2.3	28	201	0.14	4.5	20	45	1.3	604
BA+B3 (2:1)	2.7	2.6	24	152	0.22	3.6	20	36	1.2	492
BA+B3 (3:1)	2.2	2.6	26	150	0.23	3.9	20	39	1.2	500
EPA-limits I	75	85	3000	4300	57	75	420	840	100	7500
EPA-limits II	41	39	3000	1500	17	18	420	840	100	2800

BA - bottom ash; B1 - biosolids I; B2 - biosolids II; B3 - biosolids III; EPA-I - maximum permissible concentration; EPA-II - maximum concentrations in an exceptional quality sludge.

The commercial potting mix, normally used in the greenhouse (sphagnum peatmoss + processed pine bark+fertilizer), was used as a control potting medium. All treatments were watered as needed (when 10% of plants showed first symptoms of water stress) using an overhead watering system. Fertilization with a nutrient solution was included in the watering schedule. Every 10 days about 200 mL 1% solution of commercial plant feed (N 15%, P 30%, K 15%, traces of B, Cu, Fe, Mn, Mo, Zn) was applied. The plants received jointly about 1.5 g of N, 3 g of P and 1.5 g of K per pot.

DISCUSSION OF EXPERIMENTAL RESULTS

Experiments in a research greenhouse: Concentrations of regulated trace elements in blends of biosolids and ash materials used to grow geranium, petunias, and marigolds were below the regulatory limits established by EPA (Table 1). Since composted biosolids were used in these blends, the tested potting mixes are regarded to be a class *A* materials and consequently they can be used for any purpose. Therefore, the biosolids/ash mixes are environmentally safe materials (low concentrations of trace metals and class *A* sewage sludge) and can be used for horticultural applications without restrictions. The tested geraniums and petunias looked healthy, had colorful flowers, and dark green leaves without any visible symptoms of toxicity. Comparing to control plants (grown in a commercial potting mix), geraniums and petunias grown in biosolids/ash mixtures had darker leaves without any visible symptoms of nutrient deficiency, apparently because of higher nitrogen (N) and phosphorus (P) concentrations in these mixtures than in the commercial potting mix (Table 2).

The blends used to grow marigolds had slightly acidic pH, higher than control mix content of main nutrients (NPK), and relatively low level of soluble salts (EC). Marigolds germinated well and grew very fast in biosolids/ash blends.

Table 2. Physical and chemical properties of blends of bottom ash and biosolids

Sample	pH	EC mS/cm	B.density g/cm^3	N %	P %	K %	Ca %
Control	6.5	0.09	0.24	0.2	0.01	0.05	0.28
BA+B1 (1:1)	6.3	1.07	0.51	0.80	0.12	0.05	0.10
BA+B1 (2:1)	6.5	0.54	0.37	0.50	0.42	0.10	0.35
BA+B1 (3:1)	6.6	0.43	0.38	0.39	0.33	0.08	0.28
BA+B2 (2:1)	6.5	0.94	0.44	0.59	0.47	0.07	0.69
BA+B2 (3:1)	6.7	0.74	0.43	0.46	0.37	0.06	0.53
BA+B3 (2:1)	6.7	2.65	0.46	0.66	0.66	0.12	0.95
BA+B3 (3:1)	6.8	2.03	0.44	0.51	0.51	0.10	0.74

BA - bottom ash; B1 - biosolids I; B2 - biosolids II; B3 - biosolids III;
EC - electrical conductivity

Table 3. Growth response of marigolds to application of bottom ash/biosolids as potting media

Treatment*	Plant height cm	Fresh biomass g/pot	Dry biomass g/pot	No. of buds number/pot
Control	$17.0^a \pm 1.0$	$11.3^a \pm 1.8$	$7.8^a \pm 0.3$	$1^a \pm 1$
BA+B1 (1:1)	$53.3^b \pm 3.2$	$266.7^b \pm 10.3$	$59.3^b \pm 9.0$	$24^b \pm 6$
BA+B1 (2:1)	$52.0^b \pm 3.6$	$252.4^b \pm 52.7$	$56.1^b \pm 14.2$	$18^b \pm 5$

BA - bottom ash; B1 - biosolids I;
*Means followed by various letters are significantly different at $P<0.05$

The tested marigolds were toller, had more flower buds, and produced 15 to 25 times bigger biomass than the control plants (Table 3). This strong effect of ash/biosolids blends on the test plant growth and development is apparently related to a higher content of nutrients than in the control mix (Table 2), a higher germination index of the tested blends, and possibly suppressing plant diseases by compost (Hoitink and Faky, 1986).

Experiment in a commercial greenhouse: Concentrations of trace elements in the blends of the bottom ash and biosolids met requirements for an exceptional quality product (Table 1). The final mix is a class *A* material and consequently can be distributed and used without restrictions. The blends had higher content of the main nutrients (NPK) than the control mix and an acceptable levels of soluble salts (Table 2). The heights, mean per plant bract cluster counts, and the mean diameters of a largest bract cluster of poinsettia plants grown in biosolids/ash blends (treated plants) were not significantly different from those of the control plants (Table 4). Aesthetically, the treated plants were as appealing as the control poinsettias. Visually, telling the difference between the treated and control plants would not be possible. Therefore, the hypothesis that the blends of bottom ash and biosolids are as effective as commercial potting mixes in supporting growth of Poinsettia plants, was confirmed by the experimental results.

Table 4. Morphology and growth response of poinsettia plants to application of bottom ash/biosolids blends as potting mixes

Treatment	Plant height* *cm*	Number of * bract clusters	Diameter of the* largest cluster *cm*
Control	29.8±2.1	6.0±0.8	26.8±3.8
BA+B1 (2:1)	27.7±2.3	5.3±0.5	23.5±2.3
BA+B1 (3:1)	24.3±2.5	6.5±0.6	22.3±2.2
BA+B2 (2:1)	27.3±3.8	5.7±0.6	26.3±1.5
BA+B2 (3:1)	28.0±0.1	5.0±0.0	29.0±0.1
BA+B3 (2:1)	24.5±0.7	6.0±0.0	23.5±0.7
BA+B3 (3:1)	30.5±6.4	5.0±0.0	22.5±0.7

BA - bottom ash; B1 - biosolids I; B2 - biosolids II; B3 - biosolids III
*Differences are not significant at $P<0.05$.

GUIDELINES FOR PREPARING POTTING MIXES

The composted biosolids used for preparation of potting mixes must be highly stable (C:N ratio around 10; low rate of respiration) and must pass a growth test (e.g., germination test ≥70%). The final blend should include about 60-75% of bottom ash by volume. If the biosolids used have higher contents of nutrients (e.g., N > 1.5%) and higher contents of soluble salts (EC > 6.0 dS/m), more bottom ash (75%) is recommended. The content of nutrients (N, P, K, Ca, Mg, B, Cu, Fe, Mn, Mo, and Zn) in the resulting blend should be identified. Content of N, P, K, Ca, and Mg should be reported. This information is necessary to evaluate fertilizer requirements, if any. The final pH of the blend should be in a range of 5.5-8.0. The final product must have consistent properties. The soluble salts of the final horticultural substrate (after mixing bottom ash and biosolids together) should be in a range of 0.5-3.0 dS/m (Table 5). Elevated levels of soluble salts can be reduced partially by leaching, but this extra step would increase the cost of blend preparation. The moisture content should be 35-50% because a product that is too dry can be hydrophobic (resists wetting) and one that is too wet can be difficult to handle and mix. Mixes containing varying amounts of organic matter may be used; however, the organic matter content of a specific blend should be consistent. Particle size (texture) of the blend can vary based on the pot/container size. Usually, coarser products may be appropriate for use in larger containers. Typically, a product with the particle size distribution from 1/4 to 1/2" is recommended.

COST ESTIMATES

The overall cost of preparing potting mixes from biosolids and bottom ash include cost of biosolids, cost of bottom ash, freight cost, and cost of blending and screening. The wholesale price of high quality composted biosolids in urban area is around $6-$8 per cubic yard without delivery. An average freight rate of composted biosolids in urban area, where trucking is somewhat competitive, is $5.00 per cubic yard up to distance of 30 miles. Since both bottom ash

Table 5. Recommended properties of biosolids-based potting mixes

pH	5.5-8.0
Soluble Salts (EC)	≤3.0 dS/m
Nutrient Content	
Nitrogen (N)	0.2-1.0 %
Phosphorous (P)	0.1-1.0 %
Potassium (K)	0.1-0.5 %
Water Holding Capacity	150-250 %
Bulk Density	0.3-0.5 g/cm^3
Moisture Content	30-50 %
Organic Matter Content	30-70 %
Particle Size	passes ½ inch screen

Trace elements..... must meet exceptional quality concentrations as stated in the US EPA's 503 Regulations (see the data below, the concentrations are in mg/kg):

As	Cd	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn
41	39	3000	1500	17	18	420	840	100	2800

and composted biosolids have similar bulk densities (800-1400 lb per cubic yard), hauling cost of bottom ash will be comparable with that of composted biosolids. Therefore, it does not matter whether bottom ash is transported to the location of biosolids for blending and screening or *vice versa*, the freight cost will be the same. In addition, it reasonable to assume that a source of biosolids will be found within a radius of 30 miles from a source of bottom ash, and a wholesale customer will be within a radius of 30 miles from a blending operation. That is why the cost estimate (Table 9) is based on freight cost of \$5.00/yd^3. If these distances are greater than 30 miles, the freight cost may be too high to make the blending operation and wholesaling bulk product competitive and profitable. In such a case, marketing of a bagged product, with a higher profit margin, should be considered. Assuming a 30-mile hauling distance, the production cost of one cubic yard of a bottom ash/biosolids potting mix would be about \$12.50 (Table 9). If this product is sold to a customer at wholesale price of \$15.00 (at 20% gross profit margin), the overall cost to a costumer would only be about 57% of total cost of purchasing a commercial potting mix. Therefore, use of bottom ash/biosolids potting mix in production of ornamentals is not only feasible technically but it can be profitable as well. In the experiment described, full a fertilization program was applied to all treatments, simply because the tested pots were included in the normal greenhouse operation structured for plants that did not have nutrients in their growing media (commercial potting mix). Bottom ash/biosolids potting mixes provide nutrients for about 6-8 months of plants growth and do not need fertilization. Because fertilization is not needed when bottom ash/biosolids potting mixes are used, extra savings for a greenhouse or nursery operator can be realized.

SUMMARY AND CONCLUSIONS

Blending class *A* biosolids and bottom ash from the electrical power utilities produces materials that meet the Federal EPA's definition for an exceptional quality product and have physical and chemical properties suitable to support plant growth in a greenhouse under research and production conditions. These products are approved for unrestricted distribution and can be used as potting mixes without a special permit. Geraniums and petunias grown in biosolids/ash blends had darker leaves without any symptoms of nutrient deficiency. Marigolds growing in blends of bottom ash/biosolids produced significantly higher biomass and had more flower buds than the control plants. The tested blends also were successful in supporting growth of poinsettia under normal production conditions in a commercial greenhouse. The performance of tested blends and a commercial potting mix as to produce healthy and visually attractive plants was not significantly different. Biosolids used as a component of potting mixes should be highly stable, contain high levels of nutrients, and have low concentrations of soluble salts. The inclusion rate of biosolids in the potting blends should be in a range of 25-33%. The biosolids/ash potting mix can be priced very competitively comparing to prices of commercial potting mix and still be a profitable. The need for fertilization will be substantially reduced when biosolids/ash potting mixes are used which means that a greenhouse or nursery operator can make savings not only on purchase of a product but also on operations by cutting cost of fertilization.

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COMPOST APPLICATION TO RYEGRASS

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ABSTRACT

Four different composts at 3 different amounts were incorporated into 4 replicated plots of Myakka fine sandy soil (Typic Haplaquod) prior to seeding annual ryegrass (Lolium multiflorum L.) The composts used were municipal solid waste (MSW), 2 yard waste composts (YW1, YW2), and a compost made of yard and food wastes (KYW). Composts were applied to supply 168, 336, or 672 total kg N ha^{-1}, by estimating ½ of the total N in the compost might be available in the first growing season. Phosphorus was supplied preplant as triplesuperphosphate (44.8 kg/ha P). Potassium was supplied as KCl (89.7 kg/ha K). In the early months after amending the soil, vigor and coverage of ryegrass were impeded by yard waste compost while MSW compost had the least adverse effects on early vigor and coverage. Supplemental N was needed with all composts. A second year of seeding ryegrass into the plots also required supplemental N to achieve an acceptable stand. Over the two year period, amendments of compost doubled the yields of ryegrass, compared to unamended plots grown with chemical fertilizer alone, however no differences in yields occurred due to the amounts of amendments used.

INTRODUCTION

Traditionally, municipal solid waste (MSW) as well as yard trimmings or kitchen scraps have been considered a disposal problem and have been landfilled, incinerated, or dumped into the ocean. These methods are increasingly being eliminated as legislation is written to alleviate adverse effects on air and water quality. Landfill space is becoming limited with many states reporting their landfill capacity will be reached by the end of the century (Repa and Sheets, 1992). Composting is an alternative method for processing MSW, yard trimming, and kitchen scraps, and removing these materials from the traditional waste stream.

Compost is increasingly being considered as a soil conditioner and fertilizer (Stratton et al., 1995). It is well documented that the addition of compost to sandy soil greatly improves tilth, soil structure and quality, as well as increasing water-holding capacity and cation exchange capacity (Cook et al., 1994; de Bertoldi et al., 1987; Elliott and Stevenson, 1977; Hernando et al., 1989; Hortenstein and Rothwell, 1972; Mays et al., 1973; Scanlon et al., 1973). Yield increases due to compost amendments have been reported for turfgrass (Bevacqua and Mellano, 1993) and corn (Mays and Giordano, 1989) as well as several vegetable crops. MSW compost can supply essential plant nutrients (Gallardo-Lara et al., 1990; Giusquiani et al., 1988; Juste and Mench, 1992; Koma-Alimu and Janssen, 1976; Tisdale et al., 1985). A detailed review of the effects of composts on crops and the environment may be found in a review chapter on the subject by Stratton et al. (1995).

At this time, over 4.86 million hectares of grassland are grown in Florida. Grasses grown on sandy soils of low fertility may benefit from additions of compost to the soil. Marginal soils with poor structure and low amounts of

organic matter and plant nutrients have shown the greatest benefits from additions of compost (Hortenstein and Rothwell. 1972; Scanlon et al.. 1973). The soils of Florida grasslands are typically sandy and of low fertility and may show much benefit from land application of composts. Short-term benefits may include increased coverage. vigor. and yields of forage grasses. Long-term expected benefits may include improved soil structure. increased water-holding capacity. increased cation exchange capacity. and possible increased retention of fertilizers. fungicides. or pesticides. More research is needed on the long-term benefits of amending soils with composts. Additional benefits of land-applying compost include the removal of MSW. and kitchen and yard wastes from the traditional waste stream and the effects that removal will have on the innumerable environmental systems involved. The research reported herein investigated the effects of amending soil with MSW compost. yard waste compost. or yard and kitchen waste compost on the vigor. coverage. and yield of annual ryegrass (Lolium multiflorum L.).

OBJECTIVES

1. To determine the effects of MSW compost. yard waste compost. or kitchen and yard waste compost on vigor. coverage. and yield of annual ryegrass forage (Lolium multiflorum L.)

2. To compare and contrast the effects of the MSW compost with those of a kitchen and yard waste compost. three different yard wastes. or ammonium nitrate on coverage. vigor and forage yield of ryegrass.

MATERIALS AND PROCEDURES

1996 SEASON PLANTING

In November 1995. 2 composts and 2 yard wastes were obtained from 4 different facilities. The MSW compost was produced by the Sumter County Municipal Composting Facility in Sumterville. FL. The kitchen and yard waste compost (KYW) was produced by the Disney composting facility in Orlando. FL. Yard waste 1 (YW1) was obtained from the St. Petersburg Municipal Greens Waste Collection program in St. Petersburg. FL. Yard waste two (YW2) came from yard wastes collected in Sarasota. FL and handled by a private company. Hereafter in general. and in tables. these materials will be referred to as N Sources. Analyzes of the five materials is shown in Table 1.

The composts and yard waste materials were applied to the soil prior to early December planting of the 1995-1996 winter annual ryegrass crop. Incorporation is described below. Three different amounts of each material were applied along with an ammonium nitrate comparison series. The amounts of amendments applied were calculated on preliminary analyzes of the amendments (provided by the supplier) with the estimate that 50% of the N in the composts and wastes might be readily available to the plants in the first growing season. For each amendment. at each calculated amount. the estimated available N from the amendment was expected to approximate the amounts of N applied as ammonium nitrate. Treatments applied are reported in Table 2.

Plots were 2.2 x 4.6 m at the Range Cattle and Education Center at Ona. FL. on Myakka fine sandy soil (Aeric Haplaquod). Four replications of each treatment were laid out in randomized complete block design. Prior to applications the soil was analyzed and results are reported in Table 3.

Concurrent with application of the ammonium nitrate. composts or wastes. P (44.8 kg/ha) and K (89.7 kg/ha) were applied. Composts. yard wastes. and the fertilizers were surface applied then disked in to 15 cm depth. Annual ryegrass seed was broadcast 33.6 kg/ha. Soil was tamped with a weighted barrel roller. Seed planted in November 1995 failed to germinate and the plots were reseeded in early December 1995. Supplemental N at 56 kg N/ha as NH_4NO_3 was applied in January. Forage was harvested March 22. and April 17. 1996. Soil was sampled in January and April 1996. The top 5 cm of soil was scraped from the surface and an auger 2.5 cm in diameter was used to take 3 samples per plot which were then mixed and frozen for later analysis. Soil moisture was calculated using field moist soils which were air dried for 3 days then reweighed.

Table 1. Analyzes of composts and wastes for soil application to annual ryegrass forage plots

N Source	pH	EC(dS/m)	C/N	%N	%P	%K	%Ca	%Mg
MSW	7.89	2.6	20.8	1.31	0.22	0.18	2.92	0.18
YW1	8.02	2.76	25.1	0.90	0.11	0.26	6.45	0.14
KYW	7.74	7.56	10.8	1.48	0.51	0.41	2.25	0.15
YW2	8.06	2.42	25.7	0.67	0.19	0.21	4.05	0.21

Table 1. (continued) Analyzes of composts and wastes for soil application to annual ryegrass forage plots

N Source	Zn	Cu	Mn	Fe	B	Cd	Pb	Ni
	mg/kg							
MSW	1210	413	630	25650	75	6	204	52
YW1	251	26	47	2000	17	0.5	41	14
KYW	84	59	150	3880	17	1.0	9.5	3
YW2	38	10	56	3165	17	0.5	9.5	2

Table 2. Materials and amounts of soil amendments or fertilizer applied

N Amount		N Source			
estimated kg/ha as N	NH_4NO_3 kg/ha as N	MSW Mg/ha.ww	YW1 Mg/ha.ww	KYW Mg/ha.ww	YW2 Mg/ha.ww
0	0	NA	NA	NA	NA
168	168	72	27	13	27
336	336	143	54	26	54
672	672	287	107.5	51.5	107.5

NA=not applied

Table 3. Analysis of unamended Myakka fine sandy soil

EC(ds/m)	0-0.1
pH	6.3-6.9
	------mg/kg------
NH_4-N	1.5-3.8
NO_3-N	0-0.5
P	6-7
K	13-19
Ca	600-700
Mg	175-200
Mn	0.5-0.8

Analysis of the forage harvest included yield, vigor, and coverage. Yield was measured by collecting completely all the clippings in a mowed strip, weighing the clippings wet and dried, and calculating yield for a hectare. Vigor was rated visually on a scale of 1 to 10, 1 representing discolored spindly seedlings with just a few leaves, 10 representing thick-bladed, large green seedlings with many blades. Coverage was rated visually using an estimate of percentage of soil surface covered by the seedlings. Vigor and coverage ratings were made on Feb 20, 1996 for the first harvest, the first season. Statistical analysis was by analysis of variance, and regression analysis (Snedecor and Cochran, 1980).

