Measurement of Material Volumes at Ohio Class IV Compost Facilities

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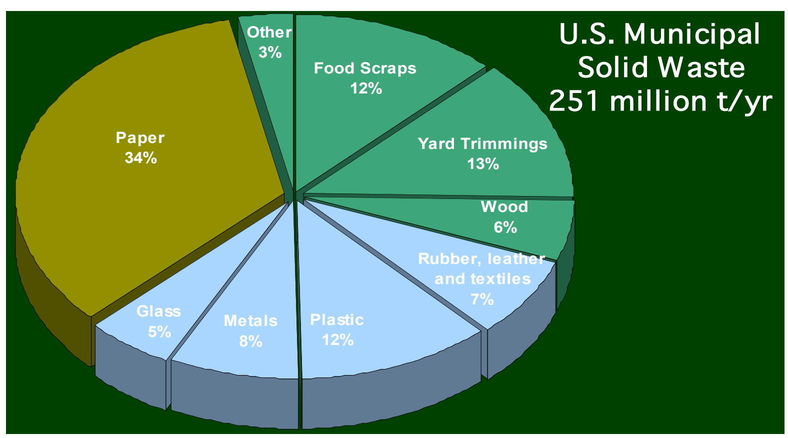
ABSTRACT:

Evaluation of procedures for measurement of volumes at Ohio Class IV compost facilities was done at eight sites in Ohio. For incoming materials, scales were used at five facilities and volumes, calculated from recorded weights, were reported to the Ohio EPA. At the other three facilities visual inspection of incoming load sizes were done and the operator reported estimated volumes of material based on truck size or number of bags received at the site. Out going material was based on volume at all sites and was determined by the bucket size of front end loader used to load-out the material. At all sites material was ground either once or twice, with grinding occurring only daily at two of the sites. Volume reduction due to grinding ranged from 7.5% to 292%. Results showed the estimate of loader bucket volume using the geometry of pile size based on a cone was generally +-20% (62-70% of time) of the predicted volume of material.

INTRODUCTION

In the U.S. over 251 million tons a year of municipal solid waste (MSW) were generated, of which approximately 162 million tons consist of biodegradable material (fig. 1). Of this waste stream, approximately 8% or 20 million tons of yard trimmings, which traditionally includes grass clippings, leaves and light brush, are composted. By weight, grass averages half of all yard trimmings while leaves and brush each provide one quarter. By volume, leaves are the biggest component. Overall the U.S. has more than 3000 yard trimmings composting facilities of which Ohio leads.

Figure 1. Classification of components and their percentages in US Municipal Waste Stream. (Source: www.epa.gov/garbage/facts.htm accessed December 13, 2007)



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In Ohio there are four classes of compost facilities regulated by Ohio EPA. They are classified as Class I, II, III and IV (Ohio EPA) depending on the type materials they receive and the size of the facility. Class I facilities may receive any solid waste and require a permit prior to construction and a license. Class II facilities can receive only yard trimmings and/or animal waste along with certain bulking materials if the Ohio EPA approves them. Separated organics can also be processed with Ohio EPA approval. Class III facilities may receive only yard trimmings and/or animal waste along with specified bulking agents. Class IV facilities may accept only source-separated yard trimmings and specified bulking agents. Yard trimmings compost from Class II or III facilities may be distributed for general use as compost upon sampling and testing for specified constituents. Ohio compost facilities are required to meet numerous requirements including facility construction, operations, testing and closure. For all compost facilities Ohio EPA requires facilities to complete an annual report consisting of the data on the amount of materials received and processed annually either on a weight or volumes basis. They must also report compost sold or given away. As such there are over 400 compost facilities either permitted or registered in Ohio.

Compost has been reported to the Ohio EPA over the past several years using the "Solid Waste Composting Facility Daily Log of Operations" data sheet. Scales, visual estimate, or the capacity of the vehicle hauling the material was used to measure the incoming material. The type of equipment available at the site is completed at the beginning of each year. Incoming material is recorded by date, load number, amount of waste, kind of waste, and waste origin if not coming from Ohio. Outgoing material is either reported in cubic yards or by the ton. After each day, data is recorded upon inspection of the facility making sure it is meeting regulatory requirements issued by the Ohio Environmental Protection Agency. If unauthorized material is brought into the site, the incident is recorded and actions by the operator are reported upon.

In order to better understand how volumes of materials are determined and reported for composting sites in Ohio, this study was undertaken to develop a consistent methodology to determine the volumes of materials accepted and produced at the compost facility. The measurement methodology includes the cubic yard estimation for piles of leaves, grass, woody materials and mixtures.

Objectives:

1. Evaluate methodology using lineal pile dimensions of diameter(s), circumference, length, and geometrical shape to calculate the volume of piles at facilities with no scales.
2. Evaluate volume of piles(at sites with scales) based on the weight of pile and bulk densities of the various compost materials i.e. incoming and outgoing, using a 5 gallon bucket (GB) and compare with results from objective 1.
3. Evaluate wet bulk densities based on the weight of compost delivered with a front end loader bucket at the compost facilities with scales and compare results with densities obtained in objective 2.
4. Evaluate volumes of the piles based on the standards of the front-end loader bucket used in composting operations.

5. Determine the moisture contents of the samples of the various materials at the different stages of composting and evaluate whether any correlation exists between bulk density, compost type, and moisture.

Results will (1) provide insight on how the weights and volumes reported to EPA are determined and enable comparison between the standards of the compost facility operator and the measurement techniques applied, and (2) assist EPA regulators in specifying procedures to calibrate equipment used in the measurement of volumes at the compost sites.

MATERIALS AND METHODS:

Data recorded during the study for the different sites was moisture, wet bulk density, dry bulk density, volumes based on the dimensions and geometrical shape of a pile, volumes based on weight of material with a front end bucket loader. Equipment used in the study for lineal measurements (fig. 2) included a 200 ft measuring tape (Model NR 18200), 26 ft/8 m measuring tape (Lufkin ULTRALOK), ground wheel (Stanley), clinometer (PM-5), and a rod surveyor at the facilities visited. The 200 ft and 26 ft tapes were used to measure major and minor axis of the compost pile base. The height of the pile was approximated by aligning the eye ball with the peak of the pile, at a distance of approximately 30 feet from the pile, using the rod surveyor. For larger piles the clinometer, which has a degree scale (left side) and percent scale (right side) was tried. It was calibrated for a horizontal distance of 66 feet from the pile. The circumference of the pile was measured with a ground wheel. For weighing the compost a bathroom scale (fig. 2f) weighing up to 400 lbs ± 0.2 lbs was used or the truck scales at the compost site (accuracy ±20 lb?).

At each site visited compost wet bulk densities were determined using weight of compost in a 5 gallon bucket. For the 5 gallon bucket, a representative sample of the compost was used to fill the bucket with the help of a shovel, leveled to ensure uniformity in the data collection (figs. 2 & 3) and weighed using the bathroom scale. The scale was placed on a leveled wooden board to eliminate the unevenness of the ground at the locations. In addition, at sites with truck scales, compost weight of a pile constructed using a front end bucket loader was also used. The compost pile was formed by dumping from one to ten buckets, ranging from 1-6 cubic yard, heaped with compost material into a cone shaped pile (fig. 3) following weighing of the filled bucket loader. At one site the weight recorded was for a roll off truck (container capacity 30 cubic yard) used to measure volume.

For moisture measurements, samples were collected in Ziploc bags (fig. 4) from each location of the pile where bulk densities were measured, transported back to the composting laboratory, and dried. For moisture determination, a 100 to 300 g sample of compost was dried in a forced air oven for 48 hours at 70 C. Weighing was done with a laboratory balance accurate to ± 0.1 g.

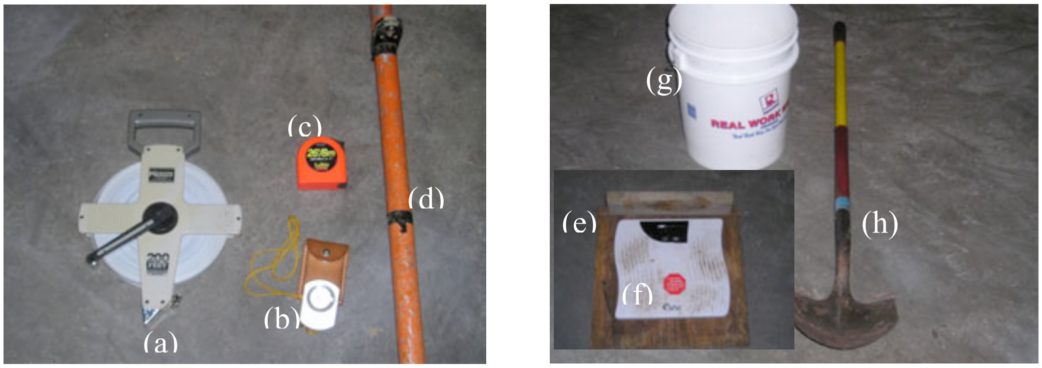

Figure 2. Instruments used for determining the pile dimensions: (a) 200 feet Measuring tape; (b) Clinometer(PC-5); (c) 26'/8m x 1" tape measure; (d) Surveyor rod. Equipment used for the wet bulk density measurement (GB): (e) wooden board; (f) weight scale (400 pounds); (g) 5-gallon bucket; (h) shovel.

