TECHNICAL SUMMARY REPORT

BEST MANAGEMENT PRACTICES FOR GREENWASTE COMPOSTING OPERATIONS: AIR EMISSIONS TESTS VS. FEEDSTOCK CONTROLS & AERATION TECHNIQUES

CONDUCTED BY
CALIFORNIA INTEGRATED WASTE MANAGEMENT BOARD
WITH SUPPORT FROM
SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

July 29, 2003

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INTRODUCTION

This Technical Summary Report documents area source emission tests conducted by the California Integrated Waste Management Board (CIWMB) and supported by the South Coast Air Quality Management District (SCAQMD) on greenwaste composting operations. The tests were conducted to evaluate Best Management Practices (BMP) for greenwaste composting operations that would result in reduced air emissions. Test procedures were designed to evaluate feedstock blends and aeration techniques and to determine how changing these variables affects air emissions from the compost. In addition to feedstock blends and aeration techniques, there are numerous operating variables in the composting process that can affect air emissions such as temperature, moisture, pH, and pile shape and size. However, due to the difficulty of isolating variables, the costs associated with testing source emissions, and limited funding, feedstock blends and aeration techniques were chosen as common variables that greenwaste composters could control. An effort was made to hold all other variables constant as much as possible.

DESCRIPTION OF TESTS

The tests were hosted by Tierra Verde Industries (TVI), a greenwaste composting facility located in Irvine, California. TVI constructed custom windrows and followed prescribed operating procedures during the test to simulate various composting environments. Emissions testing were conducted on four standard sized, full-scale windrows. Figure 1 shows two of the test windrows. Feedstock materials for the windrows were prepared and weighed on October 25, 2002; windrows were constructed on October 26, 2002. Table 1 provides a description of each windrow. (Note that the test conditions are not reflective of TVI's normal operation and therefore emission results from the tests have no relationship to expected emissions at the TVI facility.)

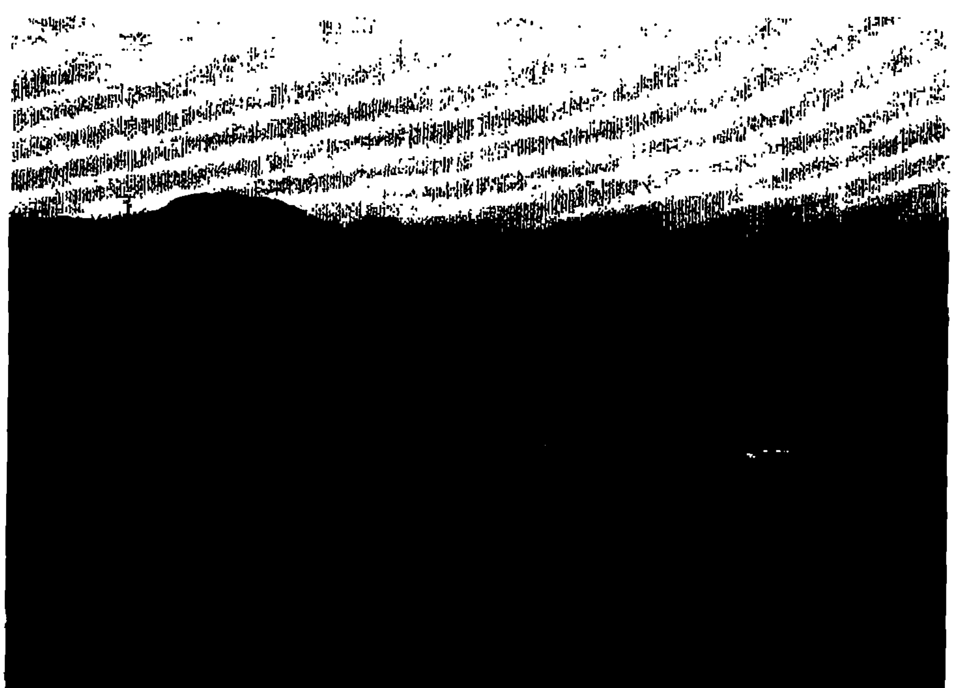

Figure 1: Two test windrows at Tierra Verde Industries

Carbon-to-Nitrogen Ratio
Test variables included feedstock blends, aeration techniques, and test pile age. Feedstock blends were controlled by the amount of grass clippings (curbside greenwaste) and the amount of woody waste (some grass clippings, but mostly leaves, brush, and wood) that were mixed together before composting. Feedstock blends were characterized by measuring the carbon-to-nitrogen ratio (C:N) in the mixture of materials. Two alternatives of feedstock blends were tested: high C:N materials and low C:N materials. To achieve a high C:N blend of materials, TVI mixed predominately woody waste with some grass clippings. To achieve a low C:N blend of materials, TVI mixed predominately grass clippings with some wood waste.

Aeration
Two aeration techniques were evaluated during the tests, static pile and turned pile. Two static pile windrows were formed to standard, full-scale dimensions and then were allowed to self-aerate by natural convection only for the entire composting life cycle. Turned pile operation involved two windrows that were constructed to the same shape and dimensions as the static pile windrows but were turned with a Scarab to provide aeration. The turned windrows were turned approximately three times per week dependent on temperature. Due to the decrease in windrow temperature that occurs during turning, turnings were conducted when windrow temperatures were high enough to withstand turning and still maintain 131°F needed for pathogen reduction requirements.

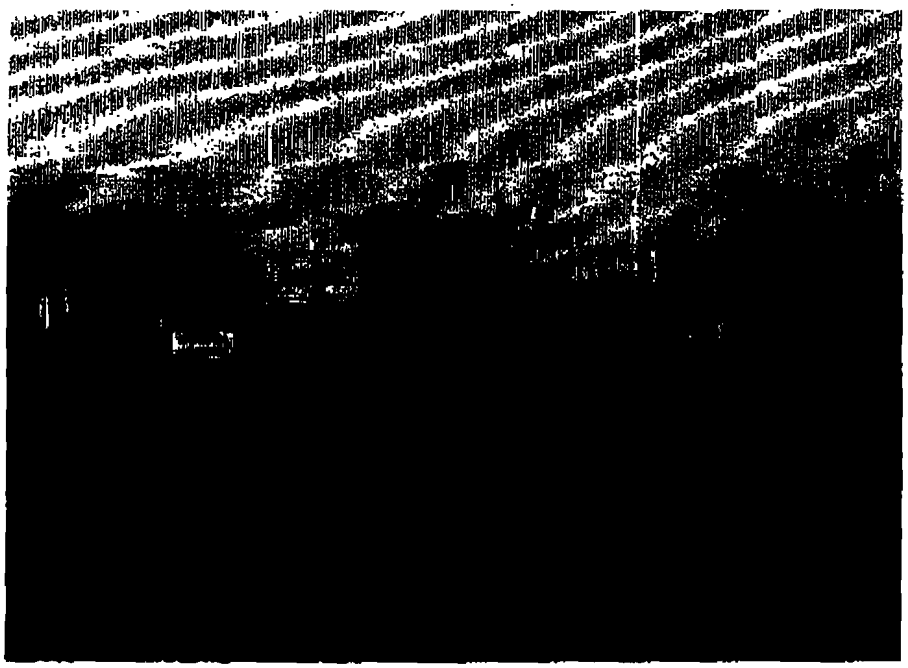

Figure 2: Scarab turning test windrow.

Pile Age
The four test windrows were allowed to remain in place for a nominal 100-day life cycle. Area source emission tests were concentrated on the initial phase of composting where emissions were expected to be higher. Since life cycle analysis of emissions was not the intent of these tests, not enough data was collected to complete an accurate analysis of how emissions change over the entire 100-day compost cycle. Rather, emissions from the first week of composting (Day 3 and Day 4) can be compared to emissions from the second week of composting (Day 11 and Day 12).

Table 1: Description of Test Windrows				
Designation	***Aeration Technique***	***Description***	***Feedstock Blend***	***Description***
Row 1	Static	Not turned; natural convection only	Low C:N	Greenwaste, grass clippings
Row 2	Turned	Mechanically turned; Scarab, ~3 times/week	Low C:N	Greenwaste, grass clippings
Row 3	Static	Not turned; natural convection only	High C:N	Woody waste
Row 4	Turned	Mechanically turned; Scarab, ~3 times/week	High C:N	Woody waste

Windrow Dimensions and Weight
The four test windrows were constructed to approximately the same dimensions in rough trapezoidal shapes that were 105 to 120 feet long, 13 feet wide, and 6 feet high. Feedstock materials were blended together to form two compost windrows with high C:N ratios and two compost windrows with low C:N ratios. Feedstock materials in the blends included: grass clippings from curbside collection, fines collected after grinding curbside greenwaste, mulch-type materials from landscapers, and wood waste. Prior to construction of the windrows, the feedstock blend for each windrow was weighed at the scale house. The two windrows with low C:N ratios were comprised of roughly 50% curbside fines, 40% grass clippings, and 10% wood waste. The two windrows with high C:N ratios were comprised of 50% landscapers mulch materials and 50% wood waste. The total amount of material in each of the four windrows weighed between [redacted] or approximately 73 tons. CIWMB staff observed the construction of the test windrows on October 26, 2002. Figure 2 below shows information on the dimensions and the amount of material placed in each windrow.

