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1. REPORT NUMBER	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER
FHWA/CA/TL-202/30		

4. TITLE AND SUBTITLE	5. REPORT DATE
The Use of Compost and Co-compost as a Primary Erosion Control Material	March 2001
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR	8. PERFORMING ORGANIZATION REPORT NO.
Claassen, V.P.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. WORK UNIT NUMBER
Soils and Biogeochemistry Section Department of Land, Air and Water Resources University of California, Davis One Shields Avenue Davis, CA 95616-8627	11. CONTRACT OR GRANT NUMBER 59A0100
12. SPONSORING AGENCY AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
California Department of Transportation 1120 N Street Sacramento, CA 95814	Final
	14. SPONSORING AGENCY CODE California Department of Transportation

15. SUPPLEMENTARY NOTES

in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. ABSTRACT

Revegetation plantings on newly constructed surfaces often fail because the organic- and nutrient-rich topsoil has been stripped away. Compost can be used to replace the organic matter and nutrients and can act as a surface mulch to protect against erosion, extreme temperatures and doughtiness. This study evaluates use of compost as a primary erosion control material. Examples of beneficial use of compost amendments for control of erosion at field sites are provided. A statewide survey of compost producers was undertaken to characterize the compost material that would be available for procurement and application to Caltrans projects. The yard waste composts are found to be beneficial, but variable in nutrient content. A long-term incubation experience showed that nitrogen (N) release rates change with time, and that extended curing after thermophilic composting increases N release rate. Long-term N release rates were in the range of the reference topsoils. Finely screened (< 9 mm) compost can be applied with hydroseeder equipment, but this application method benefits from addition of other structural material (straw, coarse wood fibers) to improve erosion control on barren slopes. The findings support the use of compost as a primary erosion control and soil amendment.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
compost, yard waste compost, co-compost, biosolids, revegetation, degraded soils, nitrogen, mineralizable nitrogen, soil organic matter	No restrictions. This document is available to the public from the National Technical Information Service, Springfield, Virginia

19. SECURITY CLASSIFICATION *(of this report)*	20. NUMBER OF PAGES	21. COST OF REPORT CHARGED
Unclassified	Unclassified	77

Reproduction of completed page authorized.

The Use of Compost and Co-Compost as a Primary Erosion Control Material

Final Report: March 2002
Research Technical Agreement # 59A0100

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Disclaimer

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Financial Disclosure Statement

This research was funded by the New Technology and Research Program of the State of California, Department of Transportation (Contract No. RTA 59A0100). The total Caltrans contract amount was $318,857.00. All of the results from this project are summarized in this report. Supplemental funding ($30,000) was provided by the California Integrated Waste Management Control Board.

Implementation Statement

Information from this research activity will be disseminated through distribution of copies of this report, through presentations to technical and general conferences, workshops and through published journal articles and through the Caltrans Publications Unit. Further details are included in Chapter 5, Conclusions, Recommendations and Implementation.

Summary

Revegetation plantings on newly constructed surfaces often fail because the organic- and nutrient-rich topsoil has been stripped away. Compost can be used to replace the organic matter and nutrients and can act as a surface mulch to protect against erosion, extreme temperatures and doughtiness. This study evaluates use of compost as a primary erosion control material. Examples of beneficial use of compost amendments for control of erosion at field sites are provided. A statewide survey of compost producers was undertaken to characterize the compost material that would be available for procurement and application to Caltrans projects. The yard waste composts are found to be beneficial, but variable in nutrient content. A long-term incubation experience showed that nitrogen (N) release rates change with time, and that extended curing after thermophilic composting increases N release rate. Long-term N release rates were in the range of the reference topsoils. Finely screened (< 9 mm) compost can be applied with hydroseeder equipment, but this application method benefits from addition of other structural material (straw, coarse wood fibers) to improve erosion control on barren slopes. The findings support the use of compost as a primary erosion control and soil amendment.

Acknowledgements

Partial funding ($30,000) was provided by the Integrated Waste Management Control Board. Pat Paswater and Betty Wong provided helpful advice during preparation of the interim report. This research was facilitated by John Haynes, Caltrans research administrator. Harlow Landphair and Jett McFalls, Texas Transportation Institute were also very helpful in facilitating the field trials. Jan Carey and Shelley Munn provided lab assistance, soil analysis and numerical compilation. The assistance of many compost producers throughout the state is appreciated.

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Chapter 1. Introduction

On a typical highway project, earthwork normally starts by scraping the ground surface, then transporting the material and placing it where fill or embankments are needed. The first layer to be excavated, usually the topsoil, is often placed at the bottom of the fill. The last layer excavated is left exposed on the final grade surface. This process results in the placement of the nutrient- and organic matter-rich topsoil at depths that are inaccessible to plant roots. Erosion control and landscaping plantings must be established in the exposed parent materials remaining at the final graded surface. The exposed geological parent material is usually a suboptimal planting medium because it is low in organic matter and often has plant nutrient imbalances (Bradshaw and Chadwick, 1980; Claassen and Zasoski, 1994, 1995).

Soil organic matter is an important constituent of natural soils because it holds the soil particles in an aggregated state, improving water infiltration and retention. Soil organic matter also supports a large and diverse microbial population that is critical to nutrient cycling. The organic matter also retains nutrients that weather out of the minerals and accumulate from plant growth and decay. In particular, the soil organic matter provides organic and mineral nitrogen (N), which is the most commonly deficient plant nutrient on disturbed soils (Bradshaw and Chadwick, 1980).

Because undisturbed soils contain large accumulations of humified soil organic matter, similar large inputs are expected to be required in order to regenerate soil function on drastically disturbed sites that have been depleted of organic matter. A second critical condition, however, is that N must be released very slowly from the organic matter in order to prevent excessive weed growth and N losses from leaching. This is especially true given the large amounts of organic amendments may be applied. Municipal yard waste compost is a potentially appropriate material for this type of application. Yard waste composts are abundantly produced within California, and preliminary data indicates that these materials have very slow release rates from their organic N fractions.

In addition, there is an environmental and social benefit derived from using these waste-stream materials for erosion control within the state. In an attempt to divert municipal yard waste from filling scarce landfill resources, the California legislature passed AB939, which required communities to reduce the volume of waste going to

landfills by 50 % by the year 2000. The cogeneration power industry had been consuming a large percentage of the organic wastes, but at the same time as AB 939 was in process, the mandate for co-generation lapsed and the utilities did not renew their contracts for the waste generated power. These two events left a glut of organic materials needing disposal. Composting became the most economical method of reducing the volume of these materials, since the composting process can reduce the volume of the organic waste stream by 50%. As a result, compost has become very readily available and is cost effective to use for erosion control, landscaping and revegetation projects. Because of this potential for use, a systematic evaluation of compost materials available around the state was needed.

The objective of the project presented here is to evaluate the potential for use of municipal yard waste compost (YWC) as a primary erosion control mulch and soil amendment material, providing a method to regenerate the soil organic matter lost from the soil during disturbance.

A. Literature review of erosion control effects in field compost applications

Use of composts on erosive decomposed granite field sites

Decomposed granite (DG) materials common to the Sierra Nevada and other locations in California represent some of the most erosive types of weathered geological materials (André and Anderson, 1961). The combination of high surface area from sand sized particles and low clay content reduces soil coherence and aggregation and allows increased particle transport. Field studies of 20 square meter plots on fill slopes as steep as 70% in the Idaho batholith indicate that bare plots can produce 3.4 metric tons/km^2 per day from bare plots, with rates up to 23,160 metric tons/km^2 reported for the first year after construction (Megahan, 1974). Erosion losses from the steep fluted sides of gullies was predominantly from raindrop impact on similar dispersed, hardsetting DG soils in studied in New South Wales (Crouch, 1990). Soil losses averaged 19.8 mm depth per year on areas without overland flow.

A protective mulch would eliminate much of this transported sediment from the watershed. The combination effect of mulches plus revegetation seeding or planting gave the greatest reduction in erosion on DG materials in Idaho (Megahan, et al., 1992). Although erosion processes during the first year after construction primarily involved

mass wasting and slumping, subsequent years were entirely surface erosion processes such as rilling, raindrop impact and splash detachment and dry creep (Megahan et al., 1992), all of which are effectively treated with mulch covers.

Erosion rates were reduced by 44 % with tree planting and 95 % with straw mulching (Megahan, 1977). Dry creep accounted for 15 to 40 % of the total annual erosion, and was increased by wind. The particle sizes of the eroded DG materials decreased through the summer months and increased rapidly in fall. Soils may have been partially crusted during summer, contributing to this variation in particle size of sediments. With the commencement of freezing and thawing cycles, unconsolidated sediments develop vertical segregation, with upper layers becoming more coarse than underlying layers (Corte, 1961).

When soils are compacted during disturbance, treatment by ripping improves hydraulic conductivity and reduces surface runoff and erosion (Luce, 1997). This type of physical treatment may not restore the natural hydraulic conductivity of an undisturbed slope, however, because the pores formed may not be continuous or may not persist through multiple soil saturation cycles such as with winter rains. Mulches protected the surface of a metamorphic material from sealing during rain events during this study, but did not prevent surface sealing of a granitic substrate. Water-stable aggregates, formed from organic matter and microbial residues, would help reduce the tendency to form surface seals and settling (subsidence and close packing) of the near-surface strata. Compost and mulch applications were recommended to preserve the open soil structure generated by ripping treatments (Luce, 1997).

An additional benefit of mulch cover is protection from wind erosion. Megahan (1978) observed significant wind-induced erosion on bare DG materials in the Idaho batholith. Wind tunnel tests indicated that soil surface roughness had little effect on reducing wind erosion of sandy soils (80 % of particles within 150 to 300 um), but that application of 5.6 ton/ha (5000 lb/ac) rates of garden and household waste compost (94 % less than 5 cm length) increased the threshold wind speed for starting of wind transport from 6 m/s to 12-14 m/s. Composts were slurried onto the soil in a hydroseed-like mix using 1 part compost to 4 parts water with continuous agitation and then dried before testing.

A compost application for erosion control on 30 % slopes in European vineyards utilized a 7.5 cm cover, which provided a 3-year service life. Water retention on the slope improved infiltration and sediment reduction exceeded yield standards for erosion

control blankets (Tietjen and Hart, 1969). Another European study reports that compost aged better in field conditions than straw or grape pomace mulch. Pomace materials washed away in overland flow while straw materials decomposed (Grill et al., 1989). Improved erosion control has been evaluated in several other European studies, usually involving a mixture of municipal and vineyard wastes as reviewed in W&H Pacific (1993).

Biosolids and MSW composts were applied as a mulch, improving revegetation in a five year study in study on highway rights-of-way in Tennessee. Reduced erosion and moderated soil temperatures are credited for improved response to seed and fertilizer compared to non-composted plots (study quoted in Storey *et al.*, 1995).

While many of the previously cited studies utilized mixed compost materials, including vineyard pomace and trimmings or municipal solid waste composts, several U.S. studies have emphasized use of composts made specifically from yard debris compost, as listed below.

Texas Transportation Institute field facility

Texas Transportation Institute's Hydraulics and Erosion Control Field Laboratory, affiliated with the Texas Department of Transportation and the Texas A&M University system, provides large, full scale experimental slopes for uniform testing of erosion control materials under field and controlled rainfall conditions. A study on compost application (Storey *et al.*, 1995) tested three materials on 1:3 slopes with both clay and sandy loam textured soils. Plot size was 6.1 m wide by 21.35 m downslope (1:3 slope plots). These materials included co-compost (mixed yard trimmings and municipal sewage sludge), shredded wood with polyacrylamide tackifier (6.75 kg/ha), and shredded wood with a hydrophilic colloid tackifier (56 kg/ha).

Treatments were amended with organic materials to a depth of 76 to 101 mm (3 to 4 in) over the plots. Soil textures on the plots were either clay or sandy loam (Storey *et al.*, 1995) to sandy clay. Slopes were constructed at 2:1 and 3:1 (run:rise) angles. Soils were seeded with a standard warm-season revegetation grass mix selected for the central Texas area. Vegetation establishment criteria were to achieve a minimum coverage of 80 percent for the clay soils and 70 percent for the sandy loam soils within 6 months of seeding. Simulated rainfall was used to test for sediment loss from the plots at rates representing 1-, 2-, and 5-year storm events. These rates were designed to model events within the Houston/Dallas/Austin region and are equivalent to 30.2 mm/hr (1.2 in/hr), 145.5 mm/hr (5.7 in/hr) and 183.6 mm/hr (7.2 in/hr) (Landphair and McFalls,

2000b). The erosion control objectives were that the treatment should protect the seed bed from a short-duration, 1-year return frequency event (99 percent probability of occurrence within a given year) within the first month after installation, from a 2-year return frequency event (50 percent probability) within the first 3 months following installation, and from a 5-year return frequency event (20 percent probability) within the first 6 months of installation. To be included in the Texas Department of Transportation-approved Material List for Standard Specification Item 169 (Soil Retention Blanket), the sediment loss had to be 0.34 kg/10 m^2 or less from the clay soils and 12.21 kg/10 m^2 or less from the sandy loam soils.

Sediment loss from the compost-amended plots during simulated rainfall tests was right at the cutoff level of 0.34 kg/10 m^2 from the clay plots and was an acceptable 3.88 kg/10 m^2 for the sandy loam plots (Storey et al., 1995). Vegetation cover was 99 percent on the clay and 92 percent on the sandy loam. The two tackified wood chip treatments produced 0.15 and 0.30 kg/10 m^2 sediment loss on the clay soil and 11.27 and 10.97 kg/10 m^2 sediment loss on the sandy loam. Vegetation establishment was around 50 percent for several of the tackified wood chip treatments, disallowing them from approval under Texas Department of Transportation standards. The fact that much of the vegetative cover established in the compost treatment came from weed seed, not the applied seed mix, points out the need for quality control in compost products. Costs for the compost were below the average cost of synthetic or organic blankets tested by the facility.

Portland Metro, Portland Oregon

The goal of a Portland Metro project was to demonstrate that yard trimmings compost can be used effectively to control nonpoint-source pollution (Ettlin and Stewart, 1993; Metro, 1994). The project used both "coarse" compost materials (containing chunks of wood and branches up to 152 mm [6 in] in length) and "medium" compost materials, the fraction remaining following screening of the coarse compost through a 16-mm (5/8-in) trommel. Leaf compost was collected from residential streets in the city of Portland.