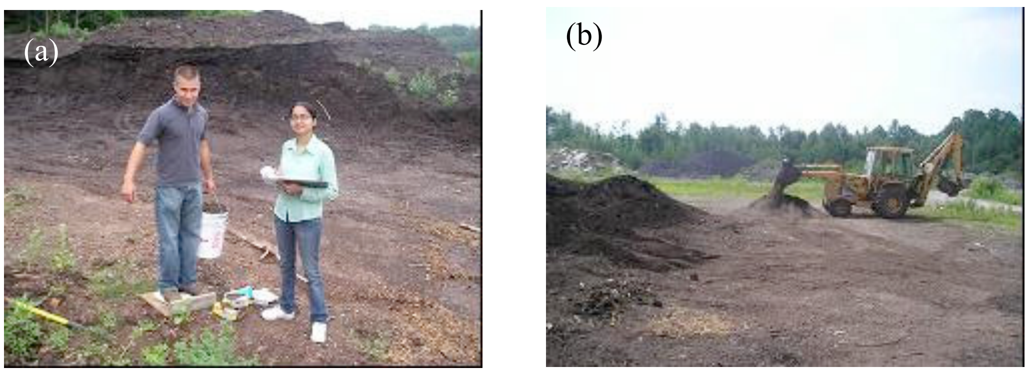

Figure 3. (a) Field set up for determining bulk density using 5 gallon pail & 400lb weight scale. (b) Formation of the cone shaped pile by front end bucket loader (1 cu. yd) at the composting site

Figure 4. Supplies associated with the moisture analysis of compost samples: (a) Ziploc bags for collecting samples from sites; (b) Sample cups used in drying oven (100-300g).

Equation for moisture content

Moisture content and bulk density are chemical and physical properties of compost materials that play an important role in achieving the optimum efficiency of the composting process. The wet basis moisture content, MC_w, is the ratio of the total weight of the free available and bound water in the wet mass of the compost sample. It is calculated using

$$MC_w = 100 * \frac{(W2 - W3) - (W4 - W5)}{W2 - W1} \qquad (1)$$

where W1 is weight of the sample empty cup ,W2 is weight of the cup filled with compost ,W3 is weight of the dried sample after 48 hours at 70 C in oven, W4 is reference cup weight before drying and W5 is reference cup weight after drying. This equation implies the reference cup is similar to the sample cup. If cups for sample are pre-dried, then (W4-W5) is zero. An alternative to oven drying would be use of a microwave where the sample is dried in small time steps of 1-2 minutes until weight of the sample doesn't change. For weighing purposes a laboratory scale accurate to ±0.1 gram or better is used.

Equations for bulk density

The bulk density of compost is a measure of the mass of the material in a given volume. It influences the compost properties like porosity, strength and resistance to compression. Both dry and wet bulk densities are assessed for compost. The wet bulk density is the ratio of wet or as received compost mass to total volume occupied while dry bulk density is the mass of the dry compost material to total volume occupied. The equation for calculation of bulk density using a small bucket and a scale is:

$$BD_S = 62.4 * \frac{W_{compost} - W_{bucket}}{W_{water} - W_{bucket}} \qquad (2)$$

where BD_S = bulk density, lb/ft^3 , $W_{compost}$ represents the weight of the small bucket (for this study ≈5 gallon) full of compost material, W_{bucket} is weight of the empty bucket, and W_{water} is the weight of the small bucket filled with water.

The equation for the bulk density using a loader bucket is:

$$BD_L = \frac{W_{compost} - W_{loader}}{V_{loader}} \qquad (3)$$

$W_{compost}$ represents the weight of the front end loader bucket (1-6 cubic yd) filled with compost, W_{loader} is weight of the empty loader, and V_{loader} is the volume of the front end loader bucket. For this study volume was determined from pile measurements or information provided by the operator of the equipment.

Converting wet bulk density to dry bulk density is done using the following equations,

$$bd_S = (1\text{-}MC_w)\ BD_S \qquad (4a)$$
$$bd_L = (1\text{-}MC_w)\ BD_L \qquad (4b)$$

where bd = dry bulk density, lb/ft^3 and MC_w is the wet moisture content (decimal) of the compost.

Equation for Volume of Cone

For a pile considered as a cone with a spherical base the volume is given by:

$$V_1 = \pi r^2 h/3 = C^2 h / (12 \pi) \qquad (5)$$

where
r = radius of the base of the pile, ft
C = circumference of circle base, ft and
h = the height of the pile, ft.

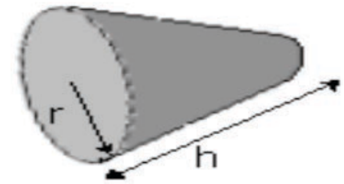

Figure 5. Cone

Pile considered as a cone with an elliptical base:

$$V_2 = \pi a b h/12 \qquad (6)$$

where
a = the major axis of the ellipse, ft and
b = the minor axis of the ellipse, ft.

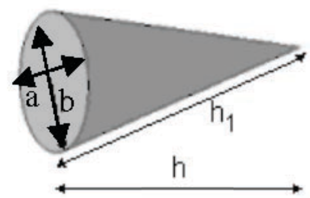

Figure 6. Elliptical Cone

Equations for Bucket Loader Volumes

Volumes of the bucket loader were determined using:

1. Weight of compost in bucket loader and small bucket bulk density,
2. Volumes of cone, i.e. pile, formed at the site by bucket loader,
3. Volume (1 to 6 cu. yd) of front end loader bucket as reported by the operator.

1. Volume of the bucket loader based on bulk density is

$$VL_1 = \frac{\sum_{i=1}^{n} (W_{full} - W_{empty})_i}{n * BD_S} \qquad (7)$$

where
VL_1 = volume of the loader bucket using a 5 gallon pail bulk density, ft^3
n = number of loads weighed
W_{full} = wt. of bucket loader with compost for each of the n trials to form the pile, lb
W_{empty} = empty weight of the bucket loader, lb and
BD_S = wet bulk density using the small bucket method, lb/ft^3

2. Volume of bucket loader based on pile volume measurements is

$$VL_2 = \frac{Vp}{n} \qquad (8)$$

where
VL_2 = volume of front end bucket loader based on pile dimensions, ft^3
V_p = volume of the pile (either V_1 or V_2), ft^3

3. Operator Volume, VL_3, was based on the company standards for the front end loaders used at the various sites in compost operations as reported by operator. The bucket size varied from 1-6 cu yd

Differences in Bulk Density and Bucket Volumes

Bulk density differences between ground BD_{Lg} and ungrounded material BD_{Lu} were evaluated using

$$\%BD_{diff} = 100\frac{(BD_{Lg} - BD_{Lu})}{BD_{Lu}} \qquad (9)$$

Loader volume differences were calculated using VL_3, VL_1 and VL_2. The equations used were

$$\%VL_{3-1} = 100\frac{(VL_3 - VL_1)}{VL_3} \qquad (10)$$

$$\%VL_{3-2} = 100\frac{(VL_3 - VL_2)}{VL_3} \qquad (11)$$

Test Procedure at Each Site

Research was carried out at eight composting facilities across the state of Ohio. At a site, each operator was asked a series of questions pertaining to the operation of the site to gain background on how facilities are operated. For collecting data at each site, the tools identified under methods were used. For the bulk densities of material, the 5 gallon bucket was filled with compost and the top striked off to maintain consistency. A person would stand on the scale with either the bucket empty or full and determine a weight. This process was completed three times for each material at the site. Samples of material were taken from each pile, categorized by age and physical characteristics, and bagged for analysis of moisture content. Where bucket loaders were available, operators were asked to move and pile 1 to 10 buckets of a material for volumetric measurements. A measuring wheel was used to measure the circumference of the pile and the 26 ft. tape used to measure the major axis, minor axis, and the height of the pile. Pictures were taken of incoming material, aged material, equipment used, and the setup of the facility.

Site 1. NC Ohio.

Medina County Facility is located in North Central Ohio and has both a Class I and Class IV composting facility. For the Class IV facility, material at the site was arranged by age: newest to oldest material. The site was arranged as followed: two year old leaf waste, one year old leaf waste, incoming yard waste, 1st ground material one month old material, 1st ground 5-6 month old material, 1st ground 10-12 month old material, and final product – 10-12 month old material – ground and screened. Figure 7a shows three cubic yard loader that was used to measure material for volumetric measurement. Figure 7b. shows the machine used to screen 10-12 month old material so it can be sold as a final product. Figure 7c. shows one year old leaf waste. Unground yard waste was scaled with the loader and pile size measured afterwards.

Figure 7. North Central compost facility.

Site 2. Central Ohio

The Kurtz Bros. facility is located near Columbus. It is a Class IV composting facility. It is a large facility that sells product to both the individual consumer and landscape businesses. Incoming waste is measured by the cubic yard using vehicle volumes; outgoing product is sold both by weight and by the cubic yard. Piles are measured once per month, turned three to four times per year, and salable products are watered when necessary to keep down the dust. Yard wastes are composted approximately 10-12 months before it is sold. Product is loaded into trucks with a "1 cubic yard bucket" and a "6 cubic yard" bucket. A portion of the ungrounded yard waste and a sample of the first ground yard waste were moved by a one cubic yard bucket, scaled, and then piled in order to take volumetric measurements. Pictures taken at the site shown are presented in Figures 8a,b,c.