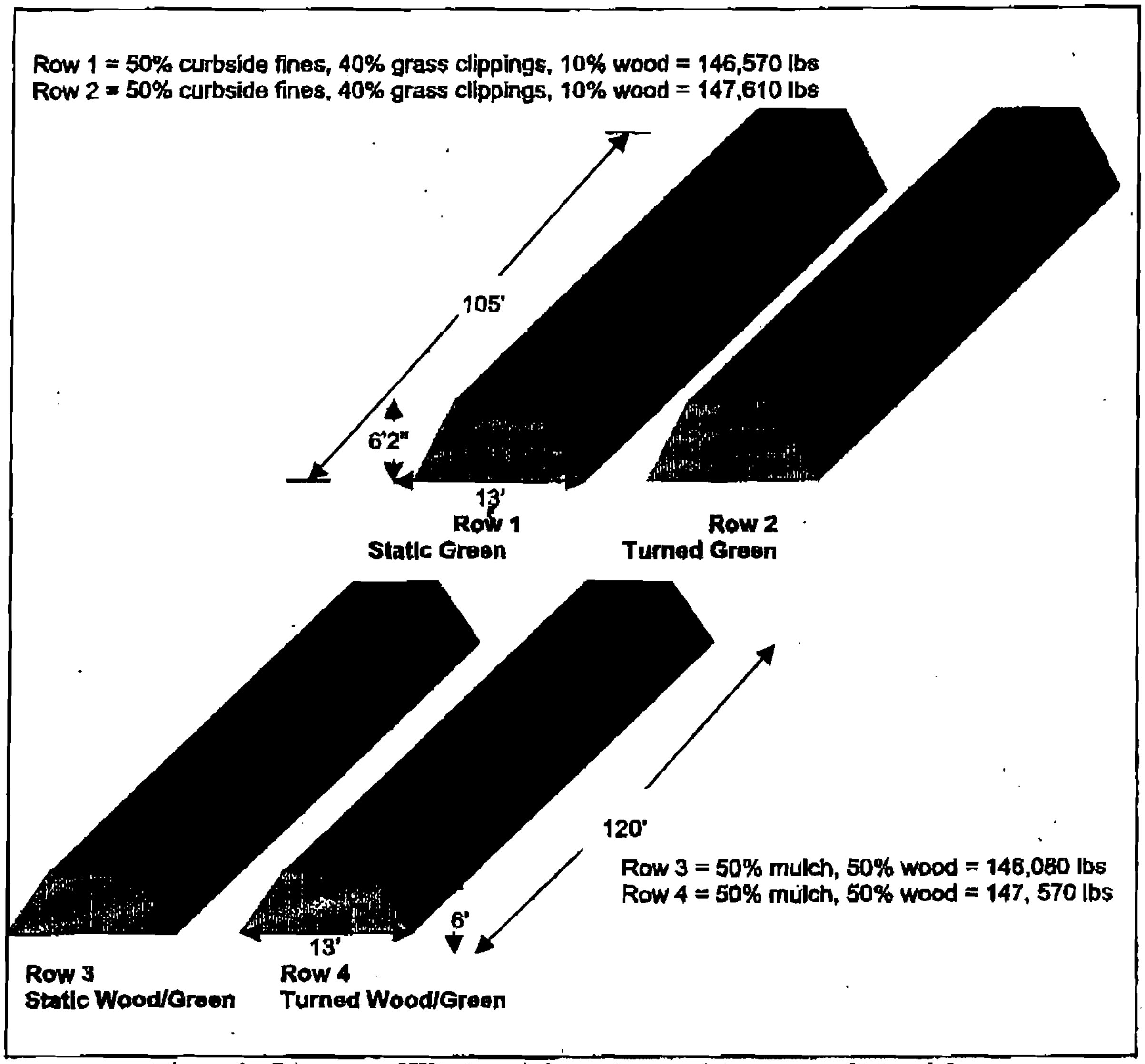

Figure 3: Diagram of Windrow Dimensions and Amounts of Materials

Emissions Testing

Source emissions tests were conducted to determine if there is a reduction in emissions from greenwaste compost windrows by controlling feedstock blends (high vs. low C:N ratio) and aeration techniques (static vs. turned). All four windrows were tested at multiple locations during the first week of composting and during the second week of composting. Tests were conducted on Day3/Day 4 and Day 11/Day 12. Each windrow was tested at 6 locations, which included the windrow ridge-top or vented locations and windrow sides or non-vented locations. Ammonia, volatile/semi-volatile organic compounds (VOC/SVOCs), and odor were sampled to describe air emissions from the test windrows. The air emission tests were performed by Dr.

Chuck E. Schmidt, an independent consultant contracted with CIWMB, and samples were analyzed at independent laboratories. The SCAQMD also provided laboratory analyses for some of the air emission samples including fixed gas analyses on the windrows and for performance evaluation samples. Mr. Mike Garibay, SCAQMD Senior Air Quality Engineer and other SCAQMD staff observed parts of the testing.

Figure 4: Isolation flux chambers test emissions at multiple locations.

Solids Testing
Compost materials were tested in the windrows to determine the C:N ratio of the feedstock blends and to measure other physical characteristics of the solid materials such as bulk density, moisture content, total solids, and volatile solids. All four windrows were tested at multiple locations during the first week of composting, during the second week of composting, and at the end of the composting life cycle. Tests were conducted on Day3/Day 4 and Day 11/Day 12 and Day 101/102. Each windrow was tested at 4 locations spaced evenly across the length of the windrow. In addition, a Solvita Maturity Index was performed on end-of-life-cycle product (Day 101/102) to determine relative completion of the composting process for each of the four test windrows. Results from the solids testing were used to track the changes in the characteristics of the compost materials across the entire life cycle.

TEST PROTOCOL
Prior to conducting the tests at TVI, a test protocol was developed. The test protocol clearly identified the purpose of the tests in evaluating Best Management Practices (BMPs) for greenwaste composting operations, the test variables to be considered and how those variables would be adjusted, the sample schedule, test methodology, and laboratory analytical methods. CIWMB conducted meetings with SCAQMD staff in October 2002 and submitted the test protocol on October 15, 2002, prior to the start of the tests, for their review. SCAQMD reviewed and approved the test protocol on October 25, 2002. The test protocol included the following constituents that were measured to determine if the BMP variables had an effect on emissions.

- Volatile Organic Compounds (VOC) – sampled using USEPA isolation flux chamber, analyzed by trap/canister collection and AQMD Method 25.3 (GC/FID)

Table 2a: Sample Schedule and Test Methodology

Test Conditions				Measurements										
Compost Age	***Feedstock***	***Description***	***Oxygen***	***VOC****	***NH_3***	***Odor***	***O2 - 4 locations***	***C:N***	***Tot Solids***	***Vol Solids***	***CO2 - 4 locations***	***Bulk Density***	***Temp - 4 locations***	***Moisture***
				SCAQMD 25.3	SCAQMD 207.1	ASTM	ASTM E-679-91	EPA 990.3	EPA 160.3	EPA 160.4	EPA 3C			ASTM 2216
Day 3, 4	Low C:N	greenwaste	Static	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X	X	X	X
Day 3, 4	High C:N	greenwaste + woodwaste	Static	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X	X	X	X
Day 3, 4	Low C:N	greenwaste	Turned	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X before/after turning	X	X	X
Day 3, 4	High C:N	greenwaste + woodwaste	Turned	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X before/after turning	X	X	X
Day 11,12	Low C:N	greenwaste	Static	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X	X	X	X
Day 11,12	High C:N	greenwaste + woodwaste	Static	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X	X	X	X
Day 11,12	Low C:N	greenwaste	Turned	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X before/after turning	X	X	X
Day 11,12	High C:N	greenwaste + woodwaste	Turned	3 vented; 3 non-vented	3 vented; 3 non-vented	X	X	X	X	X	X before/after turning	X	X	X
QC Samples				8	8	4	4	4						
Total Number of Samples				56	56	12	32 min	12	10	10	48 min	8	32 min	8

Table 2b: Product Quality Sample Schedule & Test Methodology

Test Conditions				Product Quality Measurements					
Compost Age	***Feedstock***	***Description***	***Oxygen***	***C:N***	***Bulk Density***	***Moisture***	***Tot Solids***	***Vol Solids***	***Solvita Maturity Index***
				EPA 990.3		ASTM 2216	EPA 160.3	EPA 160.4	
Finished Product	Low C:N	greenwaste	Static	X	X	X	X	X	X
Finished Product	High C:N	greenwaste + woodwaste	Static	X	X	X	X	X	X
Finished Product	Low C:N	greenwaste	Turned	X	X	X	X	X	X
Finished Product	High C:N	greenwaste + woodwaste	Turned	X	X	X	X	X	X
Total Number of Samples				4	4	4	4	4	4

Low C:N = greenwaste; High C:N = greenwaste + woodwaste
Static = natural convection, non-turned static windrow
Turned = windrow that is turned 1-3 times/week with Scarab-type equipment
V = Vented; NV = Nonvented
USEPA TO-15 as VOC speciation at one (1) location per windrow per day; 8 total.
Note 1- the odor samples are to be collected from the flux chamber and not in-situ in the pile like the oxygen samples.
Note 2- SCAQMD typically requires duplicate 25.3 sample collection.

TEST RESULTS

Table 3 through Table 7 show the test results. Samples were taken on October 29, 2002 (Day 3), October 30, 2002 (Day 4), November 6, 2002 (Day 11), November 7, 2002 (Day 12), February 4, 2003 (Day 101), and February 5, 2003 (Day 102). Test results are shown by either calendar date or compost age, e.g. Day 3. All of the solids data and the compost quality results are shown in Table 3. The air emissions or flux data are shown in Table 4 for the static windrows tested on Day 3, Table 5 for the turned windrows tested on Day 4, Table 6 for the static windrows tested on Day 11, and Table 7 for the turned windrows tested on Day 12. For the air emission data, the CIWMB contractor Dr. C. E. Schmidt prepared a Technical Memorandum, which is included in the Appendix of this Technical Summary Report. Although the air emission data is summarized here in Tables 4 through 7, additional details are available in the Appendix. Also included in the Appendix are sample data sheets, lab data sheets, and chain of custody for the solids samples.

Table 3: Summary of Solids Sample Collection Data (Days 3, 4, 11, 12, 101, 102)

