Contaminated Soil Composting: Amendment Selection and Process Monitoring

FINAL REPORT

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SECTION 1
EXECUTIVE SUMMARY

Composting of soil that has been contaminated with TNT, RDX and HMX requires selection and adjustment of source ingredients in order to result in a successful process. Compostable source materials are likely to be required in large quantities and therefore a suitable and economic selection process is needed.

Woods End Research Laboratory conducted a series of tests and pilot trials in order to develop an amendment selection procedure and a means to optimize the soil inclusion rates. The basis for this study was the field composting pilot trials conducted at the Umatilla Depot Activity (UMDA) site by Roy F. Weston, Inc. (Weston, 1991; Weston, 1993). The strategy for amendment selection is to: identify and analyze mixed ingredients from a region; evaluate the qualities of individual materials and the impact of various amendment mixtures on soil rate, and the impact of the process technology on compost microbiology.

Results of the compost amendment survey demonstrated that a diverse range of material was available within a 60 mile radius of the compost site. Manure materials varied widely in analytical traits, as did food processing residues. There was less variability with hay and feeds and still less with wood products. The expected variability by season and year must be taken into account when formulating compost recipes. The most important traits selected for were C:N (carbon:nitrogen) ratio, texture and respiration potential.

Laboratory trials using the carbon-dioxide respiration method revealed that materials like food-processing residues had very high respiration potentials and could be used to favorably influence the composting process in terms of rate of decomposition and heat attained. Manures like poultry which were readily available performed well but induced rapid ammonification at high inclusion rates and were therefore diluted with dairy manure. Sawdust was a reliable source of organic carbon and was important to dry the relatively moist food and manure ingredients.

Optimization trials demonstrated the ability of favorable compost mixes to carry soil loads up to 30% by volume without detracting from quality. A special adiabatic bench-scale unit was tested and successfully predicted the differential heating potential of the different blends with soils. Compost porosity tests revealed that textural integrity was significantly reduced with windrow turning, and was diminished to low levels by normal compaction in compost piles.

Compost monitoring methods, which included microbiological screening, did not indicate significant differences within treatments of compost seeding trials or when comparing aeration technologies. Screening results found large populations of aerobic and facultative anaerobic bacteria in all of the composts. Although reduced aeration initially resulted in production of fermentative compounds, including volatile organic acids, they disappeared rapidly after 2 to 3-weeks of composting. Bacterial tests indicated only very low counts of obligate anaerobes despite low O_2 readings in field tests. Thus, compost microbiology tests confirmed the diversity and resiliency of the compost process used.

SECTION 2
INTRODUCTION

Several munitions sites throughout the United States have sediment lagoons contaminated with trinitrotoluene (TNT), various nitramine explosives (HDX, RDX, or Tetryl), or with nitrocellulose propellants (Bongiovanni et al., 1984; Rajat et al., 1991). A variety of technologies have been proposed for site decontamination and restoration. Among these, biological remediation focuses on microbiologically enhanced degradation of explosives contaminated soils. The interest in biological approaches dates from about 1979 (Suler, 1979; Smith et al., 1980; Isbister et al., 1982; Doyle et al., 1986; Weston, 1988; Weston, 1993).

Biologically induced degradation has been demonstrated in laboratory composts, greenhouses and in pure culture, at rates which are consistent with microbial respiration in those systems. For example, white rot fungus, *Phanerochaete chrysosporium*, has been shown to degrade TNT and RDX in pure culture (Fernando and Steven, 1990) as it has also been demonstrated to decompose PAHs (Qiu Xiujin and McFarland, 1991; McFarland et al., 1989). Apparently, the degradation mechanism is largely an oxidative process. The anaerobic removal of TNT has also been demonstrated (Boopathy, 1993).

Previous and mostly earlier approaches to field remediation of explosives contaminated soils have focused on a variety of feasible technologies: incineration, alkaline hydrolysis, aqueous thermal decomposition, ultraviolet radiation, land-farming and composting (Noss and Chyrek, 1983-4; Rajat et al., 1991). Incineration is an expensive technology, although complete oxidation is theoretically possible. Alkaline hydrolysis is an acceptable process for nitrocellulose degradation. In land-farming the degradation rates may be slow (Weston, 1985). Composting has been thought suitable for lagoon sediment highly contaminated with TNT or RDX if aerobic, thermophilic conditions are used (Doyle et al., 1982).

The composting approach emphasizes an enhanced milieu for microbial growth with the idea that the greater populations and higher turnover rates will induce more rapid, or more complete, or both, forms of degradation or humification. Theoretical advantages in the composting procedure include the aerobic, oxidative nature of the process which encourages mineralization and its apparent resistance to the toxic effects of hazardous wastes. However, composting requires substantial amounts of supplemental organic materials to provide the appropriate environment for high-rate decomposition. Furthermore, composting requires material-specific management and monitoring.

This report concerns specific aspects of identifying and preparing suitable composting amendment mixtures and the scientific monitoring required to properly manage the composting process (Brinton & Droffner, 1994).

SECTION 3
THE COMPOSTING PROCESS

Composting differs essentially from other biodegradation approaches such as solid phase bioremediation in the following ways:

- The organic content is raised to high levels by addition of other ingredients;
- Rapid microbial combustion induces heat formation causing thermophilic microorganisms to multiply.
- The process is managed by controlled additions of air and moisture, and sometimes by frequent turning of the piles.

While the principle of composting is simple, the actuality of composting contaminated soils is more complex. It involves balancing large amounts of variable but compatible ingredients and management of moisture and oxygen levels which are constantly changing over time. Furthermore, the large increase of density and loss of pore space resulting from soil inclusion may adversely influence the composting outcome, in particular with regard to whether heating can be sustained and to what extent an aerobic environment is maintained. Thus, gross physical qualities must be manipulated and managed for physical, chemical and biological reasons.

It is estimated that contaminated soils at the Umatilla Depot Activity site contain approximately 2% organic matter (including the TNT, HMX, RDX and other trace explosives); actual analysis by Woods End Laboratory of uncontaminated soil around the washout lagoons showed 1.2% organic carbon, or about 2% organic matter[1]. With such a small amount of metabolizable organic content, the likelihood of building up a sufficiently large microbial population to effect thermophilic degradation at high soil-loading rates is certainly questionable. Furthermore, there is a need to manage the process for successful biotransformation since various pathways including both step-wise reduction and oxidative mechanisms may be involved in TNT degradation, but are not clearly understood. Consequently, a more involved process of selection, management and quality control are needed.

1. Organic-C x 1.72 = Organic Matter (Page, 1982)

Since composting implies a diverse set of factors of both a physical and biological nature, some definitions are in order. Composting is a process, in fact, where a variety of unicellular organisms, predominantly bacteria, degrade organic wastes. The bacteria that accomplish this degradation include mostly organisms with the ability to use oxygen as a final electron acceptor (aerobic). However, facultative anaerobes, which are capable of the above but also produce metabolic by-products, are also found in large numbers. Other organisms including obligate anaerobes (true anaerobes) may also be present in composts but generally perish or sporulate in the presence of oxygen. Finally, a group of aerotolerant anaerobic bacteria exist which are capable of growing in the presence of oxygen but produce metabolic by-products without oxygen being used as an electron acceptor.

Other aspects of the definition of composting as aerobic are complicated for biochemical reasons. For example, mineralization is defined as production of CO_2 and water from organic compounds and is effected only by aerobes. However, heterofermentative activity by several organisms including anaerobes also produces CO_2 in addition to compounds like CH_4, ketones, organic acids and alcohol (Moat, 1979). Theoretically, degradation of ^{14}C-TNT could result in labeled CO_2 without aerobic mineralization having been involved, but under circumstances not considered to be anaerobic. Thus, theoretically, TNT can be degraded not only under conditions that are aerobic or anaerobic but also simultaneously, in view of the varying microenvironments which apparently exist in composts. Presently, very few studies are available which would elucidate these interactions.

SECTION 4
BACKGROUND OF TNT COMPOSTING

Efforts to compost explosive and propellant contaminated soils at the field scale were initiated in projects at the Louisiana Army Ammunition Plant (LAAP) and the Badger Army Ammunition Plant (BAAP) in 1987 through 1989. The LAAP and BAAP projects focused on demonstrating the technical viability of the composting approach. Both involved the static-pile layout similar to the Beltsville Method (US EPA Manual, 1980). The simple layout utilized standardized ingredients such as commercial grade alfalfa and horse-feed, time-controlled aeration and simple checks on process quality via temperature measurements and moisture control. Additionally, the LAAP trials incorporated a comparison of high temperature (55^{o}C) "thermophilic" composting and medium-temperature (30–45^{o}C) "mesophilic" ranges. A quantitative model for deriving compost-mix formulas was not used nor was process monitoring included beyond temperature and moisture checking. Furthermore, as cost analysis based upon these studies revealed the soil-fraction used in composting is the most important factor controlling overall economics (Weston, 1989b), the need existed to optimize amendment selection to reduce their cost.

The UMDA composting projects expanded on the scope of previous work by adding an optimization procedure to determine appropriate compost mixtures from local available resources, as well as a monitoring model to describe the composting process. In addition, mechanically agitated in-vessel (Weston, 1990) and windrow composting (Weston, 1992) technologies were evaluated. The objectives stated for the Umatilla studies (Weston, 1991; Weston, 1993) which specifically involve this report include:

- Selection of optimal carbon sources and bulking agents;
- Determination of the highest loading rate of soil applicable to static pile and mechanically agitated in-vessel technology;
- Comparison of performance of mechanically agitated in-vessel vs. static pile technology;

- Evaluation of transformation rates in relation to augmenting with compost seed and control of operating parameters such as turning frequency and aeration rate;
- Determination of optimization of environmental parameters such as moisture, temperature, pH, and oxygen content.

SECTION 5
SITE AND PROJECT LAYOUT

The Umatilla Depot Activity (UMDA) compost project layout has been described in other reports (Weston, 1990; Weston, 1991). The site is located in a semi-arid environment on about 20,000 acres in Hermiston, Oregon.

In 1990 USAEC conducted an optimization field study to test two types of composting systems (Weston, 1990). These systems included:

- Aerated static pile tanks with positive flow aeration and temperature feedback control;
- Mechanically Agitated In-Vessel (Fairfield) tank digester for mixed composting.

The objective was to compare the two-systems where variables included different soil loading rates, different compost recipes and addition of compost inoculants (Weston, 1991).

In preparation for the composting project Woods End Research Laboratory was contracted to develop suitable compost recipes with source ingredients found in the area of the Umatilla base. The assumption was that the economics and versatility of explosives composting could be improved by developing a materials selection and compost recipe model suitable for use at this base, and also any other base, in relation to the region.

In order to satisfy the need to optimize compost recipes, several steps were needed, among them:

- Develop a list of regional agricultural activities which influence availability of compost source materials;
- Secure samples of pre-selected materials and perform laboratory analyses to fully characterize them;
- Develop model recipes and pre-test in bench-scale pilot setups before full-sale selection and implementation.

After the amendment selection process was completed, a series of steps were taken to address the testing and implementation of the chosen recipes:

- Bench-scale monitoring of compost test mix respiration;
- Design and construction of an adiabatic composter for bench scale tests in order to pre-determine efficacy of mixtures.

At the completion of this phase and start-up of the composting process, additional steps were taken to fulfill the need to monitor the process and evaluate it microbiologically:

- Compost process monitoring protocol to establish composting performance;
- Microbiological parameters to determine efficacy of various treatments.

SECTION 6
INVENTORY OF SOURCE MATERIALS

A composting project which does not rely on commercially purchased, standardized ingredients must be able to efficiently evaluate and assess local resources as replacements. The purpose of this study is to report on the resource inventory protocol developed for the UMDA study by Woods End. The compost project ultimately utilized regional-available materials at a significant cost savings to the project (Weston, 1991).

An inventory was made of agricultural and food-industry activities likely to produce organic residues within a 50–100 mile radius of the Hermiston site (see Table 6-1 and Figure 6-1). The list of potential ingredients was compiled and a testing protocol established to screen these materials. Samples were obtained and Woods End developed data for each of the potential compost ingredients. Following this, suitable materials were chosen for bench-scale testing. The following sections describe this process.

The Oregon Department of Agriculture (DoA) was contacted to obtain published information on agricultural activities (Oregon Dept. of Agriculture, 1989). Woods End and Weston evaluated the listed farm practices and visited the region to follow-up the report and identify the typical residues. Table 6-1 gives a compilation of potentially compostable materials identified through this process.

The regional evaluation identified agricultural and forestry by-products including fresh materials and waste products which are potential candidates for inclusion in composting. The data indicated that many of the ingredients are available within 10 miles of the Umatilla Depot Activity base, while some key ingredients are as far as 80 miles either east or west.

While the study identified other wastes, they were further distant than about 80 miles, at which point hauling costs rise steeply. Traveling beyond these distances may impose excessively high transportation costs. For reference, the city of Portland is 180 miles away. Sewage sludge biosolids were not included in the survey. These biosolids are certainly available in the local region. In at least one previous research trial, however, composting contaminated soil with a sludge/woodchip blend gave poor results (Doyle et al., 1986). Additionally, there are potential disadvantages to using sludges, including odor, pathogens, metal content and public perception.

Table 6-1 Agricultural Materials Found in North-East Oregon Suitable for Composting Ingredients

Raw Materials	Present Use and Disposition	Distance	Availability	Relative Amount
	Vegetable/Plant Residues			
Alfalfa, Fresh	Hay + Silage	local	May-Oc	large
Alfalfa (spoiled)	Dumped / burned	local	May-Oc	moderate
Apple Residues and peel Cake	Cattle Feed	local–60mE	Sep-Apr	moderate
Asparagus pieces	Cattle Feed	local†	May	moderate
Carrots/Culls	Cattle Feed	local–60mE	All year	moderate
Corn Silage	Cattle Feed	local	All year	large
Corn Stalks/Stover	Cattle Feed	local	All year	large
Peas (Vines-Hulls)	Cattle Feed	local–40mE	June	large
Potato Sludge	Land Applied/Filled	local	All year	large
Potato Seed Culls	Land Applied/Filled	local	May-June	v. small
Onion/culls	Land Applied/Filled	local	Fall/Spring	large
Mint Silage	Mulch, Feed	local	All year	large
	Animal Manures			
Buffalo Manure	Range spread	local	All year	small
Chicken Manure	Land applied & Sold	80mW	All year	large
Dairy Manure	On-Farm spreading	local	All year	small
Duck Manure	In pens	local	Seasonal	v. small
Feed-lot Manure	Feedlot stockpiled	local	All year	large
Horse Manure	Private use near stables	local	All year	small
	Woods Products			
Woods Splinters	Land applied/bedding	30mE	All Year	small
Chipped Wood	Paper plant	local	All Year	large

Table 6-1 (Continued) Agricultural Materials Found in North-East Oregon Suitable for Composting Ingredients

Raw Materials	Present Use and Disposition	Distance	Availability	Relative Amount
Sawdust	Paper	local-30–70mE	All year	large

KEY: † Local = within 10 mile radius of base; (m) = miles; (W) west, (E) east, etc. Small ≤ 100 tons per site/season. Moderate 100–1000 tons. Large >1000 tons

The data on available materials clearly indicates that relatively large amounts of food & fiber type materials exist in the area for composting. On the other hand, lesser and more variable amounts of manures exist, or in the case of a large amount of one type of manure, the supply is more distant. Each region will have its unique waste stream composition. The inventory data underscore the importance of a materials management protocol being established prior to undertaking a composting project.

The data presented in Table 6-1 does not fully reflect seasonality of production and business decisions which influence availability. Also, not all operators of farm enterprises are able to discuss their waste by-products or certainly could not predict long-term availability. During the 3 years in which the UMDA field tests were conducted, considerable variability of the quantities and availability of materials was experienced. For example, at least two providers of manure by-products for composting went out of production in this period.

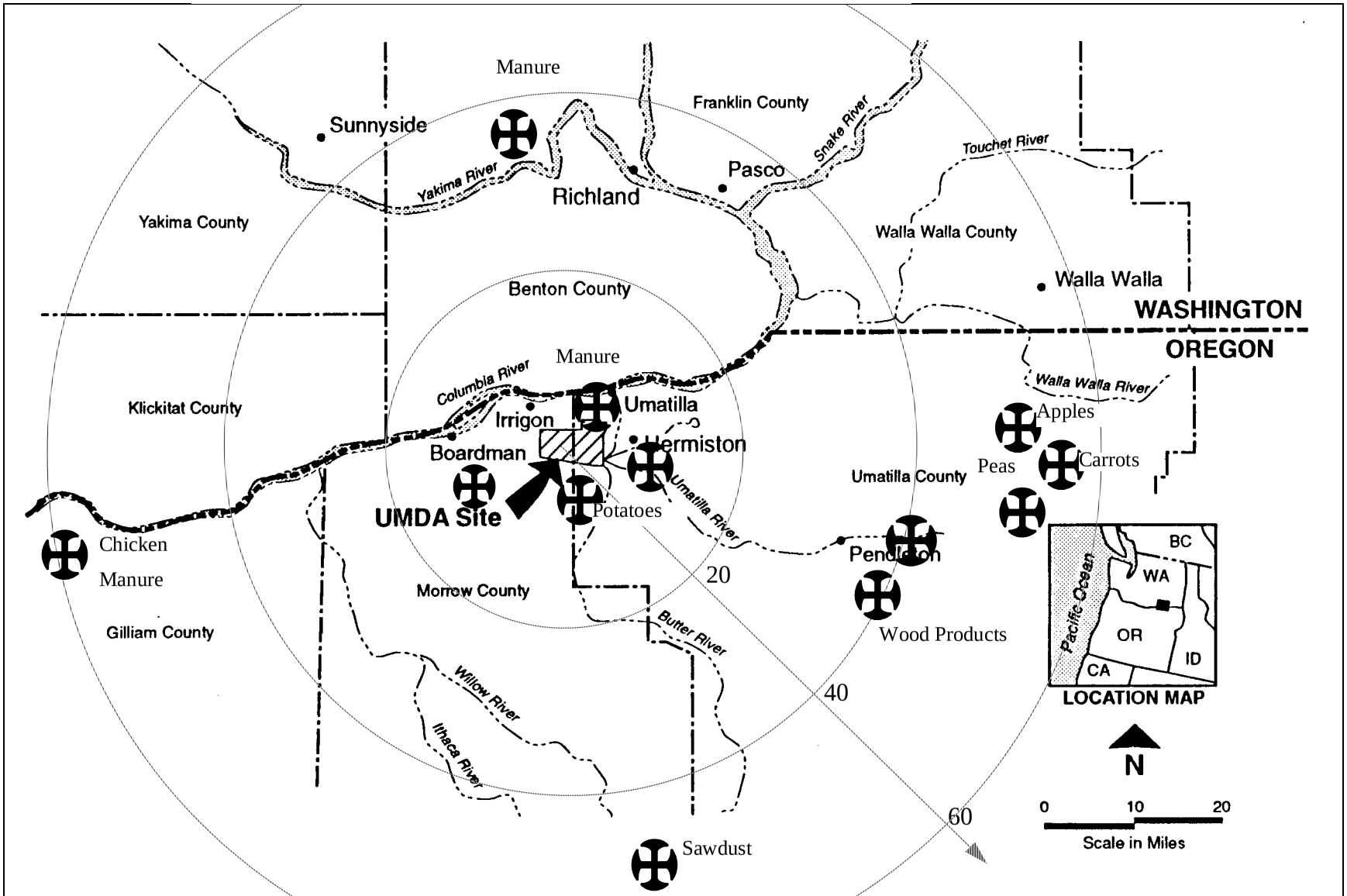


Figure 6 - 1 Location of Key Source Materials and Relative Distance from Compost Site

SECTION 7
SOURCE MATERIALS TEST SCOPE

While it is theoretically possible to compost with single-source ingredients, it is generally held that effective composting requires a basic blending of different types of materials. The blending of available materials achieves several results:

- provision of sufficient bulk-porosity to enable adequate aeration for aerobic composting;
- provision of metabolizable energy in the form of carbon-rich matter;
- provision of adequate moisture and nutrients to support microbial generation.