1997 SEASON PLANTING

Seed planted in early December 1996 failed to germinate due to severe drought, and ryegrass was reseeded January 3, 1997. Phosphorus (44.8 kg/ha) and K (89.7 kg/ha) were applied as in 1996. Supplemental irrigation as well as an application of supplemental N (56 kg/ha N as NH_4NO_3) was needed to obtain a single harvest of forage on February 24, 1997. The next scheduled harvest, a month later, was canceled due to severe drought and death of the grass.

RESULTS

VIGOR

Plots grown with ammonium nitrate had good vigor especially at the highest amount of N fertilization (Table 4). Plants in this treatment were robust, well-shaped plants with many blades of good color and extension of rhizomes was readily apparent. Plants grown with MSW compost had moderate to fair vigor which decreased somewhat at the highest amount of MSW application. Plants grown with the two yard wastes and the yard waste with kitchen waste (YW1, YW2, and KYW, respectively) appeared pale and stunted, with fewer leaves and fewer apparent rhizomes than those grown with ammonium nitrate (Table 4). In plants grown with KYW vigor increased as the amount of application increased (Table 4). Significant linear regressions occurred with ammonium nitrate and KYW.

COVERAGE

Coverage is reported as the percentage of soil that is covered (100 - the %that is bare). Coverage was greatest in plots with ammonium nitrate, and coverage increased as amount of N increased (Table 5). MSW amended plots showed the next greatest coverage between 44 and 77% and increasing with amount) while KYW amended plots had only about 50% of the soil covered with grass. The yard waste amended plots (YW1, YW2) had only about 1/3 of the soil covered with growth, and with higher amounts of application less coverage occurred (Table 5). Significant linear regressions occurred with ammonium nitrate and KYW.

Table 4. Vigor of grass planted in amended plots (1-10 rating*)

N Amount				N Source		
kg/ha	NH_4NO_3	MSW	YW1	KYW	YW2	Mean
0	1.68	1.68	1.68	1.68	1.68	1.68 d
168	3.12	3.25	2.25	2.50	2.88	2.39 c
336	5.38	3.37	2.38	3.00	2.75	3.12 b
672	8.25	3.00	2.38	3.37	2.75	3.56 a
Mean	6.61 a	2.82 a	2.17 a	2.34 bc	2.52 bc	

*Vigor (10 = premium color. large. evenly-shaped leaf blades. 1= yellow and/or purple color. stunted plant with curled or twisted leaf blades)
Means within columns or within rows followed by the same letter are not significantly different ($p \leq 0.05$).

Table 5. Coverage of grass planted in amended plots*

N Amount				N Source		
kg/ha	NH_4NO_3	MSW	YW1	KYW	YW2	Mean
0	44.4	44.4	44.4	44.4	44.4	44.4 b
168	70	70	37.5	43.8	36.2	47.1 b
336	89.5	77.5	35.0	55.0	35.0	53.5 a
672	99.5	76.2	35.0	56.2	32.5	54.7 a
Mean	75.8 a	67.0 b	47.8 c	49.8 c	37.0 d	

*Coverage (% of plot area covered by vegetation. visual estimate)
Means within columns or within rows followed by the same letter are not significantly different ($p \leq 0.05$).

YIELD

Yield differed greatly between harvests made on 3-15-96. 4-17-96. and February. 1997 and the different harvests are reported in Tables 6. 7 and 8. Yields were especially low where no amendment was made to the soil. but was also quite low where ammonium nitrate was the amendment. At the March 1996 harvest. MSW and KYW produced the highest yields and ammonium nitrate the lowest. With MSW or the two yard wastes. yields were lower at the highest amount of application than at the amount just below. At the March harvest. all of the amendments except ammonium nitrate or KYW resulted in lower yields at the highest amounts of application (Table 6). By the next monthly harvest there was no difference in yield between amounts of amendments other than with ammonium nitrate: any amount of organic amendments produced about the same yield (Table 7). At the April 1996 harvest. the MSW. and yard waste treatments produces the highest yields. ammonium nitrate the lowest. Plants grown only with ammonium nitrate had the lowest forage monthly yield in both March and April of 1996 (Tables 6 and 7). In 1997. kitchen and yard waste compost (KYW) produced the highest yields of ryegrass. and ammonium nitrate the lowest (Table 8). At the highest amounts of application. MSW compost produced lower yields than at the next lower amount (Table 8).

Table 6. Yield of monthly ryegrass harvest 3-15-96 (kg/ha dw)

N Amount				N Source		
kg/ha	NH_4NO_3	MSW	YW1	KYW	YW2	Mean
0	26.5	26.5	26.5	26.5	26.5	26.5 c
168	74	1795	1730	1337	1497	1261 a
336	159	1873	1370	1546	1200	1232 a
672	496	1283	1153	1795	1024	1050 b
Mean	189 e	1244 a	1070 bc	1176 ab	937 c	

Means within columns or within rows followed by the same letter are not significantly different ($p \leq 0.05$).

Table 7. Yield of monthly ryegrass harvest 4-17-96 (kg/ha DW)

N Amount				N Source		
kg/ha	NH_4NO_3	MSW	YW1	KYW	YW2	Mean
0	164	164	164	164	164	164 b
168	317	3313	2953	2507	3117	2557 a
336	473	3377	3118	2896	2676	2584 a
672	666	3308	3137	3402	3306	2753 a
Mean	405 c	2541 a	2343 ab	2242 b	2316 ab	

Means within columns or within rows followed by the same letter are not significantly different ($p \leq 0.05$).

Table 8. 1997 Ryegrass yields in response to N source and N Amount (kg/ha DW)

N Amount				N Source		
kg/ha	NH_4N0_3	MSW	YW1	KYW	YW2	Mean
0	346	346	346	346	346	346c
168	588	906	915	1105	996	894b
336	786	1124	1244	1147	1036	1072a
672	1311	880	1087	1420	1071	1129a
Mean	662b	823b	903ab	1017a	862ab	

Means within columns or within rows followed by the same letter are not significantly different ($p \leq 0.05$).

DISCUSSION

Within a month of establishing the first crop of ryegrass. some growth impediment was visibly evident with certain amendments. Some of the impediment appeared physical as in plots amended with yard waste two (YW2). Some of the decrease in vigor and coverage may also be attributable to nutrient deficiency. primarily N. Coverage and vigor of the plants was least in plots amended with the yard wastes. and these yard wastes had higher C/N ratios than did the MSW or KYW (Tables 1. 4 and 5). In both years supplemental N was applied after the amendments were applied. In 1996. prior to supplemental N fertilization the plants were visibly stunted and colored as to suggest severe N deficiency. especially on plots where yard wastes had been applied. This effect was most likely due to N immobilization by soil microbes as the yard waste decayed in situ. In plots where only chemical fertilization was used the N was out of the root zone within a month to six weeks. and plants receiving the N fertilizer without a waste amendment produced less forage yield than those grown with waste amendment and a small one-time application of N. Yields were best where the wastes with lower C/N ratios and supplemental N were accompanied by good growing conditions such as adequate soil moisture and cool temperatures. as was the case in the April 1996 monthly forage harvest.

CONCLUSIONS

1. Applications of yard wastes can result in impediment of vigor and coverage of ryegrass if seeding directly follows amendment incorporation.

2. Yield of ryegrass is greater with addition of organic matter to soil. provided enough N is made available to the crop.

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DEVELOPMENT AND PRELIMINARY VALIDATION OF A COMPOST PROCESS SIMULATION MODEL

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INTRODUCTION

Physically based process models are key for design of industry and municipal scale bioconversion centers (Haug, 1993; Das and Keener, 1995, 1996,1997). Presently there are procedures for specifying carbon and nitrogen amounts in a crude manner. However, time required for a process to run its course because of the host of environmental variables and thermal/physical/chemical interactions bearing on the conversion process is an unknown without simulation modeling.

The complex and dynamic interactions within bioconversion systems are a fundamental component of the knowledge base necessary for developing a sustainable composting infrastructure. Physical and biological processes occurring in most bioconversion systems are not well understood primarily due to the myriad of possible substrates and highly dynamic temperature-moisture conditions. This lack of understanding has resulted in much empiricism being the norm in current bioconversion/composting literature. The current approach to designing commercial composting operations is the reliance on pilot project data. Golueke (1977) is recognized as a pioneer in the use of pilot project data for full scale design. Hansen et al. (1989), Keener et al. (1996, 1997) and Das et al. (1997a,b,c) used pilot scale approaches for developing full scale designs. They also began efforts to model the processes.

At present there is a reasonably good process model (Haug, 1993) for the bioconversion of biosolids (product from activated sludge treatment of municipal waste). These models have not been tested sufficiently for other substrates. Preliminary work to date suggests that serious shortcomings of the Haug (1993) approach must be overcome when generalizing to a broader range of substrates. Keener et al. (1996, 1997), Das and Keener (1997), and Das et al. (1997a,b,c) represent pioneering contributions to this end. They considered the compost reactor as a homogenous substrate mix. Stombaugh and Nokes (1996) developed an n layer model for evaluating effects of varying physical-microbiological parameters through the reactor.

Process models are evaluated by comparing predicted state variables with measured state variables in bench, pilot and full scale composting operations. Thoroughly documented process models enable one to design full scale operations without the costly steps of bench scale and pilot scale trials, except for the bench and pilot trials

required to develop and validate the model. Models may be deterministic, stochastic, steady-state or dynamic. All natural environmental bioprocesses are dynamic. Although conditions may often approach steady state, an understanding of the dynamics is essential if the influences of changes in conditions is to be predicted. A wide variety of platforms facilitate the development of dynamic models. Snape et al. (1995) reviews common modeling platforms. STELLA®, a PC-based simulation program with an excellent graphics interface will be used in this work.

In designing a bioconversion system for a previously untested waste stream, five steps are ideally performed. These are (1) Feedstock characterization, (2) Pilot scale process evaluation. (3) Product testing, 4) Design parameter evaluation, and (5) Scale up of system. The feedstock characterization includes a complete physical and chemical characterization as defined by the Compost Council. Respirometric data are also collected in the feedstock characterization. This data are modeled in the pilot phase, which produces product necessary for quality evaluation. Sound process models employing data gathered in the feedstock characterization and tested in the pilot phase are useful in the scale up phase. This procedure has been applied here to determine degradation coefficients of textile industry solids during composting. A systematic evaluation of the composting process at a pilot level including waste stream characterization, oxygen uptake, CO_2 evolution rates, amendments and degradation rates are described here.

The objective of this paper is to present a simple model evaluated using cotton gin trash and wool processing wastes.

MODEL DEVELOPMENT

The model, adapted from Haug (1993), is presented in simplified form. It is developed starting from the assumptions which follow below.

1. C/N ratio lies between 10 and 30 for good composting
2. Moisture content lies between 40% and 60% wet basis.
3. The carbon, nitrogen, oxygen and hydrogen in the biodegradable volatile solids fraction of the incoming substrate stream is known. Nonbiodegradable materials do not participate in the reaction.
4. First order kinetics are applicable and the biodegradable fraction can be characterized with one rate constant.
5. Temperature, oxygen, free airspace and moisture have multiplicative effects on the first order rate constant.
6. Aerobic metabolism stops at oxygen concentrations below 6% and the system does not become anaerobic.
7. Substrate mixture is homogeneous.
8. Particle size is sufficiently small such that particle geometry is compatible with pilot scale containers (e.g., largest particle dimension is 10 times smaller than the pilot scale reactor). Particle should be small enough such that oxygen diffusion into the particle is not limiting.
9. The compost reactor may be modeled as a continuous flow stirred tank reactor (CFSTR) at steady state.

Assumptions 1 and 2 assure that composting is generally possible. Assumptions 3 through 7 lie at the heart of the modeling effort to be described. Assumption 7 must be satisfied in the scaled up system. Assumptions 8 and 9 are important in the modeling effort and in scale up itself. It is commonly assumed that particle geometry effects may be safely ignored in the scale up process.

Invoking assumption 3, one may write the following relationship describing the fate of biodegradable solids in an aerobic composting system as

$$C_aH_bO_cN_d + \left(\frac{4a+b-2c-3d}{4}\right)O_2 \rightarrow aCO_2 + \frac{b-3d}{2}H_2O + dNH_3 \quad (1$$

where subscripts a,b,c,d describe the relative molar amounts of carbon, hydrogen, oxygen and nitrogen respectively in the dry portion of the biodegradable volatile solids fraction (BVS). The above equation indicates that biodegradable solids combine with additional oxygen to yield carbon dioxide, water and ammonia in stoichiometric quantities. Carbon dioxide and ammonia go off in gaseous form (further assuming that measures are not in place to trap the ammonia). The water evolved, along with the water comprising the moisture content of the incoming volatile solids, is available for evaporation which usually occurs during aeration. The equation says nothing about how fast or slow the reaction may occur. The equation in itself gives no hint of the temperatures one may expect during the course of the reaction.

Decomposition occurs as a first order reaction rate of the substrate available. The reaction rate is modeled using first order kinetics as described as

$$\frac{d(BVS*density*Vol)}{dt} = -k_d*(BVS*density*Vol) \qquad (2$$

where t represents time in days, k_d is the composite degredation rate constant, BVS represents the biodegradable volatile solids fraction in the reactor at time t (e.g., the term on the left of equation 1), density is the dry solids bulk density in the reactor, and Vol is the reactor volume. The product BVS*density*Vol represents the grams of BVS in the reactor. BVS is expressed in grams and time is expressed in seconds. BVS is computed by multiplying total solids (TS) by a factor representing the fraction of BVS in the substrate. Nonbiodegradable solids (NBS) is TS-BVS.

Following Haug (1993), the composite degradation constant is represented by multiplicative subfactors for temperature, oxygen, free air space and moisture content as

$$k_d = k_T \cdot k_{Moisture} \cdot k_{FAS} \cdot k_{O_2} \qquad (3$$

where k_T is the temperature correction, $k_{moisture}$ is the moisture content correction, k_{FAS} is the free airspace correction and k_{o_2} is the oxygen concentration correction.

Temperature is adjusted with the Arrhenius correction as

$$k_T = k_{dR1}[C_1^{(T-TR1)} - C_2^{(T-TR2)}] \qquad (4$$

where k_{dR1} is the degredation constant ideally obtained from respirometric studies, TR1 and TR2 are reference temperatures, C_1 and C_2 are Arrhenius temperature coefficients and T is the substrate temperature. Following Haug (1993) TR1=20C, TR2=60C, C_1=1.066 and C_2=1.21. These constants describe mixed mesophillic cultures commonly found in solid waste degredation and thus considered robust with respect to common substrates. The degredation coefficient k_{dR1} is particular to each substrate or substrate mixture and thus must be measured respirometrically (or estimated using curve fitting techniques. Haug (1993) discusses the derivation of degradation constants from respirometer data.

Moisture variation effects are modeled using an empirical logistic function. Haug (1993) found the following equation was adequate for biosolids composting.

$$k_{Moisture} = \frac{1}{e^{(-17.64[1-moisturefraction]+7.062} + 1} \qquad (5$$

where moisturefraction represents the moisture fraction (wet basis) of the substrate. Moisture fraction can vary with time in composting and can be calculated based on a moisture balance and solids balance to be discussed below. This relation in effect says that microbes function best in high moisture conditions and conversely do not function in dry conditions.

Free air space (FAS) is important in composting environments because it is highly correlated with oxygen transfer within composting reactors. Data suggests that optimum moisture content for composting is between 55 - 65%. That optimum exists because of rate limiting moisture films which reduce oxygen diffusion in pilot scale and commercial scale systems. Reaction rates proceed most rapidly in an aqueous environment of 100% moisture (used in the respirometric evaluation), however above 65% pilot and commercial scale systems tend to become oxygen limited, thus the aerobic assumption becomes compromised. The moisture correction factor is 1 at 100% and decrease in a logistic curve as moisture content decreases. The FAS correction is given as

$$k_{FAS} = \frac{1}{1+e^{[-23.675*FAS+3.4945]}} \qquad (6$$

where nomenclature has been defined previously.

Free air space in reality decreases with time because particles constantly consolidate. However, free air space is left constant because the interactions of particles and moisture which affect FAS through the composting process on beyond the scope of this preliminary study.

Oxygen concentration (as measured from exhaust gas, Vol%O) can be limiting particularly when aeration is limited. Haug (1993) assumed a Monod type relationship written as follows to model oxygen limitation. The Monod relationship is given as follows.

$$k_{O_2} = \frac{Vol\%O}{Vol\%O+2} \qquad (7$$

The Vol%O is the percentage of oxygen in the incoming air. The constant 2 is the percentage of oxygen where the process is 50% limited. In reality, oxygen concentrations will be considerably above 6% to keep the reactor from becoming facultative or anaerobic. At oxygen percentages of 6% or above (see assumption 6) the k_{O_2} will not be less than 0.75. Consistent with the CFSTR reactor, it is assumed that the oxygen in the FAS in the reactor is the same as that measured in the exhaust gas.

Balances may also be written describing the state of solids, liquids and gases flowing through the compost reactor. Solids are typically partitioned into biodegradable and nonbiodegradable solids. Assuming a continuous flow stirred reactor may be used to model the process, the biodegradable solids may be written as

Rate of storage = input - output + sources - sinks (8a

or

$$\frac{d(BVS*Vol*density)}{dt} = ((BVSI-BVS)*through)+0-(k_d*BVS) \qquad (8b$$

where BVSIN is the biodegradable volatile solids entering the reactor (g/g dry solids), BVS is the biodegradable volatile solids fraction (g /g), the term density is the dry bulk density (g/m^3) at time t, through is the dry solids throughput rate (g/s), Vol is the reactor volume (m^3) and other nomenclature are as defined previously.

The nonbiodegradable solids balance reflects the addition of fixed nitrogen to the nonbiodegradable solids. Ammonia fixation represents approximately 1 % of the starting mass of compost. When microbes consume the substrate they fix some of the nitrogen into a stable organic form. This portion of N fixed is calculated from a 12% N composition of cells and a cell yield per gram of substrate. The mass of the fixed N is added to the non-degradable fraction of the compost.