Eight erosion control treatment plots were established at St. John's Landfill, Portland, OR, measuring 2.74 x 9.75 m (9 x 32 ft) on slopes of 34 percent (19 degrees). Surface runoff was directed onto plastic sheeting at the base of the slope and collected in barrels. Treatments included three compost treatments applied as 7.6 ± 2.5 cm (3 ± 1

in) surface mulch layers: 1) 15 cm (6 in) minus "coarse" mixed yard debris compost, 2) 1.6 cm (5/8 in) minus "medium" screenings of the same material, or 3) 1.6 cm (5/8 in) screened compost made from just leaf materials. In an additional treatment, the "medium" and "leaf litter" composts were also shaped into 45 cm high and 100 m wide berms (18 x 39 inches) to act as sediment control barriers. A sediment fence (Amoco 2122 fabric) and a hydromulch treatment (wood fiber/tackifier mixture; Silva-Fiber Plus, Weyerhaeuser Co. Tacoma, WA) were evaluated for sediment yield compared to an unamended control plot. The hydromulch was specified at 120 gal/ac of 36 – 48 lb of product per 100 gallons water, but on these field plots it was applied at an extra heavy rate by the contractor. During and after three storm events in March 1993, 364 samples were collected and tested for suspended solids, settleable solids, turbidity, total solids, metals, nitrate N, total N, and chemical oxygen demand. Total suspended solids is stated to be the most important single parameter to measure in evaluation of erosion control efficiency.

The untreated control and the sediment fence yielded the highest average total suspended solids (8442 and 6348 mg/L). The compost barrier and the coarse-screened compost yielded 562 and 436 mg/L. The "leaf litter" compost (7.6 cm blanket application) yielded 380 mg/L and the hydromulch treatment yielded 341 mg/L. The "medium" mixed yard debris compost blanket yielded the lowest total suspended solids for the test period, producing 147 mg/L. Other compost effects, such as metals adsorption and other water quality data are also evaluated. The need for high-quality, mature compost was noted.

Subsequent to this study, field plots were constructed in the Portland area utilizing compost as erosion control material. Objectives were to demonstrate use and to increase the market demand for yard trimmings compost materials. Three field sites were established on roadside, housing development, and mobile home park projects. All compost materials were applied to a depth of 76 to 102 mm (3 to 4 in). Materials were brought to the top of the slope by tractor bucket or backhoe. Materials were then spread by hand. The first site (Springwood Drive, Beaverton) had a 14-degree slope at the bottom and a 7.6 m (25-ft) slope length, and the slope drains into an existing wetland. At the second site (Marylhurst, Lake Oswego), slopes ranged from 0 to 30 degrees. The third site (McLoughlin Boulevard, Portland) contained two areas with slope angles of 35 degrees and slope lengths of 3 to 18.3 m (10 to 60 ft). A third area had a slope angle of

15 degrees and a slope length of 4.6 m (15 ft), and a fourth area had a 1- to 5-degree slope and a slope length of 48.8 m (160 ft).

Results from the three demonstration projects suggest the following beneficial uses from compost application. A thick compost layer can provide a surface covering for foot or vehicle traffic onto soils that are otherwise too muddy and wet to support traffic. A compost layer at the exit of a site will reduce mud tracking onto local streets and into storm drains. A 76-mm (3-in) layer of compost was found to be effective. One demonstration site coordinator suggested using a specification of a "minimum" of 3 inches. Compost screened to 38 mm (1½ in) or less is recommended for erosion control on steeper slopes. Slopes of up to 35 degrees were effectively treated. The compost layer should be extended over the top of the slope for 0.6 to 1 m (2 to 3 ft) at a 300- to 450-mm (12- to 18-in) depth to diffuse ponded water entering the top of the slope. Compost that has been screened to 19 mm (¾ in) or less is recommended for slopes that are to be landscaped. A moisture content of less than 25 percent makes application most efficient and enables the compost layer to readily adsorb larger amounts of rainfall immediately after application. Mature compost will function to release nutrients into the soil more readily than immature compost. Contaminants (plastic, glass, undecomposed plant material) detract from the aesthetic benefits of compost amendment. As a result of the study and field plots, members of several local governments incorporated the use of compost into their specifications.

Shredded brush studies

The use of shredded brush as erosion control mulch was reviewed by Texas Transportation Institute staff (Storey *et al.*, 1995). Shredded wood mulch provides physical benefits because it adsorbs rainfall energy, slows water flow over the surface, reduces crusting allowing increased infiltration, moderates soil temperature and wind speeds at the soil surface, and reduces evaporative loss of soil moisture. The carbon materials in the compost stimulate microbial activity, facilitate generation of water-stable aggregates, and provide a variety of microclimates for improved seed germination. Fiber lengths of 10 to 20 cm (4 to 8 in.) are stated to be adequate for loose straw, while wood fiber lengths for coarse compost mulches are about 7.6 cm (3 in), with application rates of 9 to 13.5 Mg/ha (8,000 to 12,000 lb/ac) for composts or 0.9 to 1.3 kg/m^2 for wood chips.

Caltrans tested surface mulch applications of composted mulch/chipped green waste in a study in District 3 (Sacramento area) and District 11 (San Diego area) (Pollock and Moreno, 1993). Mulch depths evaluated included 15, 30, and 45 cm (6, 12, and 15 in). The mulch layers did not completely control weeds, even at the 30 cm depth at the Sacramento (District 3) location, but in the San Diego trials (District 11) weed growth on the 30 cm deep mulch plots was suppressed. The shallower 15-cm depth plots had 50 to 60 % of the weed growth as the control plots, which were densely covered with weeds. A lag time between the start of rainfall and the moistening of the soil was observed, with a greater lag time associated with greater mulch depths. Pooling of water at the soil level killed some of the trees on the plots. Drainage and weed growth is somewhat dependent on the percent of fine materials in the compost. The best material of those used was stated to be that with uniform sized 6 mm (1/4 in) particles with fewer larger and smaller sized particles. At the San Diego site, illegal dumping of chipped material from private contractors increased as soon as chipped material for the project began to be delivered to the site. Wood waste chips were recommended to be less than 15 cm.

The most efficient method of application turned out to involve five or six workers and a single tractor with a front bucket. Using this combination, a field crew could place 80 to 100 cubic yards of compost per day. Larger crews increased potential for accidents because of crowding and reduced productivity because of worker inactivity. Bed widths of 10 m (30 feet) were able to be constructed with the most even depths. Use of larger equipment (articulated front loader) had the effect of incorporating soil into the compost during loading and moving, which increased weed growth the subsequent season.

Overall, plant growth was improved with mulch treatment, as a result of greater retained moisture, less extreme temperatures and improved soil conditions. The green waste compost was noted as providing little, if any nutrient benefit during the period of the study. The study period was noted as being too short to evaluate the long-term effects of compost mulch treatments on landscape plantings and soil chemistry.

Another study titled "Evaluation of Compost and Co-compost Materials for Highway Construction" was completed by Caltrans (Sollenberger, 1987) but the materials actually tested were at least 80 % municipal solid waste derived materials mixed with biosolids, not yard waste composts, as is the focus of the current study. No tests of erosion control effectiveness were made in this study.

Chapter 2. Survey of compost materials produced in California.

A. Statewide compost nutrient content analysis

Layout of Study

Composts from 22 California producers of yard waste compost (YWC) or co-composted materials (CCM) products were sampled in December 1998 and January 1999 for plant nutrient availability. The purpose of the sampling survey was not to check products against a quality standard, but to evaluate the range of material that would be available to Caltrans at a given point in time, should a revegetation project require YWC for use as a primary erosion control material or soil amendment. Cooperating producers are listed in Table 1.

Sampling and Analysis Methods

A standard sampling protocol was used for collection of material from each facility. Each producer identified their "finished" material that would potentially be shipped out to a large project. Four evenly spaced sampling locations were established around appropriate piles or windrows. A 4-liter (1.057-gal) volume was collected at each sampling point. Samples were collected at 1-m depths into the pile at a vertical height of about 1–3 m from the base of the pile. Temperatures were measured at each sampling point to characterize whether the pile was still active and generating heat or if it had cooled off. Samples from the surface of the pile were not collected because this zone made up relatively little of the volume of the pile and the material was more exposed to transient conditions such as leaching or drying.

One composite compost sample was created for each producer's material from the four individual samples and was submitted for commercial compost analysis (A91 compost evaluation, Soil and Plant Laboratory, Santa Clara, California). Following analysis, all data were averaged and compared by compost source material type (including yard waste materials compost, biosolids/green material co-compost, agricultural byproduct composts, or other sources).

Individual samples from each sampled bag were also tested at the UC Davis soils and revegetation lab for available nitrogen, since N is commonly limiting in drastically disturbed soils that need revegetation. Available N data were analyzed at three levels of detail: 1) by using one composite sample from each producer and then

Table 1. List of compost and co-compost producers, in alphabetical order, with compost source material listed at right. YWC: yard waste compost; CCM co-composted materials (biosolids bulked with yard waste and composted); AGC: agricultural materials compost. See Appendix C for a complete key to acronyms and abbreviations.

Producer	Source Material
1. Agri-Fuels, Inc., 24478 Road 140, Tulare, CA 93274	YWC
2. BFI Organics, Newby Island Composting Facility, 1601 Dixon Landing Rd., Milpitas, CA 95035	YWC
3. Brea Green Recycling, 1983 Valencia Ave., Brea, CA 92621	Uncomposted green materials
4. Cold Canyon Landfill, 2268 Carpenter Canyon Rd., San Luis Obispo, CA 93401	YWC
5. Community Recycling and Resource Recovery, 1261 N. Wheeler Ridge Rd., Lamont, CA 93241	CCM
6. Contra Costa Landscaping, P.O. Box 2069, Martinez, CA 94553	YWC
7. EKO Systems, Inc., 8100-100 Chino/Corona Rd., Corona, CA 91720	AGC
8. Foster Farms, 12997 West Highway 140, Livingston, CA 95334	AGC
9. Gilton Resource Recovery Transfer Station, 880 South McClure Rd., Modesto, CA 95354	YWC
10. Greenway Compost, 3210 Oceanside Blvd., Oceanside, CA 93056 (El Corazone)	YWC
11. Mt. Vernon Recycling Facility, City of Bakersfield, 2601 S. Mt. Vernon Ave., Bakersfield, CA 93309	YWC
12. New Era Farm Service, 23004 Rd 140, Tulare, CA 93274	AGC
13. North Valley Organic Recycling, P.O. Box 1159, Chico, CA 95927	YWC
14. Recyc, Inc., 114 Business Center Dr., Corona, CA 91720	YWC
15. Redding, City of, Transfer/Recycling Facility, 2255 Abernathy Ln., Redding, CA 96003	YWC
16. Sacramento, City of, Solid Waste Division, 20 28th St., Sacramento, CA 95814	YWC
17. San Diego, City of, Environ. Serv. Dept., 9601 Ridgehaven Court, Ste. 320, San Diego, CA 92123	YWC
18. San Joaquin Compost, 12321 Halloway Rd., Lost Hills, CA, 93249	CCM
19. Santa Rosa, City of, Laguna Treatment Plant, 4300 Llano Rd., Santa Rosa, CA 95407	CCM
20. Sonoma Compost, 550 Meacham Rd., Petaluma, CA 94952	YWC
21. Turlock, City of, 901 S. Walnut Rd., Turlock, CA 95380-5123	CCM
22. Upper Valley Disposal and Recycling, P.O. Box 382, 1285 Whitehall Ln., St. Helena, CA 94574	Grape pomace composts
23. Zanker Road Resource Mgmt., 705 Los Esteros Rd., San Jose, CA 95134	YWC

averaging by compost type (yard waste, biosolids or agricultural byproducts), or 2) by using averages of four collected samples from each producer, or 3) by using four subsamples within each of the four collected samples from each producer. This progressively more detailed level of analysis was used to indicate the source of variability within the compost N data set. For example, does the variation occur between producers (resulting from different producer methods or feedstock differences), or within one producer's material (pile to pile consistency), or within a single collected sample

(analytical consistency). Average values are presented in Table 3, and the confidence intervals for several typical ranges are presented as percentages of the mean. These can also be used as confidence intervals for estimating variation above and below the target field application rate.

Long-term N release patterns of soils and composts were evaluated in aerobic incubation columns (Stanford and Smith, 1972). Incubation columns were made from PVC pipe (20 cm high x 5 cm diameter) and were filled with various soil materials or compost mixtures. All columns were incubated at 30 °C in a humidified enclosure, with periodic leaching and analysis. Four reference soil materials were tested in the columns as 50:50 mixtures of field collected soil (< 6.5 mm) and clean quartz sand (to improve drainage and extraction). The six selected compost materials were mixed with very low organic matter, decomposed granite sand at a rate equivalent to 500 kg total N/ha, simulating a compost treatment to a barren DG site. The low, ambient N release from the DG matrix is subtracted from the graphed plots of the compost samples. Each treatment was replicated three times.

Reference soil materials were collected from two locations in northern California (Table 2) for comparison with N release rates from composts. Granitic soil samples were collected from the Luther Pass area, Hwy 89 in El Dorado county, mile post 2.5. The granite topsoil (labeled "GT") was collected from the 2-10 cm depth and is mapped as a Meeks very stony loamy coarse sand (sandy-skeletal, mixed Entic Cryumbrept) (Rogers, 1974). These sites are vegetated with Jeffrey pine (*Pinus jeffreyi*), mountain big sage (*Artemisia tridentata*), snowberry (*Symphoricarpos mollis*), mule's ears (*Wyethia mollis*) and California brome (*Bromus carinatus*). The granitic subsoil labeled "GS" was from an adjacent road cut area that supported a moderate vegetative cover of intermediate wheatgrass (*Elytrigia intermedia*) and lupine (*Lupinus* sp).

Sedimentary soil samples were collected in the Coast range in western Colusa county (State Route 20, mile post 8.6) at 300 m elevation. The sedimentary topsoil (labeled "ST") is mapped as a Contra Costa loam (fine, mixed, superactive, thermic, Mollic Haploxeralf) (Reed, 1999) collected from a plant community of dense perennial grass (*Nassella pulchra*) and scattered oaks (*Quercus kelloggii*). The sedimentary subsoil labeled "SS" was from a cutslope of weathered sandstone and siltstone that was very sparsely vegetated with scattered annual grasses (*Avena*, *Bromus*) and deerweed (*Lotus scoparius*). Compost materials were mixed into a matrix of decomposed granite

collected from Caltrans right-of-way near Emerald Bay, state highway 89, simulating a soil amendment on a harsh, DG revegetation site.

N mineralization rates of selected compost materials were compared to the rates of N release from the soil materials. Yard waste compost (YWC) 1 was composted according to EPA 503 regulations, but had minimal (< 60 day) processing time. YWC 2 was from a municipal facility with moderate (about 120 days) curing. The YWC 3 material was produced by a municipal facility, but had an atypically long (18 month) post-compost curing, due to a lack of demand for compost products during a wet year. YWC 4 was from a commercial facility that utilized about 100 days processing time (initial grinding to final product) but with frequent turning. YWC 2 and 3 were from locations in the Central Valley of California, and may have potentially greater proportions of green lawn clippings in the feedstock, while YWC 1 and 4 were from coast range locations with potentially greater proportions of shrubby or woody feedstocks. CCM A was from a conventional co-composted (biosolids and yard waste) outdoor, mixed pile process, while CCM B was an intensively composted material in a controlled climate facility that was monitored and mixed more frequently (several times per day).