All these traits are compromised to some extent by inclusion of contaminated soil which does not fulfill any of the above criteria. Consequently, selecting the appropriate materials and testing in advance to identify and confirm traits is important for successful soil composting.

Based on the resource inventory, samples were obtained of materials for which availability was certain for the period of the pilot project. Before obtaining samples, materials were evaluated to determine those most acceptable as compost ingredients.

The following table (Table 7-1) gives general guidelines on key traits used to pre-select potential compost ingredients. Pre-selecting compost ingredients based on this table does not necessarily prove they will be acceptable. Pre-testing to confirm desired traits is employed. Recommendations are offered here as to what tests or quick procedures can be applied to efficiently and rapidly evaluate and pre-screen materials.

7.1 MATERIALS AND METHODS

Compost source material samples are obtained by collection of representative materials. Previous work has identified aspects of sample collection and preparation for pre-testing contaminated soil compost materials (USGS, 1992). Precollection and analysis of compost source materials applied generally-accepted procedures (Page, 1982; US EPA, 1986; Greenberg et al., 1992; Horwitz, 1992). Presently, there are no standardized protocols to analyze compost source materials. It is customary to adapt waste water methods for compost ingredients. Several materials were examined in this study which were essentially food by-products. It is generally held that testing these ingredients may be similar to analyzing agricultural product materials with methods similar to those found

in AOAC manuals (Horwitz, 1992).

Table 7-1 Selection Criteria for Source Materials for Contaminated Soil Composting Trials

Ingredient	Key Traits	Limitations
	MANURE:	
Cattle Manure	Med C:N High Microbes	VOA, high moisture
Chicken Manure	High N, Lime Content	pH, Ammonia
Pig Manure	Liquid application	Odor, Supply
Horse Manure	Med/high C:N, Loose tex- ture	Variability of bedding
	VEGETABLE MATTER:	
Alfalfa Hay	Coarse Texture, Nitrogen	Dust, mold, loss of tex-ture
Potato Culls	High Available Energy	Variability, VOA , mois-ture
Apple Pomace	High Available Energy	Availability, pH
Mint Silage	High Available Energy	Availability
	WOOD MATERIAL:	
Wood Splinters	Mixed/Coarseness	Supply
Wood Chips	Very Coarse Texture	Need final screening
Sawdusts	Fine texture, High C:N	Variability, Moisture, Supply

Table 7-2 outlines the protocol for screening source materials as applied in the course of the UMDA project. Expected ranges are given for each attribute and the appropriate analytical reference which provides methodology. The ranges bracket levels expected for source ingredients and active composts made from them which contain contaminated soil, based on UMDA data. Materials which fall outside the indicated ranges would be considered highly atypical and potentially problematic. This does not mean that all values that fall within the brackets are suitable for composting. It is the average composition after mixing all ingredients that determines suitability.

Table 7-2 Testing Protocol and Expected Ranges for Screening Compost Materials for Contaminated Soil Composting

Attribute Examined	Summary of Rationale and Result for Test Indicated	Expected Range & Unit	Method(s) Reference
Total Solids (TS)	Establishes moisture and dry matter content	0–70% FS FS= fresh solids	(US EPA, 1986; Greenberg et al., 1992)
Water Holding Capacity (WHC)	Establishes water holding capacity which determines ideal moisture levels	50–250% TS TS = total solids	(Page, 1982; Horwitz, 1992)
Bulk Density (BD)	Establishes volume unit weight and porosity which influences shrinkage and air flow potential	600-1400 lb / yd^3 FS	(Horwitz, 1992; Page, 1982)
Total Nitrogen (TKN)	Establishes most important nutrient need for balancing with total carbon	0.3–4.5% TS	(Page, 1982; Greenberg et al., 1992; Horwitz, 1992)
Organic Matter†	Establishes total carbon (volatile solids x 0.54) from which assumptions about respirable energy potential are made	15–99% TS	(US EPA, 1986; Greenberg et al., 1992)
Oxidation-Reduction Potential (ORP)	Establishes balance of oxidizing and reducing factors influenced by rate of decomposition and air supply	-150–350mV FS	(Greenberg et al., 1992)
Carbon to Nitrogen Ratio (C:N)	Indicates nutritional balance based on ratio of total organic carbon : total nitrogen	12–45‡	(Page, 1982; Greenberg et al., 1992)
pH	Establishes limits for microbial suitability or conditions requiring control	4.0–9.2	(Page, 1982; Horwitz, 1992)
Ammonium (NH_3 + NH_4)	Identifies potential for N-loss and volatilization hazard	0.01–0.30 TS	(Page, 1982); Horwitz, 1992)
CO_2-respiration rate	Establishes metabolic rate or respirable carbon potential	0.2–25% C / day^{-1}	(Page, 1982)
Volatile Organic Acids (VOA)	Confirms products of anaerobic respiration	300–25,000 ppm TS	(Greenberg et al., 1992)

† Range observed from UMDA composts and ingredients.‡ High C:N products not included in range

In addition to physical/chemical screening, micro-biological tests are advisable. These procedures

fall into the category of pathogen related and process control tests. Due to the highly variable nature of raw materials, there is little justification to suggest that compost source materials be subjected to extensive microbiological tests for the purpose of determining mix recipes; however, there may be cause to ascertain possible hazards to workers from presence of *Salmonella* or *E. coli* in manures and farm wastes which may pose health risks. The following table (Table 7-3) identifies microbiological pre-screening which is advisable but was not undertaken in the UMDA trials. Some of the traits were, however, measured in active composts (see Table 12-2). A discussion of microbiological and viral health hazards and regulatory limits for solid waste is provided in recent reports (US EPA, 1985; Berg, 1983; US EPA, 1993).

In addition to pathogen related tests as identified in Table 7-3 other tests to group bacteria by activity classes were employed in this study. An outline of this approach is seen in Table 7-4.

Testing composts for microbiological activity in the manner proposed from Table 7-4 is often not routinely performed in composting. In this study, the groups of aerobes, anaerobes and obligate anaerobes were examined. The objective of this testing was to distinguish organisms in terms of the type of respiratory activity. We selected this approach since the type of activity is valuable to interpret composting. For example, the presence of *Clostridium* would confirm anaerobic compost conditions which might result from inadequate aeration.

Table 7-3 Microbiological Testing Protocol (Proposed) and Expected Values for Screening Materials for Composting

Attribute Examined	Summary of Rationale and Result for Test Indicated	Expected Range & Unit	Method(s) Reference
Clostridium spp.	Indicates anaerobic development and potential presence of pathogenic viruses, protozoa and worms	10^2–10^5 cfu / g^{-1} FS†	(Cabelli, 1977)
Coliforms	The presence of coliforms suggests fecal contamination and the presence of a variety of pathogens	10^2–10^7 cfu / g^{-1}	(Hajna and Perry, 1943; US EPA, 1985; US FDA, 1986; Greenberg et al., 1992; US EPA, 1993)
Fecal Coliforms	Coliforms which grow at 44.5^{o}C producing gas which suggests fecal contamination	10^2–10^3 cfu / g^{-1}	(Hajna and Perry, 1943; US EPA, 1985; US FDA, 1986; Greenberg et al., 1992; US EPA, 1993)
E. coli	Suggests human pathogen contamination. This is a test for presence of the enzyme glucuronidase but does not include the virulent strain of hemorrhagic *E. coli* 0157:H7 nor the pathogen Shigella	10^2–10^4 cfu / g^{-1}	(US EPA, 1985; US FDA, 1986; Greenberg et al., 1992)
Streptococcus fecalis	The presence of this organism suggests fecal contamination and the presence of viruses	10^2–10^5 cfu / g^{-1}	(US EPA, 1985; US FDA, 1986; Greenberg et al., 1992)
Salmonella spp.	Salmonella is associated with pathogen contamination from food-animal material sources	10^0–10^3 cfu / g^{-1}	(Wilson et al., 1990; Curiale et al., 1990; US EPA, 1985; US FDA, 1986)

† FS = fresh solids (wet weight); cfu= colony forming units

Table 7-4 Microbiological Testing Protocol for Description of the Composting Process

Biological Activity	Organisms Involved & Measured	Expected Range & Unit	Method(s) Reference
Aerobic Respiration- (includes facultative anaerobes). Use oxygen as electron acceptor	Psuedomonas spp. Bacillus spp. (Aerobes) *E. coli*, *Salmonella* spp., *Klebsiella* spp., *Vibrio* spp., *Legionella* spp. *Yersinia* spp. *Erwinia* spp. *Enterobacter* spp., *Proteus* spp.(facultative anaerobes)	10^2–10^9 cfu / g^{-1} FS†	(US EPA, 1985; US FDA, 1986; Greenberg et al., 1992)
Aerobic Fermentation tolerate oxygen but do not use O_2 as electron acceptor	Streptococcus spp., Staphylococcus spp., *Enterococcus* spp.	10^2–10^4 cfu / g^{-1}	(US EPA, 1985; US FDA, 1986; Greenberg et al., 1992)
Anaerobic Respiration- includes obligate (true) and facultative anaerobes do not tolerate oxygen, produce organic by-products, incomplete degradation, little or no heating	*Campylobacter* spp., *Clostridium* spp., *Bacteroides* spp., (obligate anaerobes) *E. coli*, *Salmonella* spp., *Klebsiella* spp., *Vibrio* spp., *Legionella* spp. *Yersinia* spp. *Erwinia* spp. *Enterobacter* spp., *Proteus* (facultative anaerobes)	10^2–10^8 cfu / g^{-1}	(US EPA, 1985; US FDA, 1986; Greenberg et al., 1992)
Obligate Anaerobe Respiration Vegetative cells killed by oxygen	Campylobacter spp., *Clostridium* spp., Bacteroides spp.	10^2–10^5 cfu / g^{-1}	(Cabelli, 1977; US EPA, 1985; US FDA, 1986; Greenberg et al., 1992)

† FS = fresh solids (wet weight); cfu = colony forming units
Notes: facultative anaerobes appear in both the aerobic and anaerobic categories

A common method of grouping bacteria is Gram staining (Balous, 1991). However, Gram staining essentially distinguishes bacterial morphology and not activity. Therefore, it does not provide useful information to evaluate a biological process.

The microbiological processes and their efficacy can be surmised also from biochemical assays. In this project, selected enzymatic assays were undertaken as a means of analyzing the type of degradative activity rather than the organism. Such assays are useful in that they are easy to perform and serve to qualitatively (and in some cases quantitatively) indicate important events. For example, the presence of urease suggests the formation of ammonia, a slightly toxic gas. Table 7-5 gives a schematic for enzymatic screening of the composting process.

In the course of the project, other assays were applied which also relate to interpretation of biological condition rather than measuring specific biochemical or microbiological traits. These included measuring temperature and oxygen content in the piles and volatile organic acids (VOA) with a special test-gel method (Woods End Research Laboratory, 1993).

7.2 RESULTS

Source materials for UMDA compost trials were subjected to the set of tests indicated, and the results are displayed by category and by year in Table 7-6 and Table 7-7.

Sample data are presented for all the source ingredients which were tentatively selected for composting. No attempt was made at the time of sampling to determine the relative quantity of each material. Thus, the averages shown within each sample group are simply database averages and have equal weight assigned regardless of availability.

A similar group of source ingredients were tested in 1991–1992 and the results are shown in Table 7-7. By testing in a subsequent year, it is possible to determine where sources of variance lie for individual traits within sampling groups. For example, in the 1990 samplings of manures, moisture was low and varied by about 50% over all the samples. However, in 1992, there was considerably less variation.

In Table 7-8 the data for the two successive years are compared. The comparisons are made on the basis of the unweighted means for samples collected within each of the specified groups. These data indicate that for traits like C:N there are no significant differences between the years (variations were within one standard deviation unit).

Table 7-5 Biochemical Tests Evaluated for Description of the Composting Process

Biochemical Trait	Characteristic Involved & Measured	Expected Range & Unit	Method(s) Reference
Anaerobic fermentation & gas Production	Anaerobic production of VOA	+ or -	(Balous, 1991; Farmer, 1985)
Anaerobic CO_2 production	CO_2-gas released anaerobically	+ or -	(Balous, 1991)

Table 7-5 Biochemical Tests Evaluated for Description of the Composting Process

Biochemical Trait	Characteristic Involved & Measured	Expected Range & Unit	Method(s) Reference
H_2S formation	Bacterial reduction of sulfur and compounds	+ or-	(Farmer, 1985, Darland and Davis, 1973)
N_2 formation	Denitrogenase catalyzed reduction of NO_3 to $N0_2$ and N_2	+ or -	(Farmer, 1985)
Urease activity	Ammonia release by hydrolysis of urea	+ or -	(Farmer, 1985)
Deaminase Activity	Formation of pyruvic aid from deamination of phenylalanine	+ or -	(Farmer, 1985)
Dehydrogenase Activity	Anaerobic respiration by reduction of 2,3,5 triphenyl-2H-tetrazolium chloride (TTC)	+ or -	(Farmer, 1985; Casida, 1964)
Hydrolase	Degradative activities of lipids, proteins by fluorescein di-acetate (FDA) hydrolysis	+ or -	(Farmer, 1985; Schnürer, and Roswall, 1982)
Cellulase	Degradation of cellulose measured by increase of reducing sugar groups	+ or -	(Farmer, 1985; Jue and Lipkje, 1985)

Notes: (+) or (-) refers to procedures which give a positive or negative only reactions.