Figure 8. Central Ohio compost facility

Site 3. Southwest Ohio

The Rumpke Facility is located near Cincinnati. It is a Class IV site and is located on the grounds of a landfill. Yard waste is brought to the site and processed by a tub grinder. The freshly ground yard waste is generally shipped out and sold to other composting facilities. Product is reported to the EPA in tons. Piles of material are not measured and the piles of material are watered on no definite schedule. Material left on sight is turned 3-4 times per year with Cat 980F wheel loader with a six cubic yard bucket. The compost was put into piles; material ranging in age from incoming to five years old. Figure 9a shows compost site with incoming material ***i*** and ground material ***ii***, fig. 9b shows roll off truck used to measure volume of compost, and fig. 9c shows measuring pile height.

Figure 9. Southwest Ohio compost site

Site 4. Southeast Ohio

The Greenleaf site is located in Marietta and is a Class IV site. Material brought to the site is charged a dumping fee. Material is ground once per year in January by a hired company. There are three piles of material at the site: Incoming material (fig. 10a), one-year-old composting yard waste (fig. 10b), and 2-5 year old final product (fig. 10c). There were no scales or loaders available upon arrival at the site. Bulk densities and samples of material were taken. Composting data is reported to the EPA in cubic yards. Visual estimate of material is made when material comes onto the site. Outgoing material is sold by the cubic yard. Composted material is loaded with either a 1 cubic yard Bobcat bucket or a 3 cubic yard wheel loader bucket.

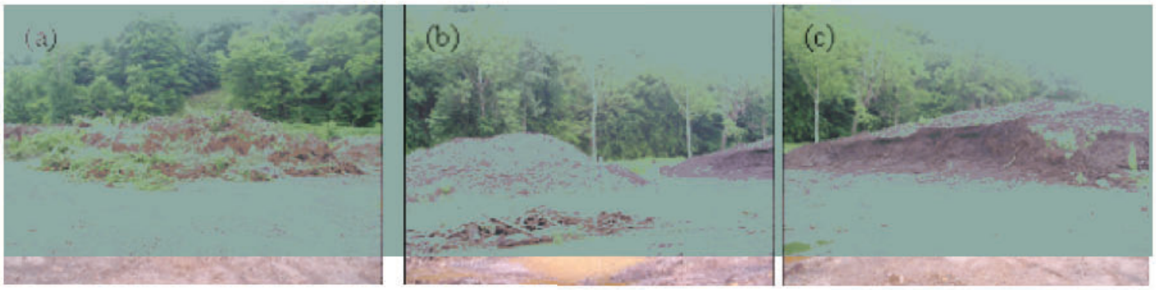

Figure 10. Southeast Ohio Compost Site.

Site 5. Western Ohio

City of Lima Compost Facility was located right outside of Lima and is a Class IV site. To the west of the site lay a railway and to the north of the site was an ethanol plant. Material in fig. 11a is freshly brought in material that has not been ground. Figure 11b shows a Case 721D Wheel Loader with a 3 cubic yard bucket. Figure 11c is a picture of ground material. No scales are available at the site. Samples were taken of the final product. No known age could be determined for the final product being sold. Composting data is reported to the EPA in cubic yards. Visual estimates are made when the yard waste arrives at the site. The facility does not water or turn their piles. A company is hired to grind and process material on the site.

Figure 11. Western Ohio compost site

Site 6. Northeast Ohio-1

The Conneaut Composting facility is located in Ashtabula County and is a Class IV site. Material was made up of three distinct piles: Figure 12a – fresh yard waste, fig. 12b - 1-2 year old leaf waste, and fig. 12c – 2-5 year old final product. Incoming composting data is reported to the EPA in tons. Samples and bulk densities were taken of the final product and the leaf waste. Piles are not measured and are not turned during the year. Outgoing material is sold by the yard.

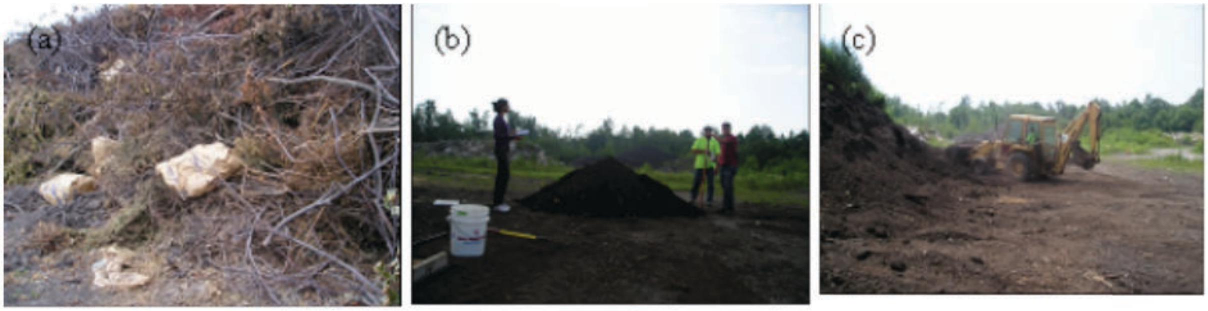

Figure 12. Northeast Ohio compost site-1

Site 7. North Central Ohio

The Barnes Compost Yard Waste Recovery facility is located in Huron County. It is a relatively large Class II composting facility that sells its product to both the individual consumer and other businesses. Scales measure incoming waste; outgoing product is sold by the cubic yard. Piles are turned every three to six weeks. Watering of piles is not generally done. Yard wastes are composted approximately 10-12 months before it is sold. Product is loaded into trucks with a 1 cubic yard bucket. Figures 13a and 13b show turning equipment used at site and windrows.

(a)

Figure 13. North Central Ohio compost site

Site 8. Eastt Ohio-2

The Earth'N Wood compost facility (fig. 14) is located Stark County. It is a Class IV composting facility. Scales measure incoming waste; outgoing product is sold by the cubic yard. A comtiller is used to turn piles weekly for the first 3 weeks. Yard wastes are composted approximately 10-12 months before it is sold. Product is loaded into trucks with a 1 cubic yard bucket.

Figure 14. East Ohio compost site-2

RESULTS

Moisture Content

Moisture for compost materials at different stages of composting for the 8 sites visited are shown in Figures 15-18. Wet moisture content varied from a maximum of 70 percent in composting material to a minimum of 6.9 percent in the screenings. Generally material moisture was 20-55 percent. For some unfinished compost it would be concluded it was overly dry, i.e. below the range of 45-65 percent (Note -summer conditions).

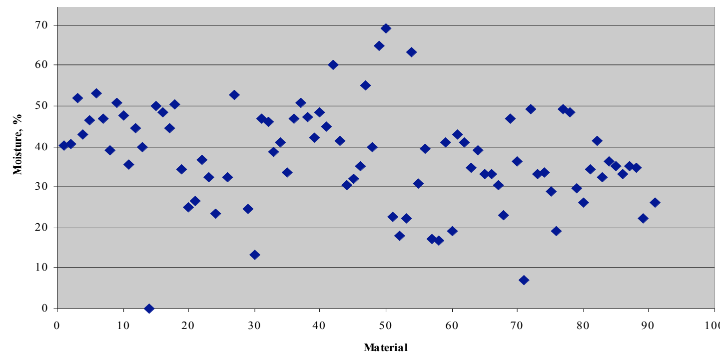

Figure 15. Moisture content of 91 compost materials at 8 compost sites.

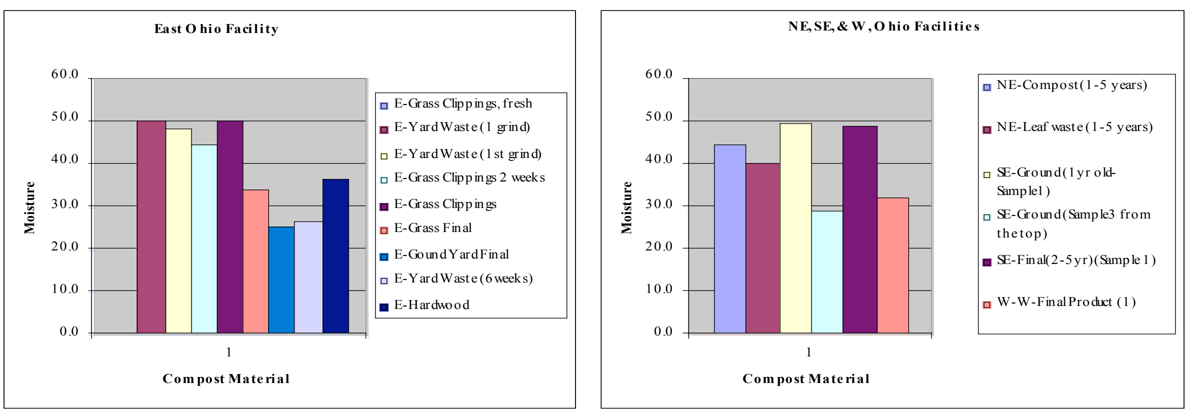

Figure 16. Compost materials moisture content at North East, South East and Western Ohio compost sites.