Following incubation for various intervals of time, mineralized N was leached out of the columns and was collected by suction lysimeters (porous cylinders for extracting soil solutions). These lysimeters were located in a three cm bed of clean quartz sand at the bottom of the incubation column. Leaching solutions contained dilute (0.01 M) $CaCl_2$ and were used to displace exchangeable nitrate and ammonium ions from the soil (Stanford and Smith, 1972). Each leaching treatment was followed by application of a dilute nutrient solution (minus N) designed to replaced leached nutrients other than N. Leached columns were returned to the incubation chamber for the next incubation interval. Soluble ammonium and nitrate were measured using a continuous flow, conductimetric soluble N analyzer (Carlson, 1978, 1986) with reduction of nitrate to ammonium in a copper-coated zinc column.

All data from compost treatments are graphed using net N release values after the baseline values from the DG matrix were subtracted. The soils and the DG matrix columns are shown as absolute values of their N release amounts. Numerical results were evaluated for statistical significance by analysis of variance, with mean separation by least significant difference (Statistica software, Statsoft, Inc., Tulsa, OK).

Table 2a. Chemical and physical characteristics of soils and DG matrix used in incubation chambers.

sample	soil type	total C	total N	C/N	particle size (g / kg)		
	wildland soils	(g / kg)	(g / kg)		sand	silt	clay
GT	granitic topsoil	28.24	1.17	24.18	890	80	40
GS	granitic subsoil	2.53	0.15	16.46	910	60	40
ST	sedimentary topsoil	31.84	2.14	14.88	430	320	260
SS	sedimentary subsoil	2.77	0.39	7.07	470	220	320
DG	decomposed granite	2.44	0.12	20.31	941	57	2

Table 2b. Chemical and physical characteristics of yard waste composts and co-composts used in incubation chambers.

sample	compost type	total C	total N	C/N	dry bulk density kg / m^3 (lb / yd)
YWC 1	yard waste	313.19	17.04	18.38	237 (399)
YWC 2	yard waste	171.78	11.46	14.99	600 (1010)
YWC 3	yard waste	242.66	15.86	15.30	492 (828)
YWC 4	yard waste	201.73	13.77	14.65	408 (687)
	co-composts				
CCM A	biosolids / yard waste	143.74	15.77	9.12	630 (1060)
CCM B	Biosolids / yard waste	346.02	29.13	11.88	270 (455)

Results of commercial compost analysis

Fourteen of the 23 California facilities that were surveyed produced yard waste composts (YWC). Four facilities produced biosolids/green material co-composts (CCM). Three produced agricultural byproduct composts (AGC). Two materials were listed as "Other", including the Brea material, which was an uncomposted chipped green yard waste material, and the "Upper Valley" material, which was a grape pomace/prunings compost. This compost was very energy rich and was tested separately from the more typical yard waste composts. The 22 remaining compost materials were averaged by source material (Table 3).

General Chemical and Physical Characteristics

YWC materials had much lower salinity than either CCM or AGC (Table 3). Much of the nearly 32 dS/m salinity measured in AGC came from KCl or NaCl. The salinity of the CCM was about half (16 dS/m) of the AGC. YWC had the lowest average salinity at 9.4 dS/m. The pH of the AGC was also the highest at 8.7. The pH of YWC averaged 7.6 while the CCM was slightly under 7.0. Salt inputs from the AGC materials could be harmful if used in high amounts. The salts or pH levels of the YWC materials will not be detrimental to soil processes when applied to soils even when used in large amounts, unless used in very dry environments.

The AGC was somewhat finer in particle size than either the YWC or CCM, having virtually all the material measure less than 1/2 in. Two-thirds of the AGC also passed the 1-mm sieve, while approximately half of the YWC and approximately a third of the CCM was that fine. Coarse sized particles will improve infiltration by increasing the large pore size needed to imbibe water into the soil.

Macronutrient Contents

Total nitrogen was highest (1.9 percent) in the biosolids/yard waste co-composts (CCM) (Table 3). YWC and AGC were lower, with 1.2 and 1.3 percent N. The amount of this N that will mineralize (release) and become available for plant uptake depends on the available C. These assays only provided an estimate of the C:N ratio (lower right column, Table 3). A ratio of less than 20 is generally expected to indicate a material that will mineralize N, although this depends on the quality of the carbon components in the organic materials. The YWC had a C:N ratio of about 19, the CCM of about 12, and the AGC of about 10. Extractable (immediately available, solution N) did not follow this trend. CCM had by far the highest extractable N at over 3100 ppm, followed by AGC at 353 ppm and YWC at 142 ppm. While total N contents and extractable (short term) N contents were measured in these commercial analyses, the ability of the compost to supply medium and long-term N for plant growth is not measured by current conventional methods. Long-term incubation experiments used to estimate N release are described below.

Table 3. Summary table of characteristics by source material from 21 compost producers, excluding source materials that are not YWC, CCM, or AGC. YWC: yard waste compost, CCM: co-composted materials, AGC: agricultural compost. See Appendix C for complete key to acronyms and abbreviations. Analyses from Soil and Plant Laboratory, Inc., Santa Clara, CA (A91 Compost Evaluation).

Total Nutrient Contents and Other Characteristics

		Total nutrient contents												Other characteristics			
		% N	% P	% K	% Ca	% Mg	% Na	% S	ppm Cu	ppm Zn	ppm Mn	ppm Fe	ppm B	TEC	half sat%	pH	ECe
All materials																	
	X	1.4	0.6	0.9	2.3	0.6	0.2	49.9	123.6	263.8	356.3	15363	58.4	513.3	60.8	7.7	14.0
	s	0.4	0.6	0.6	0.7	0.2	0.1	50.5	89.0	168.4	136.3	7261	19.3	156.8	25.2	0.6	9.2
	CV	30.5	97.4	64.8	30.5	34.5	61.8	101.2	72.1	63.8	38.3	47	33.0	30.5	41.5	8.1	65.6
Yard waste composts (YWC)																	
	X	1.2	0.3	0.8	2.0	0.6	0.2	20.5	75.4	182.5	343.9	14874	58.4	485.6	64.1	7.7	9.4
	s	0.2	0.0	0.3	0.5	0.2	0.1	21.7	31.0	50.5	125.7	7351	13.4	88.3	22.0	0.3	4.4
	CV	17.8	18.2	30.1	23.3	29.0	50.9	106.1	41.2	27.7	36.6	49	23.0	18.2	34.3	3.5	46.4
Co-composted biosolids/green materials (CCM)																	
	X	1.9	1.5	0.4	2.6	0.5	0.2	96.4	261.5	536.8	283.8	18785	48.0	691.5	66.0	7.0	16.8
	s	0.6	0.5	0.1	0.6	0.1	0.0	33.4	43.6	190.5	92.5	8939	19.0	241.4	39.2	0.7	5.8
	CV	29.4	29.9	32.8	21.9	22.9	26.4	34.6	16.7	35.5	32.6	48	39.6	34.9	59.4	10.3	34.4
Agriculture byproducts composts (AGC)																	
	X	1.3	1.2	2.1	3.0	0.9	0.4	125.2	164.7	279.3	511.0	13082	72.3	405.0	38.7	8.7	31.9
	s	0.5	0.6	0.7	1.2	0.3	0.1	43.2	115.4	130.2	150.5	4819	38.8	145.4	7.0	0.4	5.3
	CV	38.7	55.0	33.8	41.0	31.8	32.8	34.5	70.1	46.6	29.4	37	53.6	35.9	18.2	4.7	16.7

Available Nutrient Levels

		NaCl extract					Bicarb extract	DTPA extract				Sat ext			Dil acid % Fe
		ppm NO_3-N	ppm NH_4-N	ppm K	ppm Ca	ppm Mg	ppm PO_4-P	ppm Cu	ppm Zn	ppm Mn	ppm Fe	ppm B	% ECe Na	meq/L Cl	
All materials															
	X	341.6	739.7	6587.0	4533.6	1436.6	493.8	17.0	78.6	72.8	265.6	2.7	29.3	53.4	0.4
	s	413.2	1239.6	2954.9	2366.1	432.0	526.3	23.2	45.0	39.7	203.0	2.3	27.3	44.4	0.4
	CV	121.0	167.6	44.9	52.2	30.1	106.6	136.0	57.2	54.6	76.4	84.2	93.0	83.1	103.4
Yard waste composts (YWC)															
	X	199.5	142.4	6752.2	4578.6	1514.9	277.4	6.4	56.1	77.0	234.6	2.0	18.7	43.4	0.2
	s	272.6	176.7	1497.8	1654.0	471.2	108.8	3.8	20.2	37.6	187.4	1.6	15.7	25.5	0.2
	CV	136.6	124.0	22.2	36.1	31.1	39.2	58.8	35.9	48.9	79.9	83.4	83.7	58.7	96.2
Co-composted biosolids/green materials (CCM)															
	X	950.8	3119.8	2898.5	6448.5	1426.5	729.5	36.1	131.5	53.0	361.0	2.3	25.5	27.8	0.9
	s	384.1	816.2	1094.7	3564.6	186.9	686.3	6.8	37.1	46.0	257.1	1.3	12.9	21.7	0.5
	CV	40.4	26.2	37.8	55.3	13.1	94.1	18.9	28.2	86.8	71.2	57.2	50.4	78.0	57.9
Agriculture byproducts composts (AGC)															
	X	192.7	353.3	10734	1770.3	1084.3	1189.3	41.1	112.7	79.3	283.3	6.9	83.8	134.2	0.3
	s	293.9	337.8	4211.1	585.5	375.6	906.6	53.2	68.1	49.2	243.5	1.3	17.9	54.5	0.3
	CV	152.5	95.6	39.2	33.1	34.6	76.2	129.4	60.5	62.0	86.0	19.2	21.4	40.6	100.4

Physical Characteristics

				These analyses on 1/2" minus material													
		% Overs, 1"	% Overs, 1/2"	Bulk density, lb/cu yd	Moisture content, %	Water, lb/cu yd	Dry matter, lb/cu yd	Organic fraction, lb/cu yd	Mineral fraction, lb/cu yd	Organic %	% of material passing screen size listed (mm)						C:N ratio
											9.51 mm	6.35 mm	4.75 mm	2.38 mm	1.00 mm	0.50 mm	
All materials																	
	X	0.0	1.4	1222.8	35.7	424.7	798.8	285.1	513.0	35.7	97.7	92.4	88.0	73.2	48.7	29.8	16.4
	s	0.0	1.3	271.4	11.1	134.2	263.7	54.9	261.7		2.7	6.9	8.9	13.0	13.9	12.6	5.9
	CV		89.6	22.2	31.0	31.6	33.0	19.2	51.0		2.8	7.5	10.1	17.8	28.6	42.2	35.7
Yard waste composts (YWC)																	
	X	0.0	1.5	1168.6	38.0	442.4	726.4	283.9	442.6	39.1	97.7	91.7	87.3	72.6	49.0	30.3	18.9
	s	0.0	1.3	254.8	9.2	146.3	189.6	21.8	194.6		2.3	6.4	7.7	9.3	10.5	11.2	5.3
	CV		84.7	21.8	24.2	33.1	26.1	7.7	44.0		2.4	7.0	8.9	12.8	21.5	37.0	28.0
Co-composted biosolids/green materials (CCM)																	
	X	0.0	2.0	1295.3	38.0	457.0	840.3	313.5	524.5	37.3	96.3	89.9	83.0	61.7	34.5	19.1	12.5
	s	0.0	1.3	343.8	15.0	87.6	406.1	52.2	378.7		4.3	9.4	11.7	15.3	15.8	13.9	3.6
	CV		65.7	26.5	39.4	19.2	48.3	16.6	72.2		4.5	10.4	14.1	24.8	45.7	73.2	29.1
Agriculture byproducts composts (AGC)																	
	X	0.0	0.2	1378.7	21.9	298.7	1081.7	253.0	826.7	23.4	100.0	98.7	97.7	91.3	65.8	42.1	10.3
	s	0.0	0.4	264.0	2.1	34.0	233.0	140.6	203.2		0.0	1.5	1.8	5.2	1.1	4.0	3.6
	CV		173.2	19.2	9.5	11.4	21.5	55.6	24.6		0.0	1.5	1.9	5.7	1.6	9.5	35.4

The variability of these N assays between producers within each source material group was moderate to high. Replicate soil samples may often have a coefficient of variation (CV) of about 20 percent. The corresponding CV for total N contents for YWC is about 18%, while the variability of CCM and AGC materials was much higher (29 and 38%). This suggests that total N values for YWC samples are reasonably consistent and can be used in general specifications requiring a given amount of total N from compost per unit area.

In contrast, the extractable N levels (N immediately available for plant growth) for YWC and AGC had CVs greater than 100 percent. A higher CV is expected from this soluble, readily changeable N pool, but this amount of variation makes specification of short-term plant available N for these materials unworkable.

Phosphorus (P) levels were 0.2 percent for YWC, 1.5 percent for CCM, and 1.1 percent for AGC. The high P level is typical for material containing biosolids. YWC had the lowest CV for total P (18 %) and individual samples can be expected to be similar to the average of these sample types.

Potassium (K) content was moderate (0.8 percent) in YWC and 0.4 percent in CCM materials. The AGC had much higher total K (2.1 percent), which contributes partly to the high salt content. Sodium (Na) was also over twice as high in the AGC as in the other two materials. Use of AGC materials on surface soils is not recommended because of salt and dispersion potentials.

Sulfur (S) content was much lower in YWC (20 meq/l) than CCM (96 meq/l) or AGC (125 meq/l).

Calcium (Ca) was similar in all source materials (2 to 3 percent). Magnesium (Mg) was twice as high in the AGC (0.9 percent) as in the CCM and YWC (0.5 to 0.6 percent).

Total copper (Cu) and zinc (Zn) were much lower than the legal limits cited for these metals in municipal solid waste compost in Minnesota and New York (Hegberg et al., 1991). Within the products sampled from California, total Cu and Zn in YWC were about a third of those in the CCM samples. Bioavailable metals were measured by the DTPA extracts, which generally followed the same trends as the total levels. Similarly, baseline data in the Santa Cruz Green Waste Demonstration Project (Buchanan and Grobe, 1977) showed little evidence for excessive contamination for metals under California Title 14 and US EPA 503 regulations.

Evaluation of compost variability within sampled California compost products

As mentioned in the previous section, the total N content data for YWC is expected to be consistent between individual compost type and actual compost product. Extractable N levels, however, had much greater variability, making this parameter difficult to specify. To evaluate the ability to characterize extractable N content from the calculated averages, we evaluated the pattern of variability of different sampling methods of YWC for extractable and total N.