Table 7-6 Laboratory Results for UMDA Source Ingredients - 1990

Material	H_20	pH	OM	TKN	C:N	NH_4-N	ORP	Salt	CO_2-C
	—as is—		— % TS —		Ratio	% TS	mV in/ out	*mmhos/ cm*	% of C_t
Animal Manure Ingredients									
Buffalo Manure	18.2	8.53	81.29	1.83	25.7	0.005	484 / 410	0.8	3.15
Duck Manure	22.5	8.90	35.97	2.15	9.7	0.355	395 / 105	7.7	9.03

Table 7-6 (Continued) Laboratory Results for UMDA Source Ingredients - 1990

Material	H_20	pH	OM	TKN	C:N	NH_4-N	ORP	Salt	CO_2-C
Chicken Manure	24.1	9.04	48.28	3.02	9.3	0.515	392 0	10.5	7.04
Horse Manure	48.0	8.84	82.97	2.60	18.5	–	391 263	5.7	–
Buffalo Manure	53.4	8.51	76.83	2.04	21.8	–	434 234	1.0	2.38
Cow Manure	63.2	7.01	45.26	1.95	13.5	–	102 55	19.4	3.89
Cow Manure	7.2	9.17	15.89	0.63	14.7	–	360 212	0.1	0.85
Chicken Manure	29.4	8.59	44.42	4.18	6.2	–	17 -33	2.8	4.88
Chicken Manure	57.2	7.02	68.62	4.60	8.7	–	256 37	9.6	2.34
Horse Manure	45.4	9.43	87.41	0.95	53.6	–	353 293	1.6	–
Buffalo Manure	55.4	8.41	73.54	1.49	28.7	–	389 319	0.8	–
Horse Bedding	68.2	9.09	74.47	1.45	29.8	–	356 268	3.2	–
MEAN:	41.0	8.55	61.25	2.24	20.0	0.292	327 180	5.3	4.20
SD :	19.9	0.78	22.53	1.20	13.3	0.261	137 142	5.7	2.70

Table 7-6 (Continued) Laboratory Results for UMDA Source Ingredients - 1990

Material	H_20	pH	OM	TKN	C:N	NH_4-N	ORP	Salt	CO_2-C
	—as is—		— % TS —		Ratio	% TS	mV in/ out	*mmhos/ cm*	% of C_t
Animal Feed/Hay Ingredients									
Alfalfa	10.9	6.10	89.47	3.10	16.7	0.030	383/356	3.2	–
Horse Sweetfeed	10.7	4.79	90.98	1.74	30.4	0.013	277/223	10.4	1.66
Straw	7.6	7.43	88.18	0.73	70.5	–	323/246	2.2	1.86
Alfalfa Hay	7.7	6.39	90.49	1.04	50.3	–	290/-101	3.5	3.62
Alfalfa	5.2	6.03	87.78	3.40	15.0	–	246/241	3.3	–
Horse Feed	5.8	5.54	94.64	1.63	33.7	–	232/213	0.3	–
Alfalfa	14.8	6.18	84.93	3.57	13.8	–	292/238	3.5	–
MEAN:	9.0	6.07	89.50	2.17	32.9	0.022	292/202	3.8	2.38
SD :	3.4	0.81	3.03	1.17	21.1	0.012	50/142	3.1	1.08
Food Processing/Vegetable Ingredients									
Vegetable Waste	72.3	3.96	94.93	2.99	18.4	0.012	179/162	1.5	7.15
Apple Pomace	92.6	4.04	93.05	2.10	25.8	0.061	175/143	1.4	24.33
Potato Waste	85.5	4.39	93.49	1.97	27.5	–	217/171	2.3	13.70
Potato Waste	83.0	4.50	76.79	1.05	42.3	0.067	105/135	0.9	12.10
Apple Waste	95.1	3.67	93.53	1.03	52.5	–	196/152	1.9	9.13
Pea Waste	83.6	3.94	72.60	3.65	11.5	–	124/70	4.8	5.37
Potato Waste	83.6	3.72	95.51	1.31	42.3	–	165/111	2.5	2.14
MEAN:	85.1	4.03	88.56	2.01	31.5	0.047	166/135	2.2	10.56

Table 7-6 (Continued) Laboratory Results for UMDA Source Ingredients - 1990

Material	H_20	pH	OM	TKN	C:N	NH_4-N	ORP	Salt	CO_2-C
SD :	7.41	0.31	9.49	1.00	14.7	0.030	39/35	1.3	7.23

Table 7-6 (Continued) Laboratory Results for UMDA Source Ingredients - 1990

Material	H_20	pH	OM	TKN	C:N	NH_4-N	ORP	Salt	CO_2-C
	—as is—		— % TS —		Ratio	% TS	mV in/ out	*mmhos/ cm*	% of C_t
Wood Product/Sawdust Ingredient									
Sawdust, plain	24.5	4.88	99.75	0.06	1018	–	297/244	0.2	0.07
Sawdust, plain	4.0	4.54	99.20	0.01	6251	–	334/233	0.1	0.07
Sawdust, chip	15.5	5.16	99.13	0.08	715	–	295/255	0.3	–
Sawdust, splinter	8.0	5.29	99.16	0.10	568	–	322/354	0.2	–
MEAN:	13.0	4.97	99.31	0.06	2138	–	312/272	0.2	0.06
SD :	9.0	0.33	0.30	0.04	2748	–	19/56	0.1	0.02

(—) indicates not analyzed; SD = standard deviation

However, it also indicates that moisture, total-nitrogen and respiration activity can show large variations. Thus, it is important to check samples close to the time of compost preparation.

Remarkable consistency in organic contents between sample groups by years is seen. Woods products, for example, showed very little variation in important traits, except in the case of moisture content. A high moisture on wood would be a problem since wood is partly used to dry out the very moist manure and food scrap (potato) fractions.

7.3 SOIL DENSITY TRIALS

High soil loading for composting is desirable from the point of view of cost-effectiveness for processing. However, high loading may adversely influence the process. In fact, the primary limiting factor in composting contaminated soil is likely to be the relatively high density and low nutrient value resulting from soil inclusion. Therefore, this project determined that high soil loading was a concern.

Probable effects of soil loading rates on compost include the following:

- Soil fraction in the mixture contains virtually no labile, organic content and will significantly reduce organic content needed for thermophilic composting;
- Soil causes a large increase in weight of material, increasing the risk of compaction;
- Soil fills the available pore space reducing the aeration or oxygenation potential;
- Soil reduces the water-holding capacity of the compost so that perturbations in moisture availability are imminent, requiring less water addition more frequently.

In order to develop a soil-loading model suitable to evaluate the limitations imposed by soil inclusion, several factors must be considered. Among them are density, water holding capacity and pore-space reduction. The objective in the model is to determine and predict upper ceilings for acceptable performance in composting.

Table 7-9 provides computations to determine bulk density from soil loading. The calculations are based on measurements of a typical compost mix (Mix "B", Table 8-1) and typical soil. The resulting bulk density is rated based on generally accepted values for compost pre-mixes (Brinton and Seekins, 1988).

Table 7-10 expands on the calculations by providing conversions of soil volume loading to weight-basis loading as well as to water-holding capacity and desired moisture. UMDA compost mix "B" was used to determine initial values. The model was tested against a variety of volume blends and found to accurately predict conditions.

According to the data, a soil volume loading of 30% means a weight addition of 50%. The increase in soil volume results in a steady increase of bulk density whereby the values approach marginal levels (for fresh compost) at or around a 30% soil rate (v/v).

It was necessary to further refine the table to convert volume to weight basis mixtures and to ascertain the influence of soil loading on other important traits such as water holding capacity and estimated ideal moisture content. The data is presented in Table 7-10.

The data in Table 7-10 indicates several important aspects of contaminated soil composting. The conversion of soil volume to a weight (mass) basis underscores concern that moderate volume loadings by soil represent large mass proportions. For example, at 30% of soil by volume the compost has 72% soil on a dry weight basis. If inorganic (soil) content is raised above 30%, the likelihood of sustained heating of the compost mass may diminish significantly. There are no published data relating heat performance to compost organic solids content.

The second UMDA study tested recycling of seed compost in 20-day cycles (Weston, 1992). The relationship of re-feeding compost to successive compost batches is suggested by previous work where re-inoculation of acclimated organisms has improved bio-degradation (NAAP Report, 1992). However, the addition of recycle compost to a compost blend consisting of a pre-mix and contaminated soil is constrained by the rule of diminishing returns, in that the use of recycle adds increasingly to ash (inorganic) content and thus may reduce the level of contaminated soil that can be processed. In order to test the hypothesis before UMDA trials commenced, a series of computations were made.

A compost which is constantly decomposing will loose labile organic to the extent that its usefulness as recycle becomes limited. Prior to initiating seed studies, therefore, some computations were made to determine recycle value. In Table 7-11 the changes in organic content resulting purely from degradation of the base compost mix is calculated for a mix containing 30% soil, assuming 6 successive batches consisting of 20 days each. The data clearly indicate that after two or three batches, the relative value of the compost in terms of organic content is very limited. If such compost is used a recycle, it will increasingly contribute more to ash than to organic matter.

In Table 7-12 the increase in compost inorganic fraction as a result of recycling the compost/soil product (Table 7-11) at a 10% addition rate is calculated per each cycle of a six batch process of approximately 20 days each is given. In this case, recycle is taken from each successive batch.

The table shows that if a recycle rate of 10% is used, then the amount of soil volume will have to be progressively decreased in order to stay at the same organic content. For example, if a soil volume loading of 25% is used, the reduction required is from 25% down to 18.7% by the end of the sixth batch. The data in these tables is used purely to illustrate the described problem of potential loss in efficiency of a continuous batch recycle system. The table suggests caution in introducing large amounts of soil to successive batches of contaminated soil compost.

—letters in the table refer to multiple samples from similar sources

Ultimately, the procedure used in the second UMDA trial (Weston, 1992) was a 5% recycle rate

whereby the inorganic contribution was more negligible. The procedure to introduce recycle into compost for UMDA is described elsewhere (Weston, 1992).

Table 7-7 UMDA Source Ingredients by Category 1991 - 1992

Material	H_20	pH	OM	TKN	C:N	NH_4-N	ORP	Salt	CO_2-C
	—as is—		— % TS —		Ratio	% TS	mV in/ out	*mmhos/ cm*	% of C_t
Animal Manure Ingredients:									
Cow Manure-a ‡	73.0	6.95	58.49	0.75	42.0	0.061	174 / 36	2.0	3.72
Cattle Manure-a	76.3	6.30	60.55	1.33	24.5	0.118	340 / 40	3.1	6.88
Cattle Manure-b	72.1	4.92	68.16	1.07	34.5	0.091	346 / 239	3.4	0.28
Cattle Manure-c	62.7	8.86	41.93	0.83	27.2	0.079	436 / 149	2.5	3.02
Cattle Manure-d	70.7	5.42	66.24	0.97	36.8	0.116	299 / 82	3.1	4.88
Cattle Manure-e	59.6	5.39	37.35	0.47	43.3	0.124	306 / 204	4.7	1.36
Cow Manure-b	76.1	6.38	79.31	1.15	37.4	–	-145 / -58	2.8	–
Hen Manure	73.1	7.71	65.16	4.48	7.8	–	-17 / -104	29.7	–
MEAN:	70.5	6.49	59.65	1.38	31.6	0.098	217 / 73	6.4	3.36
SD :	6.1	1.32	13.86	1.28	11.7	0.025	201 / 120	9.4	2.39

Table 7-7 (Continued) UMDA Source Ingredients by Category 1991 - 1992

Material	H_20	pH	OM	TKN	C:N	NH_4-N	ORP	Salt	CO_2-C
	—as is—		— % TS —		Ratio	% TS	mV in/ out	*mmhos/ cm*	% of C_t
Food Processing/Vegetable Ingredients									
Onion Shook	56.2	4.38	85.66	1.04	44.3	0.013	192 / 98	2.2	3.04
Apple Waste	92.1	5.15	94.70	1.02	50.1	0.014	298 / 256	1.2	0.10
Apple Pomace	78.5	4.72	93.60	1.26	40.1	0.002	321 / 350	0.5	2.61
Potato Cake	86.7	3.51	56.62	1.06	28.8	0.004	158 / 155	1.5	0.53
Potato Fries	85.8	4.40	95.53	1.17	43.9	0.042	321 / 170	2.0	1.79
MEAN :	79.9	4.43	85.22	1.11	41.4	0.012	258 / 206	1.4	1.61
SD :	14.1	0.60	16.46	0.10	7.9	0.016	77 / 98	0.7	1.28
Animal Feed/Hay Ingredients:									
Alfalfa Hay	10.1	7.90	85.08	2.95	15.6	–	316 / 208	9.8	–
Alfalfa Hay	29.3	8.45	79.21	3.43	12.5	0.110	397 / 170	5.2	0.59
Mint Silage	58.6	8.39	76.88	3.84	10.8	–	328 / 58	15.5	–
Pea Hay	38.0	6.90	89.68	1.37	35.4	–	315 / -39	5.2	–
MEAN :	34.0	7.91	82.73	2.89	18.6	–	339 / 99	8.9	–
SD :	20.1	0.71	5.79	1.08	11.4	–	39 / 112	4.8	–

Table 7-7 (Continued) UMDA Source Ingredients by Category 1991 - 1992

Material	H_20	pH	OM	TKN	C:N	NH_4-N	ORP	Salt	CO_2-C
	—as is—		— % TS —		Ratio	% TS	mV in/ out	*mmhos/ cm*	% of C_t
Woods Product/Sawdust Ingredients:									
Sawdust, plain	16.5	5.07	98.84	0.07	816	0.010	344 / 290	2.0	0.19
Sawdust, pine+fir	56.0	6.11	99.36	0.05	1095	–	378 / 305	0.2	–
Sawdust, pine+fir†	57.1	4.34	99.47	0.05	1061	–	337 / 233	0.4	–
Sawdust, hem-lock	17.2	5.07	99.86	0.04	1202	–	382 / 274	0.5	–
MEAN:	36.7	5.15	99.4	0.05	1044	–	360 / 276	0.7	–
SD :	22.9	0.73	0.45	0.01	163	–	23 / 31	0.8	–

SD - standard deviation
(–) not analyzed;
† aged pine+fir samples.

Table 7-8 Summary Lab Results for UMDA Source Ingredients 1990 - 1992

Material	H_20	pH	OM	TKN	C:N	NH_4-N	ORP	Salt	CO_2-C / C^{-1}
	—as is—		% dry basis result				mV in/ out	*mmhos/ cm*	%
Animal Manure Ingredients									
1990 MEAN:	41.0	8.55	61.25	2.24	20.0	0.292	327 / 180	5.3	4.20
1992 MEAN:	70.5	6.49	59.65	1.38	31.6	0.098	217 / 73	6.4	3.36
Animal Feed/Hay Ingredients									
1990 MEAN:	9.0	6.07	89.50	2.17	32.9	0.022	292 / 202	3.8	2.38
1992 MEAN :	34.0	7.91	82.73	2.89	18.6	–	339 / 99	8.9	–
Food Processing/Vegetable Ingredients									
1990 MEAN:	85.1	4.03	88.56	2.01	31.5	0.047	166 / 135	2.2	10.56
1992 MEAN:	79.9	4.43	85.22	1.11	41.4	0.012	258 / 206	1.4	1.61
Wood Product/Sawdust Ingredient									
1990 MEAN:	13.0	4.97	99.3	0.06	2139	–	312 / 272	0.2	0.06
1992 MEAN:	36.7	5.15	99.4	0.05	1044	–	360 / 276	0.7	–

(—) not analyzed

Table 7-9 Relation of Volume to Weight and Effect of Soil Loading on Compost Bulk Density

Soil Or Compost Volume in Mix		Bulk Density	Value
Soil[a]	Compost[b]	lb/yd^3	(Rating)
0	100	945	acceptable
5	95	1018	acceptable
10	90	1091	acceptable
15	85	1164	acceptable
20	80	1237	acceptable
25	75	1310	acceptable–marginal
30	70	1382	marginal
35	65	1455	marginal to poor
40	60	1528	poor
45	55	1601	very poor
50	50	1674	very poor

[a] UMDA soil @ 1.42 g/cc bulk density

[b] Compost data based on Mix-B ingredients (see Table 8-1@ 0.56 g/cc.)

Table 7-10 Effect of Volume Loading on Soil Mass and Reduction on Water-Holding Capacity (WHC) and Ideal Moisture of Compost Piles

--------Soil Composition--------				Mix Bulk Density	WHC in % of	Ideal Moisture
Soil[a]	Compost[b]	as is	dry basis	lb/yd^3	dry wgt[c]	% as is[d]
0	100	0.0	0.0	945	225.0	61.2 ok
5	95	11.8	24.2	1018	175.9	55.2 ok
10	90	22.0	40.3	1091	143.3	50.1 ok
15	85	31.0	51.7	1164	120.1	45.7 ok
20	80	38.9	60.3	1237	102.7	41.8 ok
25	75	45.9	66.9	1310	89.2	38.4 ok/marginal
30	70	52.1	72.2	1382	78.4	35.4 marginal
35	65	57.8	76.6	1455	69.6	32.8 m to poor
40	60	62.9	80.2	1528	62.3	30.4 poor
45	55	67.5	83.2	1601	56.1	28.2 v.poor
50	50	71.8	85.8	1674	50.7	26.2 v.poor

[a] Based on measured soil density of 89 lbs/ft^3 (1.42 g/cc) bulk-density

[b] Compost pre-mix of 61% water @ 0.56 g/cc bulk-density

[c] Compost @ 225% WHC and soil @ 22% WHC

[d] Based on assumption of 70% of WHC

Note: Compost used is Mix B, Table 8-1

Table 7-11 Organic Matter and Ash Content in Successive Compost Batches

ORGANIC MATTER %	ASH CONTENT %	Successive Batches @ 20days each
30.0[a]	70.0	Run 1
22.5[b]	77.5	Run 2
16.9	83.1	Run 3
12.7	87.3	Run 4
9.5	90.5	Run 5
7.1	92.9	Run 6

[a] Based on measured data for UMDA compost with 30% soil added
[b] Based on 25% loss of organic matter as determined from bench-scale 20 day runs.

Table 7-12 Relationship of Feed (Recycle) Rate to Increase in Ash Content and Resulting Change in Soil Rate to Maintain Constant Conditions in Composting Using 10% Feed Rate

Batch Sequence	Soil Wgt	Mix Wgt	Base % Ash	Feed Wgt	Blend %Ash	Vol Soil	Soil Rate To Maintain
Notes:	(a)	(a)	(b)	(c)	(d)	(e)	Same Inorg (f)
B1	46.0	54.0	66.7	0.0	66.69	25.0	0.0%
B2	46.0	44.0	77.6	10.0	74.02	29.0	-4.0%
B3	46.0	44.0	77.6	10.0	74.37	26.6	-4.5%
B4	46.0	44.0	77.6	10.0	74.63	27.2	-5.0%
B5	46.0	44.0	77.6	10.0	74.82	27.3	-5.6%
B6	46.0	44.0	77.6	10.0	74.97	27.4	-6.3%

Notes to Table 7-12:
(a) pounds in 100 lbs fresh wgt compost/soil blend
(b) the computed inorganic content without feed additions
(c) the mount of feed (recycle compost) in 100 lbs of soil/compost blend
(d) the inorganic level in compost after feed is added at specified rate
(e) Volume of contaminated soil as % of total compost
(f) The change in contaminated soil loading to counteract increase in Ash

SECTION 8
LABORATORY RESPIRATION TRIALS OF INGREDIENTS

Loading of compost with non-organic soil material acts to dilute the ingredients which are responsible for heating and active degradation. In composting contaminated soil, it is a primary objective to optimize the soil inclusion. Therefore, the need exists to maximize the degradation potential of the non-soil component. We measure this by evaluating the carbon-dioxide respiration rate of added ingredients.

A respiration quotient is the rate of CO_2 release relative to the mass of the included material. By increasing this as high as possible, the ability of the compost to carry a high soil-load is thereby maximized. Therefore, monitoring of source ingredients for respiration potential is an important selection tool, enabling operators to maximize soil through-put.

A series of laboratory trials were undertaken to evaluate the contribution of various selected compost ingredients to the overall compost-respiration process.

Three aspects were evaluated in these trials:

- Respiration quotient of all source ingredients;
- Respiration rate of blended (compost mix) source materials;
- Respiration rate of blended mixes as influenced by soil loading.