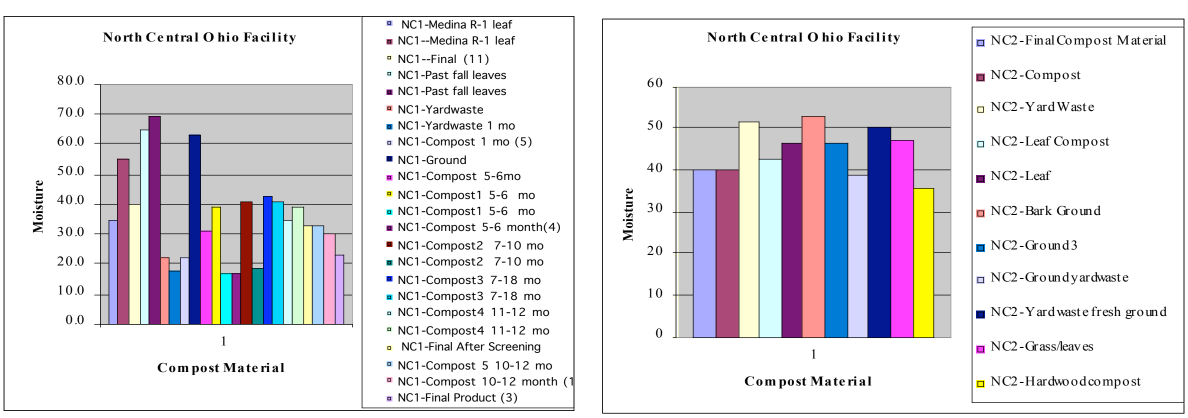

Figure 17. Compost materials moisture content at North Central Ohio compost site.

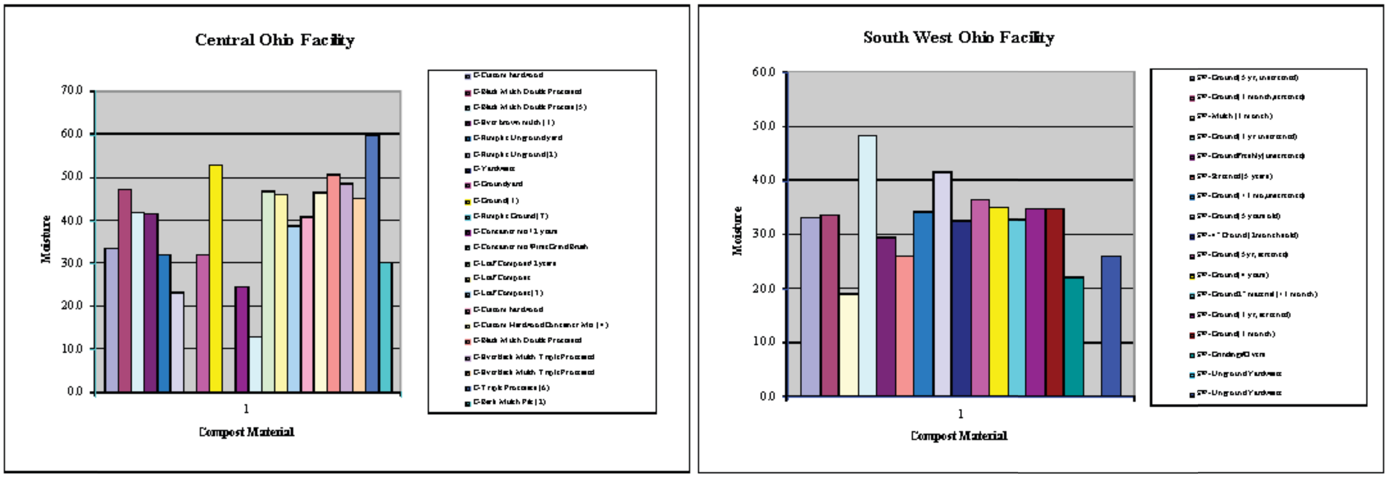

Figure 18. Compost materials moisture content at Central and Southwest Ohio compost site.

Bulk Density

The 5 gallon bulk densities ranged from 8 lb/ft^3 (4 inch freshly ground) to 48.8 lb/ft^3 (5 year old ground) for compost materials at various sites (fig. 19). The dry bulk densities varied from a maximum of 5.4 lb/ft^3 to 32.4 lb/ft^3. Results for bulk density did not show any correlation between BD (wet or dry) and moisture for the materials tested. Although no relationship was determined between bulk density and moisture contents as a part of these studies, wet bulk density should increase with moisture contents due to filling of pore space with water for a given material (water density is 62.4 lb/ft^3). Figures 20-22 presents wet bulk densities for the sites studied.

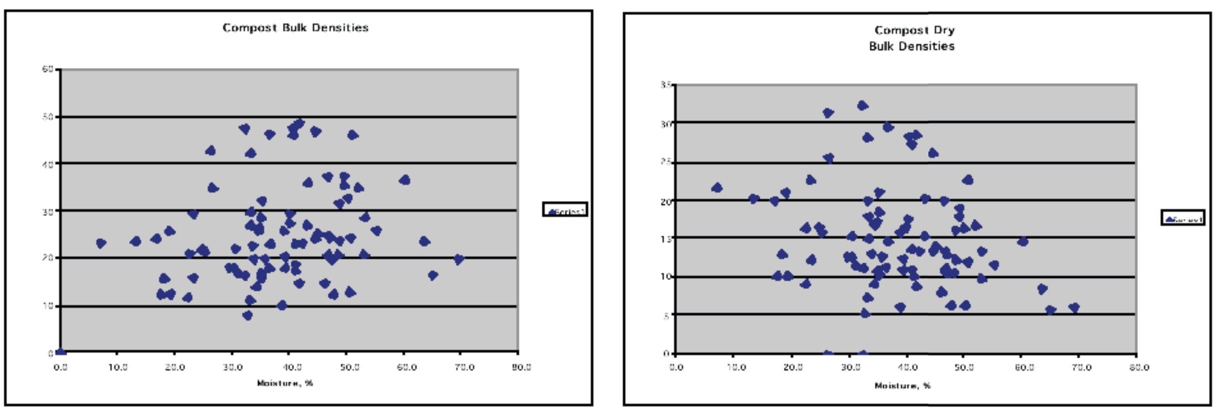

Figure 19. Plot of 5 gallon pail wet and dry bulk densities versus moisture.

Results for BD_L and BD_b at three test sites gave a linear relationship of

$$BD_L = 1.25\ BD_b - 1.62$$

with an R^2 of 0.7814 (fig. 23). On a percentage basis bulk density based on loader weights and operator stated loader volumes was an average of 25 percent higher then the small bucket gave. This higher bulk density is likely due in part to the front loader bucket containing more material than the designed loader bucket volume.

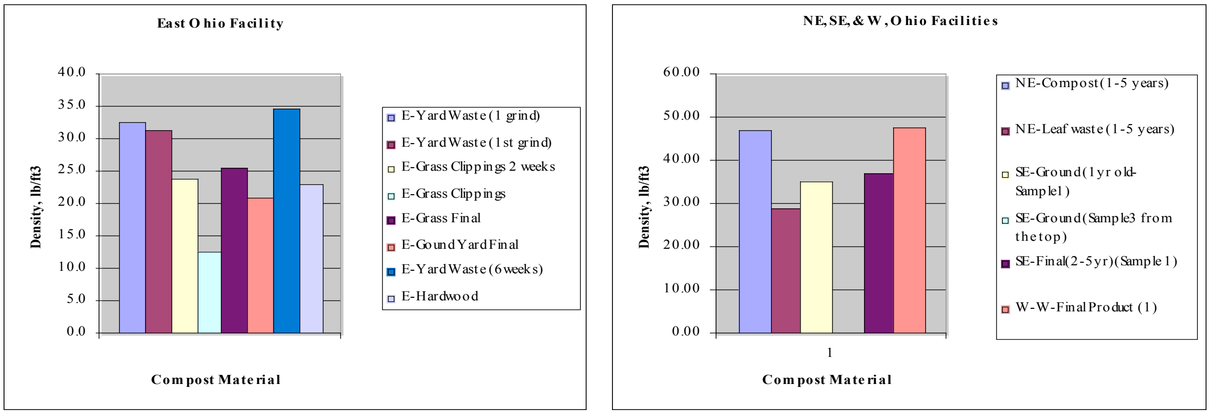

Figure 20. Wet bulk densities using 5-gallon pail for compost material at Northeast, West, and Southeast composting sites.

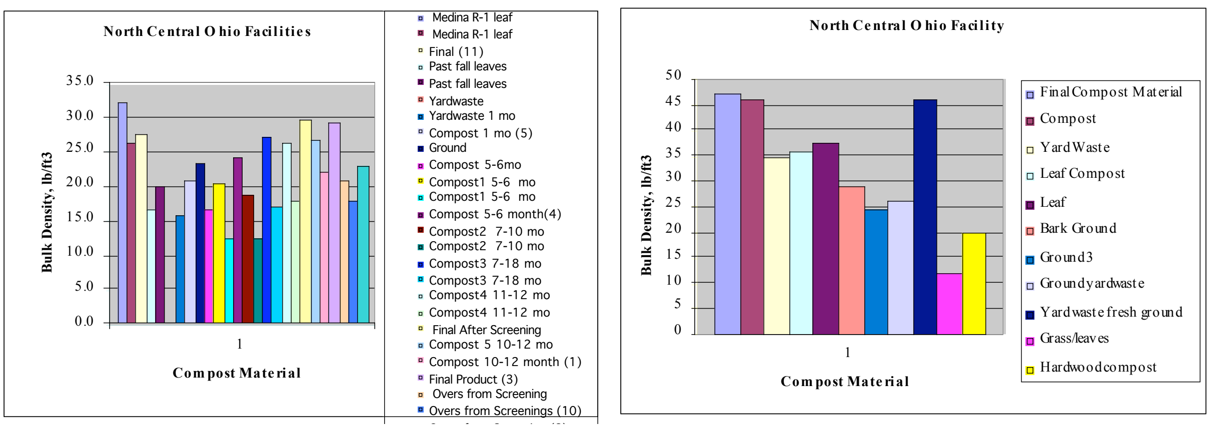

Figure 21. Wet bulk densities using 5-gallon pail for compost material at North Central composting sites.