Results of research lab N availability tests

Because composts vary with age and location, accurately estimating the N content is difficult. We analyzed several sampling methods to see how closely the average N content could be estimated from sample results. Averages calculated for *total* N show that the calculated average will be within 6.8 % of the calculated mean when using a confidence interval of 90 %. This is interpreted to indicate that the true mean is estimated to fall within 6.8 % of the sampled mean in 9 out of 10 analyses when using four samples per compost producer. If the confidence interval is relaxed to 80 % (sample mean is accurate 8 out of 10 times), the true mean is estimated to fall within 5.3 % of the calculated mean. If the confidence interval is relaxed to 67 %, the true mean is estimated to fall within 4.0 % of the calculated mean. This suggests that total N analyses, if replicated and averaged, will provide a numerical result that is between 4 and 7 % of the true mean, and that N analysis accurately represents N in the compost samples.

Using this same type of analysis, the variation in measured *extractable* N levels was also evaluated for three confidence intervals (90, 80, and 67 %). These data were also compared for: 1) variation within a general compost type, 2) variation within the product from each producer or 3) variation within each sample collected from each producer (Table 4). Using the 80 % confidence interval as an example, the measured extractable ammonium levels will vary within about 26 % of the estimated mean when all producers are included within the compost type. This is interpreted to mean that the actual compost sample or load delivered to the site would be within 26 % of the average for that compost type in 8 out of 10 times. When the variability within the four samples

taken from each producer is evaluated, the analysis results will vary within 20 % of the true mean. But when four subsamples are analyzed with each of the collected bags, the mean will vary only within about 3 % of the mean. This suggests that much more of the variation measured in extractable ammonium levels occurs between producers and within different parts of the pile at each producer, rather than within the volume sampled at each point (about 4 L). This suggests that replicated analysis is a representative indicator of that portion of the pile, but that different parts of the piles and different producers can vary about 20 to 25 % above and below the indicated mean. Estimation of ammonium yields in field situations should account for this variability.

The variability in extractable nitrate content has a somewhat different pattern. In this case, variation between producers is about twice that within a producer (between different piles at each producer) and variability between producers is about four times the variability within each collected sample volume. In both cases, variation in evaluation data would be improved by collecting a greater number of samples at each producer location, rather than by attempting more accurate sample analysis. These data indicate that extractable nitrate samples can predict the actual content within 29 % of the actual mean for each producer that is sampled and analyzed. If data from the general category of yard waste compost is used, the extractable nitrate will be within ± 67 % of the mean. Extractable nitrate is a more variable pool than extractable ammonium and is more difficult to evaluate. Analysis of the compost material from each producer before field amendment is the best way to evaluate the potential effects of a given compost amendment.

The pattern of variability in anaerobic mineralizable N differs from that of both extractable ammonium and nitrate. In this case, the variability between different parts of the piles at each individual producer is greater than the variability between producers. The reasons for this high pile-to-pile (within producer) variability are not known, but may include aspects of pile treatment at unique to each producer location, including unequal turning, exposure to the atmosphere, internal leaching, etc. Again, the composts vary less within the sampled 4 L volume at each point on the pile than between piles or producers.

Autoclaved / KCl extracted N availability methods were also tested to evaluate if they correlated with long-term N release data (next section). Increasing length of autoclaved time increased N yield (2 versus 6 versus 18 hour) but the relationship (coefficient of determination, r^2 = 0.75 to 0.81) and significance level (p = 0.10 to 0.13)

were moderate. None-the-less, the data were less variable than with other extractable N methods, suggesting that some chemical analysis of N yield potential may yet be developed. Further development of these tests is anticipated following improved organic matter fractionation methods.

The interpretations of these data are that total N in the compost delivered to the site can be expected to be within 4 to 6 % of the analyzed mean for YWC materials. Extractable (immediately available) N, however, may vary from 25 % to over 80 % of the analyzed mean, depending on N pool and confidence requirements. This wide range makes careful control of field applications difficult. Analysis of composited (subsampled and mixed) samples from the particular material selected for a site is more representative than using general averages. As demonstrated by the long-term incubation studies, however, the amount of N in these extractable fractions is small, meaning that variation in this parameter may not be important for field response. Total analysis is the most consistent analytical indicator among different compost types and producers, but this test provides no information on bioavailability.

Table 4. Variability in extractable N yield between type, producers and samples. Values are percent variation above or below the mean at different confidence intervals (C.I.). Means reported in mg N/kg compost except total N, which is in percent.

	extractable NH4			extractable NO3			anaerobic min. NH4			% total N		
% C.I.	90	80	67	90	80	67	90	80	67	90	80	67
mean	277.1			112.5			83.2			1.3		
% ± X type	33.2	25.8	19.5	86.4	67.3	50.9	57.6	44.9	33.9	6.8	5.3	4.0
% ± X prod	26.0	20.3	15.3	37.0	28.8	21.8	72.4	56.4	42.6			
% ± X bag	3.5	2.7	2.1	18.4	14.4	10.9	17.4	13.6	10.2			

	2 hour autoclave			6 hour autoclave			18 hour autoclave		
% C.I.	90	80	67	90	80	67	90	80	67
mean	308.3			437.1			636.2		
% ± X type	33.1	25.8	19.4	23.6	18.4	13.9	18.7	14.6	11.0
% ± X prod	20.4	15.9	12.0	12.7	9.9	7.5	8.3	6.5	4.9
% ± X bag	2.1	1.6	1.2	2.4	1.9	1.4	2.3	1.8	1.3

B. Long-term aerobic incubation

A primary reason for application of yard waste compost to field sites is to provide the long-term N release needed for plant establishment and growth on low-nutrient substrates. Measurement of N release rates in field situations is difficult because annual release rates are low (1 to 3 %) compared to yearly, seasonal and spatial variability (perhaps 20 %). This makes detection of small changes in N release difficult to measure in field situations. For this reason, N release rates of various compost materials were measured in controlled lab conditions rather than in the field, using reference soil materials for comparison. The aerobic incubation method was selected because it utilizes soil microbes to decompose organic matter and release N as opposed to the extraction methods discussed previously. Because the incubation chambers are moist and warm, they mineralize (release) N faster than in field plots. A rough estimate is that they are about three times faster than winter season release rates from plots in sandy substrates from the Central Valley of California near Merced (Claassen and Hogan, 1998).

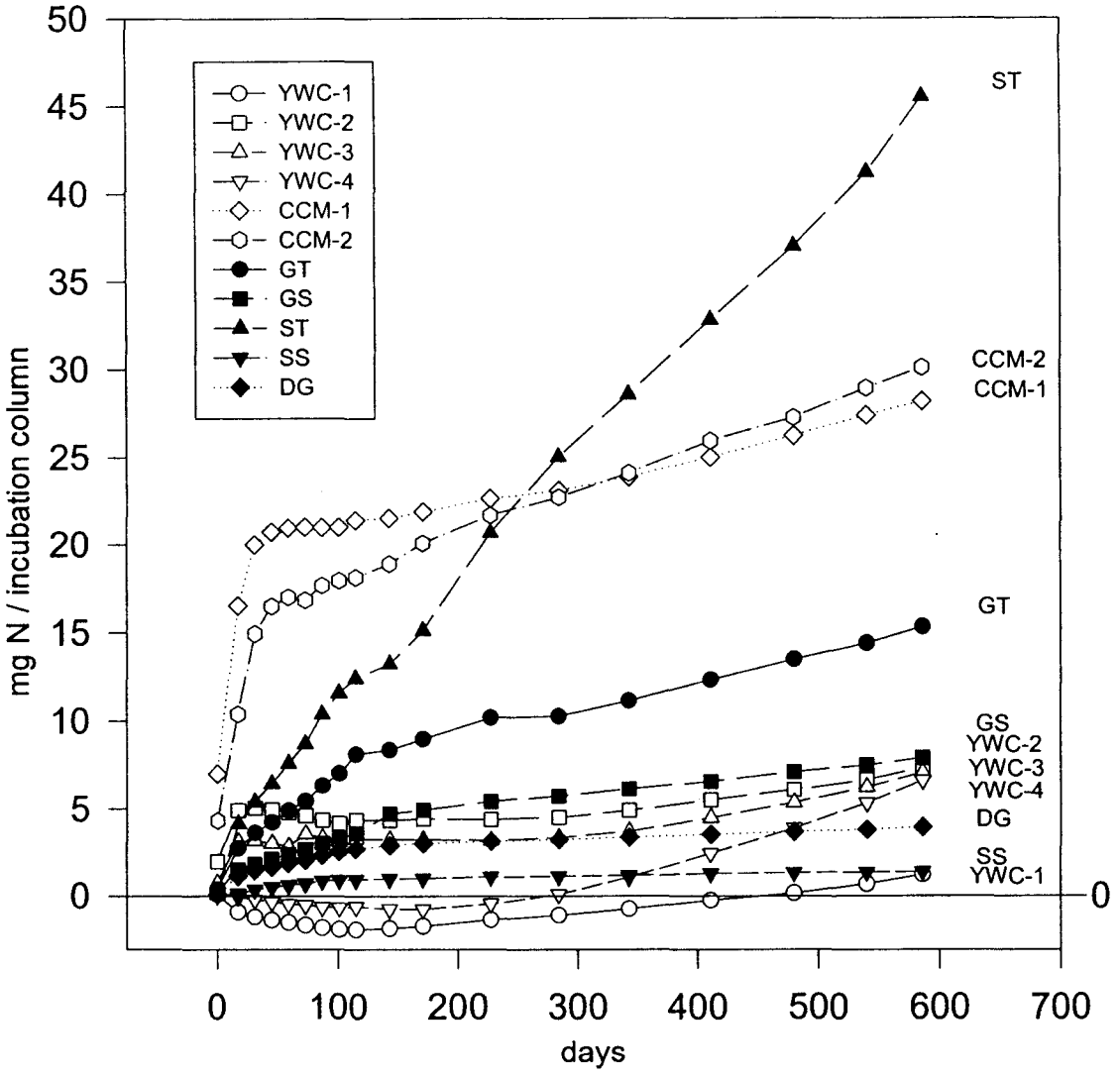
Overview of long-term incubation results

The N release patterns measured by long-term aerobic incubation of various yard waste composts differed widely even though they were all from the same general type of source material (Figure 1). Yard waste composts 2 and 3 provided a positive N release as soon as they were incorporated to the soil. Composts 1 and 4, however, required additional decomposition in the soil before net N mineralization occurred. These latter two materials were fibrous and had low dry bulk densities (data listed in Table 2). The initial period of negative N yield (immobilization) caused compost 1 to have the lowest cumulative N release of all compost materials and soils, while YWC 2, 3 and 4 had similar cumulative N yields at the end of the incubation period. The co-compost materials yielded about 4 times greater cumulative mineralized N than the yard waste composts. They released about twice as much N as the granite topsoil, but only about two thirds of the cumulative N release as the nutrient rich, sedimentary topsoil, given that the composts were loaded at 500 kg N/ha (approximately 36 Mg/ha dry weight compost, or about 45 cu yd/ac).

Long-term (cumulative) N release rates

The amount of N released from YWC materials, expressed as a percentage of the total N content, ranges from 6 to 7 % (except YWC 1 which was about 1 %). This is equivalent to about 35 kgN/ha, similar to the estimated N release rate of the granite subsoil. The DG matrix (as an example of a barren, unvegetated road cut) had an estimated N release (within the first several months) of 10 to 15 kg N/ha and almost none thereafter. The granite topsoil also released about 6 % of its total N, similar to the YWCs. This topsoil contains a much larger total N pool (1,140 kgN/ha to 15 cm, estimated 50 % coarse fragments), and the cumulative N release from incubation is also estimated to be larger, amounting to 73 kg N/ha. The sedimentary topsoil released about 12 % of its total N content (estimated at 2086 kg N/ha to 15 cm depth, estimated 50 % coarse fragments), and the cumulative incubation yield is calculated to be 224 kg N/ha. The very high release rate of the sedimentary topsoil may be a result of a combination of high microbial biomass populations and a clay-and organic matter-rich soil structure. The co-compost materials released about 27 % of their total N content, which (assuming a 500 kg total N loading rate) is equivalent to 135 kg N/ha.

These data suggest that a YWC amendment containing about 1000 kg total N (approximately 72 Mg/ha dry weight compost, or about 90 cu yd/ac, or approximately 1.7 cm (5/8 to 3/4 inch) thickness before incorporation) would provide cumulative N release amounts similar to the granite topsoil but still less than that of the sedimentary topsoil. While the total cumulative amounts are



Nitrogen yield (N mg) over a 540 day
aerobic incubation of soils and amended soils (minus control substrate).

Figure 1. Long-term aerobic incubation of soil and compost. Soil columns contain 100 % volumes from topsoils or subsoils (Tahoe or coast range) or decomposed granite matrix (Emerald Bay). The co-composted materials (CCM) or yard materials composts (YMC) contain enough organic material to equal a 500 kg total N/ha amendment. Note that these incubation columns are maintained at 30 °C which is approximately 3 times the biological activity measured in the San Joaquin valley (Merced area) during the winter growing season and mineralization curves for the Tahoe Basin will be considerably slower.

similar to the cumulative N release of the reference topsoils, the *rates* long-term, steady state release may be a better gauge of appropriate N release levels, as discussed in the next section.

Evaluation of the slope of the curves in Figure 1 shows that, although YWC 2, 3, and 4 have similar cumulative amounts of N release by the end of the incubation period, they have much different *rates* of N release per month during the latter (steady state) part of the incubation (Table 5). Long-term rates of N release were calculated as an average of the last five measurement intervals from 284 through 586 days. By this measure, YWC 4 provides N at long-term rates exceeding the other three yard waste composts as well as the granitic topsoil and one of the co-composts. Even though YWC 2, 3, and 4 provide the same cumulative N release, the rate of N release from compost 4 is over twice that of composts 2 and 3. These data suggest that amendment with YWC 1, 2, or 3 containing between 1.3 to 2 times the 500 kg total N/ha (650 to 1000 kg N/ha) would provide N release similar to the granite topsoil. Application with YWC 4 would match the long-term rate of N release with only a 400 kg total N/ha amendment.

Table 5. Rate of long-term (steady state) mineralizable N release from incubation columns (30°C), averaged for the last 302 days of incubation (day 284 to 586). Composts are loaded at 500 kg N/ha equivalent rate. Rates from soils are calculated on an area basis. The left data column lists micrograms of N mineralized per day of incubation per column. Means followed by different letters differ significantly ($p < 0.05$). The right hand data column lists the calculated amount of N yield per hectare per 30 day month during the final, steady state period of N release.

Incubation material	daily rate µgN/day	steady state rate kg N/ha month
Colusa subgrade	0.867 a	0.1
Decomposed granite control	2.363 a	0.4
Luther Pass subsoil	7.035 b	1.1
Yard Waste Compost 1	7.611 b	1.2
Yard Waste Compost 2	9.078 b,c	1.4
Yard Waste Compost 3	12.224 c	1.9
Luther Pass topsoil	16.366 d	2.5
Co-compost A	17.125 d	2.6
Yard Waste Compost 4	21.402 e	3.2
Co-compost B	24.995 e	3.8
Colusa topsoil	66.801 f	10.2

Whether these differences are attributed to feedstock, producer management, or season is not known at this time. Co-composts would provide long-term N release equivalent to the granite topsoil when applied at rates of 480 and 330 kg total N/ha. More effective prediction of behavior of composts is needed to fine tune use for revegetation performance. In the mean time, yard waste compost can be used effectively in a wide range of low-nutrient field situations, but plant cover and growth may vary with time and with compost source.