8.1 RESPIRATION RATE OF SOURCE INGREDIENTS

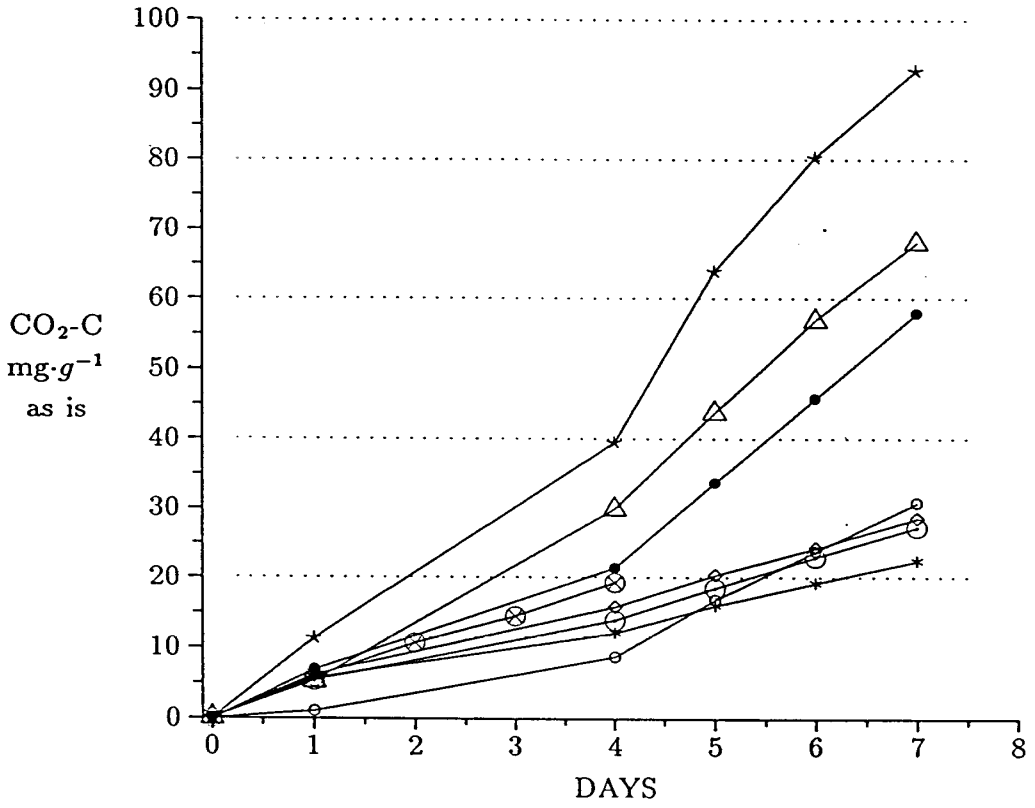
Separate source ingredients were evaluated for respiratory rate by preparing the sample in respiration jars where the only manipulation includes adjusting moisture to optimal levels (Page, 1982). Several regional wastes were selected as potential candidates for composting. The CO_2-incubation results are shown in Figure 8-1.

Compost source materials showed respiratory quotients in the order Apple > Potato > Vegetable > all manures. The group of vegetable matter wastes averaged more than 3-times the cumulative carbon-dioxide than the manure group. This is not surprising since food wastes contain large proportions of simple carbohydrates which are readily utilized by microorganisms. It strongly supports the concept of utilizing food materials as inputs to composts which contain significant amounts of soil.

Pre-testing of source ingredients for carbon-dioxide release potential is useful to identify potential

high performers for composting. Implicit in this project has been the assumption that materials showing high respiratory qualities are valuable for soil-composting.

Figure 8 - 1 CO_2 Respiratory Rated of UMDA Compost Source Materials



SAMPLE KEY:

Sample ID: ◇ [Cow Manure] — ○ [Horse Feed] — ✳ [Duck Manure] —
⊙ [Chicken Manure] — ● [Vegetable Waste] — ★ [Apple Waste]
△ [Potato Waste] — ⊗ [Potato Processing Sludge]

Conducting respiration trials of single ingredients is as a rule not recommended. This is because the materials are often very low or high in moisture, pH or other traits which may require adjustments to be made. Furthermore, the materials can vary in terms of microbial substrate suitability. Treating them separately can result in different behavior then when blending together later as in a compost.

In our trials of ingredients, we adjusted only to achieve optimal water, determined as 60–80% of

the water holding capacity (WHC). However, unless the same manipulation of the material is practiced for composting the danger exists that the laboratory results will not compare with field experience. We therefore chose to prepare actual recommended compost blends and test them by the same respiration procedure.

Two groups of source ingredients were selected and prepared into test compost blends, as seen in Table 8-1. The mix "A" is typical of traditional composts with manure and sawdust as the principal ingredients with one added higher energy food ingredient (see Table 8-1). In contrast, mix "B" selects for more energy (based on respiration trials) with vegetable/food scrap and more available nitrogen in the form of poultry manure. Poultry manure had 3-times more nitrogen than horse manure tested in 1990 (see Table 7-6). Vegetable scrap and potato waste came in 2nd and 3rd in respiration trials next to apple pomace and were more available (see Figure 8-1).

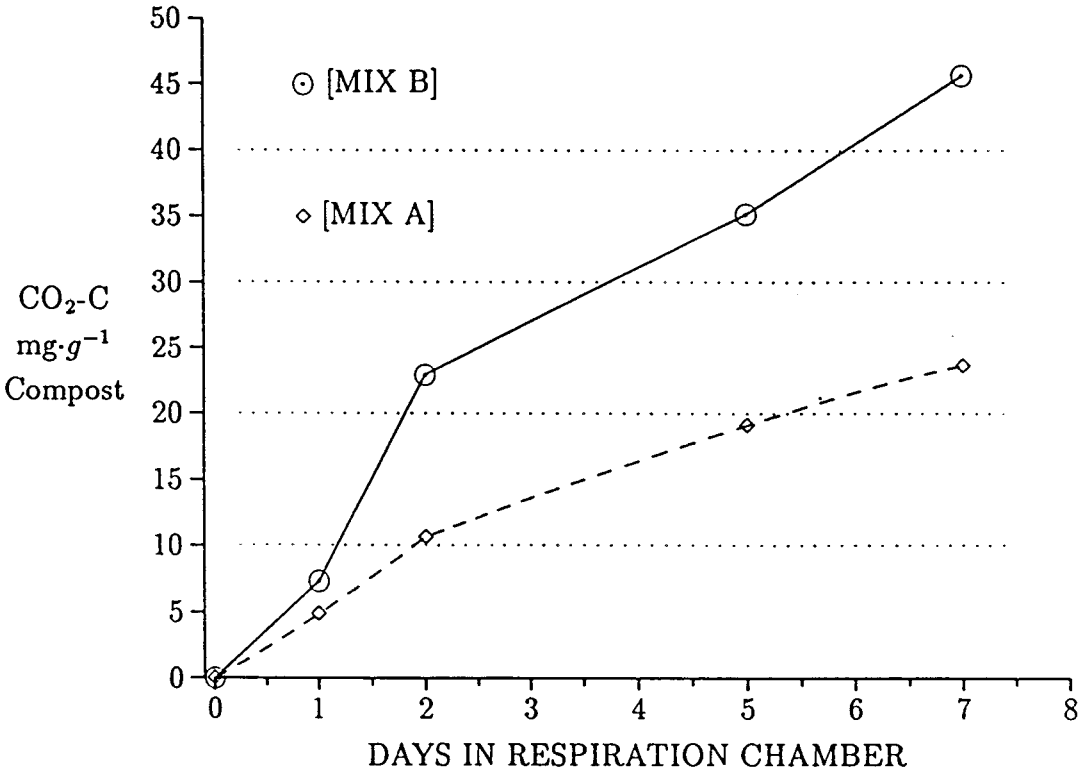
The two groups of selected ingredients or "recipes" were blended to achieve the same C:N ratio and moisture content. The target C:N was 35–40. In blending, we select first on C:N and secondly on moisture. The two groups were run in 7-day respiration trials to determine the total CO_2 potential. The results are graphed in Figure 8-2.

Table 8-1 Composition of Selected UMDA Composts for Respiration Trials

Ingredients Used In Compost Mix	MIX A	MIX B
	Fresh Weight Basis	
Sawdust	20%	30%
Horse Manure	44%	-
Apple Pomace	36%	-
Chicken manure	-	20%
Vegetable Scrap	-	15%
Chopped Potato	-	35%
TOTALS	100%	100%

There were no differences in the two composts in the first day of composting. After 2 days, the differences increased. The results of this trial indicate that the "improved" recipe out-performed the basic mix in terms of CO_2 respiration by almost a factor of two over 7 days. These data support the conviction that diverse blends of compost ingredients containing both high-energy, nutrient-rich ingredients may be superior for compost heat production.

Figure 8 - 2 CO_2 Respiratory Rate of Two UMDA Pre-Selected Compost Blends Without Added Soil



The recipe scheme was further refined by adding additional mixtures to the basic recipes "A" and "B". These are identified in Table 8-2. The strategy included:

- Mix-2 Substituting apple pomace for vegetable scraps;
- Mix-3 Substituting horse manure for chicken manure;
- Mix-4 Substituting straw for half the sawdust;
- Mix-5 Alternate blend with reduced chicken manure;
- Mix-6 Substituting straw for half the sawdust in new blend.

The results of the respiration trials are shown in Figure 8-3. Only slight improvements to the per-

formance of Mix B were achieved. Substituting apple pomace for vegetable scraps reduced the overall respiration, probably on account of the low pH of the pomace. When we split the bulking material (sawdust) with rye straw, no improvement was noticed (treatment 4 versus treatment 1).

Two potential problems regarding the recipes were noted. Chicken manure tends to produce large quantities of ammonia and needs to be slightly reduced. Also, apple pomace is readily available in the Oregon/Washington region and therefore it would appear to be useful to include it in future compost programs. The loss in some performance with apple pomace addition as noted in previous trials was re-examined. New mixes which slightly increased the content of bulking agent and reduced poultry manure were prepared with the idea of offsetting the high moisture of the pomace and vegetable scraps.

Table 8-2 Composition of Diverse Ingredient UMDA Compost Blends Tested in UMDA Respiration Trials

Ingredient to Compost	Mix 1 (B-Table 14)	Mix 2 (Alt-1)	Mix 3 (Alt-2)	Mix 4 (Alt-3)	Mix 5 New Mix	Mix 6 Alt-New
	Fresh Weight % Basis					
Hardwood Sawdust	30	30	30	15	46	23
Rye Straw	-	-	-	15	-	23
Horse Manure	-	-	20	-	-	-
Apple Pomace	-	15	-	-	12	12
Chicken Manure	20	20	-	20	15	15
Vegetable Scrap	15	-	15	15	-	-
Chopped Potato	35	35	35	35	27	27
TOTALS	100	100	100	100	100	100

The data in Figure 8-3 indicate further increases in respiratory rate with the adjustments. Cutting the bulking agent (sawdust) with hay or straw gave noticeable improvements. Thus, future recipes were based on splitting the bulking between sawdust and straw (see Weston, 1993). Ultimately, apple pomace availability was too seasonal for inclusion in the pilot UMDA investigation and was eliminated in favor of cull potatoes. Additionally, it was necessary to further dilute the chicken manure with cow manure as a result of high ammonification rate observed.

8.2 LABORATORY COMPARISON OF SOIL INFLUENCE

The effect of adding soil to pre-selected compost blends was evaluated in a series of bench-scale respiration trials. We incubated the mixes from the previous trial (Figure 8-3 and Table 8-2) with soils up to 57% by wet weight (40% volume). The results computed to 7-days (cumulative CO_2-C) are seen in Figure 8-4.

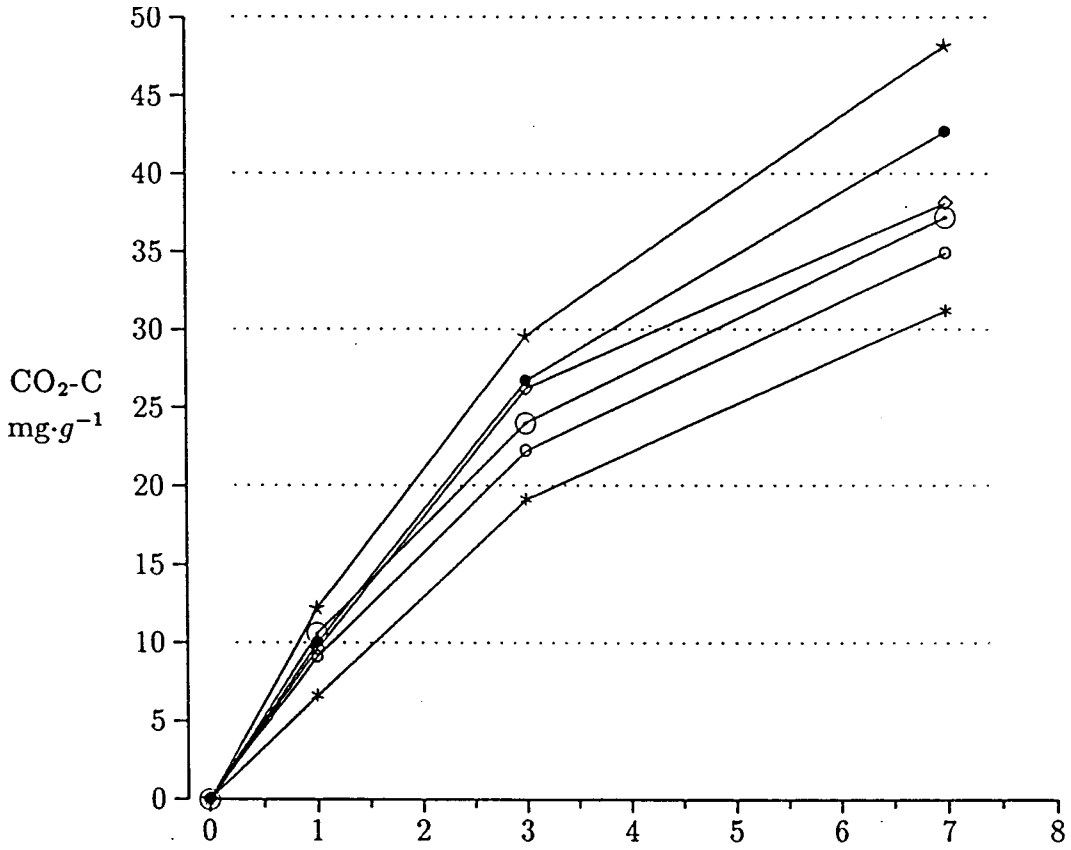
The data from these trials underscore the fact that different compost mixtures tend to behave increasingly similar as the soil rate increases and that the addition of soil causes a proportional reduction in respiration rate.

In accordance with the data in Figure 8-4, an increase in soil causes a significant reduction of carbon-dioxide respiration. Theoretically, the respiration should decline in exact proportion as the percentage soil increases (the amount of soil on a weight basis may be found from data presented in Table 7-10).

However, some of the data reveals that the rate of loss of respiration potential does not decline as fast as would be predicted from the soil inclusion percentage. Furthermore, the greatest decline occurs with small additions of soil; a curvi-linear relationship exists for some of the recipes (including Mix B and its alternates) so there may be a diminishing reduction evident at higher rates.

The factor of declining respiration was examined by adding soil to mix A and B at different rates and calculating the respiration in terms of original organic content (compost minus soil). These trials indicate that in the case of A the organic degradation rate was constant at all soil percentages, which theory predicts. In the case of mix B, the CO_2 rate increased per unit of organic matter with increasing soil volume (see Figure 8-5). Since there were no replicates we can not say if the effect is significant. However, the information is certainly hopeful since the goal of the project is to optimize soil loading to composts.