Date	Time	Age	S or T	C/N Ratio	Sample ID	C/N	Bulk Density (lb/cy)	Moisture (wt%)	Tot Solids (mg/kg)	Vol Solids (mg/kg)	Solvita
10/29/2002	842	3 Day	Static	Low	SPL1	20	400	32	620000	410000	
10/29/2002	852	3 Day	Static	Low	SPL2	16	330	42	560000	370000	
10/29/2002	900	3 Day	Static	Low	SPL3	18	380	37	610000	360000	
10/29/2002	925	3 Day	Static	Low	SPL4	20	610	52	440000	260000	
					Ave	**18.5**	**430**	**41**	**557500**	**350000**	
10/29/2002	945	3 Day	Static	High	SPH1	51	510	55	480000	440000	
10/29/2002	950	3 Day	Static	High	SPH2	59	580	60	480000	450000	
10/29/2002	1011	3 Day	Static	High	SPH3	56	570	56	490000	450000	
10/29/2002	1020	3 Day	Static	High	SPH4	51	610	51	550000	500000	
					Ave	**54.25**	**568**	**56**	**500000**	**460000**	
10/30/2002	848	4 Day	Turned	Low	MPL1	26	520	50	540000	350000	
10/30/2002	854	4 Day	Turned	Low	MPL2	25	420	50	550000	350000	
10/30/2002	858	4 Day	Turned	Low	MPL3	26	450	48	600000	370000	
10/30/2002	900	4 Day	Turned	Low	MPL4	28	440	44	570000	360000	
					Ave	**26.25**	**458**	**48**	**565000**	**357500**	
10/30/2002	905	4 Day	Turned	High	MPH1	64	430	48	1200000	1100000	
10/30/2002	905	4 Day	Turned	High	MPH2	65	470	38	640000	600000	
10/30/2002	911	4 Day	Turned	High	MPH3	100	410	31	660000	610000	
10/30/2002	915	4 Day	Turned	High	MPH4	68	460	35	580000	540000	
					Ave	**74.25**	**443**	**38**	**770000**	**712500**	
11/6/2002	1020	11 Day	Static	Low	SPL1	17	1100	39	490000	290000	
11/6/2002	1030	11 Day	Static	Low	SPL2	18	1200	36	480000	290000	
11/6/2002	1035	11 Day	Static	Low	SPL3	18	1300	36	530000	350000	
11/6/2002	1040	11 Day	Static	Low	SPL4	20	1100	51	520000	350000	
					Ave	**18.25**	**1175**	**41**	**505000**	**320000**	
11/6/2002	955	11 Day	Static	High	SPH1	73	720	38	500000	460000	
11/6/2002	1005	11 Day	Static	High	SPH2	63	770	38	500000	470000	
11/6/2002	1010	11 Day	Static	High	SPH3	60	780	40	540000	510000	
11/6/2002	1015	11 Day	Static	High	SPH4	70	710	39	490000	450000	
					Ave	**66.5**	**745**	**39**	**507500**	**472500**	
11/7/2002	905	12 Day	Turned	Low	MPL1	26	760	45	470000	280000	
11/7/2002	912	12 Day	Turned	Low	MPL2	28	770	44	510000	310000	
11/7/2002	915	12 Day	Turned	Low	MPL3	27	660	45	560000	350000	
11/7/2002	920	12 Day	Turned	Low	MPL4	23	760	39	590000	360000	
					Ave	**26**	**738**	**43**	**532500**	**325000**	
11/7/2002	925	12 Day	Turned	High	MPH1	72	760	42	580000	520000	
11/7/2002	926	12 Day	Turned	High	MPH2	75	560	48	600000	560000	
11/7/2002	923	12 Day	Turned	High	MPH3	74	660	42	540000	500000	
11/7/2002	930	12 Day	Turned	High	MPH4	66	550	46	620000	580000	
					Ave	**71.75**	**633**	**45**	**585000**	**540000**	
2/4/2003	1050	101 Day	Static	Low	SPL1	14	630	40	710000	380000	7
2/4/2003	1055	101 Day	Static	Low	SPL2	22	400	37	730000	390000	7
2/4/2003	1100	101 Day	Static	Low	SPL3	14	630	43	730000	360000	7
2/4/2003	1105	101 Day	Static	Low	SPL4	15	700	40	720000	380000	7
					Ave	**16.25**	**590**	**40**	**722500**	**377500**	
2/4/2003	1110	101 Day	Static	High	SPH1	54	820	68	600000	570000	7
2/4/2003	1113	101 Day	Static	High	SPH2	54	750	65	610000	570000	7
2/4/2003	1116	101 Day	Static	High	SPH3	54	870	64	600000	560000	7
2/4/2003	1120	101 Day	Static	High	SPH4	67	700	65	600000	570000	7
					Ave	**57.25**	**785**	**66**	**602500**	**567500**	
2/4/2003	1137	101 Day	Turned	Low	MPL1	16	1200	63	710000	370000	6
2/4/2003	1140	101 Day	Turned	Low	MPL2	15	1300	54	640000	350000	5
2/4/2003	1143	101 Day	Turned	Low	MPL3	18	1500	56	640000	410000	6
2/4/2003	1146	101 Day	Turned	Low	MPL4	17	1300	58	650000	420000	7
					Ave	**16.5**	**1325**	**58**	**660000**	**387500**	
2/4/2003	1124	101 Day	Turned	High	MPH1	62	800	66	610000	530000	7
2/4/2003	1127	101 Day	Turned	High	MPH2	53	760	67	590000	550000	7
2/4/2003	1130	101 Day	Turned	High	MPH3	53	870	67	620000	580000	7
2/4/2003	1133	101 Day	Turned	High	MPH4	56	960	64	620000	570000	7
					Ave	**56**	**848**	**66**	**610000**	**567500**	
2/5/2003		102 Day	Turned	High	Sample 1-Row4						5
2/5/2003		102 Day	Static	High	Sample 2-Row 3						5
2/5/2003		102 Day	Turned	Low	Sample 3-Row 2						4
2/5/2003		102 Day	Static	Low	Sample 4-Row 1						3

0.0196 lbs / (1000 ft² / hr) (24 hr / day)

Table 4: Summary of Day 3 Static Pile Flux Data

Position	AGE	S or T	C/N Ratio	FID lb/1000ft2,hr-1	CO (ppmv)	Tracer	Advect CF	NH3 lb/1000ft2,hr-1	TNMHC lb/1000ft2,hr-1	Odor D/T	(D/T)/1000ft2,hr-1
Lowest	3 Day	Static	High	0.00089	126	184	1.5	.00020	0.0	NA	NA
Middle	3 Day	Static	High	0.0051	103	193	1.9	.00020	0.0	NA	NA
Top	3 Day	Static	High	0.14	42	183	4.4	.00020	0.2	NA	NA
Lowest	3 Day	Static	High	0.00085	132	184	1.4	00020	0.01	NA	NA
Middle	3 Day	Static	High	0.0024	123	193	1.5	00020	0.01	NA	NA
Top	3 Day	Static	High	0.15	39	183	4.7	00020	0.0	15,000	33
Ave				0.050			2.6	00020	0.07	15,000	33
Lowest	3 Day	Static	Low	0.0029	136	184	1.4	00037	0.048	A	NA
Middle	3 Day	Static	Low	0.0025	168	193	1.1	0.00	0.048	A	NA
Top	3 Day	Static	Low	0.25	16.8	183	11	00037	0.47	A	NA
Top	3 Day	Static	Low	0.014	177	184	1.0	00037	0.0288	3,300	1.6
Middle	3 Day	Static	Low	0.021	177	193	1.1	00037	0.039	A	NA
Lowest	3 Day	Static	Low	0.011	14.6	183	13	00037	0.125	A	NA
Ave				0.050			4.7	0.000	0.126	3,300	1.6

(0.0212)

Table 5: Summary of Day 4 Turned Pile Flux Data

Position	AGE	S or T	C/N Ratio	FID lb/1000ft2,hr-1	CO (ppmv)	Tracer	Advect CF		NH3 1000ft2,hr-1	TNMHC lb/1000ft2,hr-1	Odor D/T	(D/T)/1000ft2,hr-1
Middle	4 Day	Turned	High	0.0037	188	184	1.1	<	0015	0.0	NA	NA
Lowest	4 Day	Turned	High	0.00032	173	183	1.1	<	0015	0.021	NA	NA
Top	4 Day	Turned	High	0.12	55.6	193	3.5	<0	0015	0.	55,000	90
Top	4 Day	Turned	High	0.0041	145	193	1.3	<	0015	0.1	NA	NA
Lowest	4 Day	Turned	High	0.10	57	183	3.2	<	0015	0.	NA	NA
Middle	4 Day	Turned	High	0.0021	108	184	1.7	<	0015	0.0	NA	NA
Ave				0.037			2.0	<	0015	0.3		90
Lowest	4 Day	Turned	Low	0.0084	131	183	1.4		00020	0.2	NA	NA
Middle	4 Day	Turned	Low	0.022	130	184	1.4		00020	0.	NA	NA
Top	4 Day	Turned	Low	0.13	52.8	193	3.7		00020	3.2	NA	NA
Top	4 Day	Turned	Low	0.0091	135	183	1.4		00020	0.07	3,300	2
Middle	4 Day	Turned	Low	0.22	30.2	193	6.4		00020	5.	NA	NA
Lowest	4 Day	Turned	Low	0.016	141	184	1.3	<	00020	0.313	A	NA
Ave				0.068			2.6	<	0020	1.61		2

Average Correction Factor for Advective Flow: Static Piles 2.6 (High C:N), Static Piles 4.7 (Low C:N)
Average Correction Factor For Advective Flow: Turned Piles 2.0 (High C:N), Turned Piles 2.6 (Low C:N)
FID (ppmv)(16/25 mol wt)(0.005m3)(1/0.13m2)=(ppmv)(0.025)(CF)=FID (mg/m2,min-1)
NH3 (ppmv)(18/25 mol wt)(0.005m3)(1/0.13m2)=(ppmv)(0.028)(CF)=NH3(mg/m2,min-1)
Flux Coversion: (mg/m2,min-1)(1 g/1,000mg)(0.0920m2/1ft2)(1 lb/454g)(60 min/1 hr)(1,000ft2) = (mg/m2,min-1)(0.0122) = (lb/1,000 ft2,)
Highest value for a replicate pair used rather than average value.
Single value used for 'average' reporting per group of data.
Odor (D/T)(0.005m3/min)/(0.13m2)=(D/T)(0.0385)(CF)=Odor (D/T)/m2,min-1
NH3 MDL- (0.1ug/ml)(25ml)/(0.008m3)= 0.3 mg/m3, (0.3 mg/m3)(18/25 mol wt)= 0.23 ppmv
Average values use MDL if ND reported

0.0196 lb / 1000ft²/hr · 5600 ft² / pile · pile / 73 tons wet = 0.0015

5.4 = 0.416

Table 6: Summary of Day 11 Static Pile Flux Data

Position	Age	S or T	C/N Ratio	FID lb/1000ft2,hr-1	CO (ppmv)	Tracer	Advect CF	NH3 lb/1000ft2,hr-1	TNMHC lb/1000ft2,hr-1	Odor D/T	(D/T)/1000ft2,hr-1
Top	11 Day	Static	High	0.0014	166	192	1.2	<0.00012	0.0120	NA	NA
Top	11 Day	Static	High	0.011	58.6	184	3.1	<0.00012	0.0213	3,900	5.8
Middle	11 Day	Static	High	0.0021	126	192	1.5	<0.00012	0.0107	NA	NA
Lowest	11 Day	Static	High	0.0010	108	191	1.6	<0.00012	0.0121	NA	NA
Lowest	11 Day	Static	High	0.00032	92	191	2.1	<0.00012	0.0187	NA	NA
Middle	11 Day	Static	High	0.00062	113	192	1.7	<0.00012	0.0134	NA	NA
Ave				0.0028			1.9	<0.00012	0.0147		5.8
Top	11 Day	Static	Low	0.011	139	192	1.4	<0.00024	0.0130	MIA	NA
Top	11 Day	Static	Low	0.028	44.7	184	4.1	<0.00024	0.046	NA	NA
Middle	11 Day	Static	Low	0.0072	15.5	184	12	<0.00024	0.083	NA	NA
Lowest	11 Day	Static	Low	0.0012	149	192	1.3	<0.00024	0.0062	NA	NA
Middle	11 Day	Static	Low	0.012	150	192	1.3	<0.00024	0.0224	NA	NA
Lowest	11 Day	Static	Low	0.054	101	191	1.9	<0.00024	0.0139	NA	NA
Ave				0.018			3.6	<0.00024	0.0307		NA

Table 7: Summary of Day 12 Turned Pile Flux Data

Position	Age	S or T	C/N Ratio	FID lb/1000ft2,hr-1	CO (ppmv)	Tracer	Advect CF	NH3 lb/1000ft2,hr-1	TNMHC lb/1000ft2,hr-1	Odor D/T	(D/T)/1000ft2,hr-1
Top	12 Day	Turned	High	0.029	36.7	184	5.0	<0.00012	1.51	12,000	28
Top	12 Day	Turned	High	0.00065	135	192	1.4	<0.00012	0.120	NA	NA
Middle	12 Day	Turned	High	0.00037	110	192	1.7	<0.00012	0.084	NA	NA
Lowest	12 Day	Turned	High	0.0014	84.8	191	2.3	<0.00012	0.194	NA	NA
Lowest	12 Day	Turned	High	0.0020	88.3	191	2.2	<0.00012	0.0313	NA	NA
Middle	12 Day	Turned	High	0.0014	129	192	1.5	<0.00012	0.0287	NA	NA
Average				0.0058			2.3	<0.00012	0.328		28
Top	12 Day	Turned	Low	0.22	53.2	184	3.6	<0.00024	0.69	MIA	NA
Top	12 Day	Turned	Low	0.053	128	192	1.5	<0.00024	0.158	NA	NA
Lowest	12 Day	Turned	Low	0.032	126	191	1.6	<0.00024	0.0180	NA	NA
Middle	12 Day	Turned	Low	0.0029	141	192	1.4	<0.00024	0.034	NA	NA
Middle	12 Day	Turned	Low	0.0028	104	192	1.8	<0.00024	0.098	NA	NA
Lowest	12 Day	Turned	Low	0.12	18.4	184	10	<0.00024	0.48	NA	NA
Average				0.071			3.3	<0.00024	0.245		NA
QC	NA	NA	NA	NA	NA	NA	2.8	<0.00022	0.049	NA	NA
QC	NA	NA	NA	NA	NA	NA	2.8	<0.00022	0.056	NA	NA