Short term (initial) N release rates.

Although the long-term N release rates tended to converge on similar values, the short-term N release rates of various yard waste composts showed two distinct patterns. This initial period is critical to plant establishment on field sites and the compost performance will be strongly influence planting success. During the initial 31 day period, composts 1 and 4 have negative release rates, resulting from immobilization of N into microbial biomass. This trend is interpreted as reflecting the process of decomposition of the fibrous materials contained in these particular composts. The immobilization phase appeared to withdraw between 1 and 6 kg N/ha from the soil during the first 31 days of incubation. A maximum withdrawal of 4 to 10 kg N/ha was estimated at about 150 days incubation.

An alternative plan for use of uncomposted, high-fiber or poorly cured composts that immobilize N is to amend the site, but to not plant for several additional months or until the next season. Seedlings would then not be exposed to the phytotoxicity that is sometimes produced during rapid decomposition, and the energy of decomposition would improve soil aggregate generation by increasing microbial activity. After the compost fully cures (several months to a season), the soil would be receptive for planting or natural colonization.

In contrast to the more fibrous or poorly cured materials, yard waste composts 2 and 3 show positive N mineralization rates immediately upon addition to the soil. These materials released a cumulative total equivalent to 25 and 16 kg N/ha during the first 31 days. The reference topsoils released N amounts equivalent to 18 and 27 kg N/ha during this period, although sieving and aggregate disruption may have increased N release values above ambient soil levels. Co-composts A and B had much greater

release rates of 76 and 102 kg N/ha during this initial period even though they were also loaded at the same 500 kg total N/ha rate as the yard waste composts. Caution should be exercised in application of biosolids-containing composts to field sites. Initial plant growth will be strongly influenced by this range in short-term available N, which varies from immobilization (removal of N from the ambient soils) with some of the yard waste composts, to abundant short-term available N released from the co-composted materials.

In general terms, the moderately to well cured YWC materials appear to work as surrogate topsoil amendments at least from the perspective of N availability. Most importantly, they appear to provide the combination of low N release rates (matching plant uptake rates) with large N contents typical of soil organic matter (to provide long-term release patterns). These characteristics are typically missing from drastically disturbed soils and cannot be provided with chemical fertilizer materials, even including current "slow-release" formulations. Given the variability measured for compost materials throughout the state, however, testing of individual compost materials is strongly recommended.

Summary of main points from long-term incubation experiments

1. YWCs and CCMs are appropriate amendments to replace slow release sources of N that were lost through topsoil removal. YWC provides the closest N release patterns to the granite topsoil. Co-composted materials have a greater long-term N release rate that may be appropriate for more rapid plant growth, but may also promote weedy invasion. Nitrogen release rates are equivalent to approximately 35 kg N/ha for YWC 2, 3, and 4 and approximately 135 kgN/ha for the co-composted biosolids, using a field loading rate of 500 kg total N/ha (approximately 36 Mg/ha, or about 45 cu yd/ac, or about 0.84 cm (3/8 inch) thickness before incorporation). Approximately double this rate provides cumulative N release rates similar to the granite topsoil.

2. YWC materials have variable initial N release amounts. YWC may either release N or immobilize (withdraw) N from the soil, depending on compost characteristics. Two yard waste composts had initial, one-month release rates of approximately 16 to 25 kg/ha, while two others immobilized 4 to 10 kg N/ha from the soil by incorporation into the microbial biomass. Extended curing after thermophilic composting reduces the chances

for immobilization. Co-composted materials release much greater initial, one-month N amounts than yard waste composts, ranging from 76 kg N/ha for a windrow processed material, to 102 kg N/ha for an intensive, automated process product. Because the incubation columns function faster than field soils, these initial release patterns are estimated to be equivalent to much of the first growing season of field application. Better compost evaluation methods are needed to predict compost behavior in field situations.

If mulches or organic materials are poorly composted, the rapid decomposition in the field can harm young seedlings. Thermophilic composting effectively eliminates this potential. The user should confirm that the producer achieved temperatures greater than 55 °C (131 °F) within the pile for 3 days during composting if the process is enclosed, or for 15 days if the process is a windrow (with least five turnings during the 55 °C phase), or for 3 days if the process is an aerated static pile. More information on compost is available at: http://esce.ucr.edu/WASTEMAN/CMJEAN~1.HTM

Advantages of application of uncomposted materials are that the energy of decomposition, including microbial activity and hyphal growth, are valuable processes in soil regeneration. This effect is likely to be expressed through improved water infiltration rates. Care must be taken to avoid pathogen transport, however. Uncomposted mulch materials should not be transported within or out of coastal counties infested with pine pitch canker. Specific information is available at: http://www.frap.cdf.ca.gov/pitch_canker/index.htm .

3. The long-term N release rates of all composted materials (YWC and CCM) become more similar to the release rates of soil materials after curing in the field for one or two field seasons. Following the initial release period, all composts were observed to complete curing and to begin to slowly release N appropriately for plant growth. Compost loading rates of between 500 and 1000 kg total N/ha would be expected to provide N release rates between that of the high elevation granitic subsoil and the high elevation granitic topsoil, but would still be lower than the fertile sedimentary reference topsoil.

4. Because of the low N contents and low rates of N release, YWCs incorporated into soils are not expected to leach N to local watersheds during rain or snowmelt events. Because most of the total N content is organically bound and is not soluble, little of the total N loaded onto the field sites is leachable. Therefore, large amounts of N in

composts can be loaded onto the site, replacing natural soil organic matter. This is an entirely different approach than amending with high rates of chemical fertilizers, which have much faster release rates, even for "slow release" chemical formulations. The greater release rates of CCM may allow some N leaching, especially if the soils are biologically inactive (sterile or cold) and if there is little other organic matter to decompose, such as mulches or plant litter.

5. Individual composts vary from the group average both between different producers and within an individual producer. Composts are best sampled by taking many samples around the prospective pile and mixing them well. A homogeneous composite (several subsamples mixed together) should be prepared and submitted for analysis.

While composts are shown to be able to replace the N release function of native soil organic matter, *the best method for revegetation is still to is to harvest, stockpile and reapply the native topsoil that was on the site before disturbance.* The quality of the organic matter is better, the harvested soil has better aggregate structure, the soil contains microbial inocula and site adapted plant seeds, and the costs are often less than regeneration of soil fertility from component parts. Extra steps may be needed to eliminate weeds, such as spraying, tillage or incorporation of topsoil beneath the surface. Harvest, stockpiling and reapplication of topsoil is usually the preferred choice for revegetation of disturbed sites.

Chapter 3. Field demonstration sites of compost use.

A. Brockway Summit, California State Highway 267, Placer County, California

In the fall of 1998 a compost demonstration was constructed directly south of Brockway Summit on State Highway 267 in Placer County, at the north end of the Lake Tahoe Basin. This project involved a long series of southwest-facing road cuts totaling 3.6 ha (9 ac), with 2:1 (horizontal:vertical) slope angles. The parent materials are volcanic mudflows that were cut to 5 to 8 m below the previous soil surface.

The existing erosion control specification for the site was modified to create three additional treatments designed to contrast the performance of various slope amendments. Each of four treatments (specified, zero control, compost, and compost plus specified) was repeated on three separate slopes (Table 6). The slope amendments were stable through the winter of 1998–1999 with only small areas of slippage. Plant growth was monitored in 2001 and 2002. Plant cover for these two years averaged 21 %. By 2002, no evidence of the previous plot locations was noted. Observation of these plots over several years suggested that even though N amendments were adequate for plant growth, the shallow rooting depths on the site limited plant growth probably as a function of very poor water availability. Based on this experience, subsequent field projects were planned using a comprehensive soil resource evaluation system that was developed to include a variety of soil characteristic measurement tests (including moisture and soil biology) in addition to nitrogen fertility.

B. Bullion Bend, U.S. Highway 50, El Dorado County, California

Bullion Bend (ELD 50, mile 32.2) is the location of a large spoil pile where mixed granitic and metasedimentary rocks from the Mill Creek landslide removal were stockpiled. The area is compacted due to the fine nature of the granitic materials from the landslide. Compost was applied to the entire area at a rate of 100 cubic meters/ha (1 cm (3/8 inch) depth). Next, fiber (300 kg/ha), grass seed (16 kg/ha), legume seed (6 kg/ha), and fertilizer (125 kg/ha 16-20-0) were applied, followed by straw for erosion

Table 6. Treatments applied to the Brockway Summit Compost Demonstration Project in Placer County, State Highway 267.

Treatment Code	Application Number	Description
SPECIFIED	Application 1	600 kg/ha compost (Hydropost), 800 kg/ha organic soil amendment (Biosol), 150 kg/ha fiber, and seed materials
	Application 2	Pine needles to a depth of 2.5 cm
	Application 3	600 kg/ha compost (Hydropost), 400 kg/ha organic soil amendment (Biosol), 150 kg/ha fiber, and 140 kg/ha tackifier
ZERO CONTROL (omit Hydropost and Biosol)	Application 1	150 kg/ha fiber, and seed materials
	Application 2	Pine needles to a depth of 2.5 cm
	Application 3	150 kg/ha fiber and 140 kg/ha tackifier
COMPOST (replace Hydropost and Biosol with equivalent N amount from YWC)	Application 1	150 kg/ha fiber and seed materials
	Application 2	Pine needles to a depth of 2.5 cm
	Application 3	150 kg/ha fiber and 140 kg/ha tackifier
	Application 4	10 cu yd (approximately 9000 kg YWC/ha)
COMPOST + SPECIFIED (amend with both YWC and specified Hydropost, Biosol)	Application 1	600 kg/ha compost (Hydropost), 800 kg/ha organic soil amendment (Biosol), 150 kg/ha fiber, and seed materials
	Application 2	Pine needles to a depth of 2.5 cm
	Application 3	600 kg/ha compost (Hydropost), 400 kg/ha organic soil amendment (Biosol), 150 kg/ha fiber, and 140 kg/ha tackifier
	Application 4	10 cu yd (approximately 9000 kg YWC/ha)

control. A tackifier treatment (250 kg/ha solids) followed. Although the vegetation community was slow to establish, a mixture of planted species and weeds gradually developed. Although the whole site was uniformly seeded, the area in which compost had been stockpiled prior to application developed especially dense stands of planted species, with fewer weeds and more perennial grasses. In this area, approximately 5 to 8 cm of compost were left on the soil surface after application. Plant composition and ground cover on this area were contrasted with adjacent areas with thinner cover and invasive stands of yellow star thistle (Table 7). Much denser stands of *Elymus glaucus* were established on the area receiving the heavy compost overlay. Plant litter cover was actually visibly higher on the heavy compost areas, but the greater plant cover intercepted more of the transect hits, making the numerical result similar between the two areas. Nitrogen fixing plants (lotus and clover species) provided greater cover on the area with the lower compost rate, suggesting nitrogen limitations to plant growth. Further soil evaluation work is planned to identify the nutrient conditions associated this area of heavy compost application and favorable plant response on an otherwise uniformly seeded area.

Table 7. Percent cover at the Bullion Bend revegetation site by plant type, litter or bare ground. Results of six randomized 10-m transects measuring cover type at 20 cm intervals, recording the top-most layer. Bottom row contains *p* values for evaluating significant differences between the two rows in each column (normal compost application versus heavy compost overlay).

	plant type and % cover						
soil treatment (n = 6)	bare ground	plant litter	*Elymus glaucus* (Stanislaus 5000 Blue wildrye)	*Lotus purshianus* (Deer weed)	*Centaurea solstitialis* (Yellow starthistle)	*Trifolium hirtum* (Rose Clover)	*Festuca sp.* (Mokelumne)
normal compost rate	17.47	10.92	9.50	25.71	17.13	9.42	9.85
heavy compost overlay	0.30	10.62	76.71	9.37	0.00	2.39	0.61
p value	0.0004	0.8743	0.0000	0.0002	0.0004	0.0384	0.0010

Chapter 4. Texas Transportation Institute erosion control field trial

A field facility with full-scale slopes and simulated rainfall testing methodology was available for standardized testing of erosion control materials at the Texas Department of Transportation/Texas A & M University's Texas Transportation Institute. Previous tests had confirmed the ability of 76 to 101 mm thick surface applications of biosolids/chipped wood compost to provide effective erosion control (Storey et al., 1995). Based on these tests, the facility was again contracted to test a fine hydroseed applied compost in combination with straw or tackifier amendments (Landphair and McFalls, 2000b; and Appendix E of this document). Slopes were described as having sandy clay texture. Slope angles were either 2:1 (run:rise) with 15.2 m (50 foot) slope length or 3:1 slope angles with 21.3 m (70 foot) slope length.

Screened compost (7 mm; 1/4 inch minus) was hydroseeded in all treatments except the largest one, in which it was applied by hand and smoothed by raking. Appropriate treatments were tackified using psyllium-based materials at a rate of 112 kg/ha (100 lb/acre). Various combinations of compost, rice straw or cellulose fiber was used to develop contrasts for erosion control effectiveness. Rainfall intensities fit 1, 2, and 5, year design storms, providing rates equivalent to the most intense 10 minute period of precipitation. The 1 year storm received rainfall at the rate of 30.2 mm/hr, the 2 year storm at 145.5 mm/hr and the 5 year storm at 183.6 mm/hr. Sediment was collected in troughs at the bottom of the slope. Additional details are provided in Appendix E at the end of this document.

Treatments were designed to provide contrasts between different potential amendment combinations. For example, 4000 kg/ha screened compost was applied with and without 4000 kg/ha straw and at a 2000 kg/h compost rate plus 4000 kg/ha straw. Compost and cellulose fiber were applied at the 4000+1000 kg/ha rate and also at the 8000+2000 kg/ha rate. A 25,000 kg/ha compost rate was hand applied, which amounts to a coverage of 2.5 millimeters (0.1 inch) in thickness. All treatments received the same tackifier treatment.

The inclusion of straw or cellulose fiber improved erosion control on the 2:1 slopes at all but the lowest compost/fiber application rate. Sediment yields declined from 354 kg/ha to 177 - 213 kg/ha with higher compost, straw/fiber, tackifier combinations.

On the 3:1 slopes, the lowest sediment loss occurred with 4000 kg/ha compost and 4000 kg/ha straw plus tackifier (25.8 kg/ha rate).