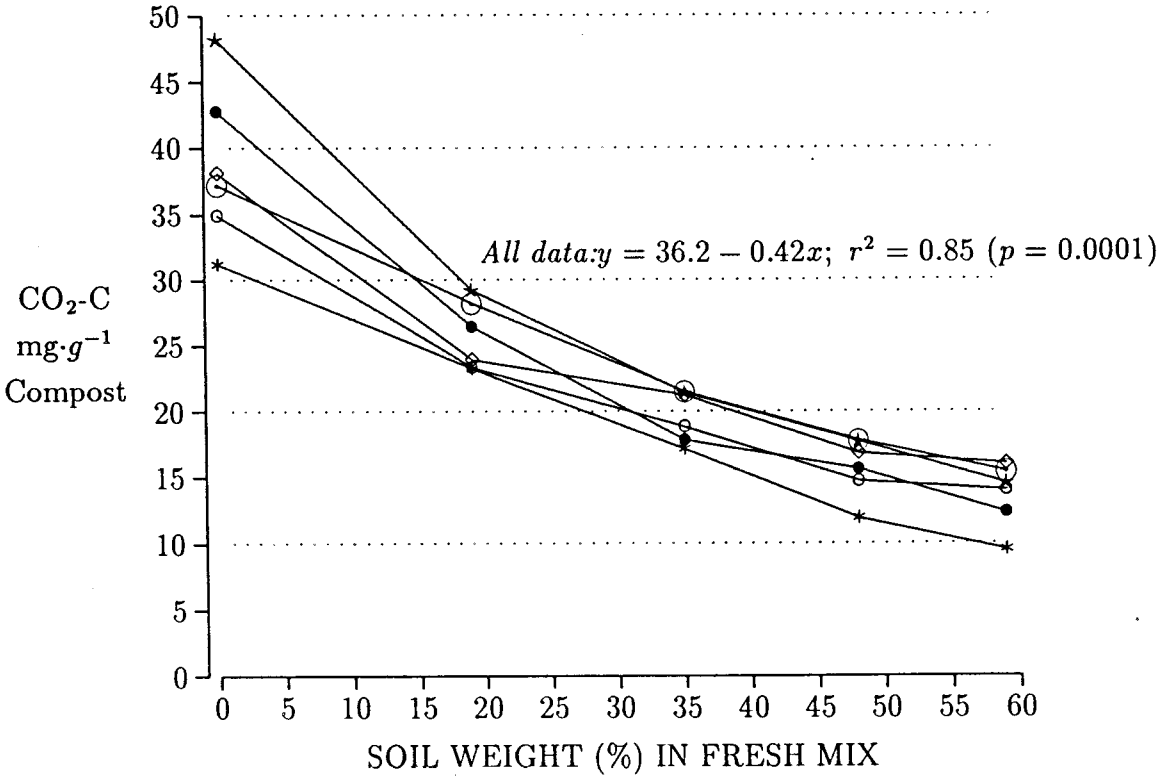
Figure 8 - 3 Performance of Selected Compost Mixtures in Respiration Trials



SAMPLE KEY (see Table 15):

Mixture ID: ◇ [MIX 1] — ○ [MIX 2] — ✳ [MIX 3] — ⊙ [MIX 4] — ● [MIX 5] — ★ [MIX 6]

Figure 8 - 4 CO_2 Respiration for Composts with Increasing Rates of Soil

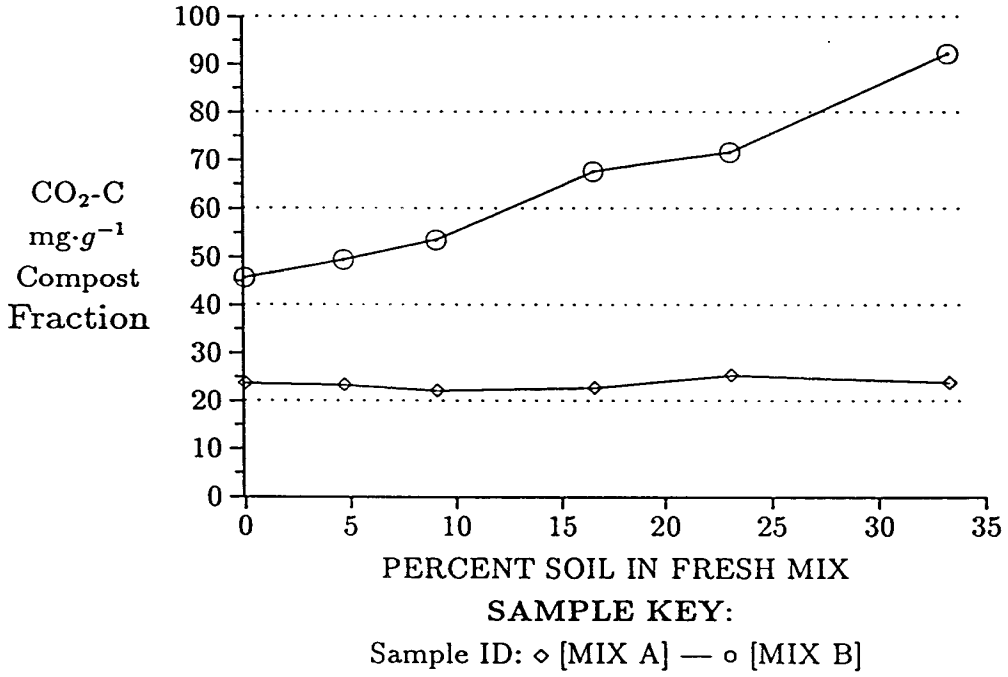


SAMPLE KEY (see Table 15):

Sample ID: ◇ [MIX 1] — ○ [MIX 2] ∗ [MIX 3] —
⊙ [MIX 4] — • [MIX 5] — ⋆ [MIX 6]

A variety of existent factors prevent this information from being extrapolated, however. For example, the trials were run at a constant temperature and therefore heat effects from varying respiration

Figure 8 - 5 Respiratory Rate of UMDA Compost Minus Soil After One Week



rates can not be examined. The observations do not allow us to determine at what percentage of soil loading organic matter degradation is optimized. Later studies (see Table 9-1) indicate a net loss in heating potential with increased soil rates.

The potential degradation of organic compounds in a soil–compost system can be defined as:

$$\textit{Potential Degradation} \propto (\textit{mg } CO_2\textit{-C / g total mix})(\textit{\% of soil}) \qquad (1)$$

where CO_2-C is data from respiration trials of a compost mix. This equation can also be written:

$$\textit{Potential Degradation} \propto (\textit{Relative Heating})(\textit{\% of soil}) \qquad (2)$$

Where relative heating is the difference of heating in a treated versus untreated sample from a self-heating adiabatic trial. Substituting the actual heating values measured from the adiabatic compost

trials and soil loading in Equation 2 gives the results seen in Table 8-3.

Table 8-3 Potential Degradation of Soil Contaminants in UMDA Compost Mixes

Vol % Soil in compost Tested	Rel. Heating (Adiabatic)[a] (A)	% Soil by wgt. (see Table 11) (B)	Relative Soil Organic Degradation (A)(B)
0	100	0	0
10	105	22	2310[b]
20	93	39	3627
30	66	52	3432

[a] See Table 7-11
[b] Arbitrary units.

The data in Table 8-3 based on the equations 1 and 2 suggests that decomposition of contaminated soil peaked at the 20% soil volume rate but was no different at 30%, while both were significantly better than 10%. The data has not been extensively tested. It does suggest that a 20–30% contaminated soil inclusion rate will be best under similar circumstances as here described.

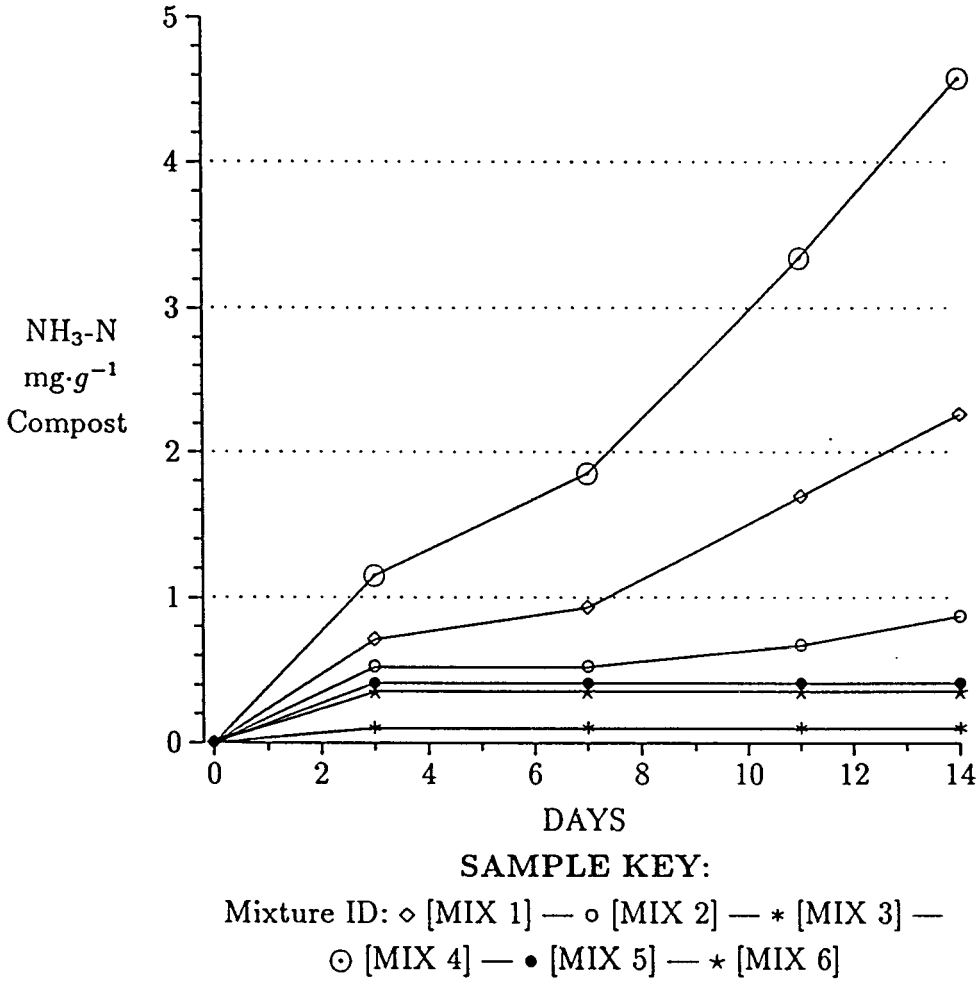
8.3 AMMONIA AFFECTS FROM MANURES

Breakdown of organic nitrogen in composting may lead to a rapid release of ammonia and subsequent rise in pH and undesired ammonia volatilization. Since chicken manure is known to cause this problem from the large amount of organic nitrogen present, and since the project region showed large availabilities of this manure, the influence on composting was evaluated.

In Figure 8-6 we depict the amount of ammonia volatilized in composts up to 14 days of incubation of the test mixtures #1–#6 (see Table 8-2). There was little or no ammonia released where horse manure was the nitrogen source. However, where chicken manure is present the ammonia volatilization was large. Where straw was substituted for half the sawdust, there was more loss. The apple pomace significantly reduced ammonia release when compared with the others.

The quantity of ammonia which is lost can influence the apparent C:N ratio of the composts. A variable amount of total nitrogen was lost in the test composts, which decreased in the order MIX-4 > MIX-1 > MIX-2 > MIX-5 = MIX-6 > MIX-3. The range of total nitrogen lost for this series

Figure 8 - 6 Ammonia Loss Rate for Various UMDA Compost Blends Without Soil

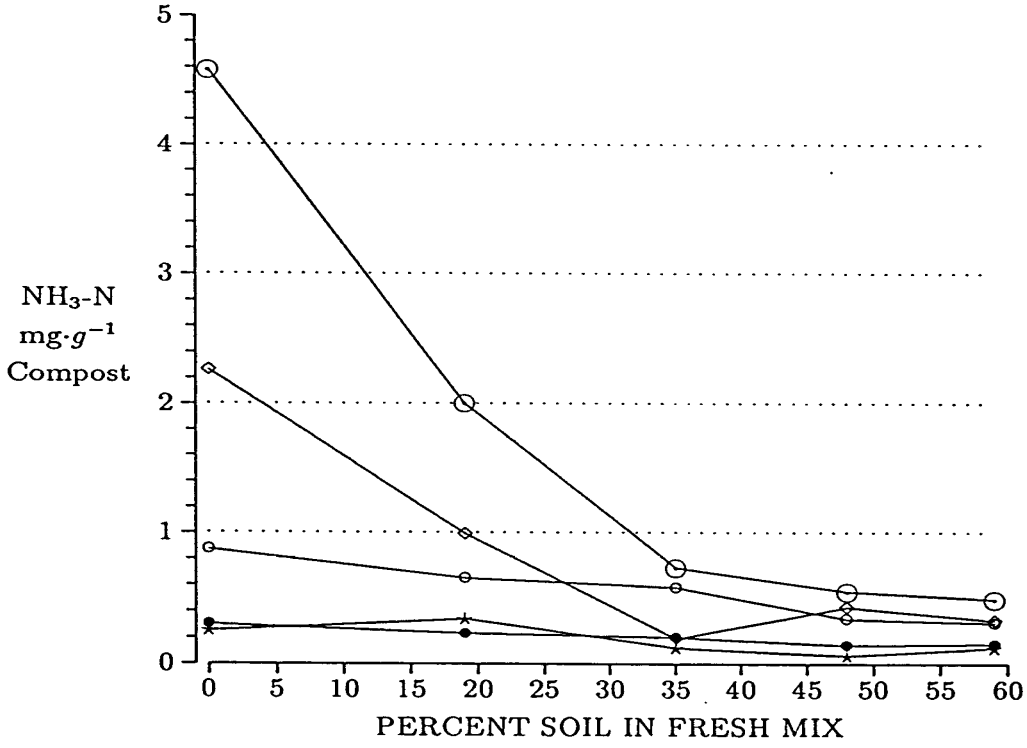


was 57%, 28%, 11%, 4%, 4%, <0.5%, respectively.

The loss of ammonia was significantly ameliorated by soil additions. The relationship is seen in Figure 8-7.

Based on data for the laboratory trials, it was recommended that chicken manure additions be limited for UMDA-soil composts. The maximum chicken manure used for the windrow trials was therefore 3–5% on a volume basis.

Figure 8 - 7 Ammonia Loss Rate for Various UMDA Compost Blends in Relation to Soil Content



SAMPLE KEY:
Sample ID: ◇ [MIX 1] — ○ [MIX 2] ∗ [MIX 3] —
⊙ [MIX 4] — • [MIX 5] — ⋆ [MIX 6]

SECTION 9
BENCH-SCALE (ADIABATIC) TESTING OF RECIPES

There is a need to test composting materials when new ingredients are to be incorporated into field demonstration trials (Sikora et al., 1983). In this study a laboratory screening model was developed to aid in selection of proper ingredients and a series of respiration trials to confirm rate of degradation.

9.1 BENCH-SCALE DESIGN

Laboratory analytical data may not provide adequate information alone on which to implement a composting program, particularly where source ingredient composition and availability change over time and where fluctuating rates of soil material are utilized. To conduct full scale pilots based on calculated mixtures of laboratory tested ingredients could result in costly errors and the risk that unsuccessful trial composts will have to be disposed of or re-treated.

Testing of compost ingredients and compost mixes with the respiration procedure is a satisfactory approach to evaluate composting. CO_2 respiration studies conducted for various ingredients may accurately predict degradation potential but they do not estimate performance and microbiological succession under various heating events found in composts.

Heating is an important parameter, but one which remains unknown in respiration trials normally conducted at static temperatures. In order to test composting heating potential prior to full scale implementation, bench scale tests are required. Therefore, Woods End developed and evaluated a test procedure to simulate compost heating.

The bench scale model for pre-testing ingredients developed in his study originated in previous research by USDA (Sikora et al., 1983). A portable bench scale unit was developed that would monitor and control a temperature differential of at least 0.1^oC up to 6^oC within a biological environment. Control mechanisms employed user supplied compressed air to cool and oxygenate the biological environment. In addition, control of a circulating bath heater is employed by means of sensing the temperature differential between the envelope of bath water and the pile chamber to assure the required heat environment.

The bench scale system dynamically insulates the test compost to simulate thermophilic temperature rise by limiting and controlling heat-loss in a real-time feed-back control mechanism. Theoretically, such as test device should help to eliminate compost mixtures which do not have the po-

tential to induce enough calorific release to sufficiently heat a compost loaded with contaminated soil under optimal moisture and aeration conditions.

Woods End evaluated original plans of a prototype bench scale unit of the USDA (Sikora et al., 1983), and set objectives and stipulated functionality for a modern electronic design (C. B. Ives Company, 1991). A simplified schematic plan for the equipment is reproduced below (see Figures 9-1 and 9-2).

9.2 BENCH-SCALE UNIT TESTING

Currently, there is no information which details the influence of soil loading on decrease in heat potential of contaminated soil composting (USATHMA, 1989; Woodward, 1990). The adiabatic units were used to evaluate the relative performance of pre-selected compost recipes using differing load rates of soil. By providing precisely the same ambient conditions, the adiabatic units provide an accurate measure of differences in heating arising from the material itself. Figure 9-3 presents the results of monitoring four-selected compost mixtures in the adiabatic units for 35 days.

The basic adiabatic model incorporates the following features:

- Bench Composter Electronic panel to operate and monitor the vessel;
- Stainless-steel sealed, vessel of 1 to 3-liter size
- Electronic control of water-bath with variable set-option to maintain at least a 1^{o}C temperature differential between the water-bath mantel and the compost inside the vessel;
- Variable aeration control to set air flow at desired points;
- Optional monitoring ability for CO_2 and O_2 production and removal.

The data in Figure 9-3 indicate an impressive rise to high heat of composts with varying amounts of soil. There is an evident diminishing function as soil rate increases. In Table 9-1 the average temperatures recorded are calculated over 35 days of performance in relation to soil loading rate. There is no loss of performance with 10% soil, but a decline sets in at the 20–30% rates.