Average Correction Factor For Advective Flow: Static Piles 1.9 (High C:N), Static Piles 3.6 (Low C:N), Average 2.8
Average Correction Factor For Advective Flow: Turned Piles 2.3 (High C:N), Turned Piles 3.3 (Low C:N), Average 2.8
FID (ppmv)(16/25 mol wt)(0.005m3)(1/0.13m2)=(ppmv)(0.025)(CF)=FID (mg/m2,min-1)
NH3 (ppmv)(18/25 mol wt)(0.005m3)(1/0.13m2)=(ppmv)(0.028)(CF)=NH3(mg/m2,min-1)
Flux Coversion: (mg/m2,min-1)(1 g/1,000mg)(0.0920m2/1ft2)(1 lb/454g)(60 min/1 hr)(1,000ft2) = (mg/m2,min-1)(0.0122) = (lb/1,000 ft2,hr-1)
Highest value for a replicate pair used rather than average value.
Single value used for 'average' reporting per group of data.
Odor (D/T)(0.005m3/min)/(0.13m2)=(D/T)(0.0385)(CF)=Odor (D/T)/m2,min-1
NH3 MDL- (0.1ug/ml)(25ml)/(0.008m3)= 0.3 mg/m3, (0.3 mg/m3)(18/25 mol wt)= 0.23 ppmv
Average values use MDL if ND reported

DISCUSSION OF TEST RESULTS

An evaluation of the test results considered the test variables of feedstock control as measured by the C:N ratio and aeration techniques, i.e. static windrows versus windrows mechanically turned with a Scarab. An additional variable that can be evaluated includes compost age since some temporal data, although limited, was taken that can be used to consider compost life cycle effects. The emissions relative to the geometric location, or windrow zone, where the measurement was taken can also be studied. Finally, evaluation of measurement techniques for VOCs can be considered for the inexpensive, hand-held FID method (Flame Ionization Detector) compared to the costly isolation flux chamber method.

Ammonia Emissions

Ammonia (NH_3) emissions were measured on the four test windrows using the isolation flux chamber at 48 locations. Test results include NH_3 emissions for static windrows, turned windrows, high C:N (woody) materials, low C:N (grassy) materials, the first week of composting, the second week of composting, and various windrow zones (lowest, middle, and ridge top of pile). Of the 48 test results for NH_3 emissions, all of the data is less than the detection limit of 0.1 ug/ml or 0.23ppmv with the exception of one sample. The flux data for NH_3 shown in Tables 4 through 7 reflect the non-detection of NH_3 by showing fluxes <0.00037 lb/1,000ft2hr. With 98% of the emission data below the detection limit for NH_3, NH_3 is not a concern. Therefore, the subsequent discussion of test results and graphs of the data do not include NH_3. For greenwaste composting operations, NH_3 emissions should not be a regulatory concern.

Effect of Feedstock Control

The effect of feedstock control on emissions was measured by C:N ratio in the windrow materials. In all cases except one, emissions of VOC decreased with increased C:N ratio in the feedstock materials. The average C:N ratio for windrows constructed of predominantly woody materials ranged from 54 to 74 with an overall average of 63 C:N. The average C:N ratio for windrows constructed of predominantly grassy materials ranged from 16 to 26 with an overall average of 20 C:N. Figures 5, 6, 7, and 9 show a decrease in VOC emissions with increased C:N. VOC emissions were decreased by 34 to 80%. Figure 8 shows a reverse trend of increased VOCs with higher C:N feedstocks. A plot of the overall averages for VOC emissions and C:N feedstocks is shown in Figure 9 which shows a 63% decrease in VOCs for high C:N ratio of 67 versus a low C:N ratio of 22. The control of feedstock blends as indicated by C:N ratio appears to be effective in reducing VOC emissions and would be a feasible Best Management Practice (BMP) operating variable for greenwaste compost facility operators to use to control VOC emissions.

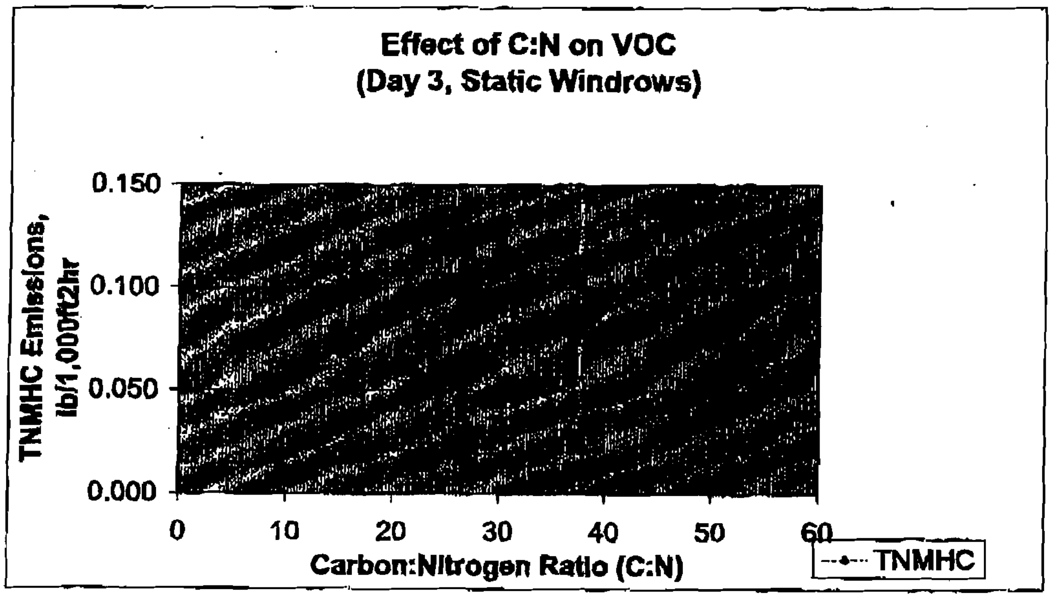

Figure 5: Reduced VOC Emissions for High C:N – Day 3, Static Windrows.

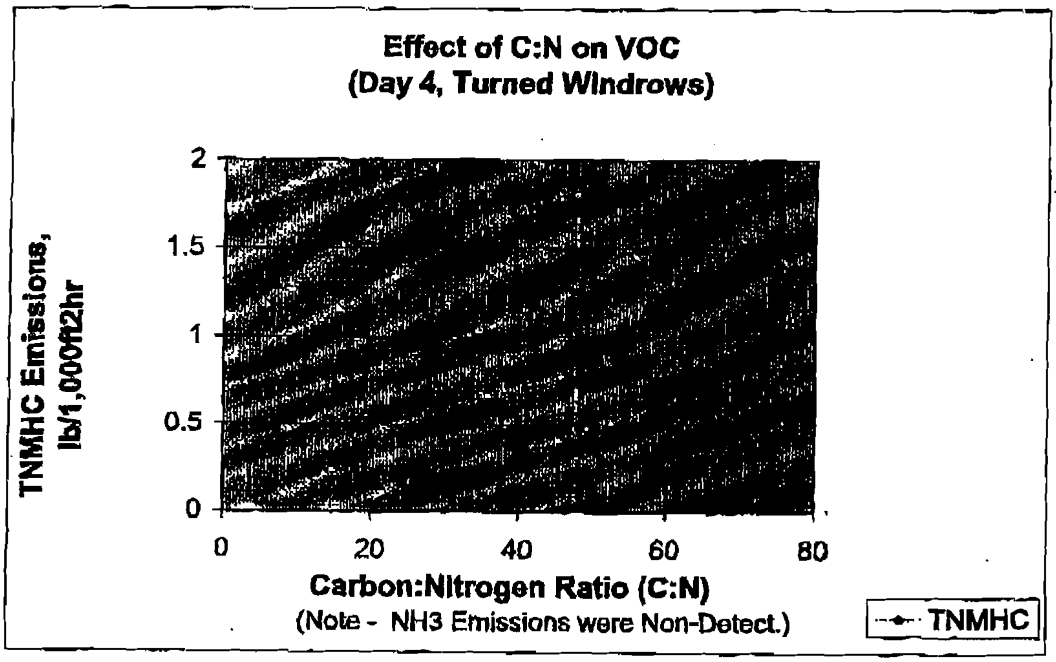

Figure 6: Reduced VOC Emissions for High C:N – Day 4, Turned Windrows.

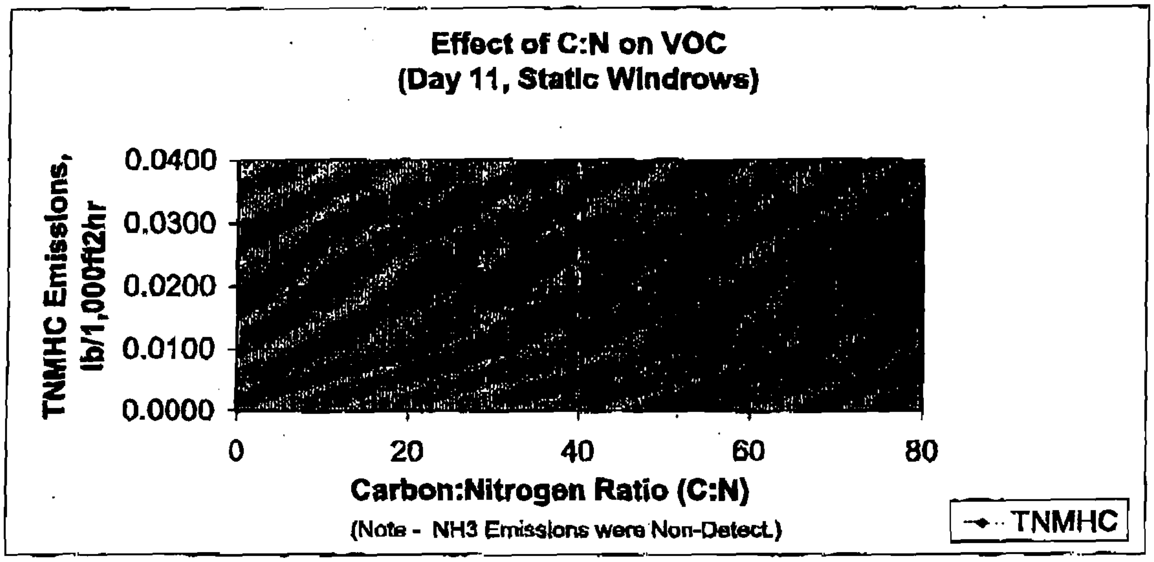

Figure 7: Reduced VOC Emissions for High C:N – Day 11, Static Windrows.