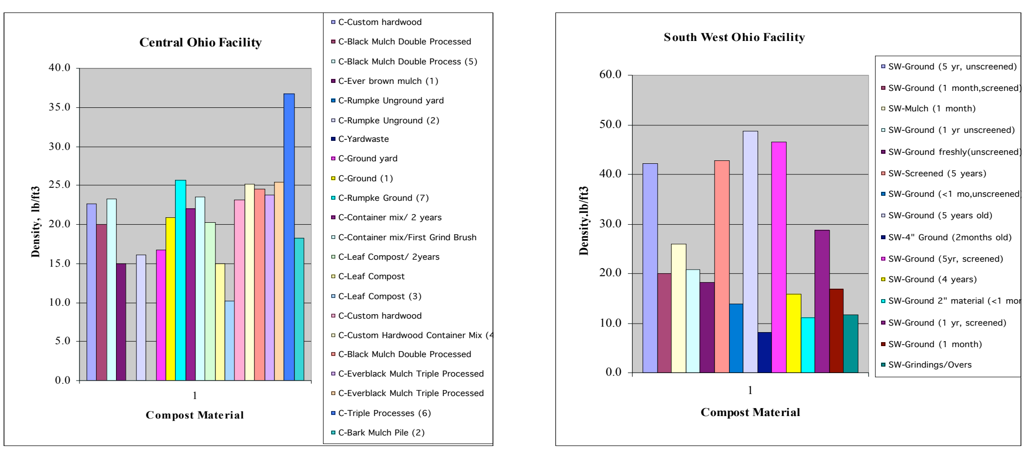

Figure 22. Wet bulk densities using 5-gallon pail for compost material at Central and Southwest Ohio composting sites.

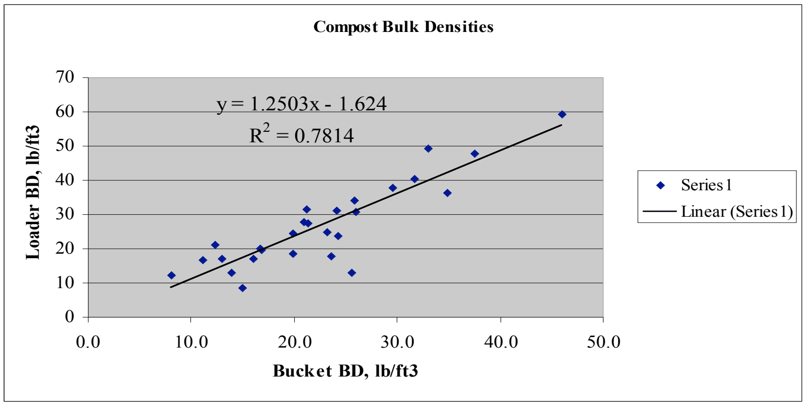

Figure 23. Loader volume wet bulk density versus 5-gallon pail wet bulk densities at Central and Southwest Ohio composting sites.

Comparison of wet bulk densities obtained by the loader bucket for the ground and ungrounded material at the different sites is presented in fig. 24 and table 1. Results showed bulk densities of ground material were from 7.5 % to 291% more than ungrounded yardwaste. Because 5-gallon pail densities on the unground material were not practical to measure, no comparison was possible based on BD_b.

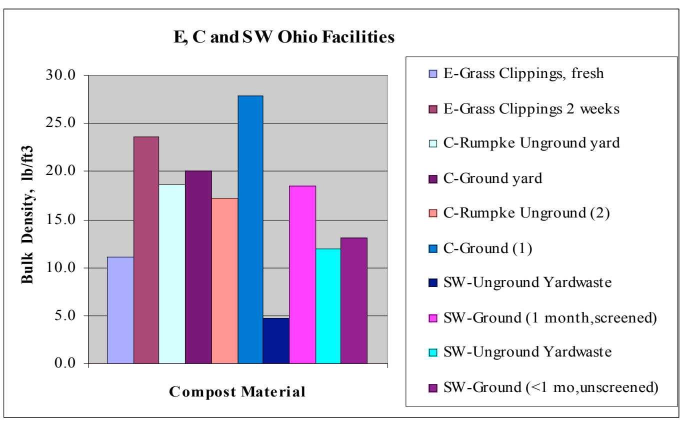

Figure 24. Loader volume wet bulk density versus grinding at Northeast, Central and Southwest Ohio composting sites.

Table 1. Percent differences in bulk densities between ground and unground materials at Northeast, Central and Southwest Ohio using loader volume wet bulk densities

	Bulk Density lb/ft^3		% Difference[1]
Description	Unground	Ground	(G-U)/U
E-Grass Clippings	11.1	23.6	113
C-yard (1 trip)	18.6	20.0	7.5
C-yard (2 trip)	17.2	27.9	62.2
SW-yard (1 trip)	12.0	13.1	9.2
SW-yard (2 trip)	4.7	18.4	291

[1]Bulk density increase due to grinding.

Pile Volumes

Evaluation of pile volumes using equations 5 and 6 are given in the appendix. A plot of volumes (fig. 25) based on the pile circumference versus volume based on pile major and minor axis showed they were linearly related. Using the circumference gave a pile volume about 16% higher ($R^2 = 0.9264$) than major/minor axis. This result was based on 29 of 31 data points (2 omitted as outliers).

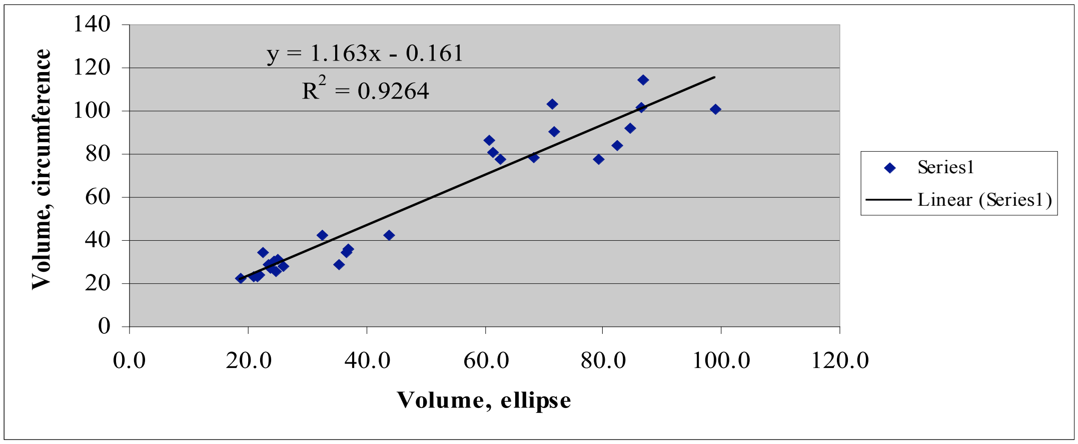

Figure 25. Compost pile volumes using ellipse and circumference equations for a cone at Northeast, North Central, Central and Western Ohio composting sites.

Loader Bucket Volumes

Differences in measured bucket loader volumes (VL_1) based on loader weights and small bucket density and operator's volumes (VL_3) are given in fig. 26. Results indicate differences were +37% to -15% at the East site, +16 to +40% at NC1, site +20% to +81% at NC2 site, and -46 to +81% at Central site. The ungrounded grass/leaf material at NC2 and ground yard at C had the 81% over estimation on volume. The general trend of predicting higher loader volumes based on weight than the design volume of the bucket could be due to overfilling of the loader bucket and/or underestimation of bulk density with a small bucket.

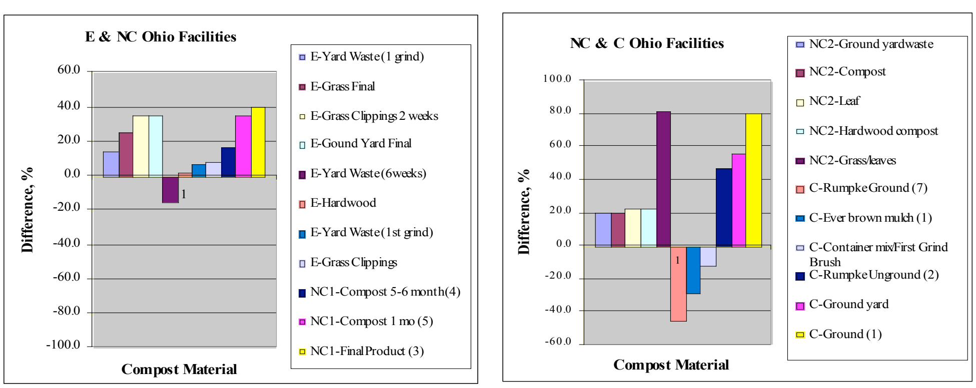

Figure 26. Percent difference in measured loader volume (weight basis) to operator's volume at Northeast, North Central and Central Ohio composting sites. [positive difference => over filling of bucket].