Total solids may be represented as

$$DrySolidOut = (BVS + NBS) * through + D * \frac{17.01}{MoleWt} * \frac{d(BVS * Vol * density)}{dt} \qquad (8c$$

where the last term represents the fixed N contribution. The nonbiodegradeable materials (NBS) contains ash plus nonvolatile biodegradable. This assumes that the system is nitrogen limited.
Gas constituents of interest are carbon dioxide, oxygen and water vapor. The balance for CO_2 is given as

$$0.000501 * DryAirin = CO_2in = CO_2out - A(44 / MoleWt) * \frac{d(BVS * Vol * density)}{dt} \qquad (9a$$

where DryAirin is the ventilation rate (g/sec), A is the stoichoimetric factor in Equation 1 and MoleWt is the effective molecular weight of the biodegradable solids fraction. The derivative of BVS with respect to time is as given in Equation 2. The constant 0.000501 is the fraction of the incoming air which is CO_2. DryAirin can be calculated from the ventilation rate (m^3/s) from the gas law as shown in Haug (1993). The equation (in metric form) is given as

$$DryAirin = \frac{(Pair - PVI) * Qair * 28.96}{235.5 * (273 + Tairin)} \qquad (9b$$

where Pair is the atmospheric pressure (kPa) and PV is the vapor pressure (kPa), Qair is the volumetric ventilation rate (m^3/s), the constant 28.96 is the molecular weight of air, the constant 235.5 is the gas constant (kPa m^3/gm mole K) and Tair is air temperature in C. The saturated vapor pressure (kPa) corresponding to Tair can be computed using

$$PV_s = 3.38639[(0.00738Tair + 0.8072)^8 - 0.00019|1.8Tair + 48| + 0.001316] \qquad (9c$$

where PVs is the saturated vapor pressure (kPa). PV is found by multiplying PVs by the relative humidity (RH).

For oxygen the mass balance appears as

$$0.2314 * DryAirin = O_2in = O_2out + \left[\frac{4A + B - 2C - 3D}{4}\right] * (32 / Molewt) * \frac{d(BVS * Vol * density)}{dt} \qquad (9d$$

where A,B,C,D are the stoichiometric coefficients of Equation 1 and the constant 0.2314 is the fraction of dry air represented by oxygen. Other nomenclature are defined as above. The water vapor pressure at the exit may be estimated as (Haug, 1993)

$$PVO = PVI + \{[PVSO - PVI] * k_{moisture}\} \qquad (9e$$

where PVO is the exit vapor pressure, PVI is the incoming vapor pressure, PVSO is the saturated vapor pressure at the exit. The PVSO is estimated using an equation similar to 9c based on the temperature of the reactor which is as yet unknown.

The total dry gas out (DryAirout, g/s) is given as

$$DryAirout = DryAirin + GasFactor * \frac{d(BVS * Vol * density)}{dt} \qquad (9f$$

where GasFactor is the summation of stoichiometric O_2 (negative) and CO_2 (positive) contributions. GasFactor is written as

$$GasFactor = A * \frac{44}{MoleWt} - (4A + B - 2C - 3D) * \frac{32}{MoleWt} \quad (9g$$

The steady state water balance is written as

output = input + sources - sinks (10a

or,

Mcoutdb*Vol*density*through +VaporOut=MCindb*Vol*density*through+VaporIn +Wadd+Wprod (10b

where MCoutdb is moisture content at exit expressed as fraction dry basis, MCindb is incoming moisture rate expressed as fraction dry basis. VaporIn is the moisture rate coming in as a vapor, Wadd is the water addition rate(g/s), Wprod is the stoichiometric water production rate and VaporOut is the rate of water vapor movement out of the system. The left hand side of Equation 10b represents moisture leaving the system. The term (BVS + NBS) represents dry material leaving the system. One may modify Equation 9b to predict VaporIn by substituting the vapor pressure of water (PV) in the incoming airstream by substituting PV in place of Pair-PV. Similarly, one may also substitute PVO in place of Pair-PV in Equation 9b to compute VaporOut. ProdWat is computed as

$$\Pr odWat = \left[\frac{B - 3D}{2}\right] * \frac{18.01}{MoleWt} * \frac{d(BVS)}{dt} \qquad (10c$$

where nomenclature has been defined previously. The moisture fraction needed in the computation of $k_{Moisture}$ can now be computed using

$$MoistureFraction = \frac{MCoutdb * Vol * density}{(1 + MCoutdb) * Vol * density} \qquad (10d$$

The temperature of the reactor at time t is required to compute the water vapor exiting the system. Temperature of the reactor is determined based on an energy balance. The energy balance can be constructed as follows.

Rate of change of energy = energy in - energy out + sources -sinks =0 (11a

The energy in is the sensible heat content of the dry substrate and the incoming water. This can be written as

energy in =MCdbin*through*CPSOL*(Tin-Tref) +Wadd*CPWAT(Tin-Tref) +Qair*CPAIR*(Tin - Tref) (11b

energy out = MCdbout*through*CPSOL*(Treact-Tref)+Qair*CPAIR*(Treact-Tref)+Latent (11c

where Latent is the latent heat contained in the saturated air leaving the system, Tin (assumed same as Tair) is the incoming temperature(C) of the substrate, added water (Wadd) and of the incoming air. Tref is an arbitrary reference temperature(C). The specific heat of air, CPAIR, is taken to be Latent heat (λ, kJ/g) may be computed as follows.

$$Latent = Qair * (Vaporin - Vaporout) * \lambda \qquad (11d$$

Vaporin and Vaporout are the water vapor in the incoming air and outgoing air respectively (gms water/gms dryair). The symbol λ is the latent heat of evaporation given as

$$\lambda = 2.501 - 0.002361 * Treact \qquad (11e$$

Vaporin and Vaporout are computed using (ASAE, 1997)

$$Vaporin = \frac{0.6219 * PVI}{Pair - PVI} \qquad Vaporout = \frac{0.6219 * PVO}{Pair - PVO} \qquad (11f,g$$

Nomenclature has been previously defined. The heat lost by conduction (e.g., the major sink term) is assumed zero. The major heat source is given by the combustion of the BVS, written as follows.

$$Source = \frac{d(BVS * Vol * density)}{dt} * HeatCnt \qquad (11h$$

where heat content (HeatCnt) is in units of kcal/gm BVS. Values for heat content may be found in Haug (1993). Equations 11b through 11h may be substituted into Equation 11a for the energy balance. All terms in Equation 11i are constant except for Treact. The energy balance presumes no condensation. Equations 3 through 11 must be solved over time, where all parameters are known or hypothesized except for the reactor temperature Treact. Software packages such as STELLA® allow one to impose conditional aeration rates (e.g., rate dependant on reactor temperature). One may also impose moisture conditions on which one may add water at a specified rate.

MODEL VALIDATION

Substrate: Data from Das et al. (1997b) composting of duster and gin trash was compared to model results. The compost process used in Das et al. (1997b) was conducive to modeling. The material was mixed and placed in a barrel with temperature control aeration. The compost was only mixed weekly as opposed to continually as the model suggests, which explains the discrepancies in the temperature during mixing. Moisture content (wet basis) was maintained at above 55% but was adjusted only weekly. The model was set to add water whenever the moisture content dropped below 55%. One kg of substrate was used. Data points for the composting are actually a four hour moving averages. The O_2 concentrations are samples taken over a minute. This varies from the data displayed by the model which are 6 hour averages of 7.2 averages. Selected model inputs are given in Table 1.

Table 1. Selected model inputs

	Unit Formula (refer to Equation 1)				ASH	BVS	MC	K_d	Energy content
	A	B	C	D	%	%	%	Day^{-1}	MJ/Kg
Duster, Wool & Gin Trash	9	11	3	1	40	19	69.1	.015	20*

* The K_d value was evaluated by qualitative best fit to experimental data

The model can incorporate changes in humidity and ambient temperature that affect energy into the system. The climate data is not available for this model and therefore not included. The temperature was set at a constant 26°C and 50% relative humidity.

Aeration: The aeration for Das et al. (1997b) was set at 40.8 m^3/day when vessel temperature exceeded 55°C. Below 55°C the flow rate was set to 0.45 m^3/day. The initial mass of the composting vessel was then used to determine specific flow rates of 7.7 m^3 /day above 55°C and 0.085 m^3/day below 55°C.

Results: Comparisons between predicted mass, temperature and oxygen were made to validate the model. The fraction of remaining solids matches within two percentage points. The actual data was collected and weighed weekly. Selected simulation results are shown in Figure 1. The dry mass decays exponentially as one would expect. The temperature and airflow dynamics behave as one would expect with aeration being controlled by temperature.

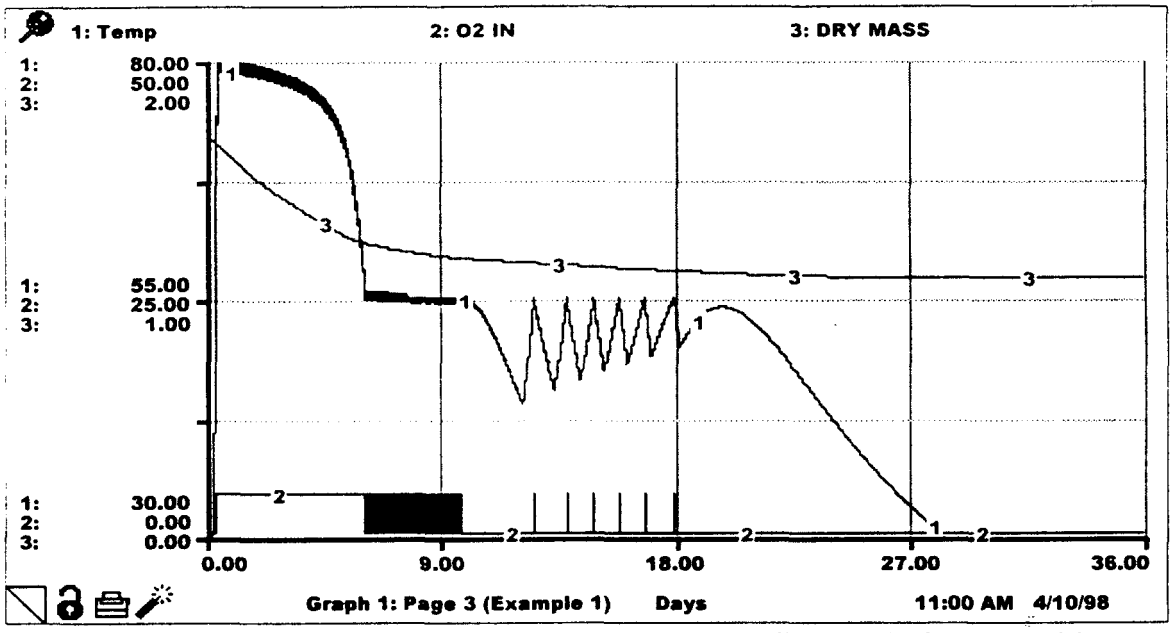

Figure 1. Selected dry mass, temperature and oxygen concentration predicted results from the model.

The temperature results appear to not match closely, particularly the time at which the reactor cools. Two reasons explain the discrepancies : incomplete mixing and excessive aeration rates. When mixing is incomplete, non-degradable material encapsulates BVS which becomes inaccessible to microbial activity. Excessive aeration rates can actually be explained as a function of incomplete mixing. The model distributes the aeration evenly. In reality, channeling through the substrates exists. The channeled air has higher velocities and a higher effective cooling of the vessel temperature. The channeling allows for hot pockets to exist in the vessel creating temperature readings which are lower than the average vessel temperature.

Note the reheating occurs in the actual data on days 7, 14, and 21 (Figure 2.). The increased reheating suggests more BVS are freed for degradation. Also, if the below 55°C aeration rate is increased the temperature will drop off sooner. Doubling the low aeration rates generates a temperature curve more closely related to the actual data. The improved fit suggests doubling the aeration rate for non-continuous mixed systems. The reason channeling does not affect the high aeration rate is because the same average aeration rate can be generated by longer run times at a lower aeration rates, particularly if the actual high aeration is over designed.

Dramatic temperature drop while aerating does not necessarily mean a finished product, but means degradation, and therefore, heat production, has slowed below the cooling affect of the aeration. During the slow degradation the pile can removed for curing or the aeration can be reduced to match the decomposition.

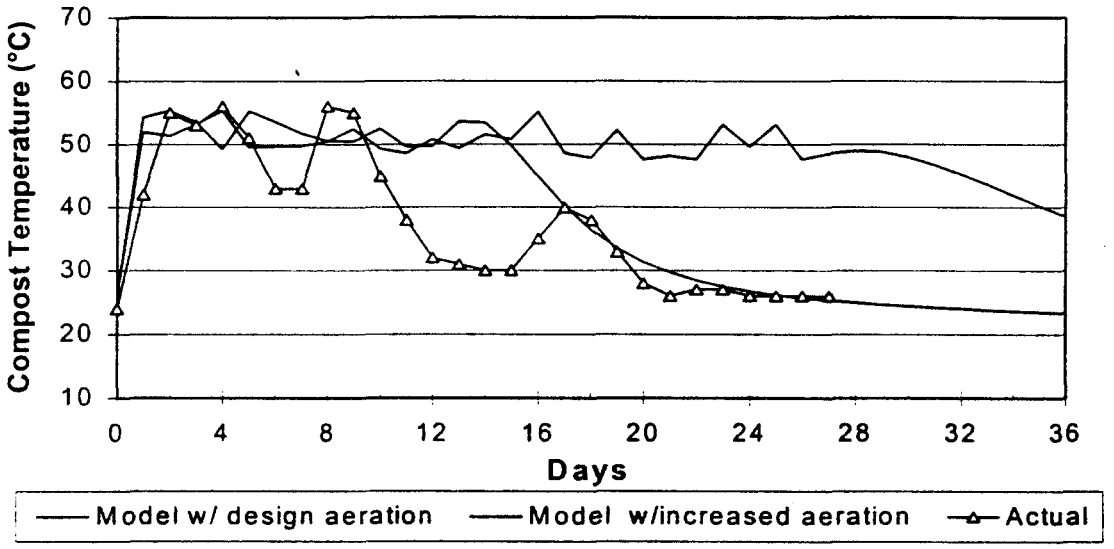

Figure 2. Temperature in composts as a function of aeration rate.

The maximum oxygen consumption rate measured, 2.7 g/mg-DM/hr, is within 15% of the modeled rate of 2.3 g/mg-DM/hr. The maximum rate measured occurred within the first day while the modeled peak does not occur until day 6. This discrepancy can point directly to an error in the model. The logistic function which accounts for oxygen limitation uses a ratio of the oxygen supplied and maximum consumption in an unlimited oxygen atmosphere. This ratio causes maximum O_2 consumption to occur after the potential maximum oxygen consumption has decreased and therefore increasing the ratio.

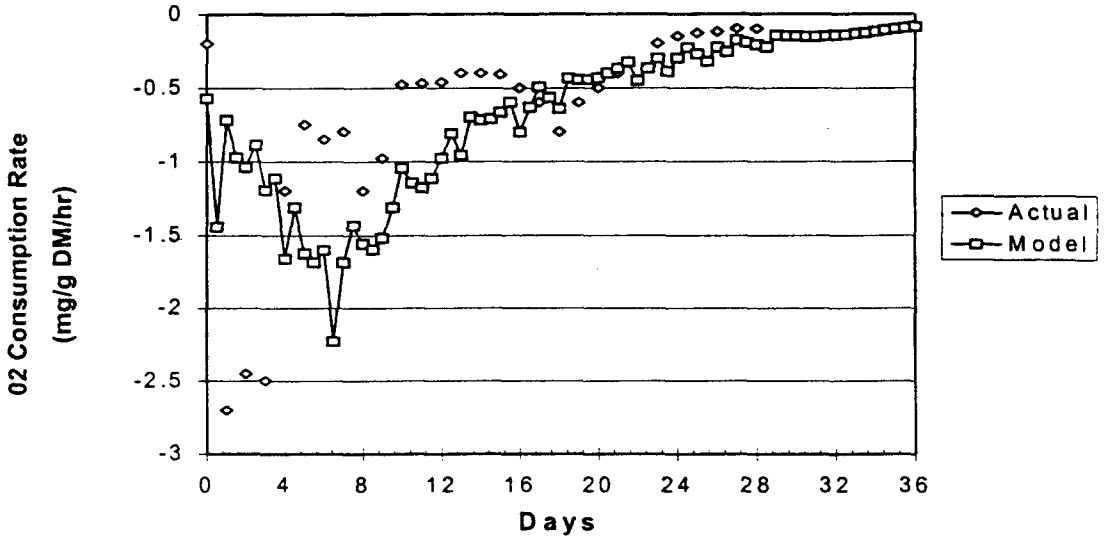

Figure 3. O_2 consumption rates.

The measurement of the O_2 consumption is questioned, because a sample of air from the head space is taken for a minute every hour. Depending on the cycling of the fan, the measurement can be skewed. If the fan is cycling during sampling it will give a false low reading and vice versa. Changing the time period that the O_2 consumption is averaged makes a large difference. The data here is a 6 hour average. The hourly averages are higher and the six minute average goes as high as 40 mg/g-DM/hr.

MODEL USES

The model can be used to evaluate "what if" questions associated with virtually all operational parameters. For example, one may develop different aeration regimes to optimize the composting process. One possibility is to develop variable speed aeration motors to maximize ramp up temperatures and prevent excessive cooling. While temperature ramp up is not a concern in steady state system, in reality substrate variability does occur. One may evaluate reactor vessel sizing in relation to the product throughput rate. A model can predict required changes to keep a composting system running optimally or to prevent system failure.

Another component an operator must control is water addition. Adding ambient temperature water has a large impact on the energy balance of the system. Modeling the affects of water addition can also help optimize that process. A difficult parameter in compost modeling to determine is the degradation coefficient. Evaluating a computed calculated degradation coefficient based on data collected at the pilot scale as was done in this study is another use of a process model.

Much remains to be done with respect to modeling the compost process. Many assumptions are necessary in terms of input parameters as well as model structure. Modeling the process enables researchers to structure their work in light of a large integrative picture.

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UTILIZATION OF COMPOSTS AS BEDDING PLANT GROWTH SUBSTRATES

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INTRODUCTION

Peat moss is the most widely used source of organic matter for growing horticultural crops in the United States. The demand for peat as a substrate constituent for bedding and pot plants has remarkably increased in recent years, thus reducing the availability and increasing cost (Nappi and Barberis, 1993). Composts may serve as qualitatively and economically as competitive alternative sources of organic matter.

Composting of organic materials such as animal manure and crop residues has a long history as an agricultural practice. Present environmental concerns and an increase in community generated wastes have accelerated the technological development of waste products composting. Today, composts derived from biosolids, animal manure and yard debris are homogeneous and easy to use.