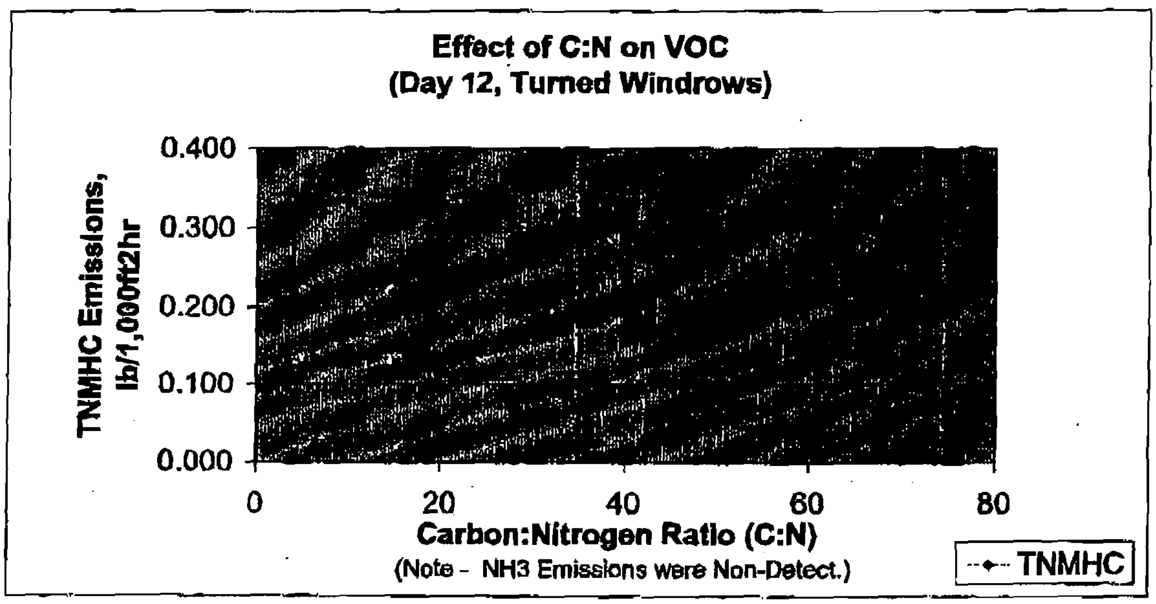

Figure 8: Increased VOC Emissions for High C:N – Day 12, Turned Windrows.

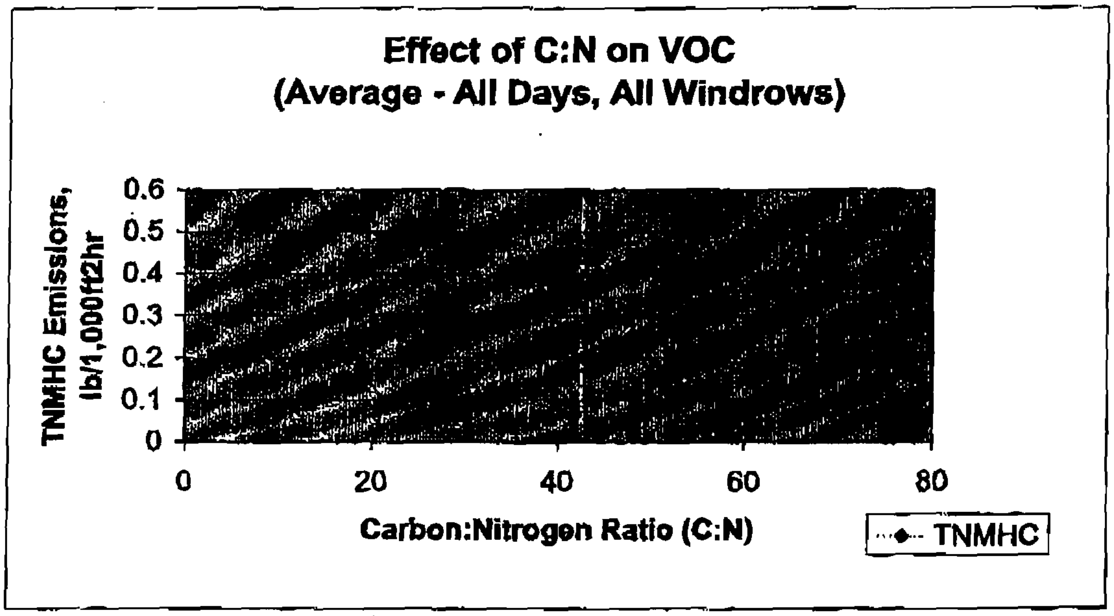

Figure 9: Reduced VOC Emissions for High C:N – Average of All Days, All Windrows.

Effect of Aeration

Emissions were measured on Day 3 and Day 11 for static windrows, i.e. windrows that were not turned but allowed to aerate via natural convection only. Emissions were measured on Day 4 and Day 12 for windrows that were mechanically turned with a Scarab. Figure 10 shows VOC emissions for static windrows compared to turned windrows. The data for Figure 10 shows the average of 12 emission measurements for static windrows on Day 3 of 0.103 lb/1,000ft2hr compared to the average of 12 emission measurements for turned windrows on Day 4 of 0.966 lb/1,000ft2hr. There is an order of magnitude increase in VOC emissions for turned windrows. A similar pattern is observed for data collected on Day 11 and Day 12. Figure 11 shows VOC emissions for static windrows compared to turned windrows for the second week of testing. The data for Figure 11 shows the average of 12 emission measurements for static windrows on Day 11 of 0.022 lb/1,000ft2hr compared to the average of 12 emission measurements for turned windrows on Day 12 of 0.286 lb/1,000ft2hr. Although emissions for both static and turned windrows have decreased by an order of magnitude compared to the previous week, there again is an increase in VOC emissions for turned windrows compared to static windrows at roughly the same age. Without data that defines a full life cycle analysis for emissions over the entire composting cycle, it is difficult to determine based on two points in time if overall emissions are increased, decreased, or the same for static windrows versus turned windrows.

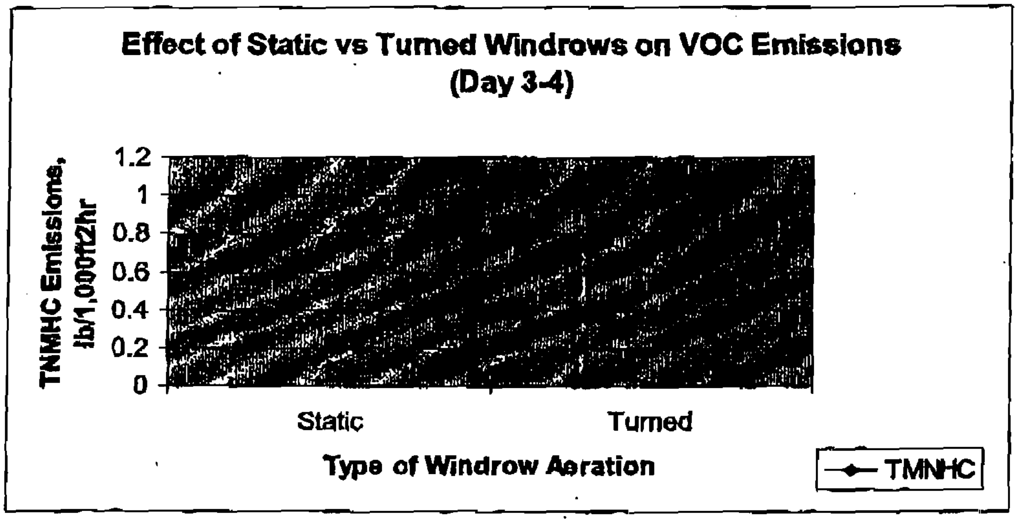

Figure 10: Increased VOC Emissions for Turned Windrow – Day 3 and Day 4.

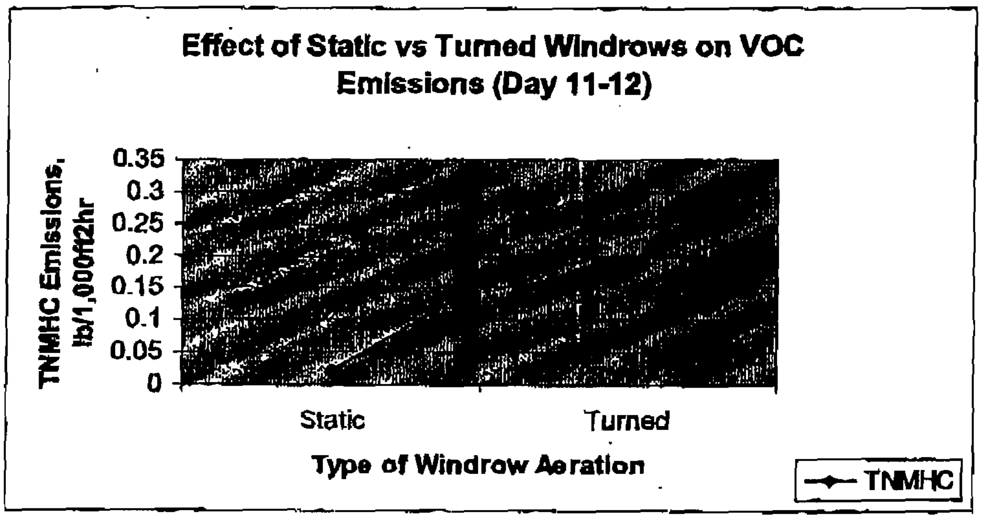

Figure 11: Increased VOC Emissions for Turned Windrow – Day 11 and Day 12.

Effect of Pile Age

The data for two points early in the life cycle during the first two weeks of composting would suggest an increase in VOC emissions for turned windrows as shown in Figure 12. However, this phenomenon may be an indication that aeration increases emissions early in the life cycle by providing a more optimal environment for aerobic reactions, while static windrows result in a steady release of emissions across the entire life cycle of composting. Figure 12 also supports the theory of higher VOC emissions early in the life cycle with emissions tapering off faster for turned windrows. Figure 13 is a conceptual plot that demonstrates this idea. To determine the relative emissions for the two scenarios, the amount of VOCs emitted for each curve must be summed for the entire life cycle, or in other words, the area under the green curve (turned) must be compared to the area under the red curve (static). As shown in the hypothetical curves, it may be possible to have significantly higher emissions at Day 3/Day 4 for the turned windrows compared to the static windrows; higher emissions at Day 11/Day 12 for the turned windrows but starting to approach the emission levels of the static windrows; and lower overall emissions (area under the curve) for the turned windrows compared to the static windrows.