Differences in measured bucket loader volumes (VL_1) based on major/minor axis technique with the operators bucket volume (VL_3) for each site are given in fig. 27. Results indicate differences were -30% to +62% at the East site, -45 to +5% at NC1 site, -13% to -4% at NC2 site, and -11 to +50% at Central site. For NE the difference was +35% (n=1) and for W it was + 5%. Results suggest that the NE, NC1 and NC2 sites were slightly biased toward less volume than stated for loader bucket, whereas, the C site was biased toward more volume than the bucket loader. Since no precise measurement of each loader bucket was made this biasing could be due to inaccurate bucket volume, as well as operator skill or use of formula for a cone.

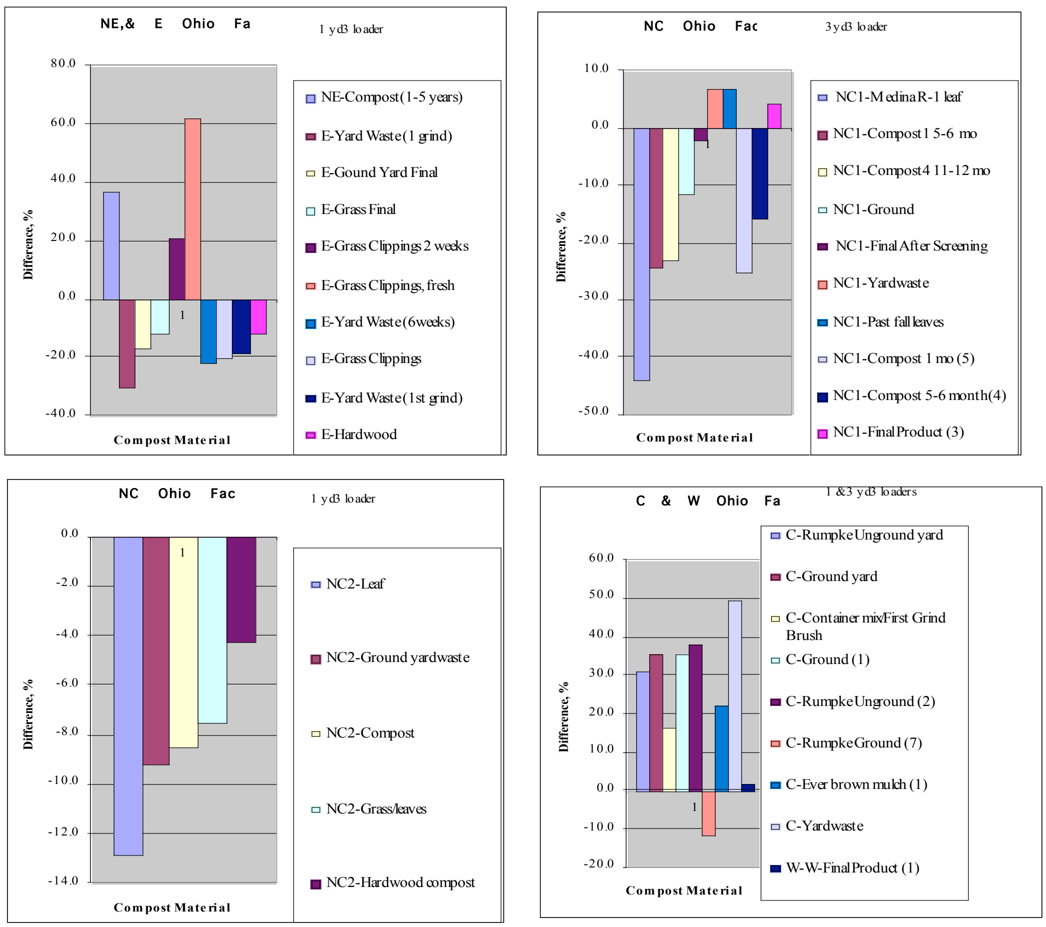

Figure 27. Percent difference in measured loader volume (ellipse) to operator stated volume at Ohio composting sites. [negative difference => under estimated bucket volume].

The general formula for a cone with an elliptical base assumes the volume is 1/3 base time the height. However, in construction of the pile, the shape is such that using 1/3 base x height may underestimate the volume. However, base on data collected use of 1/3 (i.e. 0.333) is recommended unless more controlled experiments would be done. A plot of the results for differences in volume (ellipse) at the six Ohio sites (n=34) is presented in fig. 27. Results showed a somewhat even balance of errors around 0 difference, with 20 volumes below and 14 volumes above the operator loader volume. On a percentage basis, 62% of the results were within 20% of the stated volume. Use of the equation for a cone based on circumference is given in fig. 28. For this method 70% of measured volumes were within 20% of the stated loader volume, including all under predicted volumes.

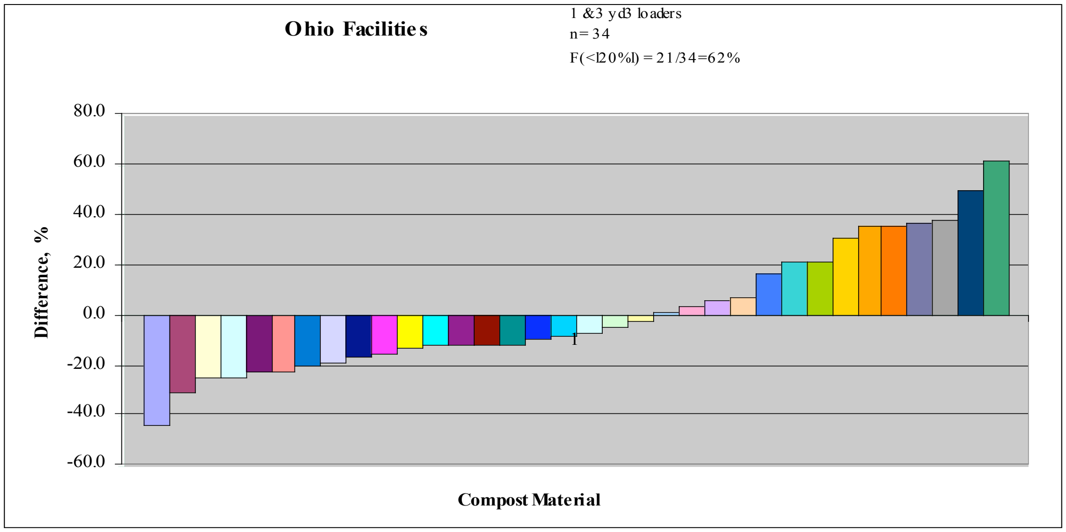

Figure 27. Percent difference in measured loader volume (ellipse) to operator stated volume at Ohio composting sites. [negative difference => predicted volume less than bucket volume].

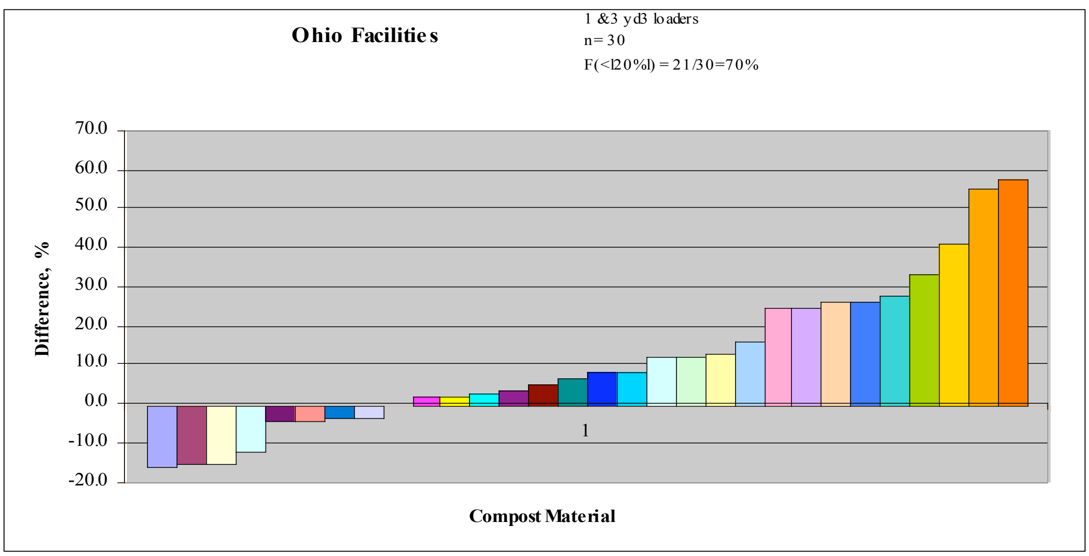

Figure 28. Percent difference in measured loader volume (circumference) to operator stated volume at Ohio composting sites. [negative difference => predicted volume less than bucket volume].

DISCUSSION AND CONCLUSIONS:

The results show that the compost volumes reported to the EPA by the compost facilities are generally within 20% of actually amounts, when accurate records are maintained on loader buckets of material received and sold. Based on results of this study, the circumference and major/minor axis estimated volumes were relatively similar, with the circumference method giving a 16% higher value. The circumference approach would require only a single person to take the measurements while the major/minor axis needs two persons to get the measurement data to determine the volume. Both the methods are economical and simple to use and can easily be taught to the facility operator for estimating loader volumes.

The method of estimating the loader volume, based on the bulk density by the small bucket and weights of the compost products for the loader bucket, showed percentage differences as high as 81 %. For this method most volumes were calculated higher than stated loader volumes, which may be due to overfilling the bucket or underestimating bulk density using the small bucket. According to this study the correlation between bulk density and composting materials based on age or moisture content could not be found.