Many composts are useful in supplying crops with macronutrients such as N, P, K, and S (Barruzunni and Del Zan, 1992; Cortellini et al., 1996; Kuo, S., 1995; Taylor et al., 1978), and also micronutrients such as Cu, Fe, Mn, and Zn (Bomke and Lowe, 1991; Dixon et al., 1995; Giordano et al., 1975). A study by Chaney et al., (1980) demonstrated that digested biosolids compost could provide sufficient trace elements such as Cu, Fe, Zn, and macronutrients P and K for growth of French Marigold (*Tagetes patula* L.) growth, although not enough nitrogen. According to Chen et al., (1988) composted cattle manure and composted grape marc contained high nutrient levels, especially P and K which were slowly released during the growing period. Composts are also useful to formulate potting substrates (Gouin, 1985; and Link et al., 1983, Tomati et al. 1993).

Composts can improve substrate physical properties when they are mixed with peat moss. When peat was used alone, air filled pore space (AFPS) was very low; however if blended with composted cattle manure and composted grape marc respectively, the AFPS and water-holding capacities were close to ideal (Chen et al., 1988). Biosolids composted with bark or biosolids composted with grape stalks had acceptable physical properties (Nappi and Barberis, 1993). Measuring physical properties for compost amended substrates intended for nursery production is insufficient. Not all composts can be expected to have comparable efficacy. Substrates containing composted biosolids and yard debris had superior performance, but not all their physical properties were within the suggested optimum range (Fitzpatrick and Verkade, 1991). According to Bugbee and Frink (1989), composts derived from biosolids, pharmaceutical and food flavoring wastes had rather similar physical properties, but plant performance was different. Composted cattle manure and composted grape marc, and their blends with peat respectively also had similar aeration and water holding capacity (Chen, et al., 1988).

Bedding and pot plants are ideally suited for utilization of composts, because heavy metals and threats to human health are of less concern (Gouin, 1982). However, there is a limited amount of published research on utilization of composts as bedding plant substrates. According to Sawhney (1976), leaf compost is well buffered at about pH 7, which is considered optimum for the growth of many plants. Yard debris compost can be added to a commercially prepared peat-based potting mix for Ageratum (*Ageratum houstonianum* Mill) up to 50% of final volume (MacCubbin and Henley, 1993). Chaney et al. (1980) showed that 33% digested biosolids compost could produce African Marigold (*Tagetes erecta* L.) equal to the complete Cornell mix. Bragg et al. (1993) indicated 30% municipal solid waste or biosolids were suitable to grow Petunia (*Petunia hybrida* Hort.) and Impatiens (*Impatiens wallerana* Hooks). French marigold growth was improved when up to 50 % Canadian sphagnum peat was replaced by composted biosolids or up to 30 % replacement of peat by composted food flavoring waste, and up to 40 % replacement of peat by pharmaceutical or cranberry wastes (Bugbee and Frink, 1989).

The objectives of this research were to determine suitability of compost -amended substrates for five species of bedding plants compared to two commercially available substrates (Sunshine Mix # 1 and Progro 300s). In order

to quantify substrate suitability, the following variables were determined:

- substrate physical properties
- substrate chemical properties
- plant growth and development
- plant tissue nutrient status including macronutrients and micronutrients

MATERIALS AND METHODS

Compost Sources and Treatments

Four compost sources were tested in this experiment: Compro ® (C), Leafgro ® (L), poultry litter (P), and Orgro (O). Compro and Leafgro were obtained from Maryland Environmental Service, Annapolis, MD. Compro is made from lime stabilized biosolids, blended with 50% woodchips and composted in a static pile process. It has rather high pH above 7.3-7.5. Leafgro is made from 50% leaves and 50% grass clippings using a turned windrow process. Poultry litter compost was produced by New Earth Service, Cambridge, MD from a mix of 50% wood chips and 50% poultry litter using a turned windrow process. Orgro was obtained from PSG Ecology Baltimore, MD. It is derived from polymer dewatered biosolids blended with 50% woodchips and composted in a static pile process. All two way combinations of the four composts, were blended at 1:1 ratio, to make six compost blends, thus a total of 10 compost sources including the four unblended composts. Composts were diluted with a base mix (peat and perlite at 1:1 ratio). The compost volumes were 25%, 33% and 50%. The ratios of compost: peat : perlite were 2:3:3, 1:1:1 and 2:1:1 respectively. Thus ,there were 30 substrates. Two commercially available substrates, were used as the controls. Sunshine mix #1 (SunGro Horticulture Inc, Bellevue, WA) is made from 70-80% peat and perlite. Progro 300S (Progro Products, McCormick, SC) has about 40% composted bark, much less peat and perlite.

Bedding Plant Species

Five species of bedding plants were tested in this experiment: Ageratum (*Ageratum houstonianum* Mill.) cv 'Blue Puffs', Impatiens (*Impatiens wallerana* Hooks) cv 'Dazzler Red', French marigold (*Tagetes patula* L.) cv 'Bonanza Flame', Petunia (*Petunia hybrida* Hort.) cv 'Madness Red', and Vinca (*Catheranthus roseus* L.) cv 'Cool Peppermint'. All the plants were obtained as plugs (800 plugs/tray) from Tagawa Greenhouses Inc., Brighton, CO.

Greenhouse Experiment

The experiment was conducted in 1996 in a greenhouse at the University of Maryland, College Park. The experimental design was randomized complete block. Each of four benches was used as a replication. For each replication of a substrate treatment, four 4-cellpacks (#804) per species were used with one plant per cell giving 16 plants per substrate per replication. The plants were transplanted on April 11, 1996. The greenhouse temperature was kept 23°C at day and 20°C at night. After 10 days growth, and weekly thereafter, the plants were fertilized with 100 ppm N of 20-20-20 (N-P_2O_5-K_2O) .

Beginning April 19, and weekly for the next 3 weeks, a 4-cellpack of substrate was taken for analyses from each replication of French marigold. The experiment was concluded on May 10. From each plot, plants from a randomly selected 4-cellpack were harvested and dried at 60°C to a constant weight.

Laboratory Analyses

All substrate samples were dried at 60°C for four days. The substrate electrical conductivity (EC) and P were determined from 3g dry samples saturated with 30 ml deionized water. The samples were shaken for 1 hour on a Thermomix Model 1480 (B. Braun, Germany). EC was measured with a Soil Tester (Beckman Instruments Inc.) following vacuum extraction (Hershey, 1989). Soluble P was determined with Spectrophotometer Model 390 (Sequoia-Turner Corporation, Mountain View, CA) at λ = 882 nm (Watanabe and Olsen,1965). Soluble N and pH were determined following mixing 30 ml of 1 M KCl to 3 g of dry sample, shaken for 1 hour on the above described shaker and filtered using Whatman #1 filter paper. Both extractable total N and NH_4^+-N were determined with a Westcan Ammonia Analyzer Model 360 (Alltech, Deerfield, IL). Total N was measured by reducing the sample

NO_3^- fraction to NH_4^+ fraction with 30 mesh zinc before determination of NH_4^+-N.

The substrate samples obtained by weekly sampling were combined, moistened and then lightly packed into one 4-cellpack (#804). The saturated weights were recorded after the cell packs were saturated with water from below for 24 hours. They were weighed again after 24-hour drainage. The substrate dry weight was recorded after 60 °C oven drying till constant weight. Container capacity and bulk density were determined similarly from the weight of oven-dried media. Container capacity was determined by weight of water in the wet substrate after 24 hours drainage.

Kjeldahl-N of plant tissue was determined by the method of Bowman et al (1988). The procedure for determining P, K, Ca, Mg, Cu, Fe, Mn, and Zn of plant tissue was as follows: 0.1-0.2 g dry whole plant tissue samples were ashed at 550°C for 3 hours. The ash was dissolved with 10 ml 3.8N HCl. The ashed solution was filtered with Whatman #40 filter paper. Hot deionized water was used to rinse the crucible and the filter paper. The final volume was brought up to 50 ml. The analyses were performed by the University of Maryland Soil Testing Lab.

RESULTS AND DISCUSSION

Plant dry weight

Overall, Leafgro and poultry litter compost amended substrates either alone or blended with each other produced large plants, with dry weights either significantly higher or not different from the controls (Table 1). When Orgro was used alone, plant growth was suppressed, more severely at higher volume. Orgro blended with Leafgro or with poultry litter produced plant dry weights which were not significantly different from the controls. The Compro amended substrates gave the poorest response; the only satisfactory substrate was with poultry litter. Not all species responded to the substrates in the same way (Table 2). Petunia had a broad adaptation, it could grow well in various substrates when other species performed poorly; even at 25% Compro alone or Compro blended with Leafgro, or poultry litter at 25-50% compost volume. Other species had slight differences with Compro containing substrates, but few differences with Leafgro, Orgro and poultry litter blends or Leafgro and poultry litter compost only substrates.

Substrate physical properties

The range of values for physical properties of the substrates was small (Table1). The air filled porosity of most substrates is near the optimum range, which is from 10 to 25% (Bugbee and Frink, 1986). The bulk density of all substrates was in the ideal range 0.15-0.50 g/cm^3 (Nappi and Barberis, 1993). According to Bugbee and Frink (1989), composts derived from biosolids, food flavoring wastes and pharmaceutical wastes had similar physical properties, and none of the physical properties we measured were likely to be a major cause of the observed growth responses. None of the substrate physical properties were significantly correlated with plant dry weight (Table 3).

Substrate chemical properties

Substrate pH

Over the 4-week experimental period, there was no significant time by substrate interaction (data not presented). All the substrates containing Compro had pH values above 7.5 (Table 4). However, the plant dry weight of CP @ 25% which had a pH of 7.7 was not significantly different from the Sunshine mix #1 (Table 1). Other treatments had pH values from 5.2 to 6.5. The highest total plant dry weight was from the treatment OL @ 25% which had an average pH of 5.2. The pH range of the experimental substrates was greater than the desirable range from 5.4 to 6.8 (Holcomb, 1994). Average (over the 4 weekly samples) substrate pH was negatively correlated with plant dry weight, (Table 3) mostly due to the high pH levels in the Compro containing substrates.

Table 1. Air filled porosity, container capacity, total porosity, and bulk density of the experimental substrates. and average dry matter accumulation of bedding plants grown in the substrates.

Substrate Compost Source[1]	Air filled porosity (%)	Container Capacity (%)	Total Porosity (%)	Bulk Density (g/cm^3)	Dry Matter (g)
C 25%	11.8	52.4	64.1	0.25	1.06 lm
C 33%	16.4	51.5	67.9	0.26	0.84 mn
C 50%	16.4	50.3	66.7	0.28	0.62 no
CP 25%	14.7	53.5	68.2	0.24	1.85 f-i
CP 33%	12.6	54.0	66.6	0.29	1.71 i-k
CP 50%	14.0	51.3	65.2	0.34	1.73 h-j
CL 25%	15.0	52.7	67.7	0.21	1.48 k
CL 33%	9.4	61.7	71.0	0.24	1.52 jk
CL 50%	11.2	57.8	69.0	0.29	1.14 l
CO 25%	13.6	54.2	67.9	0.23	1.06 lm
CO 33%	17.8	48.3	66.1	0.24	0.72 no
CO 50%	14.8	52.1	66.9	0.34	0.49 o
O 25%	18.5	49.8	68.3	0.20	1.04 lm
O 33%	16.4	53.4	69.8	0.23	1.04 lm
O 50%	17.2	51.1	68.2	0.25	0.49 o
OP 25%	16.5	51.5	68.1	0.22	2.20 a-c
OP 33%	18.0	50.2	68.2	0.24	2.15 b-e
OP 50%	14.0	53.3	67.3	0.29	2.04 c-g
OL 25%	13.6	58.2	71.9	0.21	2.39 a
OL 33%	14.5	56.9	71.4	0.21	2.29 ab
OL 50%	13.6	58.1	71.7	0.25	1.84 g-i
L 25%	18.1	51.1	69.2	0.18	2.04 c-g
L 33%	14.0	55.6	69.6	0.19	2.08 b-f
L 50%	11.0	60.6	71.5	0.22	2.12 b-e
LP 25%	18.8	51.4	70.1	0.20	1.87 f-i
LP 33%	10.9	58.2	69.1	0.24	2.18 ad
LP 50%	17.1	52.4	69.5	0.25	2.05 c-g
P 25%	15.2	54.4	69.6	0.26	1.86 f-i
P 33%	20.2	46.9	67.1	0.24	2.04 e-g
P 50%	19.9	47.9	67.8	0.32	1.97 d-g
Sunshine mix #1	9.3	72.9	82.2	0.11	1.95 e-h
Progro 300S	13.1	57.7	70.9	0.20	2.12 b-e

[1]C = Lime stabilized biosolids; P = Poultry litter; L = Yard debris; O = Polymer dewatered biosolids; 25% = 25% compost, 37.5% peat and 37.5% perlite by volume; 33% = 33% compost, 33% peat and 33% perlite by volume; 50% = 50% compost, 25% peat and 25% perlite by volume.

[2] Means followed by the same letter are not significantly different (LSD 0.05).

Table 2. Effects of substrate composition on dry weight of each of 5 species as compared to the control substrates. (Sunshine Mix #1 and Progro 300S).

Substrate Compost Source[1]		Ageratum	Impatiens	Marigold	Petunia	Vinca
C	25%	-[2]	-	-	=	-
C	33%	-	-	-	-	-
C	50%	-	-	-	-	-
CP	25%	=	=	=	=	=
CP	33%	=	-	=	=	=
CP	50%	=	-	-	=	=
CL	25%	-	-	-	=	-
CL	33%	-	-	-	=	-
CL	50%	-	-	-	=	-
CO	25%	-	-	-	=	-
CO	33%	-	-	-	-	-
CO	50%	-	-	-	-	-
O	25%	=	-	-	-	-
O .	33%	-	-	-	-	-
O	50%	-	-	-	-	-
OP	25%	=	=	=	+	=
OP	33%	=	=	=	=	=
OP	50%	=	=	-	=	=
OL	25%	+	=	=	=	=
OL	33%	+	=	=	=	=
OL	50%	=	-	-	=	=
L	25%	=	=	=	=	=
L	33%	=	=	=	=	=
L	50%	=	=	=	=	=
LP	25%	=	=	=	=	=
LP	33%	=	=	=	=	=
LP	50%	=	=	=	=	=
P	25%	=	=	=	=	=
P	33%	=	=	=	=	=
P	50%	=	=	=	=	=
Sunshine Mix #1		2.52	2.13	2.97	1.94	1.29
Progro 300S		3.19	1.98	3.26	2.53	1.30

[1] C= Lime stablizied biosolids; P = poultry litter; L = yard debris; O = Polymer dewatered biosolids; 25% = 25% 7.5% peat, 37.5% perlite (v:v:v); 33% = 33% compost, 33% peat, 33% perlite; 50% = 50% compost, 25% peat, 25% perlite.

[2] Indicates significantly (0.05) less dry weight than the lower control substrate; + indicates significantly (0.05) greater dry weight than the higher control substrate; = indicates not different than both control substrates.

[3]Dry weight (g) for each specie following grown in the control media.

Table 3. Coefficients of correlation between mean piant dry weight and substrate physical and chemical properties.

Variable	Correlation coefficients	P value
AFPS[1]	-0.157	0.3917
CC[2]	0.322	0.0720
D_B[3]	-0.329	0.0662
pH	-0.493	0.0041
EC[4]	-0.831	0.0001
P	-0.384	0.0302
NH^+_4	-0.154	0.4004
NO^-_3	-0.309	0.0853

[1] Air filled pore space, [2] Container capacity, [3] Bulk density, [4] Electrical conductivity

Substrate electrical conductivity (EC)

Substrates containing Leafgro or poultry litter compost had lower EC than the other substrates (Table 4). Although the treatment OL @ 50% had an EC of 15 dS/m, the plant dry weight was not significantly different from Sunshine mix # 1. According to Bunt (1976) and Holcomb (1994), this EC is excessive. Over the 4 -week growth period, treatment EC changes occurred in an irregular pattern . However, the EC of most treatments had no significant changes after the first week of growth (data not presented). Among the variables measured, EC was most closely related to plant growth (Table 3).

Substrate phosphorus (P) concentration

The poultry litter compost treatment contained the highest water soluble P concentration (Table 4). All the substrates contained P concentration above 6 ppm. According to Holcomb (1994), the optimum P range is about 6-14 ppm. Substrate water soluble P levels were significantly correlated with plant dry weight perhaps due to the low P levels of the high pH Compro containing substrates (Table 3).

Substrate ammonium (NH_4^+) concentration

Substrates containing Orgro had high NH_4^+ concentration (Table 4). Many plants in Orgro-amended substrate at the highest level (OL @50) died, perhaps due to the high NH_4^+ concentration (Bugbee and Frink, 1989; Jeong and Lee, 1992a and 1992b; Lemaire and Dartigues, 1983,).

Substrate nitrate (NO_3^-) concentration

Over the growth period, substrate NO_3^- had no significant substrate with time interaction (data not presented). Average substrate NO_3^- concentration followed same pattern as the NH_4^+ concentration (Table 4). Orgro containing substrate exhibited higher NO_3^- concentration, and the concentrations became significantly lower over the 4-week experiment (data not presented). Substrates containing Leafgro, poultry litter and their blends had the lowest NO_3^- concentration, but the concentrations did not change significantly over the growth period. Neither substrate NH_4^+ nor NO_3^- were significantly correlated with plant dry weight (Table 3).

Plant tissue chemical compositions

Plant tissue N concentration

Plants from Orgro amended substrates had the highest N concentration (Table 5). In contrast, plants from substrates amended with Leafgro, poultry litter and their blends had less than 3 % N concentration. Plant tissue concentration N less than 3% may not be sufficient for many plants (Dight, 1977). However, in this experiment plant growth from those treatments was not reduced. The correlation coefficient between plant dry weight and tissue N concentration was –0.205 (Table6) suggesting that N uptake did not limit growth.

Plant tissue P concentration

Plant tissue P concentration from Compro amended substrates was lower (Table 5). This is because those substrates had pH above 7.5, which probably affected P availability. Most of P concentrations were above 0.3 %, which should be sufficient for plant growth (Holcomb, 1994; Jones, et al., 1991). The correlation coefficient between tissue P concentration and plant dry weight of 0.745, is the highest among the tissue nutrient concentrations (Table 6).

Plant tissue K concentration

Plant K concentration from substrates amended with Orgo and blends of Compro and Orgro were the lowest, about 3.1-3.5 % (Table 5). They should not be deficient in that both Holcomb (1994) and Jones et al. (1991) indicated that K in the range of 1.0 to 5.0 % is sufficient. The lower K of plants growing in substrates amended with Orgro could be due to high NH_4^+ levels of those substrates, which may have suppressed K uptake. The correlation coefficient between tissue K concentration and plant dry weight was 0.700 (Table 6).

Plant tissue Ca concentration

Plant tissues from Compro amended substrates had rather high Ca concentration (Table 6), probably because Compro is produced from lime stabilized biosolids. Other substrates had much lower Ca concentration. They should be in the appropriate range because Ca average concentration in plant dry matter higher than 0.5 % is considered to be sufficient for plant growth (Jones, et al., 1991). The significant negative correlation coefficient is probably due to the very high Ca levels in the lime dewatered biosolids (Table 6).