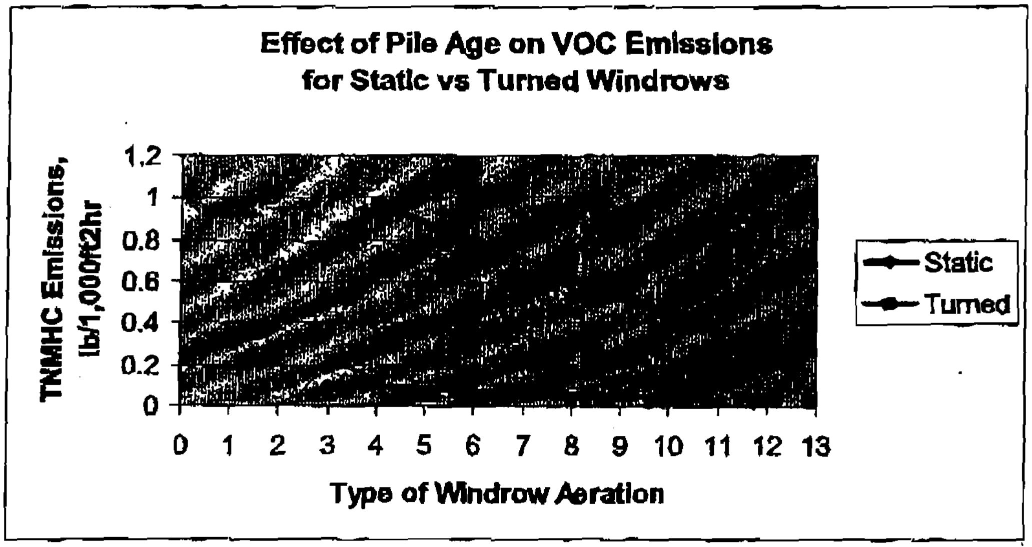

Figure 12: Decreasing VOC Emissions over Time.

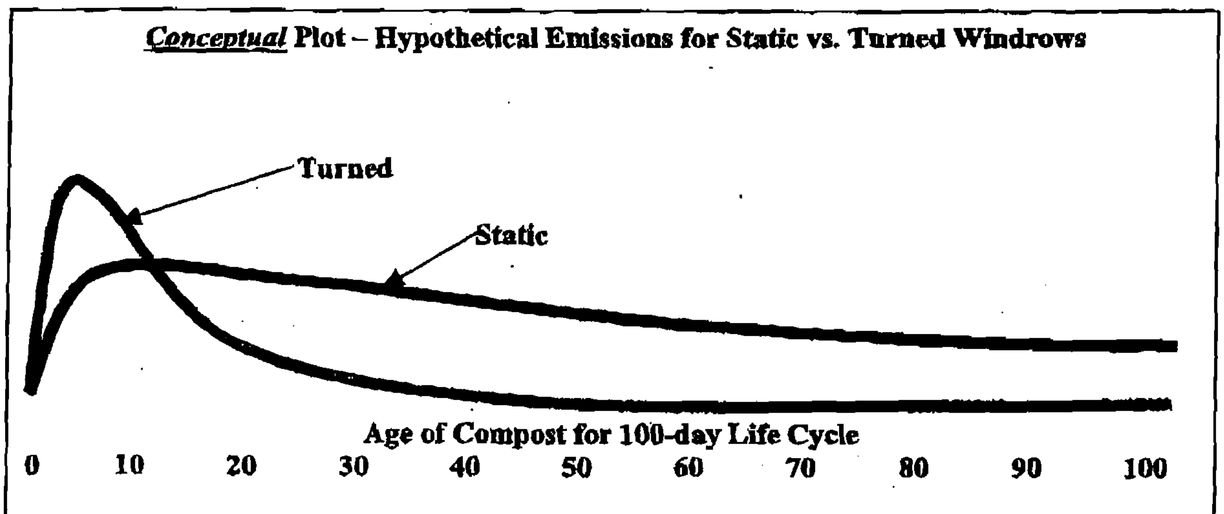

Figure 13: Conceptual Plot of Life Cycle Emissions

the effects of pile age on bulk density. Figure 15 shows the how the volatile solids change over time.

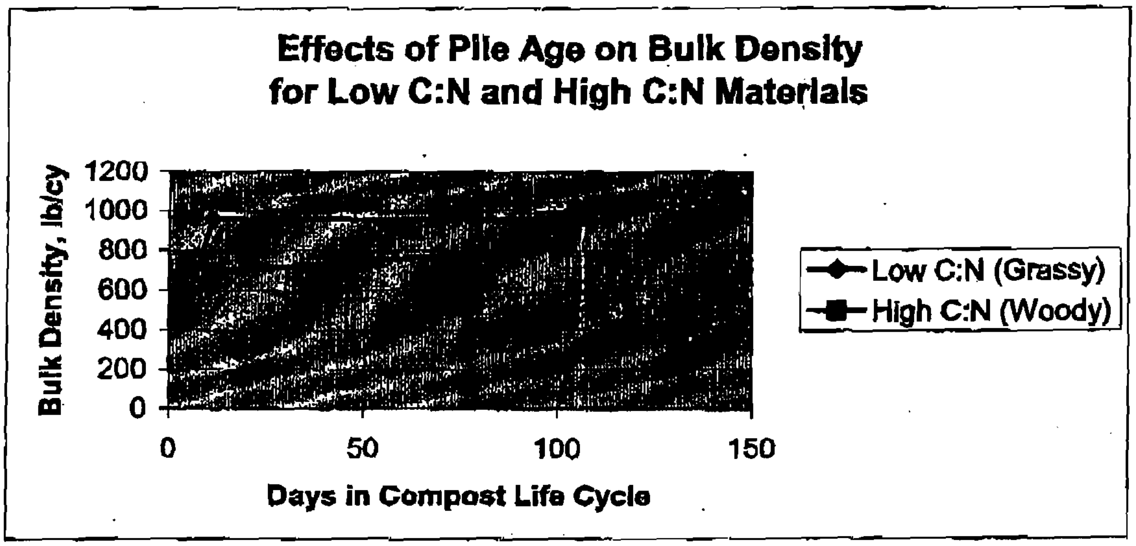

Figure 14: Effects of Pile Age on Bulk Density.

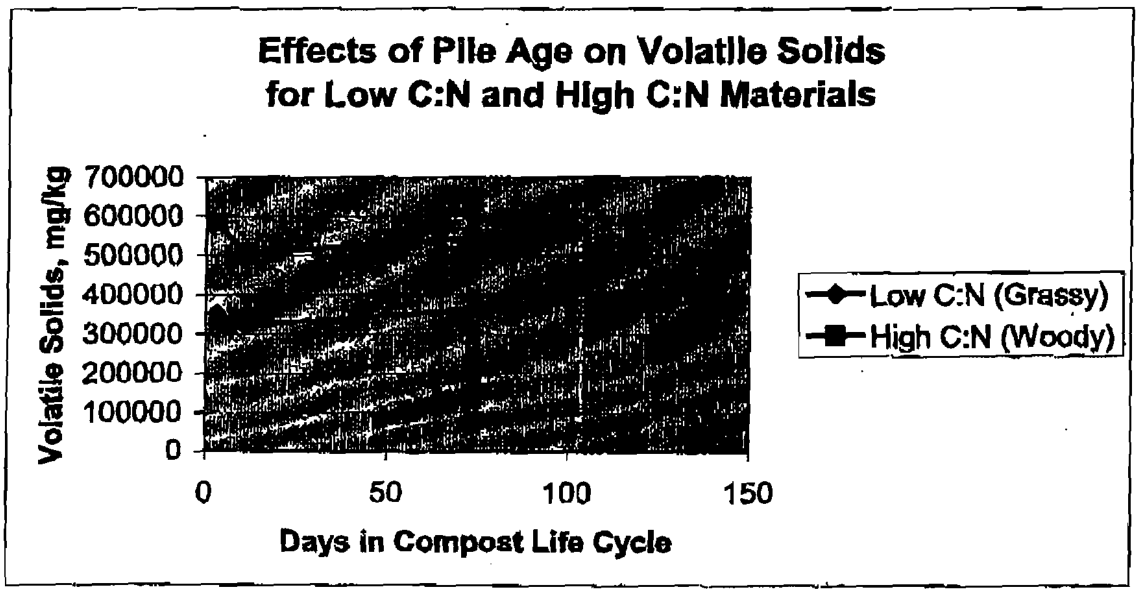

Figure 15: Effects of Pile Age on Volatile Solids.

Product quality tests were also conducted to evaluate the quality of the compost product near the end of the life cycle. Samples were taken on Day 101 and Day 102 and analyzed for a Solvita Maturity Index, an indicator of finished compost. Data for Solvita tests are shown in Table 3. The average Solvita Maturity Index for static windrows was 5.9 while the average Solvita

Maturity Index for turned windrows was 6.6. A Solvita test result in the 5 to 6 range indicates active compost moving into the curing stage. A Solvita test result in the 6 to 7 range indicates curing compost moving into the finished product stage. Since turned windrows have a higher average Solvita that approaches the finished product stage, this would indicate that the static windrows required a longer life cycle to complete the composting process. This is consistent with the conceptual plot of life cycle emissions discussed in Figure 13 but would need to be confirmed with more data. Field observations during product sampling on Day 101 and Day 102 also indicated that the static windrows contained evidence of white strands or filaments characteristic of actinomycetes and fungi that were still actively composting organic materials. The turned windrows did not contain visual evidence of these organisms. See Figure 16 for a photo of the compost product at Day 101 for the static windrows.

Figure 16: White residue, center of photo, indicates active compost for static windrow, Day 101.

Emissions Relative to Windrow Zone

Each windrow was tested at 6 locations when emission samples were taken with the isolation flux chamber. The test locations included the windrow ridge-top, the sides of the windrow halfway between the ground and the top of the windrow, and the base of the windrow near the ground. The reason for testing for emissions in different windrow zones was to identify directional movement of air intake and emissions outflow. The theory was that for a classic trapezoidal shaped windrow, airflow in would occur at the base and sides of the windrow while emissions out of the windrow would happen on the ridge-top locations. By comparing the relative VOC fluxes for given windrow zones, directional movement can be determined and venting locations vs. non-venting locations can be identified. Figure 17 and Figure 18 show emissions for the various windrow zones. As shown in these figures, emissions are greatest for the ridge-top locations with the base and side locations of the windrow contributing substantially lower overall emissions. This data confirms the model directional airflow of air intake at the base and sides of the windrow and emissions out of the ridge-top of the windrow. This information can be used to proportionally weight emission factors for trapezoidal windrows when evaluating absolute pounds of emissions from a given windrow or facility. For the data shown in Figure 17 and Figure 18, 22-33% of the total emissions for the windrow are coming from the base and sides while 66-76% of the total emissions are coming from the windrow ridge-top. Figure 19 shows the total emissions by windrow zone as the average of all of the data for all days and all windrow types. This profile shows more of a 50/50 split of emissions from the tops and sides of the windrows, with 53% of the total emissions for the windrow coming from the base and sides while 47% of the total emissions are coming from the windrow ridge-top.