The 8000 compost/2000 fiber, the 4000 compost/4000 straw and the 2000 compost/4000 straw treatments on the 2:1 sandy clay slopes qualified for TxDOT use on the basis of sediment control, but failed on vegetation establishment criteria. The same treatments plus the 4000 compost/1000 fiber also qualified for sediment control on the 3:1 sandy clay slopes, but also were rejected on the basis of vegetation establishment. The reason for poor stand establishment was not evaluated. In general, though, the results were less satisfactory than measured in previous studies utilizing 76 to 101 mm applications of whole compost, which produced a 38.8 kg/ha sediment loss. The increased sediment loss rate was attributed to the small particle size of the compost material.

Another variable is the geometry of the straw material used in the application. Another Caltrans sponsored study (Landphair and McFalls, 2000; URS Greiner Woodward Clyde, 2000) contrasted crimped or tacked straw compared to other materials. The erosion control effectiveness of the blanket materials was not duplicated in some applications of loose rice straw partly because the fibers in the blanket were processed and were more pliable, while the baled rice straw had thicker stem materials in it that bridged small gullies rather than conforming to the small scale contours of the site. With less straw-to-ground contact, surface erosion increased.

Chapter 5. Conclusions, Recommendations and Implementation

Conclusions and Recommendations

Examples from published literature have shown widespread use of composts to control erosion and improve soil conditions. Negative impacts are few. Large rates of YWC compost application have been shown to have low leaching rates, making them suitable for regenerating topsoil fertility and biological activity. Use of compost in erosion control applications increases soil organic content and increases microbial activity and populations, in contrast to chemical fertilizers, which do not. A thick compost layer can also improve access onto soft soils and can reduce tracking of mud onto local streets and into storm drains.

This study confirmed the nutrient benefits of compost application. Long-term improvements resulting from compost application can be expected, but short term results may be variable depending on compost characteristics. Considerable variability exists between producers and with different batches from a given producer. Evaluation of each product is needed before application to field sites. Better methods are needed for rapid evaluation of bioavailable nutrients in composts for use in field situations.

Conclusion # 1.

Long-term nitrogen release rates from most yard waste compost materials approached the N release rates of moderately fertile soils. Composts were shown to be able to regenerate the N availability characteristics of low-nutrient substrates that have been stripped of topsoil organic matter. Well cured composts and co-composts (biosolids blends) approached the N release rates of highly fertile soils. Compost application provides longer N release duration compared to chemical fertilizer and also provides organic materials for improved infiltration and microbial activity.

Recommendation # 1.

Because compost products and the soils that are to be revegetated vary in fertility and water availability, analysis of potential compost sources and soils at the site is strongly recommended before amendment. Even after adequate N fertility amendment, some sites may still support insufficient plant cover if water or other nutrient

deficiencies restrict plant growth. Improved soil and compost tests can guide selection of appropriate amendments to harsh and variable site conditions.

Plant available N on drastically disturbed sites (on which the majority of the topsoil and organic matter has been removed) can typically be regenerated with a 500 to 1000 kg N/ha application of typical, common yard waste compost. This N application rate is roughly equivalent to 36 to 72 Mg/ha dry weight of compost (32,143 to 64,286 lb/ac), or a volume of 85 to 170 m^3/ha (45 to 90 cu yd/ac), or a thickness of 0.84 to 1.7 cm (3/8" to 3/4"). This rate can be reduced for sites that are not as nutrient poor as drastically disturbed sites.

Conclusion # 2.

Several categories of composts require special consideration for best utilization in field situations to avoid negative impacts on field sites. Poorly composted or poorly cured materials will not be biologically stabilized and can have atypical effects. Information on checking compost processing is available at: http://esce.ucr.edu/WASTEMAN/CMJEAN~1.HTM and at http://www.tmecc.org/tmecc/ . Cautions regarding use of uncomposted materials, especially in coastal regions are found at http://www.frap.cdf.ca.gov/pitch_canker/index.htm .

Recommendation # 2.

A. Fibrous or poorly cured yard waste composts can have an initial period of N immobilization when high carbon materials are being decomposed. This period may last from several months to several years. Additional available N may need to be added to support plant growth N during this period.

B. Fibrous or poorly cured yard waste composts may benefit soils in other ways than just N availability. Composts are rich sources of other nutrients as well as organic materials that improve water infiltration into the soil and water retention within the soil. The continued decomposition of compost by soil microbes further helps build soil aggregates, which improve drainage and water retention. If weed seeds and pathogen propagules have been killed, uncured materials can be used as surface mulches, or incorporated if N immobilization is not a problem. Do not transport infested, uncomposted materials to uninfested areas.

C. Co-composted materials (biosolids blends) have much larger N release rates than yard waste composts. Co-composts should be used at about one half to one

quarter of the amount of yard waste compost or at sites with rapid plant growth to absorb the higher N release rates. Because of the slow rate of N release, most yard waste composts are expected to have small or non-existent potential to leach N to watercourses, even when using large amendment loadings.

D. Sites with residual fertility (topsoils not completely removed, or some soil material has been re-applied to the site) may not need compost amendment. Additional N may accelerate weed growth. Surface applied wood chip mulches may provide erosion control, microbial activity and mulch effects (temperature and evaporation protection) without the additional fertility of a compost material.

E. Non-composted materials may produce phytotoxic compounds during decomposition. Any unprocessed plant material amendments other than wood chips should be stabilized using US EPA regulation (40 CFR, Part 503c) thermophillic composting, which sterilizes against weed seed and pathogen propagules.

Conclusion # 3.

Compost may be applied by hydroseeder. This technique replaces the low-nutrient cellulose or wood fiber amendment with a higher nutrient material. Compost screened to 3/8 inch worked well in hydroseeders and did not plug the pump or nozzles.

Recommendation # 3.

Erosion control was excellent with whole compost surface amendments. Hydroseeded compost should be applied with straw in order to provide structural strength. A typical application sequence would be

A. Apply seed, 2000 kg compost/ha, 400-500 kg fiber/ha. (A 20-25 % fiber mixture is needed to create a pumpable slurry.

B. Apply 4 Mg/ha wheat or barley straw (3.5 Mg/ha rice straw) evenly.

C. Apply 3000 kg/ha straw, 600 kg/ha fiber, slow release fertilizer (if needed), and 200 – 300 kg tackifier.

Higher application rates of compost may be more economically amended by dry application methods.

Conclusion # 4.

Compost materials are variable from producer to producer. Variability in source material, processing method and curing time have significant effects on field performance. Current short-term compost evaluation methods do not correlate to long-term incubation N yields. Prediction of compost N release in the field using rapid lab evaluation methods is not currently possible. Total N levels in YWC are consistent, however.

Recommendation # 4. Additional work needs to be done to improve and speed up evaluation of compost materials and prediction of N release behavior in field conditions. Until better site by site analysis is available, an interim recommendation is to apply in the range of 72 Mg/ha (dry weight) compost to extremely low-nutrient sites and in the range of 36 Mg/ha compost to low- or moderate- nutrient sites, or sites with shallow soils. Incorporate into the top 15 cm if possible. The compost material should be moderately to well cured, meaning 3 to 6 months curing after the thermophillic compost process is complete. If poorly cured yard waste compost is used, supplemental N may be needed to support plant growth. Recognizing the variability of compost N release behavior, the site should be monitored to detect if plant growth is too slow so that supplemental N can be applied if needed.

Implementation

Results of this study have been incorporated into Caltrans erosion control practices. Nearly all current projects use compost amendments.

Results have been presented to national professional meetings (Soil Science Society of America, High Altitude Working Group, International Erosion Control Association), and to workshops presented for the Society of Ecological Restoration. An interim report was posted on the California Integrated Waste Management Board website at:

http://www.ciwmb.ca.gov/Organics/Pubs.htm, Compost Demonstration Project, Placer County: Use of Compost and Co-Compost as a Primary Erosion Control Material, select publication # 443 99 018.

The results of this study will be used to continue to refine Caltrans erosion control specifications and compost evaluation.

This report will be disseminated through normal state and federal distribution channels. It will also be distributed to all district Landscape Architecture and Environmental offices. Copies of the report will be made available for purchase from Caltrans Publications Unit. Press releases will be sent to trade and professional journals to advertise the availability of this report.

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Appendix A: Tables 8–13

Laboratory Analysis of Compost Materials From Statewide Compost Survey

Table 8. Macronutrient concentrations of compost materials, by producer. See Appendix C for key to abbreviations and acronymns.

		Total Concentrations – Macronutrients						
Producer code #	Source	% N	% P	% K	% Ca	% Mg	% Na	% S
1	YWC	1.35	0.32	1.27	1.84	0.48	0.16	17.10
2	YWC	1.47	0.20	0.91	2.07	0.53	0.16	2.20
4	YWC	1.08	0.18	0.61	1.96	0.66	0.14	6.10
5	YWC	0.92	0.26	0.46	2.16	0.77	0.09	12.70
6	YWC	1.32	0.32	1.20	2.49	0.57	0.27	36.40
7	YWC	1.20	0.27	1.02	1.68	0.44	0.24	11.20
10	YWC	0.96	0.20	0.68	1.62	0.39	0.27	58.80
12	YWC	1.06	0.28	0.99	1.86	0.51	0.10	23.10
14	YWC	1.34	0.24	0.67	2.64	0.63	0.06	11.90
15	YWC	1.32	0.30	1.01	1.55	0.45	0.26	16.80
16	YWC	1.00	0.19	0.74	1.38	0.68	0.15	9.60
17	YWC	1.32	0.26	0.80	1.68	0.59	0.10	4.20
22	YWC	1.71	0.27	0.45	2.19	0.54	0.04	2.20
24	YWC	1.42	0.27	0.92	3.08	1.07	0.11	74.40
111	CCM	1.50	1.06	0.53	2.90	0.63	0.17	131.20
119	CCM	2.73	1.28	0.26	1.77	0.38	0.11	53.90
120	CCM	1.92	2.10	0.35	2.55	0.50	0.13	88.10
121	CCM	1.56	1.60	0.54	3.01	0.42	0.20	112.50
208	AGC	1.68	1.72	2.98	4.36	1.17	0.53	123.10
209	AGC	1.50	1.26	1.76	2.26	0.60	0.39	169.40
213	AGC	0.73	0.47	1.69	2.26	0.93	0.27	83.10
303	Other	0.89	0.14	0.62	1.53	0.37	0.16	14.30
323	Other	2.30	0.41	2.87	0.91	0.40	0.04	16.90

Table 9. Micronutrient concentrations and other chemical characteristics of compost materials, by producer. See Appendix C for key to abbreviations and acronymns.

		Total Concentrations – Micronutrients					Half sat %	Other Chemical Characteristics			
Producer code #	Source	ppm Cu	ppm Zn	ppm Mn	ppm Fe	ppm B		TEC	pH	Qual lime	ECe
1	GMC	128	226	249	11970	42	45	371	7.7	low	16.0
2	GMC	48	145	199	8057	48	116	513	7.9	low	5.1
4	GMC	56	135	459	20510	68	48	433	7.3	low	6.4
5	GMC	54	130	430	19620	67	50	481	7.2	low	7.6
6	GMC	119	287	277	14180	84	52	456	7.8	med	13.6
7	GMC	40	111	221	7853	45	91	456	7.4	none	6.3
10	GMC	106	239	340	36850	69	61	356	7.3	low	12.9
12	GMC	59	168	249	12440	64	38	398	7.7	med	13.8
14	GMC	85	191	383	12600	75	56	573	8.0	med	6.3
15	GMC	46	207	252	11040	49	62	572	8.0	low	14.0
16	GMC	41	127	248	12410	41	69	521	7.9	low	7.7
17	GMC	114	185	501	14350	46	62	487	7.6	low	5.5
22	GMC	71	181	629	9817	61	95	691	7.8	low	2.6
24	GMC	88	223	377	16540	59	52	490	7.5	med	13.8
111	CCM	290	490	288	30030	70	42	976	7.4	med	21.5
119	CCM	202	337	404	11770	37	112	673	6.7	low	9.3
120	CCM	256	795	180	11420	28	26	388	6.1	x	21.2
121	CCM	298	525	263	21920	57	84	729	7.7	low	15.2
208	AGC	154	379	636	17420	116	38	243	8.2	h	37.5
209	AGC	285	327	553	7895	42	46	448	8.9	low	31.2
213	AGC	55	132	344	13930	59	32	524	8.9	med	26.9
303	Other	51	116	185	10010	40	61	355	7.3	low	5.4
323	Other	33	38	120	4582	60	71	748	7.6	low	9.0

Table 10. Available nutrient concentrations, by producer. See Appendix C for key to abbreviations and acronymns.

		Available Nutrient Levels									
		NaCl extract					Bicarbonate extract	DTPA extract			
Producer code #	Source	ppm NO_3-N	ppm NH_4-N	ppm K	ppm Ca	ppm Mg	ppm PO_4-P	ppm Cu	ppm Zn	ppm Mn	ppm Fe
1	YWC	485	11	8434	3133	925	231	5.8	50.0	50.0	226.0
2	YWC	36	12	8444	3798	2174	358	6.0	62.0	94.0	198.0
4	YWC	40	197	5191	4005	1254	128	4.2	24.0	88.0	106.0
5	YWC	962	14	4541	5802	1787	209	7.8	48.0	50.0	204.0
6	YWC	25	248	8571	3168	860	218	16.2	98.0	64.0	364.0
7	YWC	27	10	7529	3294	1540	281	1.8	42.0	110.0	62.0
10	YWC	163	79	5784	3791	1147	86	12.4	94.0	32.0	754.0
12	YWC	476	360	7283	3478	698	278	3.4	54.0	36.0	140.0
14	YWC	84	616	6057	6057	1550	269	6.6	46.0	76.0	140.0
15	YWC	165	13	8369	4990	1582	524	5.4	58.0	56.0	172.0
16	YWC	25	94	6501	4323	1966	390	3.6	34.0	56.0	70.0
17	YWC	24	81	7012	3728	1784	336	5.4	62.0	170.0	156.0
22	YWC	263	19	3963	9263	2097	307	4.0	50.0	74.0	202.0
24	YWC	18	240	6852	5271	1845	268	7.6	64.0	122.0	490.0
111	CCM	793	3298	3750	10767	1344	200	43.2	176.0	46.0	664.0
119	CCM	1335	3904	2141	5376	1690	762	29.0	104.0	118.0	280.0
120	CCM	1187	1972	1781	2271	1414	1688	40.4	98.0	10.0	56.0
121	CCM	488	3305	3922	7380	1258	268	31.6	148.0	38.0	444.0
208	AGC	20	7	5902	2446	1206	650	17.0	152.0	54.0	564.0
209	AGC	26	682	12682	1453	1384	2236	102.0	152.0	136.0	158.0
213	AGC	532	371	13619	1412	663	682	4.2	34.0	48.0	128.0
303	Other	21	229	4983	2781	1191	105	1.2	32.0	68.0	74.0
323	Other	21	1180	22064	1317	1641	1089	1.6	18.0	86.0	148.0

Table 11. Available nutrient concentrations, by producer. See Appendix C for key to abbreviations and acronymns.