Plant tissue Mg concentration

Mg concentration from substrates showed a fairly narrow range (0.52 – 0.90%). Mg concentration was above 0.4 % (Table 5), suggesting that Mg was probably not Mg deficient (Holcomb, 1994). The correlation coefficient between tissue Mg concentration and plant dry weight was 0.14 2 (Table 6), suggesting no relationship between plant dry weight and Mg concentration.

Plant tissue micronutrient concentration

The micronutrients, Cu , Fe, Mn, and Zn did not exhibit systematic trends relative to substrates (Table 5). The data indicated no micronutrient deficiency or toxicity. There probably was no Mn toxicity since sweet potato contained up to 1380 ppm Mn before severe toxicity developed (Jones, et al., 1991). The lowest Mn concentration was above 50 ppm in this experiment, which is the lower limit of maximum level for general crops recommended by Holcomb (1994). For other species, Mn concentrations were generally between 100 to 300 ppm. The highest Zn was about 470 ppm (Table 5), which is above maximum upper limit (Holcomb, 1994). Plants from Orgro or Orgro blended substrates had Zn concentration over 100 ppm. Plants from rest of the substrates had Zn concentration from 50 to 100 ppm (Table 5). This range is more than sufficient for plant growth, which is reported to be 15 to 50 ppm (Jones et al., 1991).

Table 4. Substrate pH, EC, water soluble P, NH_4, NO_3 and Total N averaged over the 4 sampling dates.

Substrate Compost Source [1]		pH	EC dS/m	P ppm	NH_4 ppm	NO_3 ppm
C	25%	7.5	14.5	7	5	87
C	33%	7.6	18.0	6	5	84
C	50%	7.8	22.2	6	5	110
CP	25%	7.7	10.4	18	6	59
CP	33%	7.6	13.1	17	4	104
CP	50%	7.7	11.0	17	3	61
CL	25%	7.6	16.8	19	5	80
CL	33%	7.6	16.2	9	5	52
CL	50%	7.6	20.4	10	4	62
CO	25%	7.5	19.7	7	93	182
CO	33%	7.5	24.2	6	103	181
CO	50%	7.6	25.8	6	148	192
O	25%	5.2	14.2	28	2879	374
O	33%	5.3	15.0	17	4232	565
O	50%	5.5	22.5	14	4722	860
OP	25%	5.3	8.4	94	1745	286
OP	33%	5.4	7.6	113	1473	217
OP	50%	5.7	11.9	120	1590	354
OL	25%	5.2	8.1	42	1469	185
OL	33%	5.4	12.4	32	2000	192
OL	50%	5.6	15.0	29	2039	314
L	25%	5.6	4.4	179	69	59
L	33%	5.9	6.0	264	34	17
L	50%	6.4	7.1	262	10	13
LP	25%	5.4	4.2	474	59	14
LP	33%	5.9	5.8	449	35	15
LP	50%	6.5	6.8	434	7	27
P	25%	5.5	5.0	668	48	25
P	33%	5.8	4.9	632	28	19
P	50%	6.3	6.1	580	9	37
Sunshine Mix#1		6.0	6.8	120	63	145
Progro 300S		5.9	6.7	103	64	277
LSD 0.05		0.2	3.2	50	212	151

[1] C= Lime stablizied biosolids; P = poultry litter; L = yard debris; O = Polymer dewatered biosolids; 25% = 25% 7.5% peat, 37.5% perlite (v:v:v); 33% = 33% compost, 33% peat, 33% perlite; 50% = 50% compost, 25% peat, 25% perlite.

Table 5. Plant tissue (average of 5 species) nutrient concentration.

Substrate Compost Source[1]		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Cu ppm	Fe ppm	Mn ppm	Zn pp
C	25%	3.76	0.44	4.32	4.64	0.73	22.8	427	215	65
C	33%	3.41	0.34	4.02	4.70	0.74	21.7	482	225	62
C	50%	3.45	0.30	3.80	5.07	0.77	22.5	798	245	65
CP	25%	3.09	0.62	5.57	3.34	0.63	23.4	326	146	70
CP	33%	3.20	0.55	5.62	3.40	0.67	22.8	327	147	68
CP	50%	3.16	0.55	6.00	3.14	0.72	25.1	436	139	78
CL	25%	3.26	0.49	5.47	3.75	0.64	17.6	226	238	64
CL	33%	3.42	0.51	5.70	3.70	0.65	17.5	294	255	68
CL	50%	3.48	0.48	5.76	3.68	0.74	21.7	459	249	71
CO	25%	4.01	0.43	3.41	4.36	0.74	18.9	396	203	75
CO	33%	4.08	0.38	5.44	4.42	0.74	19.8	588	211	77
CO	50%	4.31	0.34	3.11	4.13	0.73	22.2	1066	203	74
O	25%	6.65	0.90	3.46	0.78	0.68	26.7	960	452	164
O	33%	6.84	0.86	3.16	0.77	0.65	28.0	1213	406	151
O	50%	7.28	0.70	3.11	0.83	0.66	29.4	1564	344	140
OP	25%	5.67	1.17	5.19	1.06	0.86	30.0	714	617	217
OP	33%	5.69	1.13	5.47	0.97	0.82	32.5	775	465	210
OP	50%	5.73	1.11	5.35	1.11	0.90	31.9	908	460	209
OL	25%	5.39	1.10	5.38	1.12	0.85	23.2	733	698	164
OL	33%	5.79	1.04	5.70	1.04	0.82	24.0	804	728	168
OL	50%	5.84	0.87	5.60	1.00	0.70	23.2	704	431	138
L	25%	2.67	0.89	6.32	1.37	0.61	14.1	218	336	91
L	33%	2.66	0.91	7.08	1.14	0.55	13.5	164	329	96
L	50%	2.81	0.88	8.04	1.09	0.55	14.8	187	370	96
LP	25%	2.64	1.02	6.13	1.17	0.64	18.3	219	323	90
LP	33%	2.90	1.01	7.00	1.00	0.60	20.6	215	229	113
LP	50%	2.99	0.96	8.10	0.82	0.52	22.1	172	177	100
P	25%	2.79	1.22	6.12	0.93	0.64	21.9	185	201	97
P	33%	2.84	1.13	6.67	0.80	0.61	21.6	178	147	97
P	50%	2.98	1.10	7.21	0.59	0.54	25.9	166	100	95
Sunshine Mix #1		2.50	0.84	3.56	1.62	1.06	13.2	156	305	03
PG 300S		3.24	0.94	5.28	2.47	1.00	12.5	172	116	110
LSD 0.05		0.32	0.06	0.34	0.20	0.06	2.5	137	49	13

[1] C =Lime stablizied biosolids; P = poultry litter; L = yard debris; O = Polymer dewatered biosolids; 25% = 25% 7.5% peat, 37.5% perlite (v:v:v); 33% = 33% compost, 33% peat, 33% perlite; 50% = 50% compost, 25% peat, 25% perlite.

Table 6. Correlation coefficients between mean plant dry weight and average nutrient concentrations of plant tissue growing in experimental substrates.

Nutrients	Correlation coefficients	P Value
N	- 0.205	0.2597
P	0.745	0.0001
K	0.700	0.0001
Ca	- 0.578	0.0005
Mg	0.142	0.4375
Mn	0.314	0.0800
Zn	0.404	0.0217
Cu	- 0.112	0.5404
Fe	- 0.495	0.0040

All treatments except Leafgro had higher Cu concentrations than the two controls (Table 5). Most plants had about 10 to 20 ppm Cu concentration except those plants from Orgro or Orgro blended substrates, and which had 20 to 40 ppm Cu. The range from 20 to 40 ppm could be approaching the toxicity level (Jones, et al., 1991). There was a wide range in Fe concentration among treatments. Holcomb (1994) did not mention an upper limit of this element. The highest Fe concentration is 1564 with OL@5% substrate. Most substrates containing Leafgro, poultry litter or Leafgro blended with poultry litter had Fe concentration lower than 250 ppm, but most of the other substrates had more than 250 ppm Fe. Jones et al. (1991) only mentioned rice could have Fe toxicity if its concentration is up to several hundred ppm, but some other species could have up to 1000 ppm without Fe toxicity. No microelement tissue concentration was significantly correlated with plant dry weight (Table 6).

CONCLUSIONS

Overall, yard debris (Leafgro), poultry litter and their blends produced good results for bedding plants. They can partially replace peat and perlite by 25 to 50%. Polymer dewatered biosolids (Orgro) blends, either with Leafgro, or with poultry litter, from 25 to 50% volume, are excellent substrates. Plant dry weight from those substrates were either equal to or greater than those from Progro 300S which was the better substrate for most species. However, when Orgro was used alone, even at 25% volume, plant growth was very poor. Many plants died at 50% volume. Overall Compro is not recommended for bedding plants. Most of the plants grew poorly when Compro was used alone or blended with Orgro, Leafgro or poultry litter. The best combination was with poultry litter at 25% volume where plant dry weight was not significantly different from Sunshine mix #1. Blends of composts from two sources often exhibited performance superior to either component alone.

Most of compost-amended substrates had similar air filled porosity, container capacity, and bulk density. Therefore, these properties were probably not major causes of variations in plant performance.

Substrate chemical properties were quite different in terms of pH, EC, P, NH_4^+ NO_3^- , and total N concentration. Orgro had very high NH_4^+ concentration and this could be the reason why some plants died with Orgro amended substrates. The good performance of some substrates could be due to the combination of proper range of pH and EC, which were 5.2 to 6.5 and 5-8 dS/m respectively; and also due to the adequate amount of P concentration and no detrimental , NH_4^+ concentration. Those composts in which plants performed poorly may have been due to the combination of detrimental factors.

Our data do not suggest that plants from poorly performing substrates have nutrient deficiencies or toxicities because most plant tissue N, P, K, Ca, Mg, Mn, Zn, Cu, and Fe concentrations are within optimum ranges. The plants from Leafgro, poultry litter and their blends amended substrates may have lower N and Ca concentrations compared to those from Compro and Compro related substrates.

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MUSHROOM COMPOST REMEDIATES ZINC TOXICITY IN COTTON

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INTRODUCTION

Flue dust is a by-product of steel industry where electric arc furnaces are used. It contains as much as 10% Zn (Weeks, 1993). A flue-dust by product was spread on cropland in the Coastal Plain of Georgia as a liming agent, both in the Tifton area (Davis et al., 1995) and in Johnson and surrounding counties. In recent years severe Zn toxicities have occurred in a number of crops in the areas where the material was spread including peanuts, soybeans, and cotton. Zinc levels in severely stunted cotton plants in Johnson county were above 2000 mg kg^{-1}, well above the critical toxicity level of 200 mg kg^{-1} for cotton (*Gossypium hirsutum* L.) found by Ohki (1975).

The most obvious method for reducing plant Zn toxicity is to raise soil pH through liming to reduce the plant availability of the metal. Williams (1980) found that for most crops tested which suffered from metal toxicity from sewage sludge, raising the soil pH to 7.0 -7.2 reduced metal toxicity compared to pH 6.2-6.5. At high pH Zn is adsorbed mostly by the organic matter where it is held as an organic complex. Therefore, raising soil pH and adding organic amendments can work together to help ameliorate Zn toxicity (Jahiruddin et al., 1985).

Higher organic matter in soils leads to lower Zn in plants whether the organic matter is natural (Romney et al., 1977) or added as an amendment to contaminated soils (Marquenie et al., 1981). Cattle manure and maize straw added to two different soils reduced Zn availability as much as 50% (Tagwira et al., 1992). White and Chaney (1980) found that organic matter was more important than Fe oxides in moderating the effects of excessive soil Zn and limiting plant uptake. It has been found that liming alone does not account for the ameliorative effect on municipal wastes in lowering plant uptake of Zn, so the organic material also contributes an effect (Mortvedt and Giordano, 1975). McGrath et al. (1988) showed that lower Zn was extracted at all pHs from soil samples with the highest organic matter than from those with the lowest organic matter indicating that organic material lowers plant availability regardless of the pH.

Since remediation of toxic soil Zn is a problem in certain Coastal Plain soils, a pot experiment was carried out to test remediation strategies and to determine the alteration of Zn in soil fractions with liming and organic matter additions. The objectives of the research were to: 1) determine the pH level that would remediate Zn toxicity to cotton in flue-dust contaminated soil; 2) to examine the effect of adding a mushroom compost on Zn toxicity remediation.

MATERIALS AND METHODS

Bulk soil samples were taken from 0-15 cm depth from a cotton field in Johnson county in the Coastal Plain of Georgia, where a flue-dust had been applied as a liming agent for approximately 10 years, ceasing four years before sampling. The flue-dust was contaminated with Zn, Pb, and Cd with the major pollutant being Zn. Two adjacent sites were sampled which were termed high-Zn soil and low-Zn soil. The high-Zn soil was from an area where the cotton plants were severely stunted (terminal growth about 5 cm) and tissue analysis confirmed that they were suffering from Zn toxicity and not from Pb or Cd toxicity. The other area had cotton plants growing well and was used as a control. The soil types for the two areas were Clarendon loamy sand (Plinthaquic Paleudult) and Dothan sand (Plinthic Kandiudult). Soil physical and chemical characteristics (Black, 1965)are given in Table 1 (Shuman and Li, 1997). Total metals were determined according to Shuman (1979).

A greenhouse experiment was carried out with 4 lime treatments (0 control, 2.24, 4.48, and 8.96 Mg ha^{-1}) and 2 spent mushroom compost treatments (67.2 Mg ha^{-1} compost and the same amount of compost plus 4.48

Table 1. Soil Properties

Zinc Status	Soil Type	Soil Classification	Sand	Clay	Organic Matter	CEC	pH	Total Zn
			---------- g kg^{-1} ----------			$cmol_c$ kg^{-1}	1:1	mg kg^{-1}
High Zn	Clarendon ls	Plinthaquic Paleudult	808	128	25	1.7	4.89	414
Low Zn	Dothan s	Plinthic Kandiudult	912	52	18	1.4	5.39	95

Mg ha^{-1} lime). The lime was laboratory grade calcium carbonate and the spent mushroom compost was screened through a 2 mm sieve. Soils were mixed with lime and spent mushroom compost and a blanket N-P-K-Mg treatment in a V-blender and potted in 3 kg-size pots. The N-P-K-Mg was 100-30-145-25 mg kg^{-1} from NH_4NO_3, KH_2PO_4, KCl, and $MgSO_4 \cdot 7H_2O$. Germinated cotton seeds (variety HS46) were planted and thinned to 4 per pot. There were 4 replications in a completely randomized design. The pots were watered daily to approximately field capacity.

Plants were harvested after 8 weeks by cutting near the soil surface and the leaves were separated for analysis. Plant tissue samples were dried at 70°C in a forced-draft oven and weighed. Leaves were ground in a Wiley mill to pass a 425μm stainless steel screen. A 0.5 g leaf sample was wet digested using a nitric-perchloric acid mix (4:1 v/v basis) with digestion completed in aluminum block heaters at 205°C. Ashed extracts were made to 25-mL volume and Zn and Mn analyzed by flame atomic absorption spectrometry. Soils were air dried, screened through a 2 mm sieve and analyzed for pH (1:2 soil:water) and for Zn by the DTPA method (Lindsay and Norvell, 1978).

A Zn adsorption experiment was carried out where one gram of soil or amended soil was placed in a 50 mL centrifuge tube and 15 mL of 0.01 mol L^{-1} $CaCl_2$ added. The pH of the suspension was adjusted using dilute HCl or KOH. Fifteen mL of the appropriate zinc solutions, as $ZnCl_2$, were added at twice the final strength and with the pH adjusted according to the treatment. The final background salt concentration was thus 0.005 mol L^{-1} $CaCl_2$. The pH treatments were 4.0 to 8.0 in steps of 1 pH unit. The Zn concentration was 1.00 mmol L^{-1}. Each treatment was replicated three times. These suspensions were shaken for 10 min. on a reciprocating shaker and placed in a 25°C water bath for 23 hr. The tubes were shaken once again for 10 min., centrifuged, and the supernatant filtered through Whatman number 42 filter paper. The solutions were analyzed for Zn by flame atomic absorption spectrometry.

RESULTS AND DISCUSSION

PLANT GROWTH

The high-Zn soil was extremely toxic to cotton with most plants stopping growth at a two-leaf stage and exhibiting severe toxicity symptoms such as yellowing of the entire leaf and development of necrotic areas as well as severe stunting. Ohki (1975) found interveinal chlorosis and enlarged necrotic areas in cotton affected by Zn toxicity in nutrient solution experiments. In strongly acidic soils, most plants become chlorotic when they are exposed to excessive soil Zn because Zn interferes with Fe uptake, translocation, and utilization in the leaves (Kabata-Pendias and Pendias, 1984; Chaney, 1993). However, in most soil systems, leaves do not contain deficient levels of Fe even when they are severely chlorotic due to excessive soil Zn (Rosen et al., 1977; White et al., 1979). In this study leaf Fe was above 100 mg kg^{-1} indicating that sufficient Fe was present for normal plant growth. Thus, the chlorosis caused by excessive Zn was likely a result of the Zn interfering with the utilization of Fe in chlorophyll biosynthesis (Chaney, 1993).

Lime treatments up to 9 Mg ha^{-1} did not ameliorate the Zn toxicity (Fig. 1), since the plant growth was statistically the same for the 9 Mg ha^{-1} as for the control. Only the compost was able to produce normal growth on this very toxic soil and adding lime to the compost did not increase growth (Fig. 1). For the low-Zn soil the lime rates

Table 2. Plant Zn for cotton grown in two soils amended with lime or mushroom compost

Zinc Status	Lime				Compost	Compost + Lime
	Control	2 Mg/ha	4 Mg/ha	9 Mg/ha	67 Mg/ha	67 Mg/ha + 4 Mg/ha
	mg kg^{-1}					
Low Zn	1079 a†	872 b	425 c	111 d	36 d	38 d
High Zn	965 d	1706 b	1975 a	1368 c	219 e	198 e

†Values followed by the same letter within a row are not different at the 5% level according to an LSD.

dramatically increased the growth up to 9 Mg ha^{-1} (Fig. 1.). The plants at the highest lime rate had no visual toxicity symptoms and no further increase in growth would be expected from higher lime rates, especially since the plants for the compost were similar to those at the highest lime rate and the soil pH was higher for the compost. This low-Zn soil was adjacent to the high-Zn soil in the field and was supporting normal plants. Evidently the Zn level in this soil was high enough to cause toxicity in the greenhouse where the roots were confined. In the field the roots may have grown below the toxic surface layer giving better plant growth than experienced in the greenhouse where no additional lime was added (control). Other data on the low-Zn soil indicated that at 40 cm depth the total Zn was at background levels (Li, 1996), so plant roots could grow into less toxic layers in the field.