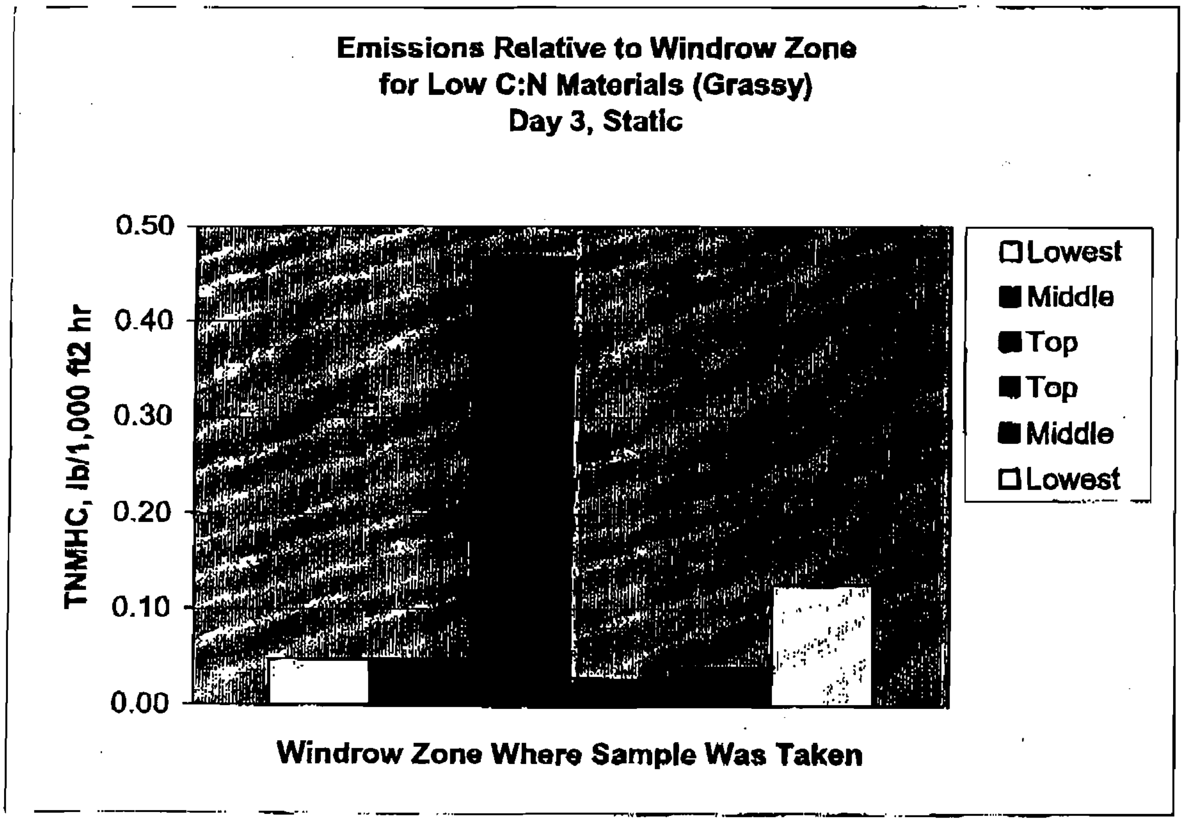

Figure 17: Emissions Relative to Windrow Zone for Low C:N Windrows

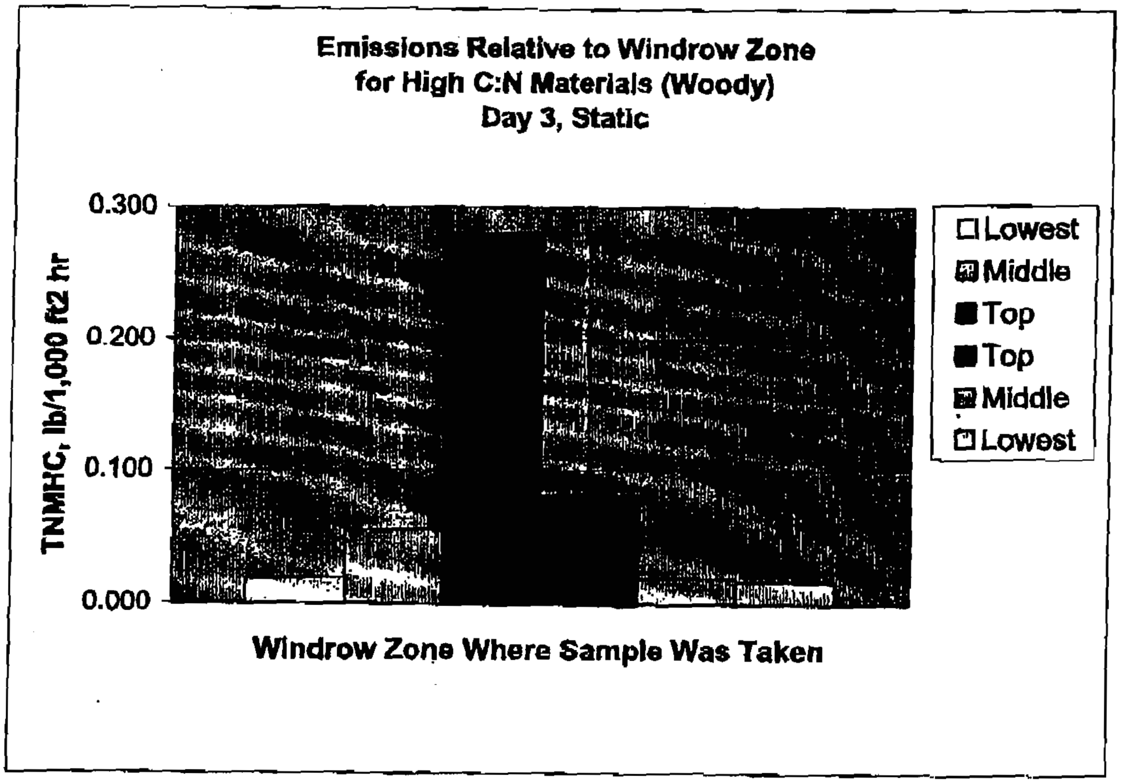

Figure 18: Emissions Relative to Windrow Zone for High C:N Windrows.

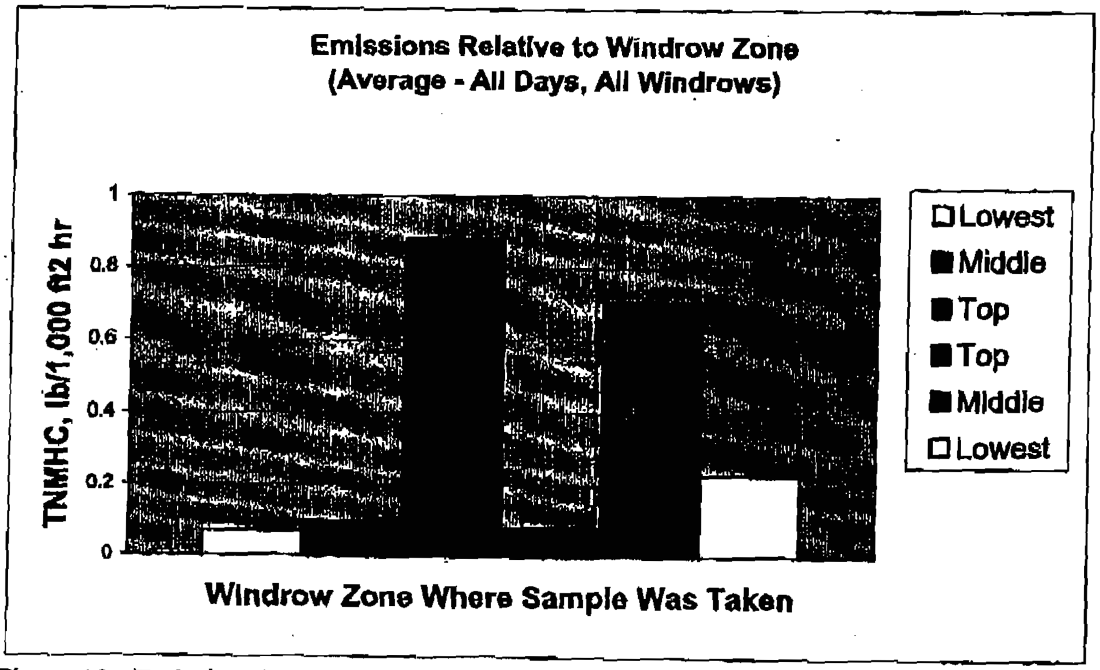

Figure 19: Emissions Relative to Windrow Zone for All Windrows.

FID Correlation to Flux Chamber Measurements

The emission results for FID method measurements can be compared with the emission results for the isolation flux chamber samples analyzed by Method 25.3. The reason for evaluating the correlation between these two methods is to identify an inexpensive method of testing for emissions where a substantial amount of data can be gathered for a wider range of operating variables. The FID method is a hand-held instrument that can be used in the field to obtain a concentration of hydrocarbons emitted from the surface of a windrow. For these tests, an FID reading was taken from the isolation flux chamber. A gas sample was also collected from the flux chamber in a canister and sent to the laboratory for VOC analysis by Method 25.3. The two results, FID and Method 25.3, can be compared to see if there is a consistent relationship between the techniques and determine how well they correlate with each other. Figures 20 through 23 show the correlation between FID and the flux chamber/Method 25.3 for measuring emissions. The data was sorted for feedstock blends and Figure 20 and Figure 21 show the correlation for high C:N and low C:N windrows respectively. The data was re-sorted for aeration technique and Figure 22 and Figure 23 show the correlation for static and turned windrows respectively. As can be seen from these figures, the R^2 factor is between 0.47 and 0.55 meaning that 47 to 55% of the data can be predicted using the exponential or power trend equations shown on the graphs. This indicates that only a moderate correlation can be drawn between the FID and the flux chamber/Method 25.3 results. Without a better correlation between measurement methods, the FID method would not be a good tool to predict the emissions that a flux chamber/Method 25.3 would identify.