To maintain accuracy and consistency in the data, sampling procedures need to be developed and followed at each composting sites. For example procedures need to be clearly followed for height measurement of a pile,. Picture analysis is also an approach that might enable determining the volume of the pile, but would not be as easily implemented as the methods used in this study.

ACKNOWLEDGEMENTS

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REFERENCES

EPA 2007. Municipal solid waste generation, recycling and disposal in the United States: Facts and Figures for 2006. www.epa.gov/garbage/facts.htm (accessed December 13, 2007).

APPENDIX

	ID	Sample Description	Moisture Ave MCw %	n Density	(lb/ft^3) Ave BD_S	(lb/ft^3) SD BD_S	(lb/ft^3) Ave BD_{L2}	(lb/ft^3) SD BD_{L2}	(lb/ft^3) Ave bd_S	(lb/ft^3) Ave bd_{L2}	% Difference BD_S-BD_L
B1	10	NC2-Final Compost Material	40.3	2	47.5	0.4			28.4		
B1	30	NC2-Leaf Compost	43.0	3	35.9	1.2			20.5		
B1	50	NC2-Ground 3	47.0	3	24.5	2.4			13.0		
B1	60	NC2-Yard waste fresh ground	50.7	3	46.2	2.5			22.7		
B1	20	NC2-Yard Waste	51.9	3	35.0	1.8			16.8		
B1	40	NC2-Bark Ground	53.0	3	28.9	1.2			13.6		
B2	81	NC2-Hardwood compost	35.6	3	19.9	0.6	24.6		12.8	15.8	-23.3
B2	51	NC2-Ground yardwaste	38.9	3	26.0	0.9	30.6		15.9	18.7	-17.4
B2	11	NC2-Compost	40.7	3	46.1	1.0	59.3		27.3	35.2	-28.7
B2	31	NC2-Leaf	46.6	3	37.6	0.6	47.7		20.1	25.5	-27.0
B2	71	NC2-Grass/leaves	47.6	2	12.3	7.9	21.3		6.4	11.1	-73.4
C1	30	NE-Leaf waste (1-5 years)	40.0		29.44	2.11			17.7		
C1	20	NE-Compost(1-5 years)	44.3		47.05	3.67			26.2		
E1	50	E-Gound Yard Final	25.1	3	21.3	1.6	27.6		16.0	20.6	-29.3
E1	30	E-Grass Final	34.4	2	25.9	3.8	34.2		17.0	22.4	-31.9
E1	20	E-Grass Clippings 2 weeks	44.5	3	24.2	0.4	23.6		13.5	13.1	2.8
E1	10	E-Yard Waste (1 grind)	50.0	3	33.0	1.0	49.1		16.5	24.6	-49.1
E1	9	E-Grass Clippings, fresh	0.0	0			11.1				
E2	51	E-Yard Waste (6weeks)	26.4	3	34.9	0.5	36.3		25.7	26.7	-4.2
E2	61	E-Hardwood	36.6	3	23.2	1.3	24.9		14.7	15.8	-7.4
E2	11	E-Yard Waste (1st grind)	48.5	3	31.7	1.7	40.3		16.3	20.8	-27.0
E2	21	E-Grass Clippings	50.3	2	13.0	8.3	17.0		6.5	8.5	-30.8
K1	30	C-Container mix/ 2 years	24.7	3	22.1	1.3			16.6		
K1	10	C-Rumpke Unground yard	32.2	3			18.6	6.5	0.0	12.6	
K1	20	C-Ground yard	32.2	3	16.7	1.5	20.0	1.6	11.3	13.6	-19.6
K1	50	C-Custom hardwood	40.8	3	23.1	3.8			13.7		
K1	40	C-Leaf Compost/ 2years	46.8	3	20.3	0.7			10.8		
K1	70	C-Everblack Mulch Triple Proce:	48.6	3	23.8	2.7			12.3		
K1	60	C-Black Mulch Double Processe	50.6	3	24.5	0.7			12.1		
K2	31	C-Container mix/First Grind Bru	13.2	3	23.6	1.1	17.8		20.5	15.4	24.6
K2	11	C-Rumpke Unground (2)	23.3	3	16.1	7.2	17.2		12.3	13.2	-6.9
K2	5	C-Custom hardwood	33.4	3	22.7	0.7			15.1		
K2	71	C-Everblack Mulch Triple Proce:	45.0	3	25.4	0.2			14.0		
K2	51	Custom hardwood	33.4		0.0	0.0	0.0				
K2	61	Black Mulch Double Processed	47.3		0.0	0.0	0.0				
K2	41	C-Leaf Compost	46.1	3	15.0	1.7			8.1		
K2	6	C-Black Mulch Double Processe	47.3	3	19.9	1.7			10.5		
K2	21	C-Ground (1)	52.8	3	20.9	0.9	27.9		9.9	13.1	-33.2
K3	82	Ever brown mulch (1)	41.5	2	0.0	0.0	0.0				
K3	62	Black Mulch Double Process (5)	42.0		0.0	0.0	0.0				
K3	92	C-Bark Mulch Pile (2)	30.3	3	18.2	1.5			12.7		
K3	42	C-Leaf Compost (3)	38.7	3	10.2	0.5			6.3		
K3	8	C-Ever brown mulch (1)	41.5	3	15.0	0.9	8.7	0.6	8.8	5.1	42.0
K3	6	C-Black Mulch Double Process	42.0	3	23.3	4.3			13.5		
K3	52	C-Custom Hardwood Containe	46.7	3	25.2	1.1			13.4		
K3	72	C-Triple Processes (6)	60.0	3	36.7	1.4			14.7		
K3	12	C-Yardwaste	0.0				5.4	1.1		5.4	
K3	22	C-Rumpke Ground (7)	0.0	3	25.6	0.7	12.8	2.9			50.2

APPENDIX

	ID	Sample Description	Moisture Ave MC_w %	n Density	(lb/ft^3) Ave BD_S	(lb/ft^3) SD BD_S	(lb/ft^3) Ave BD_{L2}	(lb/ft^3) SD BD_{L2}	(lb/ft^3) Ave bd_S	(lb/ft^3) Ave bd_{L2}	% Difference BD_S-BD_L
L1	10	W-Final Product (1)	32.0	3.0	47.66	4.18			32.4		
M1	30	NC1-Yardwaste	22.7				8.9			6.9	
M1	90	NC1-Final After Screening	33.1	3	30.0	1.5			20.1		
M1	80	NC1-Compost4 11-12 mo	34.7	3	26.5	2.8			17.3		
M1	10	NC1-Medina R-1 leaf	35.1	3	32.5	1.5			21.1		
M1	50	NC1-Compost1 5-6 mo	39.2	3	20.5	2.2			12.5		
M1	60	NC1-Compost2 7-10 mo	40.8	3	18.9	0.9			11.2		
M1	70	NC1-Compost3 7-18 mo	43.0	3	27.2	1.1			15.5		
M1	95	NC1-Overs from Screening	46.7	3	21.0	4.2			11.2		
M1	40	NC1-Ground	63.3	3	23.6	6.2			8.7		
M1	20	NC1-Past fall leaves	64.9	3	16.7	6.1			5.9		
M2	51	NC1-Compost1 5-6 mo	17.3	3	12.4	0.7			10.3		
M2	11	NC1--Medina R-1 leaf	55.1	3	26.3	1.6			11.8		
M2	31	NC1-Yardwaste 1 mo	18.1	3	15.8	3.9			12.9		
M2	21	NC1-Past fall leaves	69.2	3	20.1	6.0			6.2		
M2	61	NC1-Compost2 7-10 mo	19.1	3	12.7	0.5			10.3		
M2	41	NC1-Compost 5-6mo	31.0	3	16.9	1.9			11.7		
M2	91	NC1-Compost 5 10-12 mo	33.2	3	27.0	1.9			18.0		
M2	96	NC1-Overs from Screenings (10)	36.3	3	18.1	3.2			11.5		
M2	81	NC1-Compost4 11-12 mo	39.2	3	18.1	0.7			11.0		
M2	71	NC1-Compost3 7-18 mo	41.0	3	17.3	3.4			10.2		
M2	12	NC1--Final (11)	39.8	3	27.7	2.0			16.7		
M3	32	NC1-Compost 1 mo (5)	22.4	3	21.2	5.1	31.6		16.4	24.5	-49.0
M3	52	NC1-Compost 5-6 month(4)	16.8	3	24.2	5.9	31.0		20.1	25.8	-28.3
M3	92	NC1-Compost 10-12 month (1)	30.4	3	22.2	2.6	0.0		15.5		
M3	93	NC1-Final Product (3)	23.1	3	29.5	3.0	37.9		22.7	29.2	-28.4
M3	97	NC1-Overs from Screening (2)	6.9	3	23.3	2.7	0.0		21.7		
MA1	10	SE-Ground (1yr old-Sample1)	49.3	10.9	35.50	1.41			18.0		
MA1	20	SE-Final(2-5yr)(Sample 1)	49.2	4.9	37.47	2.47			19.0		
MA1	12	SE-Ground (Sample3 from the t	29.1								
R1	10	SW-Ground (5 yr, unscreened)	33.1	3	42.2	1.2			28.2	0.0	
R1	20	SW-Ground (1 yr unscreened)	48.3	3	20.8	2.8			10.8	0.0	
R1	30	SW-Ground (<1 mo,unscreened	34.2	3	13.9	1.9	13.1		9.2	8.6	6.0
R1	40	SW-Ground (5yr, screened)	36.4	3	46.5	2.4			29.6	0.0	
R1	50	SW-Ground (1 yr, screened)	35.0	3	28.6	4.4			18.6	0.0	
R1	60	SW-Grindings/Overs	22.2	3	11.7	1.9			9.1	0.0	
R1	70	SW-Unground Yardwaste	26.1	3			12.0			8.9	
R2	11	SW-Ground (1 month,screened)	33.7	3	19.9	1.0	18.4		13.2	12.2	7.5
R2	21	SW-Ground freshly(unscreened	29.5	3	18.3	1.1			12.9		
R2	31	SW-Ground (5 years old)	41.6	3	48.8	0.9			28.5		
R2	41	SW-Ground (4 years)	35.1	3	15.9	5.7			10.3		
R2	51	SW-Ground (1 month)	34.9	3	16.8	1.6	19.6		10.9	12.8	-16.7
R2	61	SW-Unground Yardwaste		3			4.7			4.7	
R3	12	SW-Mulch (1 month)	19.0	3	26.0	14.1			21.1		
R3	22	SW-Screened (5 years)	26.2	3	42.8	4.4			31.6		
R3	32	SW-4" Ground (2months old)	32.5	3	8.0	1.7	12.0		5.4	8.1	-49.9
R3	42	SW-Ground 2" material (<1 mon	33.0	3	11.2	1.4	16.7		7.5	11.2	-50.0