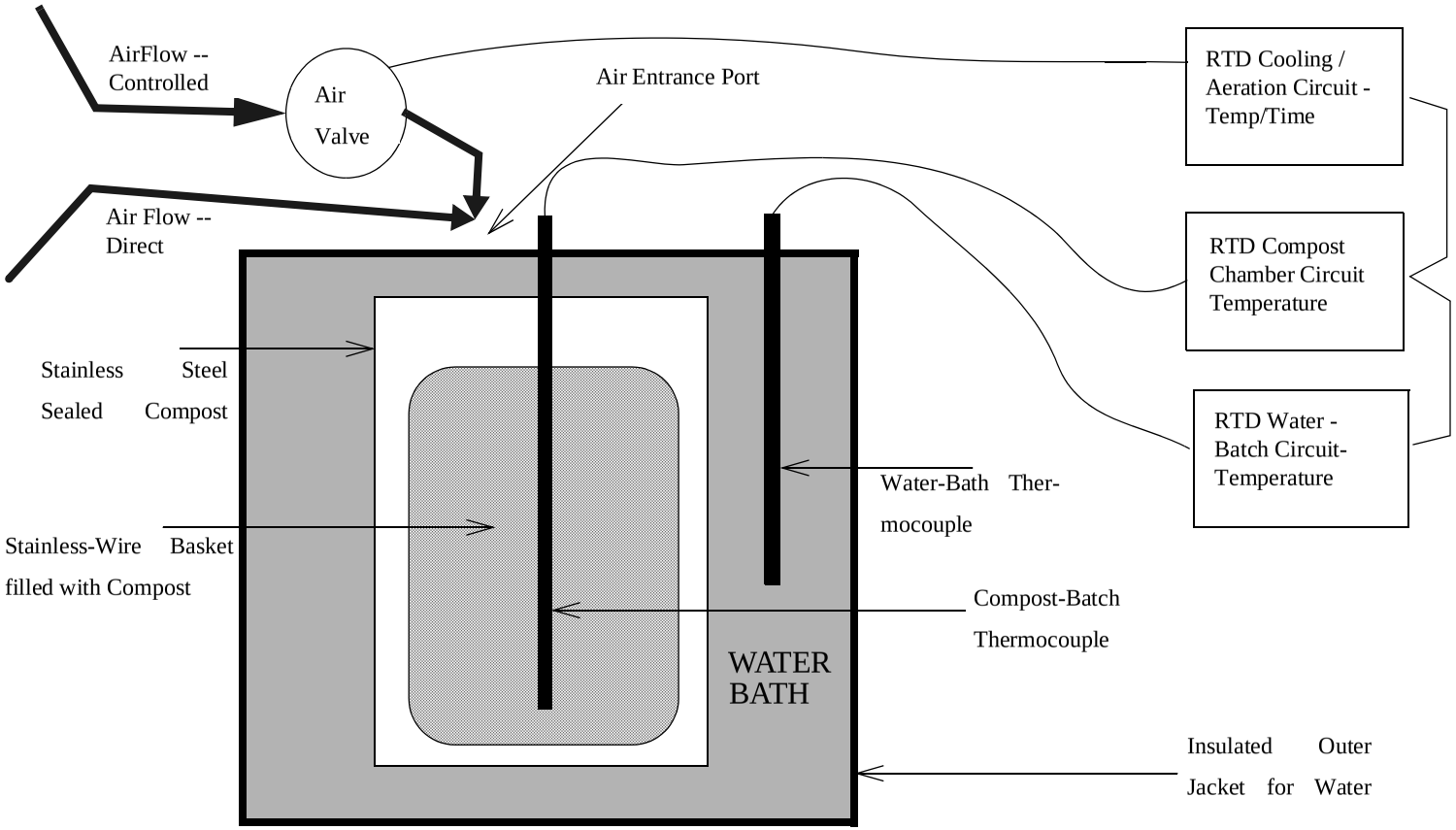


Figure 9 - 1 Plan of Adiabatic Composter Unit Used by Woods End Research Laboratory to Test Compost Mixtures for Contaminated Soil Composting

UMDA Adiabatic Composter

Functional Control Diagram

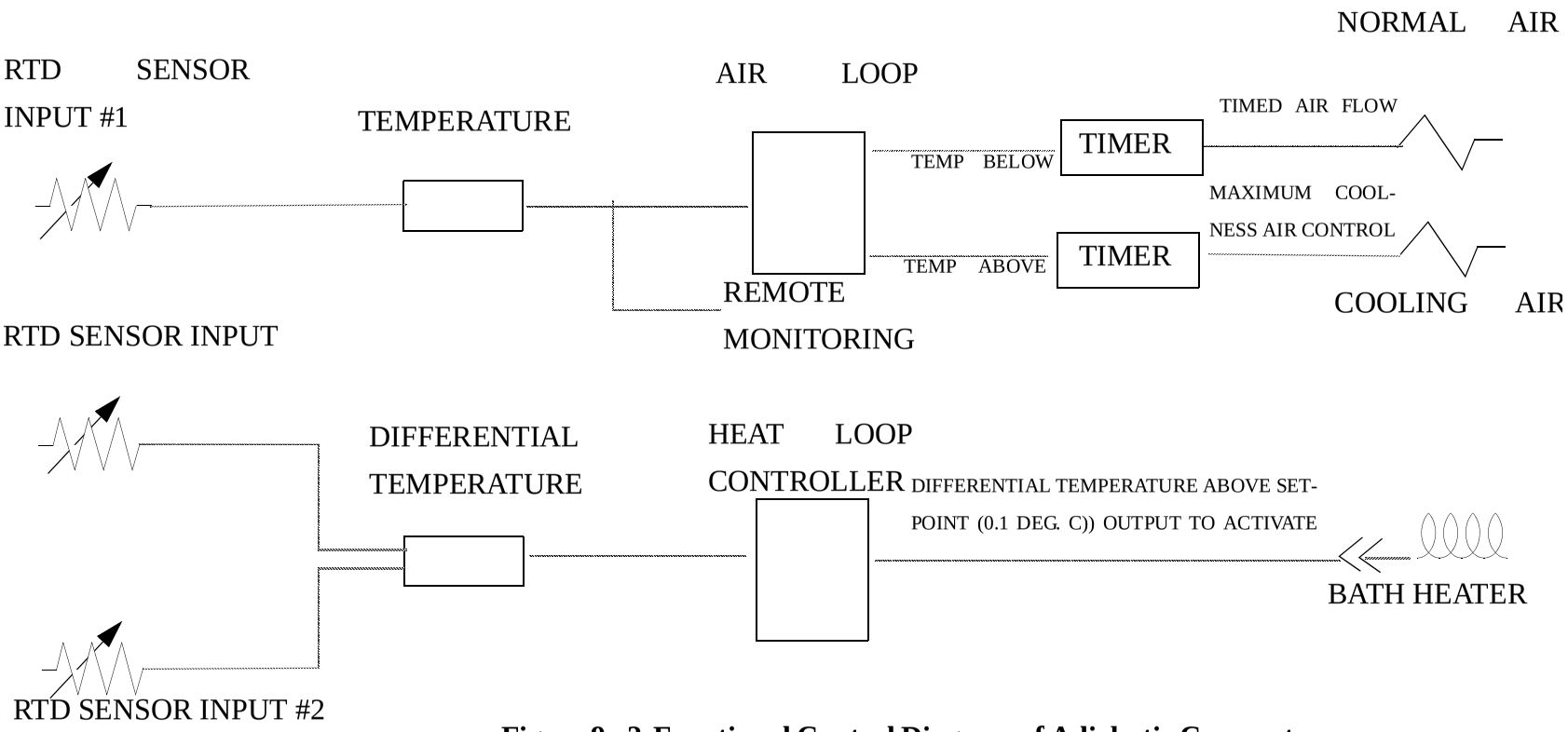


Figure 9 - 2 Functional Control Diagram of Adiabatic Composter Unit Used by Woods End Research Laboratory to Test Compost Mixtures for Contaminated Soil Composting

Table 9-1 Soil-Loading Influence on Observed Heating in Adiabatic Composter Units

Treatment Type	**Temperature Observed Avg C^o 35 Days**
Control, Basic Compost Mix	49.7
+ **10%** v/v Contaminated Soil	50.2
+ **20%** v/v Contaminated Soil	47.8
+ **30%** v/v Contaminated Soil	42.3

In Figure 9-4 the relative rise over ambient in laboratory trials with the adiabatic unit loaded at differing soil rates was plotted. The data show that soil inclusion results in a non-linear decrease in heating ability as the percent soil volume is increased.

Thus, if the line in Figure 9-4 is extended, it is estimated that an inclusion rate of 40% soil volume will result in an average temperature rise of only 10^{o}C within 35 days. While the data from this trial is limited, it corroborates the other respiration trial results where the performance of several compost blends at soil loading up to 35% by volume were evaluated (see Figure 8-4). In the first UMDA trials, soil loading at 40% resulted in significantly less heating and contaminant degradation than lower volumes (Weston, 1991).

Figure 9 - 3 Temperature Performance of Compost Pre-Mixes in Adiabatic Composter Units

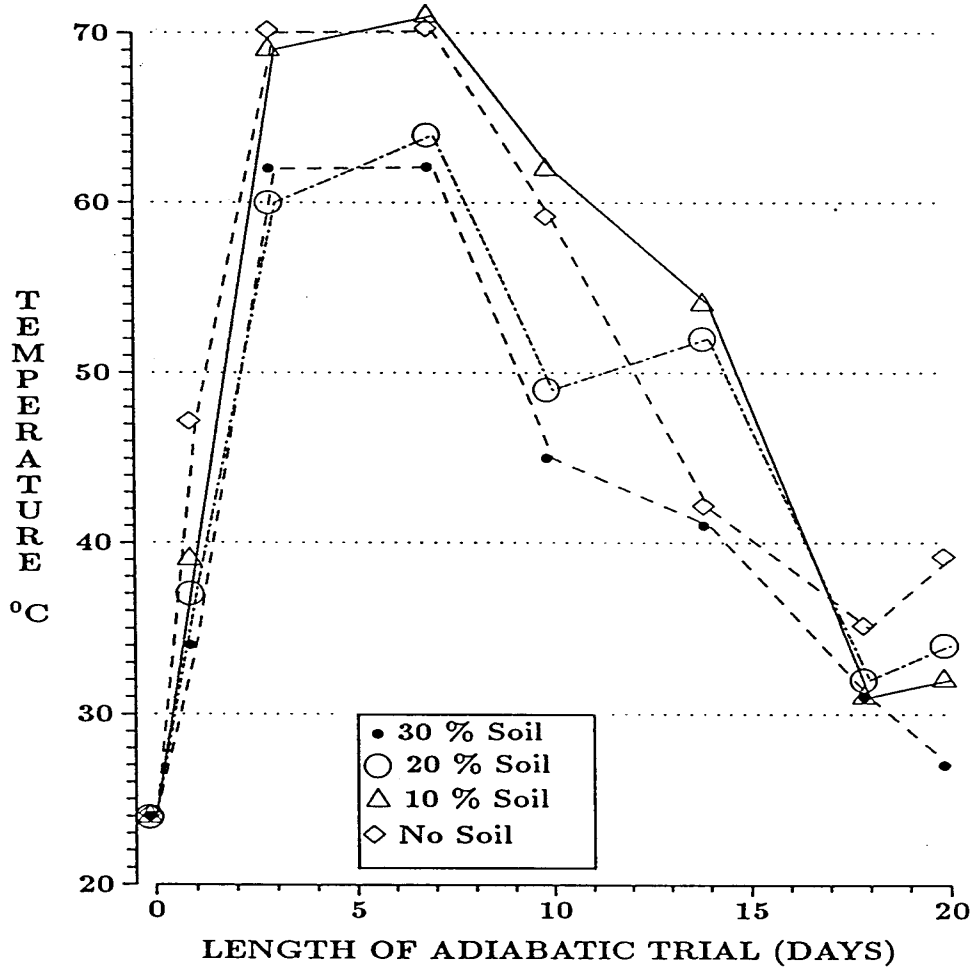
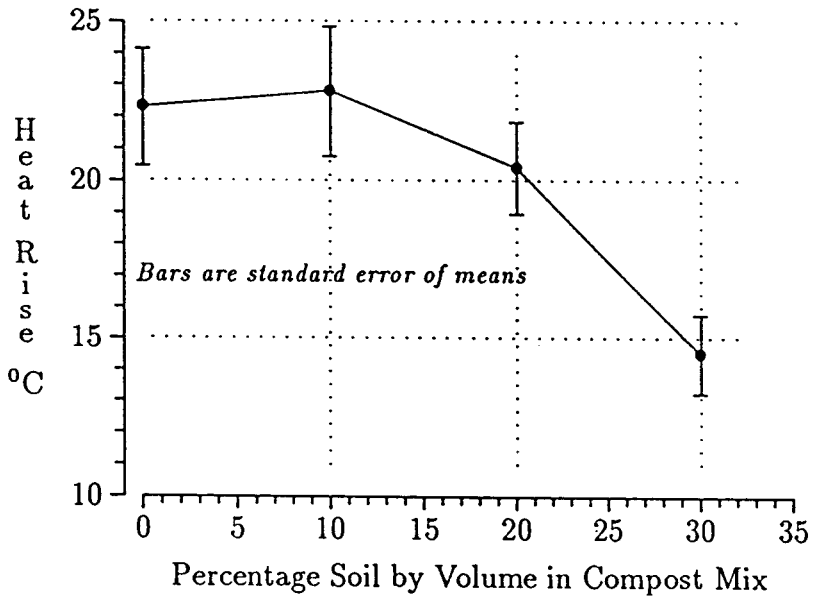


Figure 9 - 4 Relationship of Soil Inclusion Rate in UMDA Compost and Average Temperature Above Ambient Attained Over 30 Days



SECTION 10
COMPOST RECIPE FINALIZATION

The data from previous trials supports the notion that high loading rates of soil for composting may be achieved. Evidence exists that there is an increased efficiency of degradation with increased soil loading up to 25% by volume. Furthermore, there is no significant decline in heating potential until around 30% by volume soil.

The recommendations suggested from this research are predicated on the fact that a procedure to optimize respiratory potential of soil composts was adopted. Under other circumstances with other compost ingredients, it can not be predicted what efficiencies or temperatures can be achieved.

This study pre-selected several traits from which optimization of the mix recipe were determined. These traits include C:N ratio, moisture content and bulk density. Additionally, we refine the procedure to evaluate texture and porosity.

The actual procedure used to compute relative quantities of two or more ingredients is based on simultaneous equation solving (Brinton and Seekins, 1988). If we have two ingredients "A" and "B" which we intend to mix, and where *C* and *N* are carbon and nitrogen contents, respectively, then in order to find the relative mixing proportions for the (A) component and for the (B) component where C and N are targeted carbon and nitrogen (C:N) portions:

$$(i)\ (SampleA)_C = (SampleB)_C = C \qquad (3)$$

$$(ii)\ (Sample\ A)_N + (SampleB)_N = N$$

The procedure is to solve first for (*SampleB*) by dividing each equation by its coefficient for (*SampleA*), eliminate (*SampleA*) by subtracting (*ii*) from (*i*), solving for (*SampleB*), and then by substitution to arrive at (*SampleA*).

The basic mixtures used in this project were computed by solving for 2 or 3 unknowns of 2 or 3 ingredients where C:N moisture and density were solved for. Other simple procedures using weighted averages have also been described (Rynck, 1992). The data collected for source ingredients as seen in Tables 7-6 and 7-7 permits extensive computations based on any attribute to be undertaken.

The recipe model and the predictive capabilities gave satisfactory results. In Table 10-1, the recipe and the prediction for two compost piles are given (Weston, 1993).

The data indicate predictability was good based on the recipe model used in the study. Organic content found was often lower than predicted; the respiration rate was high enough that between measuring fresh samples and mixing the recipes, some solids loss could have occurred.

Table 10-1 Prediction from Recipe and Actual Observed Values for Day 0 UMDA Composts

TRAIT	Recipe Value	CWR7 Found	CWR8 Found
Density, lb/ft^3	52	53	53
Moisture, %	29.7	32.0	32.4
Organic Matter % as is	16.6	13.2	14.2
C:N Ratio	31.8	22.9	26.6
Total-Nitrogen % as is	0.276	0.284	0.286

We selected a C:N ratio of 32–40 as optimal for composting during the UMDA trials. This study does not evaluate the effect of varying ratios of carbon to nitrogen. Increasing carbon relative to nitrogen is known to cause longer, cooler composting processes. Theoretically, increased C:N should also cause greater carbon loss, since composts tend to stabilize at or around a C:N of 15–17 (Parnes, 1990).

The ideal amount of moisture used in composting can not be given without first knowing the water-holding capacity and the soil content. In this project, the required moisture was determined from the data presented in Table 7-10, as was also the bulk density percentage water holding capacity.

SECTION 11
COMPOST POROSITY FACTORS

Theoretically, compost mix formulas and composting conditions are likely to affect the porosity and hence resultant oxygen penetration of the compost piles. Field tests during the second phase of the UMDA study demonstrated that oxygen in the core of the unaerated windrow was measurably depleted shortly after turning (see Figure 11-1) (Weston, 1993). This suggested that the refresh rate of air may have been less than the consumption rate. The factors that influence the relationship are compost porosity and oxygen consumption rate. Since oxygen consumption is a positive factor which has been deliberately selected for in composting contaminated soil, it was felt to be important to focus on porosity which controls refresh rate.

A laboratory trial was established to determine the influence of pile size and turning conditions on the apparent porosity or pore-volume of the composts (see Figure 11-2). Porosity is defined as the amount of free air space not occupied by particles or water. Compost porosity is determined as follows (Page, 1982):

$$\% \text{ porosity} = 100\% - (\text{wet bulk density} / \text{particle density}) \times 100\% \qquad (4)$$

The compost bulk density (g / cc^{-1} total volume) has been shown to change in proportion to increasing age and increased soil content. Furthermore, the compost particle density measured by the water displacement method (Page, 1982) increases with age and soil content. If particle density is not taken into account, then computations using the difference method (total volume less dry bulk density) (Page, 1982) tend to underestimate actual air volume.

The data in Figure 11-2 indicate that the air volume in static piles ranged from 65 to 52% and was significantly greater than the porosity for turned windrows which ranged from 50 to 27% at simulated depths. The reduction in porosity with depth into the pile results from the increase in compaction from overlying material and is influenced by the bulk density of the product. The depth is simulated in the laboratory by applying pressure equivalent to the bulk density.

Reduction in compost air volume may adversely influence composting performance since it means that oxygen will become depleted more quickly. There is little information regarding optimal values for compost porosity. Values above 50% air space have been recommended for active composts (Lechner, 1992). Windrow turning by high-speed mechanical agitation in this project may have acted to break-down texture-bearing materials and is likely to explain the lower porosity in the windrow samples. Since the oxygen readings seen in Figure 11-1 are taken near the core, the

reduction in porosity observed with depth may be a contributing factor. Data collected in the second UMDA trial support that this porosity factor did not adversely affect explosives removal, since removals in windrows were better than or equal to those in static piles.

The effect of sample depth of daily turned windrows with and without added air was evaluated in a separate trial, seen in Figure 11-3. The data indicates that compost porosity from windrow systems is fairly uniformly low under all circumstances.