Producer code #	Source	Sat ext ppm B	Sat ext % ECe Na	Sat ext meq/L Cl	Dil acid % Fe
1	YWC	1.8	19.4	70.4	0.1
2	YWC	0.7	8.0	21.8	0.2
4	YWC	1.0	12.7	39.4	0.2
5	YWC	2.8	2.6	7.0	0.2
6	YWC	5.1	41.5	66.2	0.2
7	YWC	0.5	17.7	33.8	0.2
10	YWC	2.3	50.4	62.0	1.0
12	YWC	5.6	21.0	59.2	0.2
14	YWC	2.4	3.2	22.0	0.2
15	YWC	0.8	42.0	85.9	0.2
16	YWC	0.4	17.7	49.3	0.1
17	YWC	1.0	6.3	25.4	0.2
22	YWC	1.0	0.9	2.3	0.1
24	YWC	2.2	18.8	62.7	0.3
111	CCM	4.1	38.7	56.3	1.2
119	CCM	1.2	9.1	9.2	0.5
120	CCM	1.5	32.0	12.7	0.4
121	CCM	2.3	22.2	33.1	1.5
208	AGC	7.6	81.7	197.0	0.7
209	AGC	7.8	102.6	107.0	0.1
213	AGC	5.4	67.0	98.6	0.2
303	Other	0.6	11.3	24.6	0.2
323	Other	0.9	1.2	6.3	0.2

Table 12. Physical and chemical characteristics of compost materials, by producer. See Appendix C for key to abbreviations and acronymns.

				1/2" Minus Material							
Producer code #	Source	Wt retained 1"	Wt retained 1/2"	Bulk dens, lb/cu yd	Moisture %	Water fraction, lb/cu yd	Dry matter, lb/cu yd	Organic fraction, lb/cu yd	Mineral fraction, lb/cu yd	Organic fraction, %	C:N ratio
1	YWC	0	0	1506	33.6	506	1000	292	708	29.2	12.0
2	YWC	0	2.6	806	50.5	407	399	286	113	71.8	27.1
4	YWC	0	0.9	1094	24.1	264	830	283	547	34.7	17.5
5	YWC	0	3.4	1653	44.5	736	917	243	674	26.5	16.0
6	YWC	0	0.4	1166	35.6	415	751	277	474	36.9	15.5
7	YWC	0	4.5	797	40.5	323	474	285	190	60.0	27.8
10	YWC	0	1.5	1088	38.8	422	666	278	388	41.8	24.2
12	YWC	0	1.5	1370	26.4	362	1010	263	745	26.1	13.7
14	YWC	0	0.8	1241	33.3	413	828	343	485	41.4	17.2
15	YWC	0	0.5	1459	47.9	699	760	271	490	35.6	15.0
16	YWC	0	1.1	935	35.7	334	601	283	319	47.0	26.1
17	YWC	0	2.5	1017	32.4	330	687	283	404	41.2	17.3
22	YWC	0	1.2	1110	56.6	628	482	299	183	62.0	20.1
24	YWC	0	0.4	1119	31.7	355	764	288	476	37.7	14.7
111	CCM	0	0.3	1501	29.6	444	1060	311	746	29.4	10.9
119	CCM	0	2.2	1036	56.1	581	455	338	117	74.3	15.1
120	CCM	0	3.5	1671	22.5	376	1300	363	932	28.0	8.1
121	CCM	0	2	973	43.9	427	546	242	303	44.4	15.8
208	AGC	0	0	1438	20.7	298	1140	409	731	35.9	11.9
209	AGC	0	0	1090	24.3	265	825	136	689	16.5	6.1
213	AGC	0	0.7	1608	20.7	333	1280	214	1060	16.8	12.8
303	Other	0	0.7	891	13.7	122	769	303	466	39.4	24.6
323	Other	0	1	1043	43.8	457	586	491	95	83.8	20.2

Table 13. Physical characteristics of compost materials, by producer.

Producer code #	Source	% passing 9.51 mm	% passing 6.35 mm	% passing 4.75 mm	% passing 2.38 mm	% passing 1.00 mm	% passing 0.50 mm
1	YWC	98.9	97.1	94.9	83.4	61.7	41.7
2	YWC	92.7	84.7	78.1	64.2	43.1	24.1
4	YWC	100	96.9	92.3	76.2	53.8	36.2
5	YWC	98.6	93	88.8	69.9	34.3	11.2
6	YWC	100	100	96.6	84.3	54.9	33.8
7	YWC	98.6	93.7	86.7	72.7	52.4	35
10	YWC	96.9	86.6	81.9	65.4	42.5	26.8
12	YWC	100	96.1	91.5	82.4	64.1	45.8
14	YWC	96.6	93.9	91.6	76.5	53.1	34.6
15	YWC	96.2	77.9	70.2	50.4	25.2	8.4
16	YWC	97.3	86.3	82	71.6	54.6	40.4
17	YWC	98	87.2	81.8	65.5	44.6	29.7
22	YWC	93.6	90.9	88.2	72.7	46.4	19.1
24	YWC	100	100	97.5	80.8	55.8	37.5
111	CCM	100	98.9	96.3	82.5	57.1	39.2
119	CCM	92	81.8	72.7	46.6	21.6	8
120	CCM	100	97	89.3	62.4	32.9	17.1
121	CCM	93.1	81.8	73.6	55.3	26.4	11.9
208	AGC	100	98.9	98.9	94.7	66.8	44.2
209	AGC	100	100	98.6	93.8	66	37.5
213	AGC	100	97.1	95.6	85.3	64.7	44.6
303	Other	99.4	98.1	94.3	82.3	62.7	47.5
323	Other	100	99.2	98.4	49.2	34.7	23.4

Appendix B: Draft Specifications

Interim Caltrans Specification for Compost and Mulch

Compost shall be derived from green material consisting of chipped, shredded, or ground vegetation; clean, processed, recycled wood products; Class A, exceptional-quality biosolids composts, as required by U.S. EPA regulations (40 CFR, Part 503c); or a combination of green material and biosolids compost. The compost shall be processed or completed to reduce weed seeds, pathogens and deleterious material, and shall not contain paint, petroleum products, herbicides, fungicides, or other chemical residues that would be harmful to plant or animal life. Other deleterious material, plastic, glass, metal, or rocks shall not exceed 0.1 percent by weight or volume. (this strict limit works well for hydroseeded compost but may need to be relaxed for dry applied materials.)

A minimum internal temperature of 57°C shall be maintained for at least 15 continuous days during the composting process. The compost shall be thoroughly turned a minimum of five times during the composting process and shall go through a minimum 90-day curing period after the 15-day thermophilic composting process has been completed. Compost shall be screened through a maximum 6-mm screen if used for hydroseeding and a 3 inch screen if used as a soil amendment or as a surface mulch.

The moisture content of the compost used in hydroseed applications shall not exceed 35 percent. Compost products with a higher moisture content may be used, provided the weight of the compost is increased to equal the weight of the compost with a moisture content of 35 percent. Compost will be tested for maturity and stability with a Solvita test kit. The compost when screened to less than 1/2 inch shall measure a minimum of "6" on the maturity and stability scale.

Note: The screen size and the maturity/stability measurement may change, depending on the intended use of the compost.

Use of organics as mulch materials (surface application)

Effective use of compost as a primary erosion control material depends on several physical and chemical characteristics. Use as a mulch material requires sufficient coarse, persistent woody material so that physical effects persist for several seasons in field applications. To achieve these objectives, the amendment material should have a low proportion of fine particles so that plant growth within the mulch layer is restricted. A range of larger particle sizes helps the material interlock on the surface and resist removal by wind or water.

Mulch specification:

20-2.08 Mulch

Unless otherwise specified in the special provisions or shown on the plans, mulch shall consist of wood chips, tree bark, or shredded bark, or any combination thereof at the Contractor's option.

Mulch materials produced from pine trees grown in Alameda , Monterey, Santa Clara, Santa Cruz, San Luis Obispo or San Mateo Counties shall not be used.

Wood chips shall be manufactured from clean wood. The particle size of the chips shall be between 12 mm (1/2 in.) and 80 mm (3 in.) in length, and not less than 9 mm (3/8 in.) in width and 2 mm in thickness.

At least 85 percent, by volume, of wood chips shall confirm to the sizes specified.

Wood chips produced from tree trimmings which contain leaves or small twigs will not be accepted.

Tree bark shall have a particle size between 12 mm and 40 mm and shall be free of salt and foreign materials such as clods, coarse objects, sticks, rocks, weeds or weed seeds.

Shredded bark shall be a mixture of shredded bark and wood; shall have a particle size between 3 mm and 40 mm in thickness and 25 mm to 210 mm in length; and shall be free of salt and deleterious materials such as clods, coarse objects and rocks. At least 75 percent, by volume, of shredded bark shall conform to the sizes specified.

A Certificate of Compliance for mulch shall be furnished to the Engineer in conformance with the provisions in Section 6-1.07. "Certificates of Compliance."

If the priority for field amendment is to achieve a long lasting mulch for surface protection, then the materials can be more coarse and woody. Shredded bark is also good because it is very slow to decompose. Materials containing a high percentage of fine particles should be avoided because weed seeds can germinate within the fines of the mulch layer. If the amendment is intended to also function as a soil building amendment, then materials with dirt or tree trimmings with leaves and small twigs incorporated into it can be used, since these will increase the rate of decomposition. These materials should be thermophilically composted before use to kill weed seeds and pathogens.

(Para 2 was revised; Instructions for use of SSP and instructions for all paragraphs were revised.)

Use when applicable. Add to SSP 20-350.

If more than one type of mulch is required for the project, call out the types such as MULCH TYPE I and MULCH TYPE II. Assign a temporary 6-digit number with alpha character for the contract item codes.

Paras 1 thru 6, use when green material is to be used and delete Paras 7 thru 11.

Mulch (Green Material)

Mulch shall be woody material. Woody materials shall consist of chipped, shredded or ground green materials such as shrubs, tree trimmings or clean processed wood products.

2

Deleterious materials such as rocks, glass, plastics, metals, clods, weeds, weed seeds, coarse objects, sticks larger than the specified particle size, salts, paint, petroleum products, pesticides or other chemical residues that would be harmful to plant or animal life shall not exceed 0.1-percent of the mulch volume. Chipping shall include shredding, grinding or other methods used to reduce mulch materials to the specified size.

3. Use when processed materials are required. Processing green material is done to reduce pathogens and weed seed within the mulch, not to change the particle size of the mulch. Delete Para 4 when Para 3 is used.

Green materials shall be processed and have reached an internal temperature of 56°C for a minimum of 15 consecutive days. During the processing period, the green material shall have been turned a minimum of 5 times.

4. Use when additional processing of green materials is required. The additional 90-day curing process required for green material shown below is not readily available statewide. Use this Para with caution. A number of suppliers do not process the material to this extent or charge so much for the green material treated in this manner that there is no cost savings. Check with suppliers before using this Para. Delete Para 3 when Para 4 is used.

Green material shall be processed and have reached an internal temperature of 56°C for a minimum of 15 consecutive days. During the processing period, the green material shall have been turned a minimum of 5 times and shall have been cured for 90 days thereafter.

Paras 5 and 6, use only one of the Paras to specify the size of green material and delete the other Para.

5

Green material shall have a particle size conforming to the provisions for wood chips in Section 20-2.08, "Mulch," of the Standard Specifications.

6

Green material shall have a particle size conforming to the provisions for shredded bark in Section 20-2.08, "Mulch," of the Standard Specifications.

Appendix C: Acronyms and Abbreviations

ac .....acre
AGC .....agricultural byproducts compost (manure, feathermeal, bedding)
bicarb .....bicarbonate extract (Olsen test)
Ca.....calcium
CCM.....co-composted materials (biosolids/green materials compost)
CFR.....Code of Federal Regulations
cm .....centimeters
Cu.....copper
cu .....cubic
CV .....coefficient of variation [(s/X)* 100]
dil acid.....dilute acid extract
dS.....deciSiemens
DTPA.....diethylenetriamine pentaacetic acid
ECe .....electrical conductivity measured on a saturated extract
extract .....the procedure of estimating the nutrient content of materials by mixing it with
.....a specific solution and removing the solution for analysis
ft .....foot
ha .....hectare
half sat %..the half saturation percentage is the percentage of water equal to half of the
..... saturated capacity of the compost
in .....inch
K.....potassium
KCl .....potassium chloride
kg .....kilogram
l .....liter
m .....meter
meq .....millequivalent
Mg .....magnesium
mg .....milligram
mm .....millimeter
N.....nitrogen
Na.....sodium
NaCl .....sodium chloride
NH_4-N.....ammonium nitrogen
NO_3-N.....nitrate nitrogen
O .....oxygen
P.....phosphorus
pH.....negative log of hydrogen ion activity
PO_4-P .....phosphate phosphorus
ppm .....parts per million
S.....sulfur
s .....standard deviation
sat ext.....saturation extract
SO_4.....sulfate
TEC .....total exchangeable cations (measured on saturation extract)
X.....mean
YWC.....yard waste compost
yd .....yard
Zn .....zinc

Appendix D. Literature review of characterization methods for mulch or compost

Use of organic amendments as soil amendments

When composts are used as soil amendments rather than as surface mulches, the fine fractions become relatively more important than the coarse particles. This results because the surface areas of the fine fractions are very large and their adsorbed nutrient contents are more bioavailable or their compounds are more decomposable. Characteristics that improve the revegetation process include moderate, but sustained nutrient release, sustained microbial activity, increased CEC, and a lack of phytotoxicity. These effects are related to the source of the compost feedstock as well as the biomaturity of the compost material. Since this study focused on yardwaste composts, the main factor that influences the performance of the material when used as a soil amendment is variation in biomaturity of the material rather than feedstock. Because "maturity" has multiple contributing characteristics, however, the evaluation of the maturity is difficult to do, as described in the following paragraphs.

The process of composting involves the "biological conversion of organic wastes, under controlled conditions, into a hygienic, humus-rich, relatively biostable product that improves land and fertilizes plants." (Mather, 1991). As the compost is matured or cured, the decomposable fractions are degraded away and the residues that remain are not energy-rich enough to cause reheating or odor problems. Because it is a process, not an endpoint, it is difficult to judge when the compost is adequately finished.

Biostabilization is important because, alternatively, the material may merely be chemically stabilized by drying, liming or heating. In this case, the compost material still contains large proportions of very degradable material and under subsequent field conditions (neutralization of the lime, rewetting) it may again become very biologically active. Therefore, biostabilization, or biomaturity, is essential for safe amendment of soils using large volumes of composts. Several methods have been attempted to predict the biomaturity of "finished" compost materials. These methods and their limitations or shortcomings are also discussed below.