APPENDIX

	ID	Sample Description	n Volumes	(ft^3) VL_1	(ft^3) VL_{2a}	(ft^3) VL_{2b}	(ft^3) VL_3	% Differnce VL_3-VL_1	% Differnce VL_3-VL_{2a}	% Difference VL_3-VL_{2b}
B1	10	NC2-Final Compost Material	0				27.0			
B1	30	NC2-Leaf Compost	0				27.0			
B1	50	NC2-Ground 3	0				27.0			
B1	60	NC2-Yard waste fresh ground	0				27.0			
B1	20	NC2-Yard Waste	0				27.0			
B1	40	NC2-Bark Ground	0				27.0			
B2	81	NC2-Hardwood compost	1	33.1	27.8	25.8	27.0	22.5	3.0	-4.3
B2	51	NC2-Ground yardwaste	1	32.3	30.4	24.5	27.0	19.5	12.7	-9.2
B2	11	NC2-Compost	1	32.6	25.9	24.7	27.0	20.6	-4.2	-8.5
B2	31	NC2-Leaf	1	33.0	28.5	23.5	27.0	22.3	5.5	-12.8
B2	71	NC2-Grass/leaves	1	48.9	31.4	25.0	27.0	81.1	16.4	-7.5
C1	30	NE-Leaf waste (1-5 years)								
C1	20	NE-Compost(1-5 years)	3		35.95	36.89	27.0		33.1	36.6
E1	50	E-Gound Yard Final	1	36.6	34.1	22.5	27.0	35.5	26.2	-16.5
E1	30	E-Grass Final	1	34.0	27.6	23.9	27.0	25.8	2.1	-11.3
E1	20	E-Grass Clippings 2 weeks	1	36.3	42.0	32.7	27.0	34.5	55.6	21.1
E1	10	E-Yard Waste (1 grind)	1	30.9	22.7	18.9	27.0	14.6	-16.1	-30.2
E1	9	E-Grass Clippings, fresh	1		42.6	43.8	27.0		57.7	62.3
E2	51	E-Yard Waste (6weeks)	1	22.9	23.0	21.1	27.0	-15.0	-15.0	-22.0
E2	61	E-Hardwood	1	27.6	27.5	23.9	27.0	2.3	2.0	-11.4
E2	11	E-Yard Waste (1st grind)	1	29.0	23.7	22.0	27.0	7.4	-12.3	-18.6
E2	21	E-Grass Clippings	1	29.2	23.0	21.6	27.0	8.1	-14.9	-19.9
K1	30	C-Container mix/ 2 years								
K1	10	C-Rumpke Unground yard	3		29.2	35.4	27.0		8.0	31.2
K1	20	C-Ground yard	3	42.2	34.1	36.5	27.0	56.5	26.4	35.3
K1	50	C-Custom hardwood								
K1	40	C-Leaf Compost/ 2years								
K1	70	C-Everblack Mulch Triple Processed								
K1	60	C-Black Mulch Double Processed								
K2	31	C-Container mix/First Grind Brusl	1	23.8		31.5	27.0	-12.0		16.7
K2	11	C-Rumpke Unground (2)	1	39.8		37.3	27.0	47.6		38.0
K2	5	C-Custom hardwood								
K2	71	C-Everblack Mulch Triple Processed								
K2	51	Custom hardwood					27.0			
K2	61	Black Mulch Double Processed					27.0			
K2	41	C-Leaf Compost								
K2	6	C-Black Mulch Double Processed								
K2	21	C-Ground (1)	1	48.8		36.6	27.0	80.6		35.6
K3	82	Ever brown mulch (1)					27.0			
K3	62	Black Mulch Double Process (5)					27.0			
K3	92	C-Bark Mulch Pile (2)								
K3	42	C-Leaf Compost (3)								
K3	8	C-Ever brown mulch (1)	1	57.9	101.0	98.9	81.0	-28.5	24.7	22.1
K3	6	C-Black Mulch Double Process (5)								
K3	52	C-Custom Hardwood Container Mix (4)								
K3	72	C-Triple Processes (6)								
K3	12	C-Yardwaste	1	0.0	213.4	121.4	81.0		163.4	49.9
K3	22	C-Rumpke Ground (7)	1	43.6	103.6	71.5	81.0	-46.2	27.9	-11.8

APPENDIX

	ID	Sample Description	n Volumes	(ft^3) VL 1	(ft^3) VL 2a	(ft^3) VL 2b	(ft^3) VL 3	% Differnce VL 3-VL 1	% Differnce VL 3-VL 2a	% Difference VL 3-VL 2b
L1	10	W-Final Product (1)	3		84.03	82.55	81.0		3.7	1.9
M1	30	NC1-Yardwaste	10		101.4	86.4	81.0		25.2	6.7
M1	90	NC1-Final After Screening	10		77.4	79.4	81.0		-4.4	-2.0
M1	80	NC1-Compost4 11-12 mo	10		78.0	62.5	81.0		-3.7	-22.8
M1	10	NC1-Medina R-1 leaf	10		87.7	45.4	81.0		8.3	-44.0
M1	50	NC1-Compost1 5-6 mo	10		80.9	61.3	81.0		-0.1	-24.3
M1	60	NC1-Compost2 7-10 mo								
M1	70	NC1-Compost3 7-18 mo								
M1	95	NC1-Overs from Screening								
M1	40	NC1-Ground	10		90.8	71.9	81.0		12.1	-11.3
M1	20	NC1-Past fall leaves	10		114.7	86.7	81.0		41.5	7.1
M2	51	NC1-Compost1 5-6 mo								
M2	11	NC1–Medina R-1 leaf								
M2	31	NC1-Yardwaste 1 mo								
M2	21	NC1-Past fall leaves								
M2	61	NC1-Compost2 7-10 mo								
M2	41	NC1-Compost 5-6mo								
M2	91	NC1-Compost 5 10-12 mo								
M2	96	NC1-Overs from Screenings (10)								
M2	81	NC1-Compost4 11-12 mo								
M2	71	NC1-Compost3 7-18 mo								
M2	12	NC1–Final (11)								
M3	32	NC1-Compost 1 mo (5)	1	109.5	86.2	60.8	81.0	35.2	6.5	-25.0
M3	52	NC1-Compost 5-6 month(4)	1	94.3	78.6	68.4	81.0	16.4	-3.0	-15.6
M3	92	NC1-Compost 10-12 month (1)								
M3	93	NC1-Final Product (3)	1	113.1	91.8	84.5	81.0	39.7	13.3	4.3
M3	97	NC1-Overs from Screening (2)								
MA1	10	SE-Ground (1yr old-Sample1)								
MA1	20	SE-Final(2-5yr)(Sample 1)								
MA1	12	SE-Ground (Sample3 from the top)								
R1	10	SW-Ground (5 yr, unscreened)								
R1	20	SW-Ground (1 yr unscreened)								
R1	30	SW-Ground (<1 mo,unscreened)	5	141.4	86.8	175.4	162.0	-12.7	-46.4	8.3
R1	40	SW-Ground (5yr, screened)								
R1	50	SW-Ground (1 yr, screened)								
R1	60	SW-Grindings/Overs								
R1	70	SW-Unground Yardwaste								
R2	11	SW-Ground (1 month,screened)	5	139.2		294.8	162.0	-14.1		82.0
R2	21	SW-Ground freshly(unscreened)								
R2	31	SW-Ground (5 years old)								
R2	41	SW-Ground (4 years)								
R2	51	SW-Ground (1 month)	5	175.6		299.5	162.0	8.4		84.9
R2	61	SW-Unground Yardwaste	5			436.8	162.0			169.6
R3	12	SW-Mulch (1 month)								
R3	22	SW-Screened (5 years)								
R3	32	SW-4" Ground (2months old)	5	225.6	103.9	40.7	162.0	39.3	-35.9	-74.9
R3	42	SW-Ground 2" material (<1 month	5	225.7	89.3	45.0	162.0	39.3	-44.9	-72.2