Figure 11 - 1 Oxygen Content in Relationship to Time After Windrow Turning of Active Contaminated Soil Compost

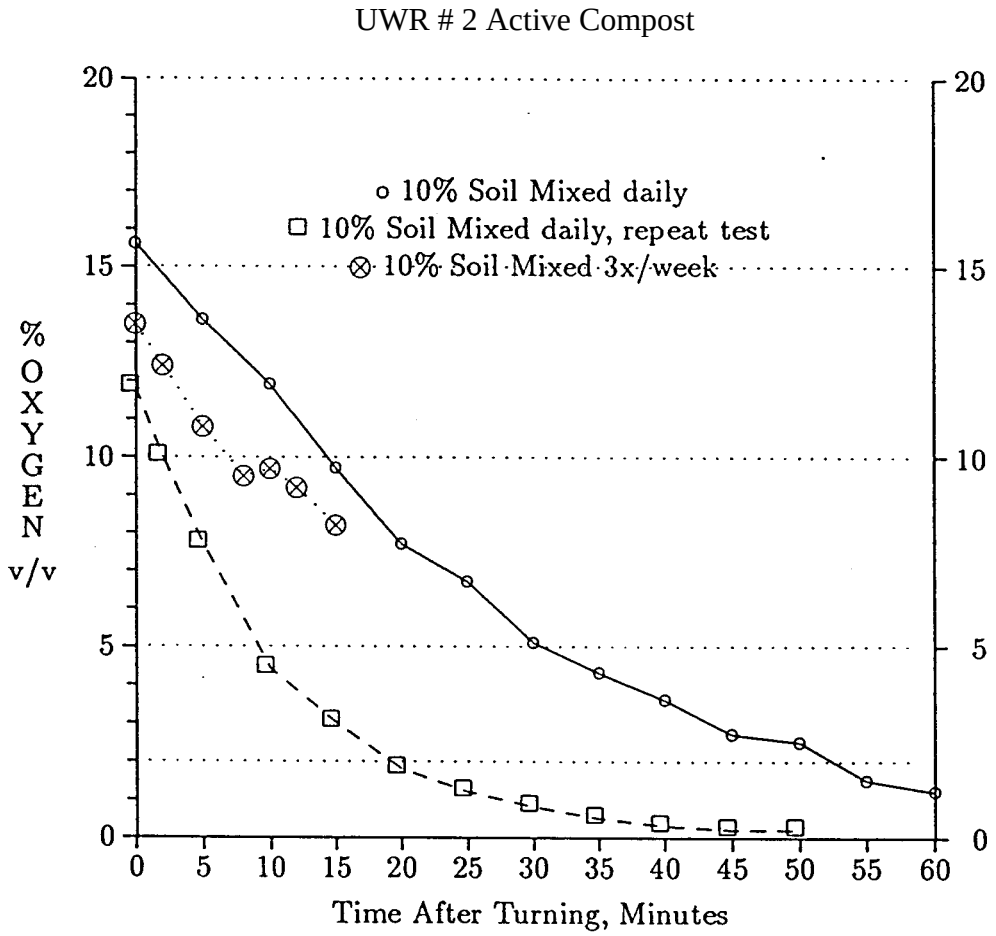


Figure 11 - 2 Compost Air Volume as a Function of Simulated Pile Depth and Pile Management

Reference WERL Lab # 2560.0 -.1 and 2573.0 - .1

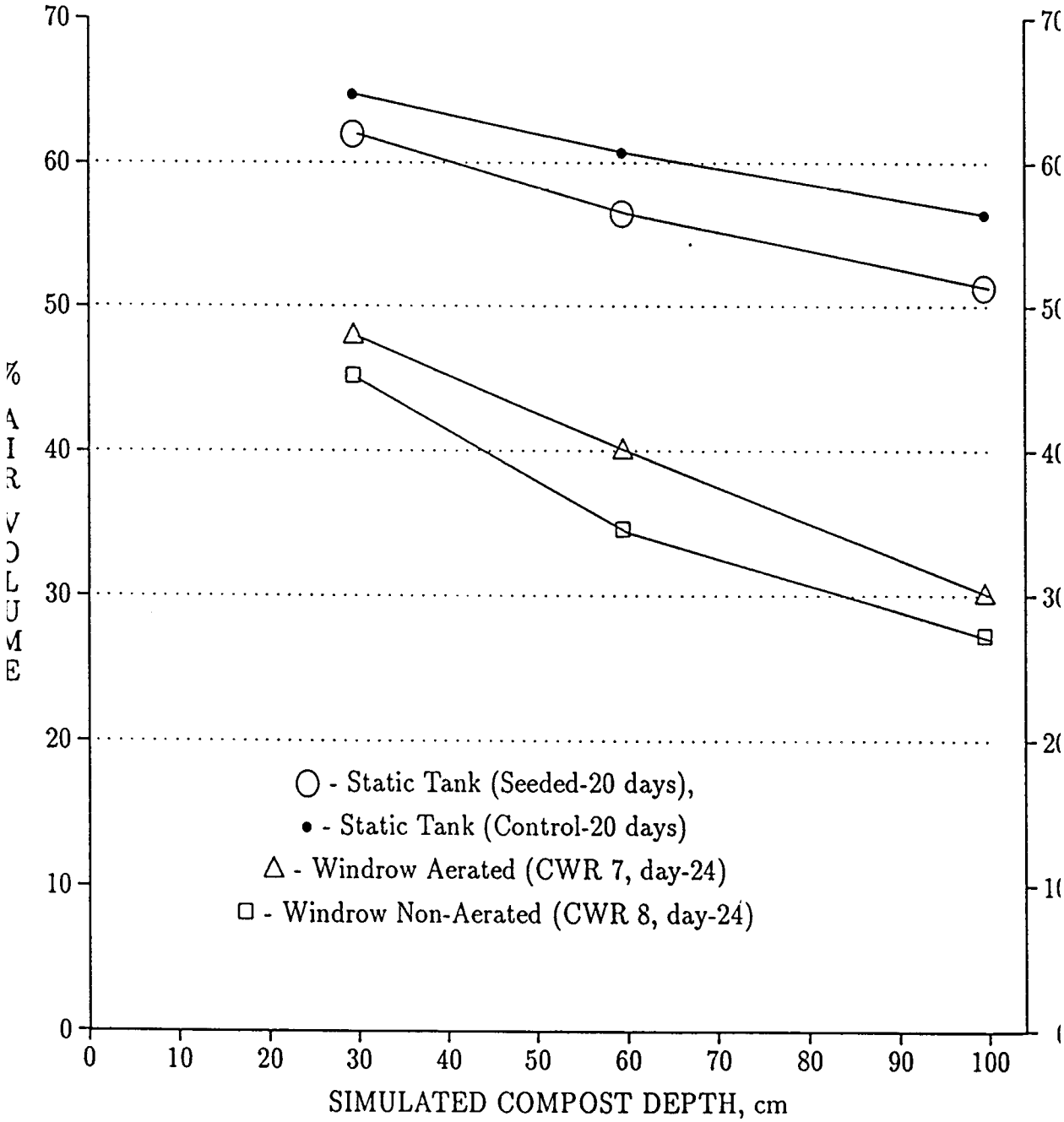
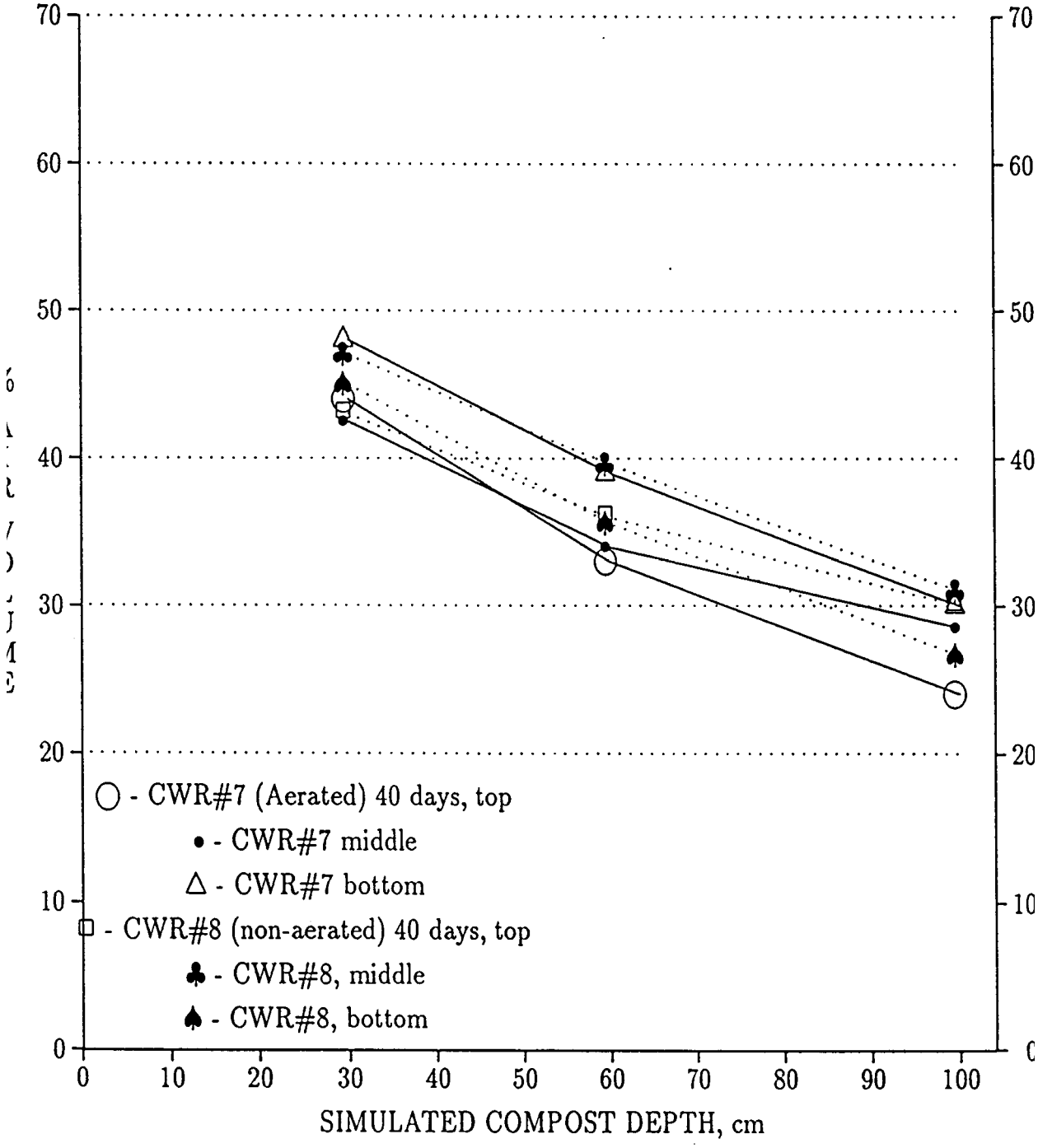


Figure 11 - 3 Compost Air Volume as a Function of Pile Management, Depth in Pile, at Simulated Depths



SECTION 12
COMPOST PROCESS MONITORING

During a composting process, events such as heat rise and loss of moisture occur and form the basis for process monitoring. For example, heat may be used to trigger cooling fans or a turning cycle, and moisture loss may be gauged to prevent over-dryness from taking place.

The need to monitor the compost process is dictated by the fact that many compost events occur rapidly and are not easily predicted, but result in changes that may need to be quickly resolved. Moisture declines during high-heating and may need to be frequently supplemented. Volume or porosity is influenced by choice of ingredients and may require adjustment to maintain effective aeration. For example, an important indicator of process quality is the level of volatile organic acids (VOA), which are increased under conditions of low oxygen concentrations and rapid breakdown.

Woods End Laboratory provided information and testing for aspects of the UMDA monitoring plan. The important traits monitored during composting included but were not limited to the following (see Table 7-2):

- Moisture content;
- Pore Space
- Volatile organic acids
- Organic matter content
- pH, ammonia content
- Microbial levels

12.1 INITIAL TEST WINDROWS

Laboratory analyses were performed during the early phase of composting of the first UMDA test windrows (UWR1, UWR2), (Weston, 1992; Weston, 1993), containing 10% uncontaminated soil. UWR1 was turned 3 times per week and UWR2 every day. The relative performance of the process was evaluated in terms of composition (C:N, pH, ammonia) and presence of volatile organic acids, potentially produced during semi-anaerobic fermentation.

The data indicates that in the early phase (first week) of composting, the contents of respective organic acids in the two samples were (on a dry basis) 16,228 mg/kg (turned 3 time per week) as against 23,696 mg/kg for the daily turned piles. Five days later we re-tested the VOAs and found them to have dropped considerably to 10,182 mg/kg for UWR1 (turned 3 times per week) and 9,461 mg/kg for UWR2 (daily). It can not be explained why at first the more rapid turning resulted in higher VOAs; it may have been a recipe factor. The VOAs in these piles quickly dropped to similar levels after about the 10th day (see Figure 12-1).

The other traits such as moisture, pH and C:N were close to expected ranges, and the pH values started on the low side and increased as the VOAs came down. For example, the average pH in the lab on the first samples was 6.0 and 5 days later it was 8.0, an decrease of two orders of magnitude of hydrogen ion. In windrows UWR5 and UWR6 we monitored for respiration rate during composting. The rate declined more rapidly in the aerated pile, and both were very low and nearly identical at day 44 (see interpretation glossary in the Appendix).

It is notable that almost one month later (day 27 sampling) the VOAs in Piles 1 & 2 had fallen to close to the minimum detectable level (MLD) of 300–600 mg/kg. Thus, if anaerobic conditions existed at one point, they did not have any lasting effect on VOAs. It is doubtful from this data if the compost process was adversely affected.

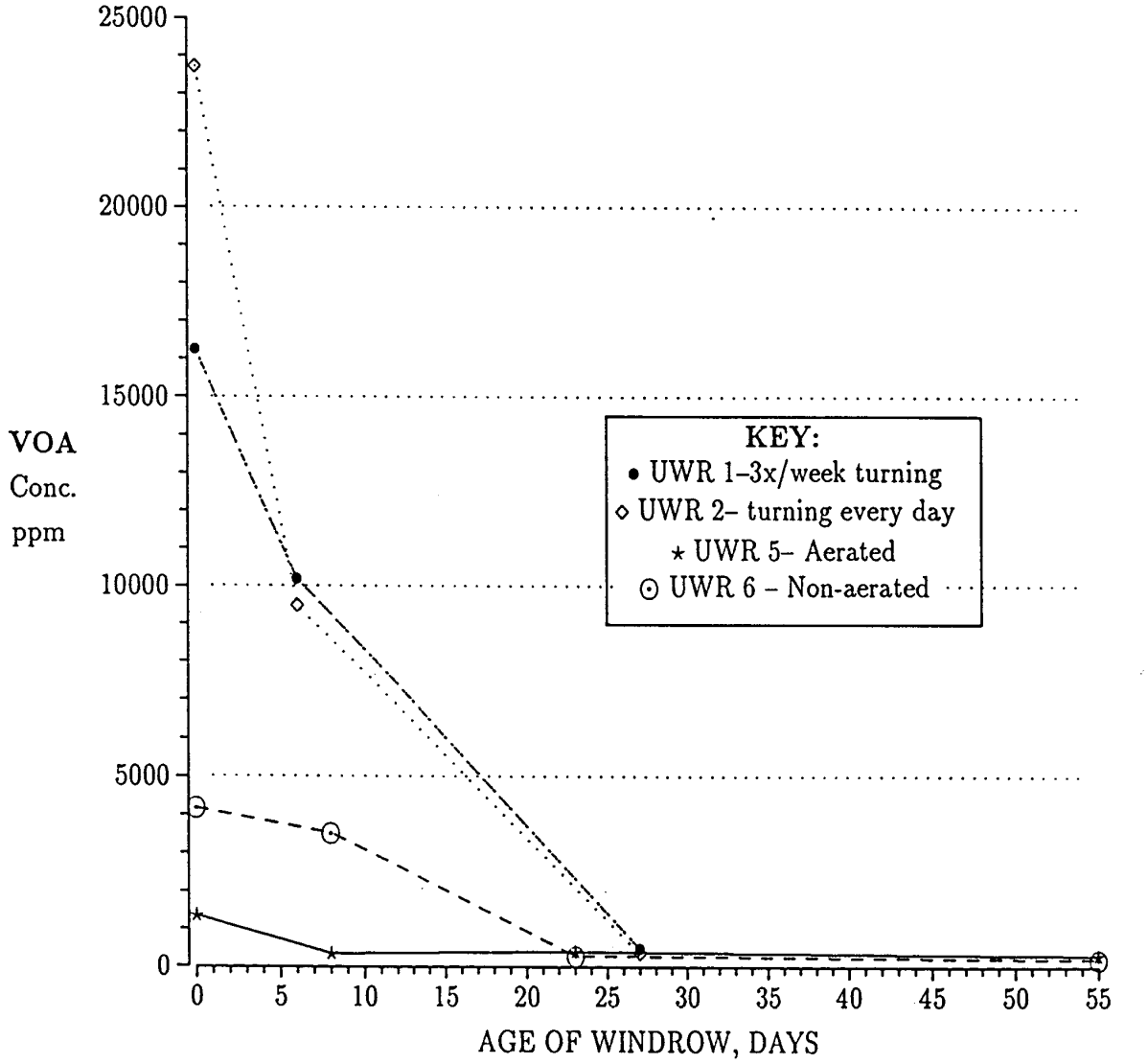
Microbiological tests were first initiated by Woods End during the Pile 5–6 sequence. These data are seen in Table 12-2.

The biochemical data indicate very high total bacterial counts for both types of piles at the outset, with rapid declines of activity during composting. There was no evidence of differences imposed by the aeration/non-aeration sequence that can be gathered from this data.

Enzyme activity was slightly higher for aerated than non-aerated piles. For example, urease was positive throughout the aerated composting, and hydrolase activity was elevated. Thermophilic hydrolase activity, however, showed no difference between the treatments. Both piles did show fermentative activity (production of VOA) at the beginning and end of the process. *E. coli* survived the composting process, which is not unusual (Droffner & Brinton, 1994).

The data in Figure 12-1 show the changes in volatile acids with age of composts for paired groups of 10% and 30% soil at similar dates. With the earlier composts, there was a very high level of

Figure 12 - 1 Volatile Organic Acid Concentration in Windrows at Different Ages



VOA initially which declined rapidly with age, and showed no relationship to whether or not air was added. In the later windrow composts, the non-aerated showed more initial VOA which did not decrease to background levels until 23 days as versus 8 days with supplemental aeration.