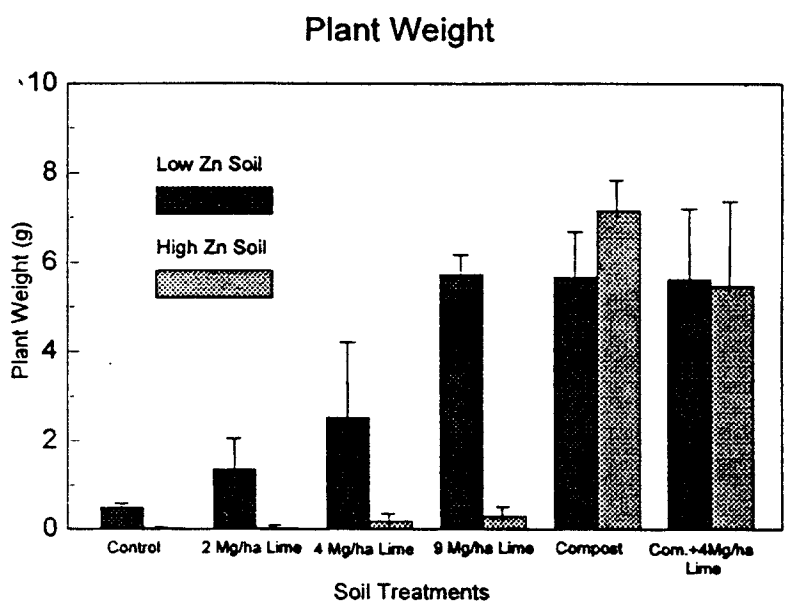

Fig. 1. Plant weights for two soils amended with four lime and two compost treatments. Error bars are for one standard deviation. (Shuman and Li, 1997)

PLANT ZINC

Plant Zn levels for the severely stunted plants grown on the high-Zn soil at the control and the 3 lime rates were variable, but obviously were in a toxic range (Table 2. Shuman and Li, 1997). The control plant Zn values for the high and low Zn soils were similar, but the plant Zn for the high-Zn soil and the 3 lime rates were higher than for the low-Zn soil. This result is unexpected and reveals the problems with analyzing very small, stunted plants which continued to live for the life of the experiment and continued to accumulate Zn during that time. These levels of Zn up to nearly 2000 mg kg^{-1} were very toxic to the plants. Only the compost treatment produced normal plants with Zn below the toxic range of 200-300 mg kg^{-1} (Ohki, 1975). The critical toxic level for cotton is also confirmed by Lee and Page (1967), who found that cotton would grow normally below 200 mg kg^{-1}, grew intermediately at 200 to 250 mg kg^{-1}, and very poorly above 250 mg kg^{-1} leaf Zn. The leaf data here suport the theory that the field problem was Zn toxicity. The lime for the low-Zn soil lowered the Zn in the plants with each increment (Table 2) and produced non-toxic levels at the 9 Mg ha^{-1} rate and for the compost as evidenced by plant growth and by the Zn levels being below the 200 mg kg^{-1} range given by Ohki (1975).

Table 3. Soil pH (1:1, soil:water) for two soils amended with lime or mushroom compost.

Zinc Status	Lime				Compost	Compost + Lime
	Control	2 Mg/ha	4 Mg/ha	9 Mg/ha	67 Mg/ha	67 Mg/ha + 4 Mg/ha
Low Zn	5.39 e†	6.08 f	6.67 c	7.06 b	7.61 a	7.57 a
High Zn	4.89 e	5.45 d	5.82 c	6.26 b	6.84 a	7.03 a

†Values followed by the same letter within a row are not different at the 5% level according to an LSD.

SOIL pH

Lime additions raised soil pH incrementally to near 7.0 for the low-Zn soil but the pH values were lower at similar lime rates for the high-Zn soil (Table 3, Shuman and Li, 1997). The results indicate that the high-Zn soil was more acid to start with (controls) and needed higher amounts of lime to ameliorate the Zn toxicity than the low-Zn soil. Amelioration of the toxicity came at pH levels of ≥7.0 for the low-Zn soil and ≥6.8 for the high-Zn soil for the compost treatments only. These results indicate that for these soils, high pH levels are necessary to ameliorate the Zn toxicity caused by the flue-dust amendment.

Compost treatments raised the pH to higher levels than did the lime at 9 Mg ha^{-1} and gave remarkable increases in growth. Adding lime with the compost did not raise the pH further. The compost may have added plant nutrients to aid plant growth, but the blanket fertilizer would have elimnated any nutrient effects. The pH level for the compost plus lime for the high-Zn soil was higher than for the compost alone, but the values were not statistically significant. It is interesting to note that where no compost was added, 9 Mg ha^{-1} lime that raised the pH to above 7.0 was necessary to ameliorate the Zn toxicity for the low-Zn soil. However, with the compost treatment for the high-Zn soil, the Zn toxicity was ameliorated at a pH level of only 6.8. Thus, it would appear that more than the soil pH was involved in the compost being able to ameliorate the Zn toxicity similar to the results of Mortvedt and Giordano (1975) with sewage sludge. The fact that the toxicity was ameliorated at lower pH by the compost is even more remarkable when the amounts of Zn in the two soils are taken into account with the high-Zn soil having over 4 times the total Zn as the low-Zn soil. Since the plants grew so poorly at the 9 Mg ha^{-1} rate for the high-Zn soil, it would seem that even at a limed pH the same as the compost, the plant growth would not have been comparable.

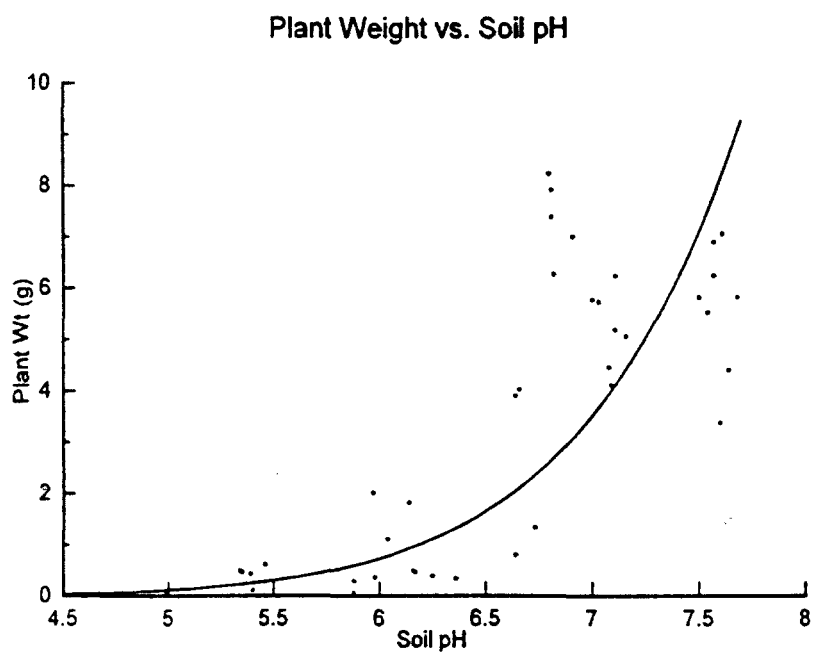

Fig. 2. Plant weight versus soil pH values. (Shuman and Li, 1997)

PLANT WEIGHT VS. SOIL pH

The regression for the plant weights and the soil pH was curvilinear and the best fitting curve was a power or geometric equation (Fig. 2) Plant weights were low at pH values below 6.5. At the higher pH values there were two groups with the highest plant weights being at pH 6.8 for the high-Zn soil with compost alone, and the other group being at pH 7.1 to 7.6, which were the other compost treatments. Thus, the amelioration of the Zn toxicity related to soil pH was fairly clear-cut with the amelioration coming at soil pH values of about 6.8 and above. This is the pH level where Zn would begin to precipitate as $Zn(OH)_2$ and the Zn would be strongly adsorbed in specific sites on clay and organic surfaces (Jahiruddin et al., 1985). Adsorption of Zn greatly increases at high pH values (Shuman, 1975). More Zn would be present in the $Zn(OH)^+$ form than the Zn^{2+} at pH >7 (Lindsay, 1979). Zinc adsorption was increased in a Norfolk soil that is from the same physiographic region as the soil used in the pot experiment at pH 5 and 6, but not at higher pH values (Fig. 3).

PLANT WEIGHT VS. DTPA ZN

Extractable soil Zn should be negatively correlated with plant growth in this toxic situation for suitability in predicting plant toxicity. The DTPA method of Lindsay and Norvell (1978) was successful in predicting Zn toxicity in that the linear correlation coefficients were negative and significant (Fig. 4) The data for the low-Zn soil gave a fairly uniform linear pattern throughout the range of soil pH. The high-Zn soil data, however, formed two groups representing a toxic group and a non-toxic group.

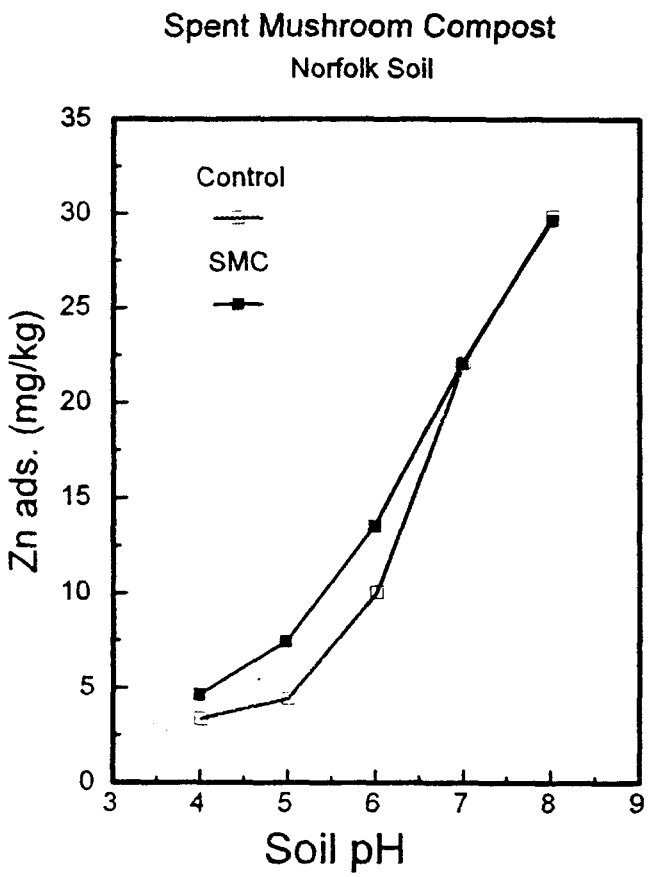

Fig. 3. Effect of spent mushroom compost on Zn adsorption by a Norfolk soil.

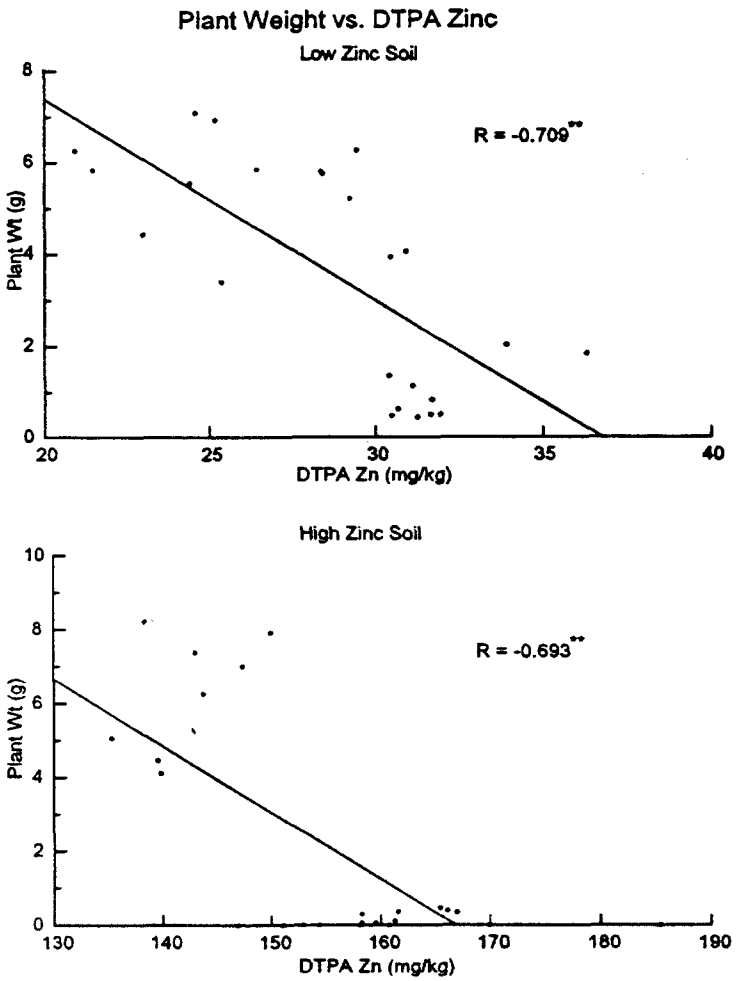

Fig. 4. Plant weight versus DTPA-extractable soil Zn for two soils. (Shuman and Li, 1997)

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A BACKYARD, FORCED AERATION, DIGESTER COMPOSTING SYSTEM CONSISTING OF *The CompostAir®* and *The CompostScreen®*

By

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INTRODUCTION

This paper is written in the style I use in my weekly Daily Times column, monthly Senior Living Newspapers column, and in the original literature I furnished to over 250 people who have taken my class in backyard digester composting. All are titled: "IF YOU CAN COOK? YOU CAN COMPOST!" I have found I am teaching and writing mostly for non-technical "senior citizens" who have the inclination and, more important, the time to attend classes, and also the time to compost.

DEFINITION

Digester composting is simply composting by insuring that a constant supply of warm, moist air penetrate the compost mass at all times to provide a supply of oxygen to aerobic (requiring oxygen to live) soil microorganisms. These microorganisms, mainly bacteria, have simple requirements—CARBON from dead and dried out plants and shrubs, NITROGEN from fresh green plant material, WATER from the same fresh green plant material, and OXYGEN from the forced aeration of the mass—to satisfy their voracious appetites. A properly operating digester composter has a environment similar to a "Joe's Diner" in the Thirties—it's warm, muggy and the ceiling fans are running.

BACKGROUND

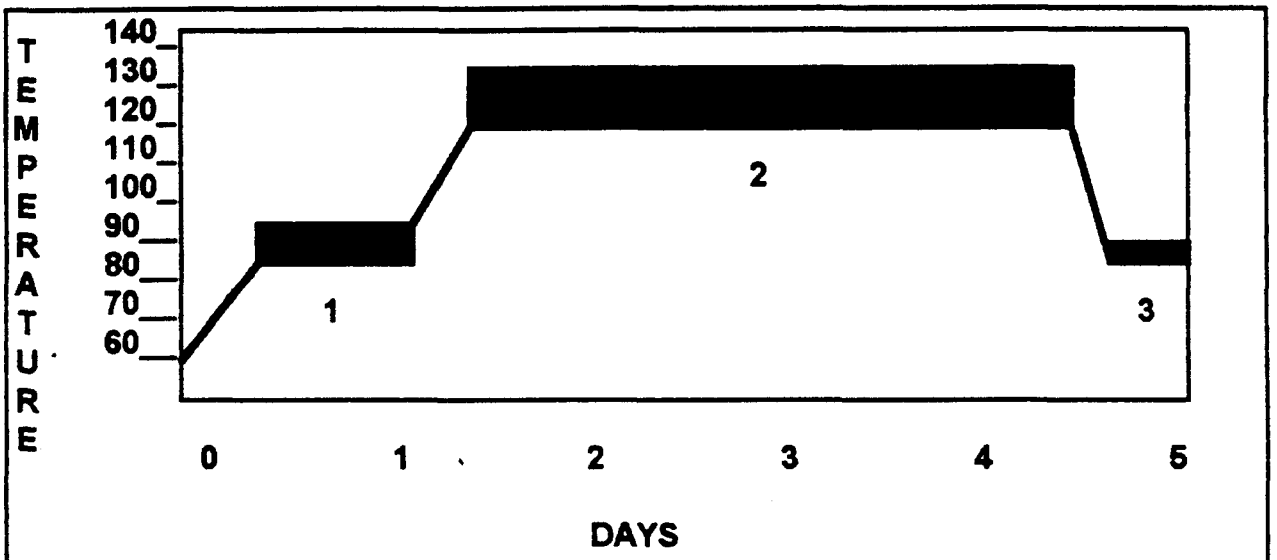
When I left our house in Maryville on a March Saturday in 1995 to attend my first composting class which was sponsored by KEEP BLOUNT BEAUTIFUL, Sue Dawson—Manager, my 82 year old mother had the last word, which was: "Composting smells!". Driving home from the class with my head spinning with bushels and carbon-nitrogen ratios, I decided the first priority would be to eliminate Mom's odor objection to having a composter outside the kitchen door. Thus was eventually born ***The CompostAir***, and later ***The CompostScreen***.

Professionally, I am a retired Mechanical & Environmental Engineer and Troubleshooter. My definition of correct troubleshooting is: keep your eyes and ears open, mouth shut, and take copious notes—until you know what is going on—so the actual problem may be identified and solved. This approach led me to ***The CompostAir***.

If aeration promotes the growth of aerobic bacteria—how could I begin composting, without any odor, using materials around the house? Before I arrived home I decided that my first effort would use: (1) a worn out 32 gallon plastic garbage can that was going to be thrown out; (2) an aquarium vibrator air pump and a 5" diameter air stone (available because of my hobby of raising Tropical fish); and a perforated pizza pan—to both protect the air stone and to distribute the air over the bottom of the garbage can. I began loading and operating ***The CompostAir*** in June of 1995 using standard composting pile lore by layering dead wood, fresh green plants, sprinkling garden soil over the plants, and watering to almost saturation during the layering.

DIGESTER COMPOSTING THEORY AS IT APPLIES TO *The CompostAir*

At outside air temperatures above 60° F the soil microorganisms become active. Finding themselves surrounded by their favorite meal (small pieces of carbon and nitrogen), and an ample and constant supply of fresh air containing oxygen, they begin eating. Dining on the carbon (dead wood) they create heat and carbon dioxide, which increases by convection the air flow throughout the mass. Snacking on the nitrogen (fresh green plants) they first free-up the water (eliminating the standard lore of adding water to the compost mass) and begin converting the plants into humus. Looking at the TEMPERATURE VS DAY Chart below you see that things happen quite fast!



Typical, Average Composting Cycle for *The CompostAir*

CONSTRUCTING *The CompostAir*

Recycle an old wheel-less garbage can or purchase a new one. Soak the 5" diameter air stone in a bowl of water and begin construction:

1. Drill a ¼" diameter hole in the side of the can 1" above the bottom of the can..
2. Drill a ½" diameter hole through the center of the lid (to let out the carbon dioxide).
3. Feed the ¼" air tubing through the hole in the side and pull most of it up to the top on the inside of the can.
4. Connect the air stone to the tubing and then pulling on the tubing outside the can, lower the air stone to the center of the bottom of the can.
5. Connect the air pump to the air stone.
6. Drop in the perforated pizza pan upside down. The pan may be supported by indentations in the bottom of the can or place three 1½" pieces of wooden block into the can. You do not want the pan resting on top of the air stone, restricting air flow only to the center of the can above the air stone.
7. You are now ready to load *The CompostAir*, but *see drawing on Page 5 for cautions and details*.