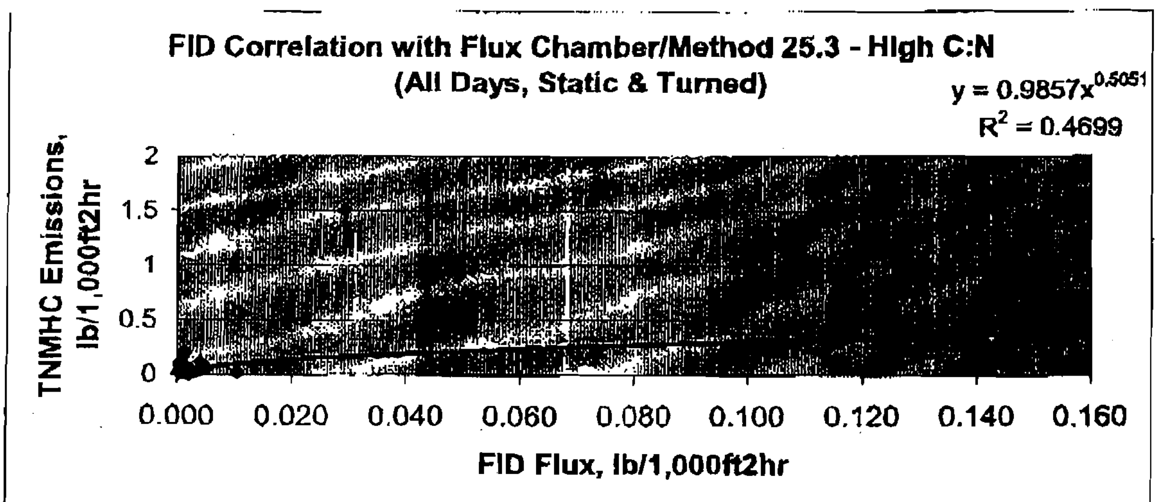

Figure 20: FID Correlation with Flux Chamber/Method 25.3 for High C:N Windrows

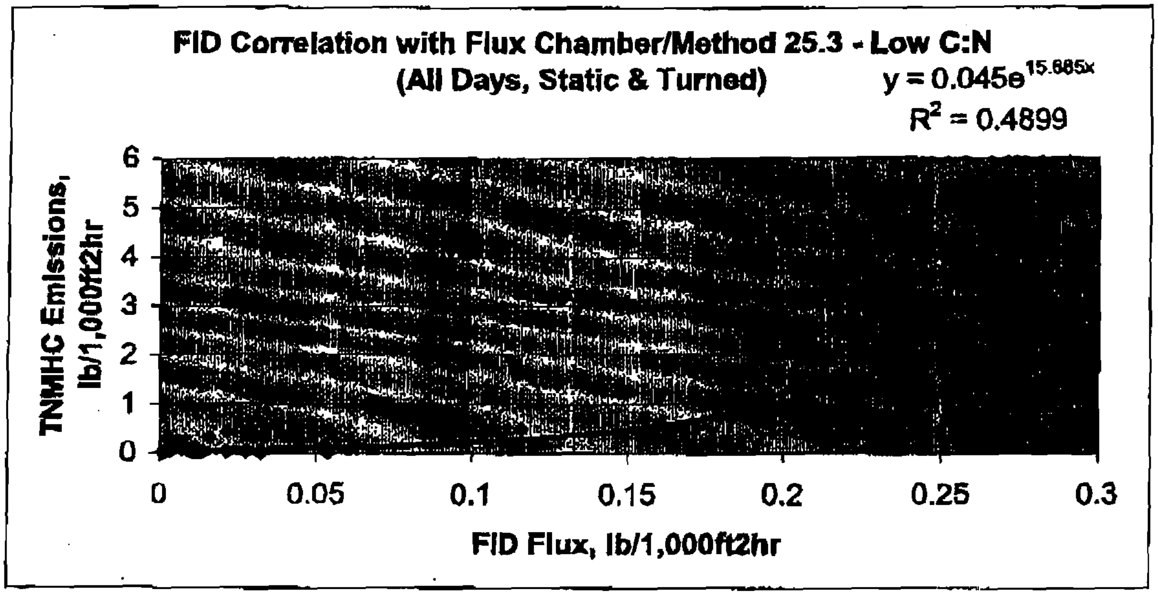

Figure 21: FID Correlation with Flux Chamber/Method 25.3 for Low C:N Windrows

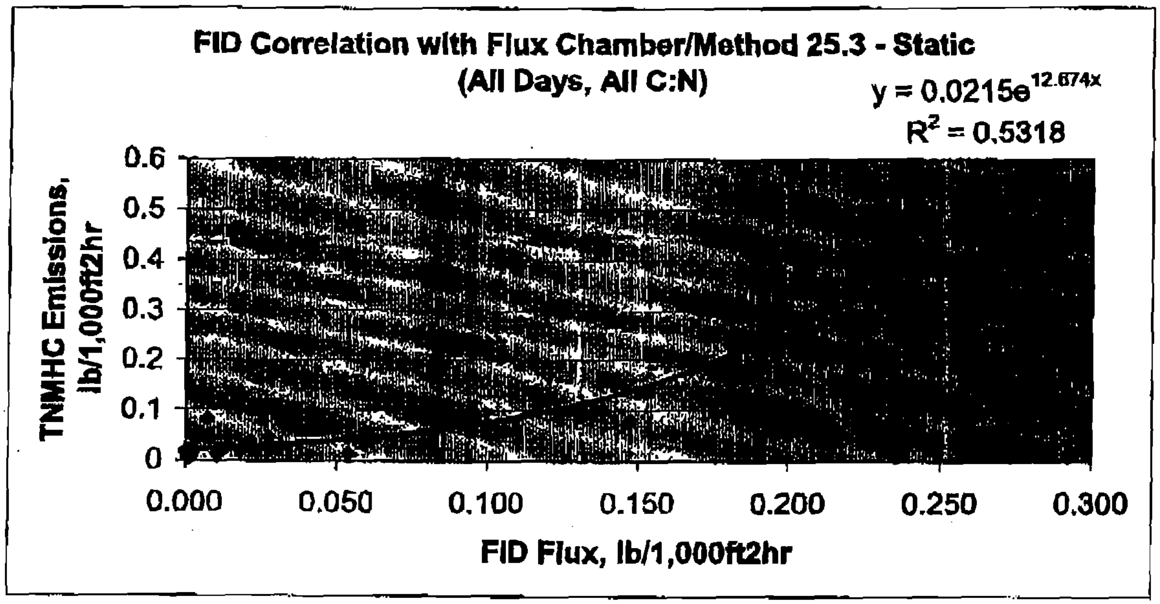

Figure 22: FID Correlation with Flux Chamber/Method 25.3 for Static Windrows.

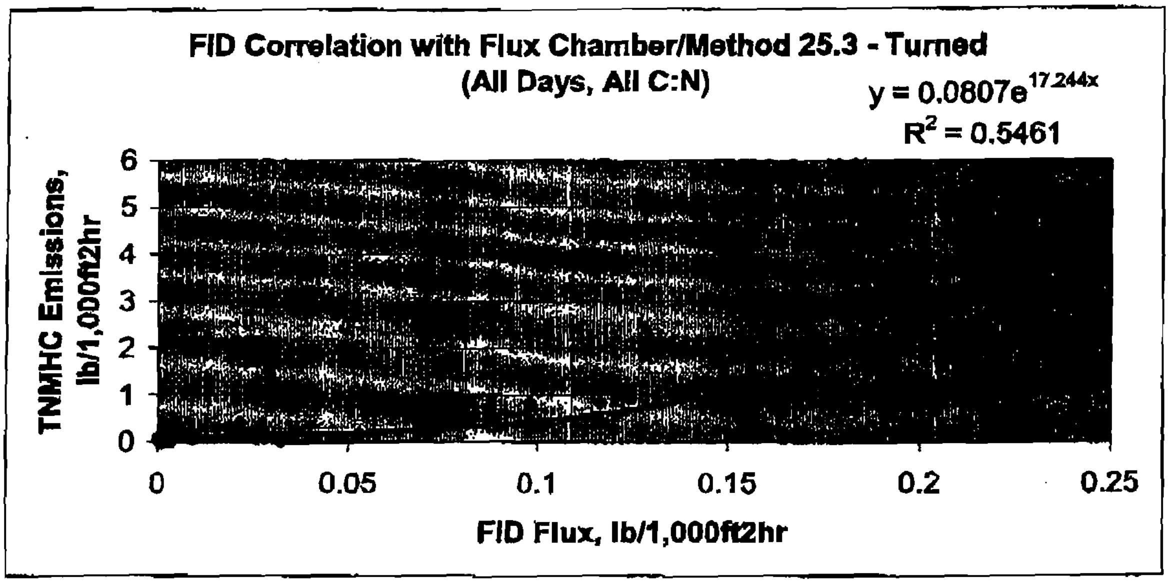

Figure 23: FID Correlation with Flux Chamber/Method 25.3 for Turned Windrows.

Emissions Per Ton of Feed

The VOC emissions for each windrow (***for the first two weeks of composting***) can be calculated based on the amount of feedstock materials in each of the four test windrows. The amounts of materials were weighed prior to constructing the windrows. Table 8 shows the VOC emissions measured for each windrow as a flux measurement in lb/1,000ft^2, hr^{-1}. The VOC emissions shown are the average of all of the flux measurements taken for each windrow during the first two weeks of the composting process. It should be noted that emission rates during the first two weeks are likely at the highest values and drop off significantly after the initial peak. To determine accurate total emission rates over the entire life cycle of the composting process, additional emission rates that are age-dependent are essential.

Also provided in Table 8 are windrow surface areas, the weight of materials in each windrow, and the calculated emission factors in lbs VOCs per day per ton of feedstock materials. The average VOC emissions were 0.344 lb/1,000ft^2, hr^{-1} for flux measurements and 0.247 lb/day/ton of feed for emission factors.

Table 8: VOC Emissions for Each Windrow				
Row Designation	VOC Emission Flux* - lb/1000ft2,hr-1	Windrow Surface Area-ft2	Windrow Amount-lbs	Lbs VOC per Day/ Ton of Feed*
Row 1 Emissions (Static, Low C:N) =	0.078	2140	146570	0.055
Row 2 Emissions Turned, Low C:N) =	0.929	2140	147610	0.646
Row 3 Emissions (Static, High C:N) =	0.047	2365	146080	0.036
Row 4 Emissions (Turned, High C:N) =	0.323	2365	147570	0.249
Ave =	0.344			0.247

*Emission flux and emission rates are based on the VOCs measured during the initial first two weeks of composting. These rates are not representative of the life cycle emission rate which would result in an average emission rate that is significantly lower than the average of the first two weeks of emissions.

CONCLUSIONS

The following conclusions summarize the findings presented in this Technical Summary Report:

- NH_3 emissions are not a concern for greenwaste compost facilities. Emission levels were non-detect in 47 of the 48 test results, equating to 98% of the test data below the detection limit for NH_3.
- VOC emissions decreased with an increase in C:N ratio in the windrow materials. Overall averages indicate a 63% decrease in VOC emissions for a high C:N ratio of 67 compared to a low C:N ratio of 22.
- Control of feedstock blends, as indicated by C:N ratio, is a feasible BMP operating variable for greenwaste compost facilities to use for minimizing VOC emissions.
- During the early stages of composting, turned windrows emit higher VOC levels than static windrows by an order of magnitude, i.e. 0.965 vs. 0.103 lb/1,000ft^2, hr^{-1} for the first week of composting and 0.287 vs. 0.0227 lb/1,000ft^2, hr^{-1} for the second week of composting.
- VOC emissions peak during the first week of composting and decline by an order of magnitude during the second week of composting, e.g. 0.103 reduces to 0.0227 lb/1,000ft^2, hr^{-1} for static windrows and 0.965 reduces to 0.287 lb/1,000ft^2, hr^{-1} for turned windrows.
- A full life cycle analysis for emissions over the entire composting cycle is needed to determine the overall effects of aeration technique on total VOC emissions. It is difficult to determine if turned versus static windrows emit the more, the same, or less VOCs.
- Turned windrows achieve compost product qualities over a shorter life cycle than static

windrow as evidenced by Solvita Maturity Index results taken at Day 101. The average Solvita test for compost in turned windrows was 6.6, which indicates curing compost moving into the product stage. The average Solvita test for compost in static windrows was 5.9, which indicates active compost moving into the curing stage. Therefore, the static windrows needed more time to complete the composting cycle.

- Emissions vary relative to windrow zone on the surface of the pile. Typically, the emissions are higher for the windrow ridgetop than for the base and sides of the windrow with 50 to 80% of the total emissions coming from the windrow ridgetop.

- Only a moderate correlation can be drawn between the FID and the flux chamber/Method 25.3 techniques of measuring VOC emissions. Although it is significantly less expensive and easier to operate, the FID would not be a good tool to predict the emissions that a flux chamber/Method 25.3 would identify, due to the low prediction accuracy of 47 to 55%.

- The average VOC emissions for the test windrows for the first two weeks of composting were 0.344 lb/1,000ft^2, hr^{-1} for flux measurements and 0.247 lb/day/ton of feed for emission factors.