Table 12-1 Laboratory Results - Initial Test Windrows

Lab-No	H_20	pH	OM	TKN	C:N	NH_3-N	$N0_3$-N	VOA	ORP	Salt	CO_2-C
	----as is----		----------% of TS----------					ppm TS	mV	*mmhos/cm*	% of C_t
Windrow UWR 1– turned 3x/week, 10% soil											
Day 3	51.2	6.06	45.90	0.96	25.8	0.000	0.000	16228	148	8.2	na
Day 9	41.3	7.80	34.65	0.75	25.0	0.000	0.000	10182	489	7.2	na
Day 30-a	42.3	8.80	27.89	0.65	23.2	0.124	0.000	624	301	6.2	na
Day 30-b	40.7	8.80	29.82	0.56	28.8	0.110	0.000	486	348	6.4	na
Windrow UWR 2– turned daily, 10% soil											
Day 3	49.0	5.98	49.51	1.15	23.3	0.000	0.000	23696	190	10.4	na
Day 9	35.3	8.25	29.89	0.78	20.6	0.000	0.000	9461	405	8.2	na
Day 30-a	37.7	8.90	22.16	0.58	20.7	0.096	0.000	347	343	7.1	na
Day 30-b	36.4	8.80	24.31	0.56	23.2	0.074	0.000	339	354	8.3	na
Windrow UWR 3– turned 3x/week, 20% soil											
Day 30-a	40.8	8.20	17.53	0.55	17.2	0.273	0.000	18242	320	8.6	na
Day 30-b	35.4	8.10	21.63	0.47	24.9	0.209	0.000	7696	304	9.7	na
Windrow UWR 4– turned daily, 20% soil											
Day 30-a	37.5	8.60	17.22	0.49	19.1	0.135	0.000	2993	331	7.0	na
Day 30-b	36.4	8.60	13.40	0.43	16.7	0.117	0.000	1698	366	6.6	na
Windrow UWR 5– 30% soil, aerated, turned											
Day 0	20.0	8.20	12.02	0.26	25.0	0.069	0.000	1349	308	3.7	3.15
Day 10	17.5	8.30	10.44	0.22	25.5	0.052	0.000	349	329	4.8	0.72
Day 20	28.3	8.00	13.72	0.23	32.8	0.029	0.008	402	49	3.8	0.55
Day 44	28.2	8.15	12.37	0.25	26.7	0.006	0.021	301	27	3.4	0.31

Table 12-1 (Continued) Laboratory Results - Initial Test Windrows

Lab-No	H_20	pH	OM	TKN	C:N	NH_3-N	$N0_3$-N	VOA	ORP	Salt	CO_2-C
	----as is----		----------% of TS----------					ppm TS	mV	*mmhos/cm*	% of C_t
Windrow UWR 6– 30% soil, non-aerated, turned											
Day 0	25.7	6.15	11.80	0.36	17.7	0.077	0.000	4168	184	5.6	3.89
Day 10	22.2	7.50	10.93	0.32	18.5	0.172	0.000	3518	229	7.7	3.32
Day 20	25.3	9.00	12.43	0.21	31.7	0.087	0.000	289	66	4.0	0.91
Day 44	27.1	7.94	17.49	0.22	43.3	0.003	0.015	197	9	3.9	0.21

(n/a) indicates not analyzed
(a-b) replicate testing)

Table 12-2 Microbiological Traits of Initial Aeration-Test Windrows

Sample	H30 °C	H50 °C	Dh	H_2S	F	Da	Ur	AER	AN	THER	FU	E.c (M)	E.c (D)	Cl
						Windrow 5 Aerated								
Day 0	7	18	106	nd	+	nd	+	10^8	10^8	10^3	$<10^2$	$<10^2$	n/t	$<10^2$
Day 10	8	16	94	nd	nd	nd	+	10^4	10^3	10^2	$<10^2$	$<10^2$	neg	$<10^2$
Day 44	0	12	132	nd	+	nd	+	10^3	10^3	10^2	10^2	10^4	pos	10^2
						Windrow 6 Non Aerated								
Day 0	4	21	49	nd	+	nd	nd	10^8	10^8	10^3	$<10^2$	$<10^2$	n/t	10^3
Day 10	1	10	98	nd	nd	nd	nd	10^3	10^3	10^2	$<10^2$	$<10^2$	neg	10^2
Day 44	4	16	51	nd	+	nd	+	10^3	10^3	10^2	10^2	10^4	pos	$<10^2$

Symbol Index to Microbiological tables
+ .....Denotes positive presence of organism, or trait measured
nd.....Denotes no organism present or no activity for trait measured.
pos .....positive DNA result
neg.....negative DNA result
n/t .....not tested for

Acronym Index
Dh.....Dehydrogenase enzyme (reductive odor activity)
H(30^oC) .....Hydrolase Activity at 30^oC
H(50^oC) .....Hydrolase Activity at 50^oC
Da.....Deaminase Activity
Ur .....Urease Activity
THER .....Thermophilic bacteria Count
FU.....Fungal Count
H_2S.....Hydrogen Sulfide Production
F .....Fermentation (VOA) production
AER.....Aerobic Bacteria Count
AN.....Anaerobic (facultative + obligative) Bacteria Count
E.c(M) .....Escherichia.coli MUG test
E.c(D).....Escherichia.coli DNA test
Cl.....Clostridia

12.2 STATIC SEED TANK MONITORING

The static vessel seed study was undertaken to ascertain influences on contaminant degradation of compost recycle. The following table gives a breakdown of the various samples obtained by Woods End for material evaluation. We have grouped the data by type of tank; first analyzing the differences in the day 1 tanks, all the initial tanks at sequences of 20 days, and finally the day-20

samples from each of the control and seeded tanks.

The static seed data indicate several important points:

- Several traits and especially organic matter content varied more between batches than between treatments– i.e. the successive mixes of the same recipe introduced a large variation;
- All initial blends were very high in VOA content and low in respiration rate.
- VOA and respiration rate decline with age; however, C:N increases as a apparent result of net loss of nitrogen (pH was high);
- Each control/seed pair of sample data are more similar to each other than to any other sample.

Table 12-3 Laboratory Results of Monitoring Static Compost Vessels

Lab-No	H_20	pH	OM	TKN	C:N	NH_3-N	$N0_3$-N	VOA	ORP	Salt	CO2-C
	---- as is----		----------% of TS----------					ppm TS	mv	*mmhos/cm*	% of C_t
Initial control tanks											
Day 0-a†	57.2	5.55	37.07	0.89	22.4	–	–	12627	90	7.0	0.15
Day 0-b	56.9	5.50	38.42	0.91	22.8	–	–	13201	87	7.2	0.15
Day 0-c	58.0	5.50	37.48	0.87	23.4	–	–	13534	86	7.3	0.15
Day 20	49.3	6.35	30.79	1.00	16.7	0.157	0.007	6818	79	5.7	2.24
Day 40	47.5	7.10	42.49	0.86	26.8	0.104	0.011	4386	92	5.4	0.58
Day 60	54.1	6.10	43.89	0.96	24.6	0.096	0.007	10832	38	6.6	0.39
Initial seeded tanks											
Day 0	52.2	5.45	27.79	0.84	17.8	–	–	14006	140	8.4	0.34
Day 20	46.5	6.45	25.56	1.04	13.2	0.168	0.006	9827	94	6.7	2.27
Day 40	50.6	6.30	39.16	0.97	21.7	0.101	0.012	9040	36	6.1	0.54
Day 60	52.3	5.17	42.83	0.98	23.7	0.079	0.006	12367	32	7.2	0.09

Table 12-3 (Continued) Laboratory Results of Monitoring Static Compost Vessels

Lab-No	H_20	pH	OM	TKN	C:N	NH_3-N	$N0_3$-N	VOA	ORP	Salt	CO2-C
	---- as is----		----------% of TS----------					ppm TS	mv	*mmhos/cm*	% of C_t
20-day sample tanks (s = seeded)											
Day 20/ 20‡	38.5	7.70	26.26	0.96	14.8	0.203	<0.001	5969	153	6.7	3.15
Day 20/ 20s	39.2	7.60	27.70	1.00	15.0	0.227	<0.001	7106	97	7.1	2.98
Day 40/ 20	33.6	8.80	45.73	0.84	29.3	0.128	0.003	1085	174	6.0	0.54
Day 40/ 20s	27.1	8.60	48.82	0.94	28.2	0.066	0.004	692	214	5.6	0.50
Day 60/ 20	47.9	9.06	43.86	0.72	32.9	0.073	0.000	414	206	4.4	0.82
Day 60/ 20s	41.4	9.11	40.49	0.81	27.1	0.055	0.003	491	194	4.5	0.42
Day 80/ 20	40.7	9.09	42.19	0.66	34.8	0.043	0.001	486	273	4.0	0.45
Day 80/ 20s	47.0	9.11	45.00	0.78	31.1	0.062	0.001	543	318	3.6	0.59

† indicates replicate testing (a, b, c) to verify uniformity.
(–) indicates not analyzed
Initial seeded tanks are at the start of each batch;
Sequence tanks are taken at 20 days after start-up of each successive batch and are either control (no seed) or (s) = seeded.

The microbiological data was collected only on some of the samples. The following points are highlighted:

- There were more microbiological differences imposed as a result of batches over time (Day 0 blends made at Day 0,20,60) than as a result of treatments (with and without recycle);
- The very first control mixtures showed unusually low microbiological properties (low bacterial counts) compared to later– this is most likely a recipe dependent factor;
- Anaerobic *Clostridium* was present in initial tanks but disappeared later;

- At 20 days, the pair (control/seed) were nearly identical, but the seeded had slightly higher enzyme activity which means more bacterial activity;
- at 60 days, the pair indicate the control has higher bacterial counts and activity than the seed.

12.3 FINAL CONTAMINATED WINDROW MONITORING

The contaminated windrows were evaluated based on periodic sampling of top, middle and bottom profile composts. The sample description is seen in the following list.

The data shows a progression of increasing pH and declining VOAs during the composting, with little or no differentiation evident from sampling the profile at various depths. The pH increased more rapidly in the windrows than in the static tanks. Respiration rates were higher in the initial windrows than in the static tanks. This is also supported by the microbiological data which shows no measurable difference between the profiles.

There is little evident difference between the piles with regard to aerobic qualities. Pile 8 which did not have supplemental air, showed higher VOA and lower pH at the outset, but this would appear to an artifact of pile mixing rather than an actual difference on Day 1 of the aeration change. Final VOA content was higher in the non-aerated sample at 691 ppm average as compared to 516 in the aerated pile; the difference is not significant. Pile 7 showed slightly higher respiration and redox activity, and lost more organic matter than pile 8. The total aerobic and anaerobic organism counts fell by several orders of magnitude from the start to the end (Day 44) of the composts.

Microbiologically, Pile 8 gave more *Clostridium* at the outset; this appears to be related to the higher VOA and lower pHs. At the end, pile 7 gave slightly higher *Clostridium* counts. However, the levels are low.

Table 12-4 Microbiological Traits of Static Vessel Seed Study

Sample	Microbiological and Bio-Chemical Indicators													
	H30 ^{o}C	H50 ^{o}C	Dh	H_2S	F	Da	Ur	AER	AN	THER	FU	E.c (M)	E.c(D)	Cl
							Initial Control Tanks							
Day 0-a	3	9	0	nd	nd	nd	+	10^3	10^3	10^5	10^2	$<10^2$	neg	10^3
Day 0-b	3	8	0	nd	nd	nd	+	10^3	10^3	10^5	10^2	$<10^2$	neg	10^3
Day 0-c	3	5	0	nd	nd	nd	+	10^3	10^3	10^4	10^2	$<10^2$	neg	10^3

Table 12-4 (Continued) Microbiological Traits of Static Vessel Seed Study

Sample	Microbiological and Bio-Chemical Indicators													
Day 20	10	19	156	nd	+	nd	+	10^8	10^8	10^2	10^6	$<10^2$	n/t	10^3
Day 60	0	29	177	nd	nd	nd	+	10^3	10^3	10^5	$<10^2$	10^4	pos	10^2
Initial Seeded Tanks														
Day 0	2	5	0	nd	nd	nd	+	10^4	10^4	10^6	10^2	$<10^2$	neg	10^3
Day 20	11	6	30	+	+	nd	+	10^8	10^8	10^3	10^6	$<10^2$	n/t	10^3
Day 60	0	17	285	nd	nd	nd	+	10^3	10^3	10^2	10^2	10^4	pos	10^2
Twenty Day Sequence Sample Tanks														
20/20	9	12	92	nd	+	nd	+	10^8	10^8	10^5	10^2	$<10^2$	n/t	$<10^2$
20/20s	19	4	190	+	+	nd	+	10^8	10^8	10^3	10^3	$<10^2$	n/t	$<10^2$
60/20	6	47	168	+	+	+	+	10^8	10^8	10^3	$<10^2$	10^3	neg	$<10^2$
60/20s	10	38	103	+	nd	nd	+	10^5	10^5	10^3	$<10^2$	10^4	pos	10^2

for key, see Table 12 - 2

Table 12-5 Laboratory Monitoring Results - Final Composts

ID LabNo	H20	pH	OM	TKN	C:N	NH3-N	N03-N	VOA	ORPx	Salt	CO2-C
	....as is			.....% of TS.....				ppm TS	as is		% TS
Windrow #7–AERATED PILES: *Day 0*											
top	28.7	5.61	17.66	0.37	26.1	0.035	0.002	3029	91	5.4	1.61
middle	36.2	5.34	24.13	0.42	30.9	0.027	0.004	4060	101	4.0	1.17
bottom	31.2	5.06	17.04	0.47	19.7	0.050	0.004	6381	88	6.3	1.23
Windrow #7– *Day 24*											

Table 12-5 (Continued) Laboratory Monitoring Results - Final Composts

ID LabNo	H20	pH	OM	TKN	C:N	NH3-N	N03-N	VOA	ORPx	Salt	CO2-C
mix	30.4	9.15	14.36	0.43	18.0	0.067	0.001	310	260	3.1	0.66
Windrow #7– *Day 40*											
top	30.4	7.07	12.62	0.36	19.1	0.011	0.004	621	166	4.4	0.45
middle	29.8	7.32	15.63	0.36	23.6	0.009	0.004	411	150	4.7	0.36
bottom	30.1	7.46	16.51	0.36	24.6	0.008	0.004	515	143	3.8	0.34
Windrow #8–Non-AERATED: *Day 0*											
top	34.0	5.03	21.90	0.43	27.5	0.051	0.001	10794	135	6.7	0.43
middle	29.9	4.95	19.89	0.42	25.8	0.034	0.001	4725	69	6.3	0.19
bottom	33.4	5.05	21.41	0.42	27.3	0.054	0.002	4647	88	7.1	1.32
Windrow #8– *Day 24*											
mix	33.7	9.15	18.95	0.46	22.1	0.113	0.000	434	317	4.9	0.90
Windrow #8– *Day 40*											
top	29.9	7.35	18.83	0.34	30.2	0.009	0.001	617	125	4.2	0.30
middle	30.7	7.44	16.61	0.33	27.0	0.014	0.001	727	86	4.0	0.34
bottom	31.0	7.40	16.59	0.33	26.8	0.010	0.001	730	77	.9	0.34

Table 12-6 Microbiological Traits of Final Windrows

Sample	H30 ^{o}C	H50^{o} C	Dh	H_2S	F	Da	Ur	AER	AN	THER	FU	E.c (M)	E.c(D)	Cl
Windrow 7														
2551.0	1	6	33	+	+	–	+	10^9	10^9	10^2	10^5	10^3	n/t	10^2
2551.1	n/t	4	61	+	+	–	+	10^9	10^9	10^2	10^5	10^3	n/t	10^2
2551.2	2	3	41	–	+	–	+	10^9	10^9	10^2	10^5	10^3	n/t	10^2

Table 12-6 (Continued) Microbiological Traits of Final Windrows

Sample	H30 °C	H50° C	Dh	H_2S	F	Da	Ur	AER	AN	THER	FU	E.c (M)	E.c(D)	Cl
2587.0	2	34	43	–	+	–	+	10^6	10^6	10^7	10^2	10^4	pos	10^3
2587.1	2	15	49	–	+	–	+	10^6	10^7	10^6	10^2	10^4	pos	10^3
2587.2	1	40	49	–	+	–	+	10^6	10^7	10^7	10^3	10^4	n/t	10^3
							Windrow 8							
2551.3	n/t	2	45	+	+	–	–	10^9	10^8	10^2	10^5	10^3	n/t	10^3
2551.4	n/t	3	18	–	+	–	–	10^5	10^6	10^2	10^5	10^3	n/t	10^3
2551.5	3	5	29	–	+	–	+	10^7	10^7	10^2	10^2	10^3	n/t	10^3
2587.3	n/t	15	49	–	+	–	–	10^6	10^6	10^7	$<10^2$	10^4	pos	10^2
2587.4	1	15	34	+	+	–	–	10^6	10^7	10^7	$<10^2$	10^4	pos	10^2
2587.5	1	12	39	–	–	–	–	10^6	10^6	10^7	10^2	10^3	n/t	10^3

n/t = not tested; for key to symbols, see Table 12-2.

SECTION 13
RECOMMENDATIONS

13.1 PRE-TESTING INGREDIENTS

Pre-testing of compost ingredients is an important pre-requisite to composting as it provides a means to assess the key traits which are important in recipe development. It is not possible to provide target values for source materials themselves. Rather, the physical and chemical traits are significant only in their bearing on the qualities of the initial compost mix. The target composition of the initial compost mixes is indicated in Table 13-1

.

Table 13-1 Target Active Compost Monitoring Traits

Trait	Target
C:N Ratio	30–40
Moisture	60-80% of WHC
Density	700-1200 lb / yd^3
Porosity	>60%
VOA Content	< 15000 ppm
CO_2 Rate	> 1.0%C / day^{-1}

13.2 COMPOST INGREDIENT HANDLING

Compost ingredients are best handled and measured on a bulk weight basis. Conversions back and forth to volume basis are at best confusing and should be performed only when needed. It is desirable to have a weigh scale on site to measure quantities as an alternative to guessing at mix recipes from variable volume data alone.

13.3 COMPOST PROCESS MANAGEMENT

Active composts should be monitored on a weekly basis for traits which are important to bring about control and successful outcome of the process. The physical, chemical and biological traits for monitoring active compost include those listed in Table 13-2. A guidance for interpretation of these and other parameters is given in the appendix (see Interpretation Sheet- Appendix A).

Table 13-2 Target Active Compost Monitoring Traits

Trait	Target
Moisture	60-80% of WHC
Porosity	>30%
VOA Content	< 2000 ppm
Aerobic Bacteria	$>10^6$ cfu/g
Obligate Anaerobes	$<10^3$ cfu/g

SECTION 14
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