LOADING *The CompostAir*

Blend equal amounts of small pieces (1½") of dead wood (carbon) and fresh plants (nitrogen) in a wheelbarrow, similar to the way you would toss a salad. The soil clinging to the plant roots will introduce enough microorganisms provided you do not shake it off when pulling the plants. It will require three 5-gallon pails of each to fill *The CompostAir*. Place the lid on the can and plug in the air pump. Once a day, beginning the 2nd day, poke into the

mass through the hole in the lid, to the bottom of the can with a ¼" diameter bamboo stake to insure the air penetrates up through the mass.

This same ¼" diameter bamboo stake, when left sticking into the mass through the hole in the lid, also serves as a "manual" thermometer. Referring to the AVERAGE CYCLE CHART ABOVE, if the stake feels cool to the touch the soil microorganisms in the compost mass are either in the range of warming up (1), or ready for harvest (3), and if it is warm (hot) they are actively feeding (2). Since that is all you really care about then there is actually no real reason to invest 15 to 20 dollars in a compost thermometer!

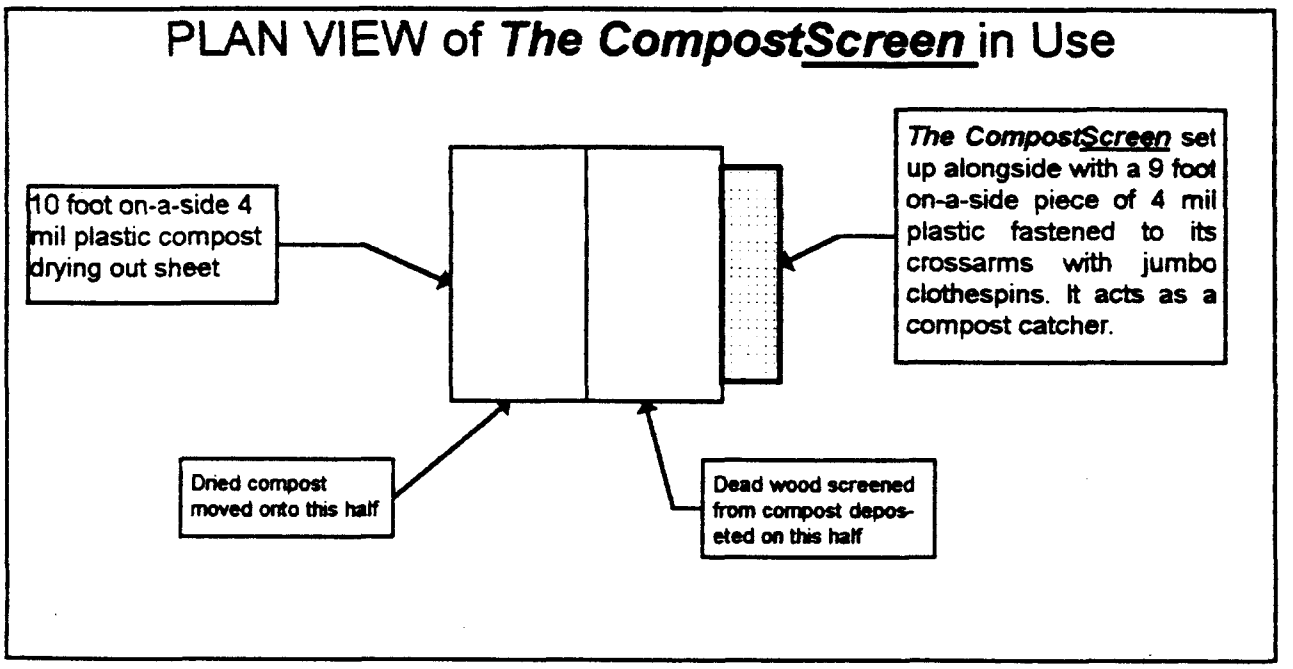
The 4th or 5th day you will find that the mass has pulled away from the side of the can, and dropped halfway down the can. The bamboo stake will feel cool to the touch, meaning the temperature has dropped back down to the 90° range (3). What you now have is about 16 gallons of sopping wet mass containing uneaten dead wood and digested green plants. The fresh green plants have become very wet, mineral rich humus (since none of the water has escaped from the mass), harvested by drying and screening—using ***The CompostScreen***.

DISCUSSION OF *The CompostScreen*

Most current screening methods are completely ludicrous because one is either using a box hung on chains (How do you empty the box without becoming a chiropractor's customer?) or doing the "Chubby Checker Twist" with a hand held box (supporting the weight of the box and material with your back). The drawing for ***The CompostScreen*** on page 6 is self-explanatory, however: (1) Flatten one end of each post, (2) Tighten cable ties with pliers.

OPERATION OF *The CompostScreen*

In the "LOADING ***The CompostAir***" paragraph I stated you had soaking wet material. On a sunny day the material (all 100 plus pounds) is emptied from ***The CompostAir*** onto the center of a section of 4 mil plastic, 10 feet on-a-side, which is then dragged over alongside ***The CompostScreen***, and the material is raked out to dry.



The support structure for the screening box may be temporarily set up within five minutes anywhere on your property. The user is never supporting the weight of the box either while screening or dumping the screened-out deadwood onto the adjacent plastic sheet. In the plan view above you just position the box between the vertical poles and "dump" to the left, at no time supporting any weight. While ***The CompostAir*** will cycle in approximately five days it does not make sense to go through the drying out and screening process unless there are more plants to load for composting.

DISCUSSION OF THE VIBRATOR AIR PUMP— AIR QUANTITY TESTING

Eighty-five percent of the vibrator air pumps manufactured for the aquarium hobby are made by one manufacturer and distributed under various trade names. They use a "small", "medium" and occasionally a "large" diaphragm. They are not rated in cubic inches per minute, but in the number of air stones they will support in different size aquariums. Very unscientific! With over 20 years in the hobby I found that the Challenger 1 and Penn Plex five inch diameter air stone combination gave me the most "bang for the buck" with respect to the amount of air introduced into an aquarium. Since this was combination available at home it is what I tried using in ***The CompostAir***. Larger capacity piston and verylarge diaphragm air pumps only reduced the temperature of the compost mass by evaporative cooling, sending the soil microorganisms back into dormancy. The Challenger 1 aquarium air pump coincidentally provided the optimum air flow through the Penn Plax ASD-L for this application.

ADVANTAGES OF *The CompostAir*

1. Since it is the fastest device available to the home composter it also has the largest capacity by volume to process fresh live garden plant material. My barber's 72 year old mother operates two of them all summer long to process her garden and kitchen waste from a much larger garden than mine.
2. Since ***The CompostAir*** is a closed system and not subject to the drying effect of winds or the over watering of rain, the soil microorganisms eating at their "Joe's Diner" completely digest all of the green plant material. You are not digging for "black gold" just at the center of the pile, as is the case in most composters.
3. Absolutely nothing produces humus richer in minerals since there is no leachate being wasted to the ground as is the case with a standard compost pile.
4. No turning over of the material is required.
5. The weight of material is manageable for senior citizens because it is never lifted
6. Low cost—it can be built in half an hour by anyone for about $30.00. Nothing else on the market comes even close.
7. If you load on a Saturday you can, if it doesn't rain the next Friday and Saturday, spread to dry on Friday and then screen out the humus with ***The Compost Screen*** and reload on Saturday (providing you have fresh plant material to load).

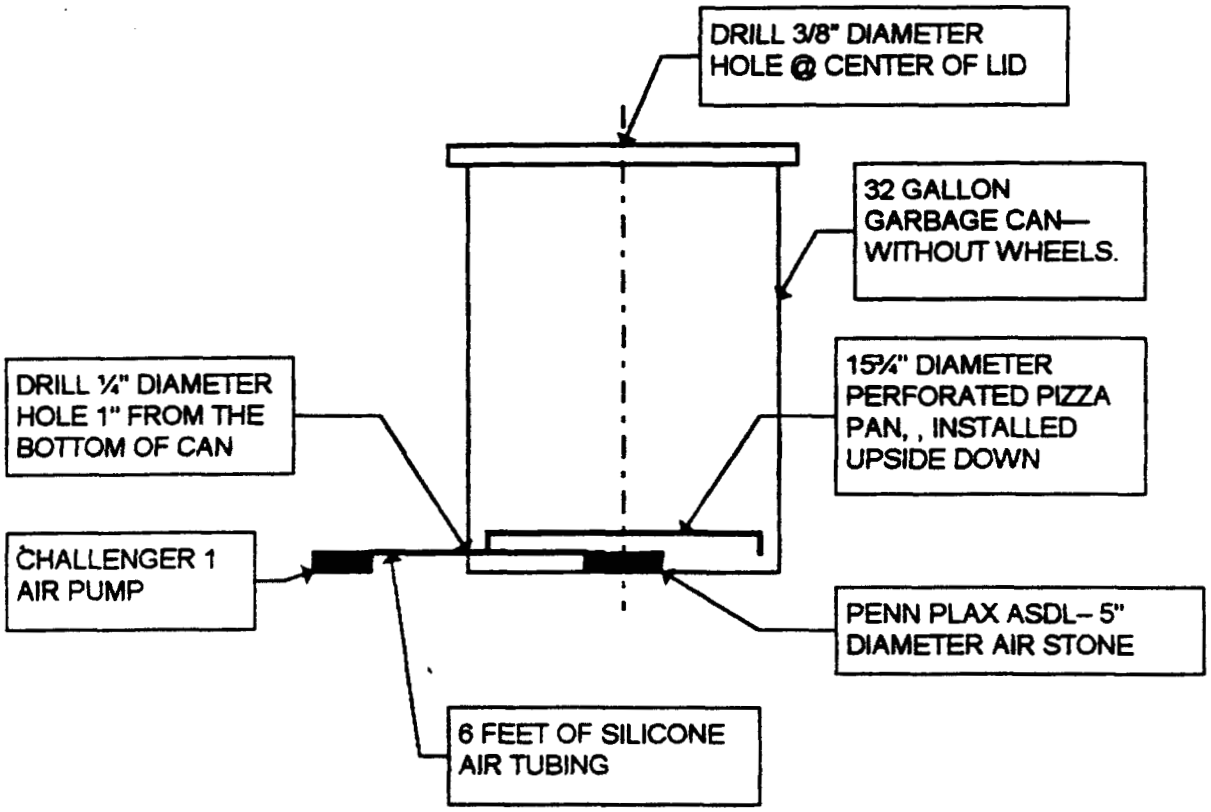
DISADVANTAGES OF *The CompostAir*

1. Because of its short cycle it does not reduce the volume of the carbon materials. I am currently running an experiment that does reduce that volume. I actually do not want to, since my property does not produce enough dead wood in the first place. I usually must supplement using pine bark mini-nuggets.
2. Even if blended in with the dead wood, grass clippings still have a tendency to mat together, shutting off the air flow..
3. It will not short cycle leaves, even when shredded, although as noted in (1) above I am possibly getting there.

SUMMATION

Over 100 of ***The CompostAir*** systems are in use in the Knoxville, TN Metro area. Try it! You'll like it!

Outline Drawing for *The CompostAir*



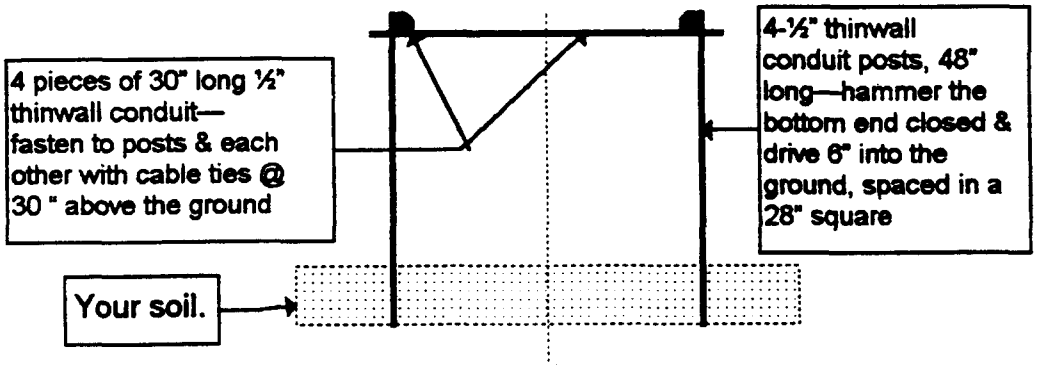
MATERIAL SOURCES—The aquarium items are available from THE MAIL ORDER PET SHOP @ 1-800-366-7387 as:

1. PENN PLAX ASD-L – 5" DIAMETER AIR STONE – ITEM A2818
2. 6 FEET OF SILICONE AIR TUBING – ITEM A5945
3. CHALLENGER 1 AIR PUMP – ITEM A0360
4. EXTRA DIAPHRAGM FOR CHALLENGER 1 – ITEM A0387

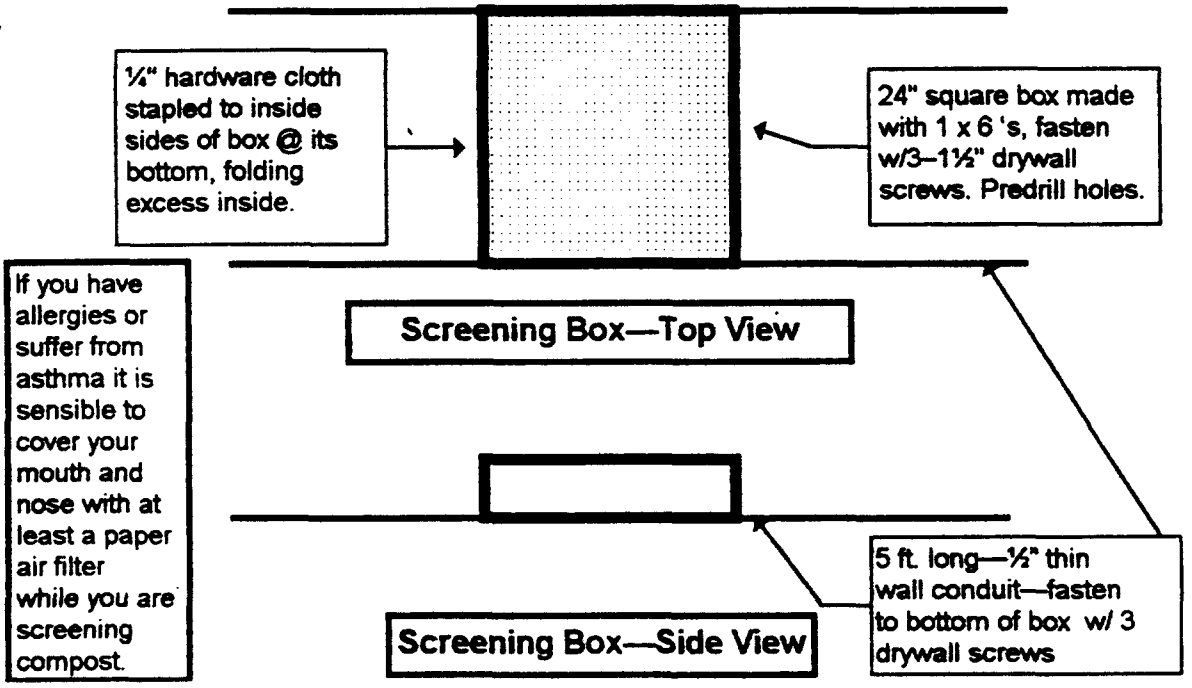
5. THE 15¾" DIAMETER PERFORATED PIZZA PAN – AT YOUR LOCAL DISCOUNT STORE.

NOTES

1. No substitutions permitted on aquarium items. Your local store may offer an "it's just the same" item. It's most often not!
2. Normal aquarium air tubing will bend and crimp.
3. My item number is correct on Item 4 above—their catalog has an error.
4. **CAUTION**—Unplug the air pump at its wall outlet before working on *The CompostAir*. THE AIR PUMP IS NOT U.L. LISTED FOR OUTDOOR USE.
5. The vibrator diaphragm on the Challenger 1 air pump will eventually wear out. I recommend ordering a spare.



Compost Screening Support Frame—Side View



QTY	ITEM
4	10 foot lengths of ½" diameter thinwall conduit
4	24" pieces of 1" x 6" lumber (1" x 8" would be even better)
24	1½" drywall screws
1	bag of 100— 8" nylon cable ties
1	36" square piece of 1/4" hardware cloth—staple inside of the box @ bottom,

Outline Drawing of *The CompostScreen*

EFFECTS OF STOCKING DENSITY AND FEEDING RATE ON VERMICOMPOSTING OF BIOSOLIDS

By

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Abstract: *The double-pronged problem of quantity, and disposal of waste streams from a myriad of industries, is becoming increasingly acute, the world over. The use of earthworms as a waste treatment technique for such wastes is gaining popularity. This method is commonly known as vermicomposting. Compared to conventional microbial composting, vermicomposting produces a product that is more or less homogenous, with desirable aesthetics, with reduced levels of contaminants and tends to hold more nutrients over a longer period, without impacting the environment. Like in other related waste treatment techniques, certain parameters need to be established for the design of efficient and economical vermicomposting systems. Specifically, the focus of this study was to investigate and establish an optimal stocking density and an optimal feeding rate for the vermicomposting of biosolids, with paper mulch provided as bedding. A stocking density of 1.60 kg-worms/m^2 (1 lb-worms/3 ft^2) and a feeding rate of 1.25 kg-feeds/kg-worm/day resulted in the highest bioconversion of the substrate into earthworm biomass while the best vermicompost was obtained at the same stocking density and a feeding rate of 0.75 kg-feeds/kg-worm/day.*

Keywords: Waste Streams, Bioconversion, Environment, Vermicomposting, Stocking Density, Feeding Rate, and Biosolids.

INTRODUCTION

Scientific investigations have established the viability of using earthworms as a treatment technique for numerous waste streams (Hand, et al., 1988; Raymond et al., 1988; Logsdon, 1994; Harris, 1990). The action of earthworms in this process is both physical/mechanical and biochemical. The physical /mechanical processes include: substrate's aeration, mixing, as well as actual grinding, while the biochemical process is effected by microbial decomposition of the substrate in the intestines of the earthworms. These physical/mechanical unit processes usually represent the largest cost associated with traditional microbial composting process. Vermicomposting therefore saves on all these unit operations. Hand et al. (1988), thus defines vermicomposting as a low cost technology system for the processing or treatment of organic wastes.

Also, as opposed to traditional microbial waste treatment, vermicomposting results in bioconversion of the waste streams into two useful products: the earthworm biomass and the vermicompost. The former product can further be processed into proteins (earthworm meal) or high-grade horticultural compost (Phillips, 1988; Sabine, 1988; Fisher, 1988; Edwards and Niederer, 1988). The latter product (vermicompost) is also considered an excellent product since it is homogenous, has desirable aesthetics, has reduced levels of contaminants and tends to hold more nutrients over a longer period, without impacting the environment.

Although the viability of vermicomposting is uncontestable, only a limited amount of work has been done on the actual application. This is especially so with respect to some critical design criteria of vermicomposting facilities. The studies presented herein investigated two such important parameters: the stocking density and the feeding rate.

EXPERIMENTAL DESIGN AND ANALYSIS

Four stocking densities and three feeding levels were investigated. The stocking densities were investigated at 0.80, 1.20, 1.60 and 2.00 kg-worms/m^2 (0.5, 0.75, 1.0 and 1.25 lbs-worms/3-ft^2), while the feeding rates were investigated at 0.75, 1.0 and 1.25 kg-feeds/kg-worm/day. Effects or responses to be investigated were: product stability, worms' biomass, pH and nutrients; N, and P. The treatments or factors of interest were the stocking density and the feeding rate, at the four levels and the three levels given above, respectively. This design fits the classical two-way factorial design. This design saves on resources by efficiently using one worm-bin (a single treatment) to simultaneously provide a replicate for a stocking density and a feeding level. A two-way analysis of variance was therefore conducted for each response being studied.

MATERIALS AND METHODS

Experiments were performed in worm-bins measuring 0.56 m X 0.38 m X 0.25 m (Length* Breadth* Depth). This provided 0.21 m^2 of exposed top surface. Known weights of earthworms (*Eisenia foetida*), commonly known as red wigglers were introduced into each of the respective similar worm-bins, to provide the desired stocking densities. To effect the four desired stocking densities mentioned above, earthworms live-biomass loading were 0.17 kg, 0.26 kg, 0.34 kg, and 0.42 kg, respectively. Three replicates for each of the four stocking densities were made. Each of the three replicates for every stocking density, were in turn, respectively, fed at 0.75, 1.0 and 1.25 kg-feeds/kg-worm/day.

Initially, all the systems were fed for two weeks and thereafter fed continuously on a weekly basis until the seventh week. During the first two weeks, feeds consisted of 4 parts biosolids to 3 parts paper mulch, by dry weight. The paper mulch was used to provide a bedding for the earthworms as well as a carbon supplement. The rest of the weekly feeds consisted entirely of biosolids. The experiments were conducted in an environment whose temperature ranged between 25±6^0 C. The substrate material were maintained moist by spraying/sprinkling the surface with water every two days using a spray can.

At every feeding, the following parameters were determined: moisture content of the feed material, pH, the volatile solids and the ash contents. These analyses were carried out immediately after the samples were obtained and where not possible, then the samples were refrigerated at 4 ^{0}C to minimize microbiological decomposition, until the analyses were done.

Solids matter were determined as residue on drying at 80 ^{0}C for 23 hours (APHA, 1989). Volatile solids were obtained by ashing the dried sample at 550 ^{0}C for 8.5 hrs (APHA, 1989). Determination of pH was made potentiometrically in a 1:10 suspension of the sample in de-ionized water, a modification of the procedure adopted from Ehart and Brian (1997). This suspension was placed on a mechanical shaker at 230 rpm for 30 minutes prior to pH measurement. In the Ehart and Brian procedure, a 0.01-M calcium chloride solution was used instead of de-ionized water. Determinations of nutrients (N and P) were made in an independent laboratory, using a Perkin-Elmer total C, N, S-analyzer. For these determinations, representative samples were dried at 80 ^{0}C for 23 hours (APHA, 1989) and then ground to provide a homogeneous sample. To obtain water extracts, 4 g of this homogenous sample was placed in 60 cm^3 de-ionized water and the mixture placed on a mechanical shaker for 30 minutes. The mixture was then centrifuged at 4000 rpm for 10 minutes and the supernatant filtered through a number 40 Whatman filter paper to obtain the water extracts.

The experiments were terminated at the end of the eighth week after which the worms were separated from vermicompost and total biomass of the worms determined. Earthworm biomass growth was taken as the increase in total earthworm biomass collected from vermicomposted material and the bedding. Values were determined as live weight after hand sorting and removal of all extraneous material. The vermicompost was analyzed for the volatile solids, ash content, moisture content, pH, and the nutrients (N and P) using the methods already described. Vermicompost in this work refers to a mix of the worms castings, digested, as well as undigested biosolids and paper mulch.

RESULTS AND DISCUSSIONS

The feedstock components' parameters were individually determined (Table 1) and then combined on a weighted basis to provide a single representative feedstock parameter. The feedstock had a weighted N-content of 3.67%, a weighted P-content of 1.52%, a weighted pH of 7.47 and a weighted VS of 76%. Water extracts parameters from the individual feedstock's components were also determined individually and later combined on a weighted basis to parameterize the extracts. For the water extracts, the N-content was 1.03% while the P-content was 0.13%. The nutrient measurements were all on dry basis. In all the worm bins, moisture was maintained at 76.3±1.6-% (w.b).

Table 1. Feedstock Components' Parameters

Component	%N	%P	%VS	pH
Biosolids	6.02	2.51	70	7.38
Paper Mulch	0.07	0.01	86	7.61
Biosolid Water Extract	1.69	0.21		
Paper Mulch Water Extract	0.04	0.00		

Tables 2 and 3, respectively, present the percent change in earthworm biomass and the pair-wise comparisons of the mean percent change in earthworm biomass, with respect to the earthworm densities and feeding levels. The results from the two-way analysis of variance (ANOVA) procedure performed on data displayed in table 2 showed that, both the earthworm stocking densities and the feed levels resulted in significantly different earthworm biomass growth. The pair-wise comparisons (T-tests) based on Least Significant Difference (LSD) method further established that, no significant difference (at α=0.05) in earthworm biomass was observed between: 1.20 kg-worms/m^2 and 1.60 kg-worms/m^2; and between: 0.80 kg-worms/m^2 and 1.20 kg-worms/m^2. The feed levels that did not result in significantly different earthworm biomass growth were at 0.75 and 1.0 kg-feed/kg-worm/day.

However, on the absolute scale, the differences are perhaps even more succinct. All the stocking densities (except, 1.20 kg-worms/m^2 and 1.60 kg-worms/m^2) and feeding levels resulted in substantial differences in the growth of earthworm biomass. The percent growth in earthworm biomass increased with stocking densities but dropped sharply at the 2.00 kg-worms/m^2 stocking density. Datar et al. (1997), investigated effect of stocking density at three levels: 1.11, 1.85, and 2.59 kg-worms/m^2, of *Eudrilus Eugeniae* (African Night Crawler) on the vermicomposting of Municipal Solid Waste (MSW). That study showed a general increase in the earthworm biomass but the increase decreased with the increase in stocking density. However, since the feed rate was also a variable, this makes it difficult to compare those studies with the studies presented here. Dominguez and Edwards (1997) also conducted a similar study on *Eisenia andrei* but on much smaller plastic flask digesters, and with pig manure. In their studies, the increase in earthworm biomass increased with stocking density. They attributed this phenomenon to earlier sexual maturity of the earthworm at the higher stocking densities. Suffice it to say that, the stocking density is an important parameter in the growth of earthworm biomass, independent of the species.

The three feed levels investigated, all seem to have resulted in a significant growth in earthworm biomass. The mean change in earthworm biomass increased with increasing feeding levels, in general (Table 3). These results suggest that, a stocking density of 1.60 kg-worms/m^2 and a feeding level of 1.25 times the stocking density, yields the highest earthworm biomass growth. It is important to note that, at 1.0 kg-feed/kg-worm/day, and 1.25 kg-feed/kg-worm/day, feeding levels, a substantial amount of substrate that was still intact/undigested was observed at the end of the experiment.

Table 2: Percent Change in Earthworm Live-weight

Earthworm Density (kg-worms/m^2)	Feed Levels (kg-feeds/kg-Earthworm/day)		
	0.75	1.0	1.25
0.80	-21.18	-19.24	138.47
1.20	8.63	47.80, 41.06	83.02, 174.24
1.60	79.12	50.41	109.24
2.00	-66.80	13.86	9.04

Table 3. Pair-wise Comparisons: Earthworm Biomass Change

Earthworm Density (kg-worms/m^2)	Mean Earthworm Biomass Change	Feed Level (kg-feeds/kg-worm/day)	Mean Earthworm Biomass Change
0.80	32.68^a	0.75	-0.06^a
1.20	75.64^b	1.0	22.27^a
1.60	79.59^b	1.25	107.75^b
2.00	-14.63^c		

^{a,b,c,1,2} Means with the same letter were not significantly different at α=0.05 level.

A two-way ANOVA procedure conducted on results presented in Table 4 showed that, the different earthworm densities produced significantly different volatile solids (VS) reductions, while the different feeding rates did not result in significantly different volatile solids reductions. This indicates some baseline conversion rate with respect to worm density. Table 5 presents the percent mean reductions in volatile solids and the pair-wise comparisons based on LSD method. Earthworm density at 1.60 kg/m^2 resulted in the highest reduction in the volatile solids. This would be expected, since this

Table 4. VS Reduction (Percent)

Earthworm Density (kg-worms/m^2)	Feed Levels (kg-feeds/kg-worm/day)		
	0.75	1.0	1.25
	11.33	12.18	12.12
0.80	11.42	14.16	12.32
	10.44	10.10	10.24
1.20	12.62	12.33,10.53	11.44,12.46
	10.41	12.92,11.40	10.07,12.84
	10.81	9.38,10.36	12.68,13.01
1.60	12.21	12.68	13.32
	12.57	13.44	12.92
	12.08	13.85	13.76
2.00	11.19	12.26	9.72
	10.50	13.04	8.46
	10.12	10.13	6.41

density also resulted in the highest growth of earthworm biomass. The reduction in VS did not significantly vary with substrate's feeding rate. But as previously noted, the1.0 kg-feed/kg-worm/day and the1.25 kg-feed/kg-worm/day feeding levels, had a substantial amount of substrate that was still intact at the end of experiment. For the purpose of treatment of the biosolids therefore, a stocking density of 1.60 kg-worm/m^2 and a feeding rate of 0.75 kg-feed/kg-worm/day, was found to be optimal.

Table 5. Pair-wise Comparisons: VS Reduction (Percent)

Earthworm Density (kg/m^2)	Mean % VS Reduction	Feed Level (kg/kg-worm/day)	Mean % VS Reduction
0.80	11.59^a	0.75	11.30^a
1.20	11.38^a	1.0	11.82^a
1.60	12.98^b	1.25	11.48^a
2.00	10.20^c		

^{a,b,c,a}Means with the same letter were not significantly different at α=0.05 level.

The pH of the vermicompost is presented in Table 6. ANOVA indicated that, the pH of the vermicompost significantly differed with both the stocking densities and the feeding rates. In general, there was a shift towards acidic conditions from the initial near neutral pH (7.47) of the substrate. The shifts appear to be directly related to the reductions in volatile solids and to the growth of earthworm biomass. The larger the increase in biomass growth, the greater the reduction in volatile solids, the more the shift towards the acidic situation. These results however contradict an observation from the earlier work of Datar et al (1997), whereby, the shift in pH was found to be in the opposite direction, and increasing with both worm density and process time. The pH shift towards acidic conditions is believed to occur because of the resulting higher mineralization of the nitrogen, and phosphorus into nitrites/nitrates and the orthophosphates, respectively. This pH shift could also be attributed to the bioconversion of the organic material into other various intermediate species of organic acids, which were neither qualified nor quantified in this study. It is also important to note that, the pH shift is not only dynamic but is also substrate dependent. Further processing of the acidic intermediate products, as well as assimilation of the resulting acidic species will have the pH shift reversing. A different substrate could result in different intermediate species and hence portray a different behavior in pH shift.

Table 6. Vermicompost pH

Earthworm Density (kg-worms/m^2)	Feed Levels (kg-feeds/kg-worm/day)		
	0.75	1.0	1.25
	6.44	6.79	5.33
0.80	6.30	7.17	5.70
	6.40	6.75	6.56
	5.67	5.45,5.45	5.46,5.70
1.20	5.78	6.01,5.11	5.72,5.32
	5.83	5.19,5.38	5.36,5.33
	5.82	5.42	5.80
1.60	5.75	5.64	5.63
	6.13	5.85	5.83
	6.36	6.16	6.19
2.00	6.98	5.94	6.27
	6.61	7.10	5.92

Table 7. Pair-wise Comparisons: Vermicompost pH

Earthworm Density (kg-worms/m^2)	Mean Vermicompost pH	Feed Level (kg-feeds/kg-worm/day)	Mean Vermicompost pH
0.80	6.40[a]	0.75	6.17[a]
1.20	5.56[b]	1.0	6.10[a,b]
1.60	5.76[b]	1.25	5.82[b]
2.00	6.39[a]		

[a,b,c,a]Means with the same letter were not significantly different at α=0.05 level.

Tables 8 and 9 summarize the results of both the percent decrease in total solids and total bulk weight. The mean percent decrease in total solids, with respect to both the earthworm densities and the feeding rates, ranged from 33 to 42% while the total bulk weight decrease ranged between 22 and 33%. On analyzing the means displayed in Table 9 for any variation (ANOVA), only total solids (TS) reduction varied significantly with earthworm density. In general, the percent reduction in TS increased with an increase in earthworm density. These results are similar to those of studies conducted by Datar et al. (1997), on vermicomposting of Municipal Solid Waste (MSW). Arguably, these percentage reductions in both the TS and the bulk weight results in substantially lower handling and transport costs of the resulting product than the original raw substrate.

Table 8. TS and Total Weight Reduction (Percent)

Earthworm Density (kg-worms/m^2)	Feed Levels (kg-feeds/kg-worm/day)					
	0.75		1.0		1.25	
	TS	Total wt	TS	Total wt	TS	Total wt
0.80	31.48	25.92	34.08	18.50	35.77	22.56
1.20	40.56	22.73	32.74	18.91	39.63	25.84
			36.08	25.16	40.87	26.63
1.60	34.72	28.37	41.63	36.79	40.75	29.99
2.00	41.11	34.54	42.11	25.98	41.10	34.93

Table 9. Pair-wise Comparisons: TS and Total Weight Reduction(Percent)

Earthworm Density (kg-worms/m^2)	Mean % Reduction		Feed Level (kg-feeds/kg-worm/day)	Mean % Reduction	
	TS	Total wt		TS	Total wt
0.80	33.78[a]	22.33[a]	0.75	36.97[a]	28.64[a]
1.20	39.41[a,b]	23.67[a]	1.0	38.06[a]	25.83[a]
1.60	39.03[a,b]	31.72[a]	1.25	39.47[a]	28.43[a]
2.00	41.44[b]	32.82[a]			

[a,b,c,a]Means with the same letter were not significantly different at α=0.05 level.

Tables 10 to 13 show the contents of the nutrients; nitrogen and phosphorus, in the vermicompost product and water extracts from the vermicompost, as well as the respective results of statistical analyses. A statistical ANOVA performed on the data showed that, for nitrogen, it is only the soluble N that did not vary significantly (at α=0.05) with the earthworm density. For P, ANOVA showed no significant variation amongst either the four stocking densities or amongst the three feeding levels, investigated.

Although, the percent concentration of N (with respect to TS) remained the same in the vermicompost as in the feedstock, the total absolute amount decreased in parallel with the decrease in the TS during the process. On the other hand, the concentration of P increased in the vermicompost by between 14% and 39%, indicating that, the absolute amount of P did not substantially change during the vermicomposting. These results suggest that N and not P, was either taken up and held in the worms' tissues or volatized. A look at the soluble portions of the two nutrients indicate that, soluble N was reduced by 35 to 50%, while the soluble P remained approximately the same. In this case, the potential environment impact from N in the vermicompost was substantially alleviated.

CONCLUSIONS

For the bioconversion of biosolids into earthworm biomass, a stocking density of 1.60 kg-worm/m^2 at a feeding rate of 1.25 kg-feed/kg-worm/day seems the optimal combination while for the production of vermicompost, the same stocking density at a feeding rate of 0.75 kg-feed/kg-worm/day resulted in completely digested vermicompost. For all the stocking densities and feeding levels investigated in this study, substantial reduction of both the TS and total bulk weights were obtained, ranging from 22 to 42%. This translates into reduced handling and transport costs of the resulting product as opposed to the original raw substrate. The vermicomposting process not only maintained the percent N-content in the product but also substantially reduced the soluble portion, thus mitigating its impact on the environment. However, even after 8 weeks into the process, the reduction in VS was still low (at approximately 12%), meaning that the material was still not stable and continued treatment was perhaps desirable.

Table 10. Total N and Total P in Vermicompost

Earthworm Density (kg-worms/m^2)	Feed Levels (kg-feeds/kg-worm/day)					
	0.75		1.0		1.25	
	N	P	N	P	N	P
0.80	3.99	2.13	3.84	2.16	3.44	1.99
	4.10	1.60	3.62	1.60	3.88	0.94
1.20	3.89	1.81	3.60,3.61	1.97,1.73	3.52,2.94	2.18,2.11
	3.49	2.12	3.56,3.11	1.95,1.80	3.64,3.83	2.07,1.98
1.60	3.74	2.24	3.99	2.27	3.78	2.22
	4.00	2.00	3.64	1.94	3.24	2.03
2.00	3.72	2.11	3.80	2.03	3.58	2.09
	4.20	2.12	3.30	1.84	3.31	1.95

Table 11. Pair-wise Comparisons: Total N and Total P in Vermicompost (Percent)

Earthworm Density (kg-worms/m^2)	Mean Percent		Feed Level (kg-feeds/kg-worm/day)	Mean Percent	
	N	P		N	P
0.80	3.81[a]	1.74[a]	0.75	3.89[a]	2.02[a]
1.20	3.56[b]	1.98[a]	1.0	3.63[b]	1.93[a]
1.60	3.73[a,b]	2.12[a,b]	1.25	3.54[b]	1.95[a]
2.00	3.65[a,b]	2.02[a]			

[a,b,c,a] Means with the same letter were not significantly different at α=0.05 level.

Table 12. Soluble Nitrogen and Phosphorus in Vermicompost (Percent)

Earthworm Density (kg-worms/m^2)	Feed Levels (kg-feeds/kg-worm/day)					
	0.75		1.0		1.25	
	N	P	N	P	N	P
1.80	0.72	0.13	0.51	0.17	0.55	0.14
1.20	0.59	0.13	0.49	0.14	0.39	0.08
			0.40	0.17	0.60	0.15
1.60	0.69	0.17	0.65	0.13	0.48	0.17
2.00	0.63	0.21	0.57	0.14	0.52	0.15

Table 13. Pair-wise Comparisons: Soluble N and P in Vermicompost (Percent)

Earthworm Density (kg-worms/m^2)	Mean Percent		Feed Level (kg-feeds/kg-worm/day)	Mean Percent	
	N	P		N	P
0.80	0.59[a]	0.15[a]	0.75	0.66[a]	0.16[a]
1.20	0.51[a]	0.14[a]	1.0	0.54[b]	0.15[a]
1.60	0.61[a]	0.16[a]	1.25	0.52[b]	0.14[a]
2.00	0.57[a]	0.17[a]			

[a,b,c,a] Means with the same letter were not significantly different at α=0.05 level.

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