The ratio of total C to total N content (C:N ratios) has often been used to describe compost maturity as a relationship of the energy source that drives decomposition (carbon) to the nutrient content (nitrogen) that is either insufficient (slows decomposition)

or excessive (creates odor or leachate problems). Generally, C:N ratios in the low teens are held to be indicative of stable organic matter, partly because soil humus C:N ratios are commonly between 10 and 12 (Stevenson, 1994). As composts mature, the C:N ratio decreases as C materials are respired off and N is accumulated in residues. Using C:N ratios is problematic, though, because organic feedstock materials have different initial fractions of C and N, so the target C:N ratios may need to be adjusted for individual materials. Also, the C or N may be contained in biochemicals that differ in their resistance to decomposition. Lignin-rich materials may have high total C contents, but because much of the C is not available for decomposition, they may become "biomature" or "biostabilized" at C:N ratios of 20 or more, compared to 10 for more degradable materials. It is also possible that enzyme systems of soil microorganisms may be more efficient than those in compost pile microbial communities. A compost that is "finished" and is generally resistant to further decomposition in a pile (will not reheat) can be further decomposed by soil microbes in field situations. This suggests that a cured compost product from a producer whose biological activity has declined may undergo significant additional decomposition in a soil system. Mathur et al, pg 75 (1993) points out that "biostable" does not mean recalcitrant or non-biodegradable.

To evaluate the bioavailability of compost substrates, water extracts have been used and the ratio of C to N is suggested as a "bioavailable C:N ratio". In this process, water soluble materials are extracted, including amino acids, straight chain acids, peptides and sugars. Easily degradable molecules decline rapidly during the composting process while N-containing residues accumulate. C:N ratios of water extracts may be between 5 and 6 in mature composts. However, the same C:N ratio can also be obtained in mixtures that are not at all biomature, such as combinations of high carbon materials (sawdusts) with small amounts of biosolids, for example. Conversely, readily biodegradable organics that are in large particles may have to be commutated (shredded) usually by soil fauna before they have adequate surface area to be evaluated by this method. Particle size and susceptibility to biodegradation are conditions that need to be included in an estimate of compost decomposability or maturity based on solution extracts. An additional caveat is that not all water extractable compounds are biodegradable.

The ratio of ammonium to nitrate in the compost materials has also been used to judge compost maturity. Immature composts can initially accumulate large amounts of ammonium through decomposition of proteins and amino sugars. As the compost

matures, ammonium decreases and nitrate increases by the process of nitrification. Heavily leached piles may have depleted nitrate levels, while compost piles that are biochemically immature may not produce elevated ammonium levels because they are too dry, to salty, have inappropriate pH levels or other limitations to microbial growth.

Chromatographic techniques (blotting chemicals on filter paper) have been used to evaluate the extent to which smaller molecular weight humic substances formed during composting become polymerized into macromolecules, indicating compost maturation or curing. While the process is well documented to occur, the extent of polymerization varies with the amount and species of soluble metal cations, and with the residual clay content contained in the mineral fraction of the particular organic material (Schnitzer and Khan, 1972; Stevensen, 1982). Humic substance production also varies greatly with the quality of the carbon materials being composted. Lignin-rich materials tend to generate more humus than lignin-poor materials, so uniform target levels of humic-type macromolecules would vary with feedstock and metal or clay content as well as state of humic molecule formation. The process of tracking composts after they have been mixed with soils in field sites is further complicated by the addition of metals or clays from soil minerals.

One producer uses this method empirically. Compost is retained in the facility until the rubbed material stains the hand darkly with humic compounds and clays. The coarse particles are also observed to be entirely degraded into fine humic-rich materials

Various spectroscopic methods have been suggested to indicate the extent of humification of composts and therefore the degree of maturity. Evaluation of the ratio of large humic molecules to small humic molecules is interpreted by the absorbance of light at 465 nm wavelength versus the absorbance at 665 nm, the so-called E_4/E_6 ratio. Relative rates of polymerization are also detectable by the amount of carbon in fulvic acids (FA) versus humic acids (HA). These methods, along with NMR, yield additional information about compost humic fractions, but trends are variable enough that they are not useful as indicators of compost maturity for the wide variety of compost materials. In addition, the methods require technical equipment not available for routine evaluation.

More direct methods for evaluating the state of decomposition include analysis of the substrate itself, the activity of the microbes, or the rate of oxygen consumption by the active microbial biomass. Decomposable carbon molecules such as polysaccharides (building blocks of sugar, starch and cellulose) can be extractable by water or hot sulfuric acid. Early stages of composting are accompanied by reductions in sugars and

some fractions of cellulose, but at different rates depending on the size and purity of the organic particles.

Dinel et al., (1996a) showed that extractable lipids become more chemically homogenous and less biologically degradable during composting. The behavior of a range of different compost materials was tested using this extractable lipid indicator by (Dinel et al., 1996b). Concentration of soluble organic compounds decreased in all compost types as successively older compost materials were sampled. To evaluate the composts, various composts were extracted first with diethyl ether (DEE) for 20 hours and then with chloroform for an additional 20 hours using a Soxhlet apparatus (glass distillation column). The extracts were dried in rotary evaporators, dried and then weighed. The DEE solvent extracted lipids that are mainly low-molecular weight straight-chain and branched alkanes, alkenes and alkanoic acids (oils and organic acids) plus smaller amounts of phenolic and alkylaromatic compounds. The chloroform solvents extracted higher molecular weight paraffinic compounds, with fewer phenolic and aromatic compounds. Although the paraffinic extracts remained fairly constant with successively older materials (about 3 to 5 g/kg), the straight chain and organic acid extracts declined greatly after about 33 days of composting for all materials, often to less than a third of their peak values. As the easily degradable fractions decreased, the proportion of the paraffinic (waxy) fraction increased, and began to shield remaining substrate from microbial or enzymatic degradation. Composts judged as mature by a suite of tests (at 59 days) had paraffinic lipid contents that were 25 % of the total lipid content or greater.

An alternative method to measure the organic fractions but *excluding* the polysaccharides. This has been operationally defined as the organic material left after two acid digests. Differences in extraction efficiencies, along with the production of additional polysaccharides by microbes during the compost process made these indicators insensitive to the state of compost maturity, because of particle size constraints and shielding of decomposable substrates by resistant layers.

Microbial activity can be evaluated by CO_2 evolution, which declines as composts mature. The respiration rate per unit of organic material would seem to be a good indicator of maturity, but the process is complicated by non-biodegradable carbon containing compounds such as wood ash, plastic contaminants, or by respiration-limiting conditions such as lack of moisture, salts or extreme temperatures. Because CO_2 evolution integrates the surface area of particles, the ability of microbes to decompose

the organic substrates and the environmental conditions in the pile or field site, it has been commonly used as a fundamental method of indicating compost maturity.

Another chemical indicator of compost decomposition involves the material left after respiration has occurred, namely the oxidized state of the remaining residue. As microbial decomposition progresses, the oxidation state of the carbon residues increases, leading to an increase in cation exchange capacity (CEC) of the compost. Municipal composts started with a CEC of 40 meq/100 g initially and rose to 70 at 5 weeks composting and stabilized at 80 meq/100 g when mature. However, other studies showed mature composts had CEC values between 25 and 83 meq/100 g total dry weight. Using only an organic matter content as a basis, the various composts ranged between 32 and 63 meq/100g. Differences in organic matter quality were cited as one difference, along with different complexation reactions by metals that were not displaced with the CEC evaluation method.

Direct phytotoxicity tests or biochemical evaluation of short chain organic acid contents can indicate immature composts. Seeds of cress are used to test for germination within solutions extracted from compost materials. Care should be given to eliminate herbicides and salts as causes for reduced germination.

A critical test for suitability of compost application to degraded soils is whether the compost material will provide a slow, steady supply of N for regeneration of the plant/microbial community. While this process is strongly related to the previously discussed maturity indexes, it may be possible to be evaluated independently by a variety of soil N availability tests. An potential reason for better performance of N release in soils compared to characterization of maturity in composts is that a much longer time scale can be used. Since plant communities continue to sequester N in biomass for multiple seasons, the organic amendment has a long time to cure, and approach the typical 1 to 3 % annual N release as a proportion to the total N content.

Despite the many tests proposed for compost maturity, few were suggested to evaluate the potential for nutrient release in field situations. We used standard soil amendment tests for comparative purposes and established soil incubation tests for plant available N soil to evaluate the potential for N release from various compost materials.

Appendix E. Texas Transportation Institute report

Performance of Yard Waste Compost For Erosion Control and Vegetation Establishment

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Research Study Number 473400
Research Study Title:
The Use of Compost and Co-Compost
as a Primary Erosion Control Material

Sponsored by:
The University of California, Davis
And
California Department of Transportation

April 2000

TEXAS TRANSPORTATION INSTITUTE
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ABSTRACT

Erosion control capabilities and the soil building benefits of yard waste compost were tested at the Texas Transportation Institute (TTI) Hydraulics and Erosion Control Laboratory, in College Station, Texas. The California Department of Transportation (CalTrans), the University of California, Davis (UC Davis), and the Texas Transportation Institute (TTI) cooperated in the testing efforts.

Several application rates of yard waste compost and yard waste compost mixed with cellulose fiber mulch or straw for the purpose of erosion control and vegetation establishment were tested. All applications used a psyllium based organic tackifier as a binder. Two performance criteria were examined: 1) sediment reduction and 2) vegetative cover produced in a 9-month growing period.

The yard waste compost mixed with straw or cellulose fiber mulch performed better with respect to sediment reduction, with straw showing a slightly better performance. The vegetation establishment data was less conclusive. It appears that the heavier applications of yard compost did have better vegetation establishment properties even though sediment losses were somewhat higher than might have been expected.

Additional analysis of the tested vegetation litter, soil and compost materials will be performed by the University of California, Davis. These findings may further clarify performance of yard compost with respect to vegetation establishment.

INTRODUCTION

In a cooperative effort, the California Department of Transportation (CalTrans), the University of California, Davis (UC Davis), and the Texas Transportation Institute (TTI) performed a set of standard erosion control performance tests on yard waste compost at the TTI Hydraulics and Erosion Control Laboratory, in College Station, Texas. The test procedures, developed by the Texas Department of Transportation (TxDOT) and TTI, evaluate a material's ability to reduce the loss of sediment and assist in the establishment of permanent vegetative cover. Furthermore, these tests determine which products warrant inclusion on the TxDOT Approved Product List.

METHODS

Plot preparation, seeding, rainfall simulation, and vegetation measurements were made in accordance with the TTI Procedures and Evaluation Criteria for Erosion-Control Blankets, Flexible Channel Lining Materials, and Hydraulically-Applied Mulch Products. A copy of this document is provided in Appendix A.

Eleven plots were used for this study. All plots were sandy clay. A soil analysis is provided in Appendix B, page 13 of this report. Two groups of plots were used based on slopes of 1:2 and 1:3. The 1:2 plots dimensions were 20' wide x 50' long. The 1:3 plot dimensions were 20' wide x 70' long. To increase the number of repetitions, all plots were subdivided into two equal widths creating 10' test plots. This allowed more sampling of vegetation. However, the rainfall simulators could not be modified to fit a 10' plot width so sediment data had to be reported for 20' plots only.

The compost was applied hydraulically using a hydroseeder, except where noted "Dry Applied", which was delivered by wheelbarrows and raked into place.

MATERIALS

Mature yard waste compost was acquired from a local source. The Plant Analysis Report is provided in Appendix C, page 15 of this report. The compost was screened to a maximum size of ¼ inch (7mm). The tackifier used was a psyllium based organic material. Tackifier was applied at the rate of 100 pounds per acre (112.26 kg/hectare). Straw was rice straw acquired locally. Supplemental mulch was a cellulose fiber product.

APPLICATION RATES

The materials were applied at rates specified by UC Davis and CalTrans as follows:

2:1 Sand Plots
4000 kg/ha compost + tack
4000 kg/ha compost + 1000 kg/ha cellulose fiber + tack
2000 kg/ha compost + 4000 kg/ha straw + tack
4000 kg/ha compost + 4000 kg/ha straw + tack
8000 kg/ha compost + 2000 kg/ha cellulose fiber + tack
25000 kg/ha compost + tack "Dry applied"

3:1 Sand Plots
4000 kg/ha compost
4000 kg/ha compost + 1000 kg/ha cellulose fiber + tack
4000 kg/ha compost + 4000 kg/ha straw + tack
8000 kg/ha compost + 2000 kg/ha cellulose fiber + tack
25000 kg/ha compost + tack "Dry applied"

SOIL PREPARATION

Each of the test plots were cleared of vegetation, repaired, and brought back to uniform grade before installation. Each plot was fumigated with a soil sterilant as recommended by TxDOT. Immediately before installation, each plot was fine graded by hand-raking the surface.

SEEDING

Each plot was seeded according to the TxDOT Standard Specification, Item 164, *Seeding for Erosion Control.* This specification is broken down by TxDOT district. The laboratory is located in the Bryan District and therefore dictates use of the seed mix for warm-season perennial vegetation for rural roads with sandy soils.

All seeding is done hydraulically. For these tests, seed and mulch were applied in a two-step process, seeding first, followed by the compost application. The seed mixture included the following species.

- Bermudagrass 1.7 kg/ha
- Green Sprangletop 1.2 kg/ha
- Bahiagrass (Pensacola) 7.5 kg/ha

TEST PROCEDURES

Starting approximately two weeks after installation, each application was subjected to a series of six simulated rainfall events of increasing intensities. Each evaluation cycle consisted of two repetitions. Rainfall intensities were based on a ten minute storm for the most extreme conditions in Texas with a Type III rainfall distribution.

- 1- year Design Storm – 30.2 mm/hr (1.2 inches per hour)
- 2- year Design Storm – 145.5 mm/hr (5.7 inches per hour)
- 5- year Design Storm – 183.6 mm/hr (7.2 inches per hour)

The sediment generated by the six simulated rainfall events was collected, sampled, dried, and weighed. This sediment loss data was averaged for all events and reported in kilograms per 10 square meters.

The vegetative density was determined using the Vegetation Coverage Analysis Program (VeCAP), a computer program developed by TTI. VeCAP uses digital photography and computer masking technology to determine the amount of vegetation cover produced at the end of the evaluation cycle. This vegetation density was reported as the final percentage surface cover.

DATA

Tables 1 and 2 indicate the sediment loss and the percent vegetation cover for each of the application rates. Sediment loss is ranked from lowest to highest and vegetation is grouped from the most to the least cover. Plot designations beginning with SA have a 2:1 slope and those designated S have a 3:1 slope.

Table 1. Results Ranked by Sediment Loss

Plot	Treatment	Vegetation Cover (%)	Sediment Loss (Kg per 10 sm.)
	2:1 Sand		
SA15	2000 kg/ha compost + 4000 kg/ha straw + tack	55.77%	17.68
SA16	4000 kg/ha compost + 4000 kg/ha straw + tack	55.34%	20.96
SA17	8000 kg/ha compost + 2000 kg/ha cellulose fiber + tack	43.93%	21.31
SA18	25000 kg/ha compost + tack "Dry applied"	43.92%	29.61
SA14	4000 kg/ha compost + 1000 kg/ha cellulose fiber + tack	28.58%	29.72
SA13	4000 kg/ha compost + tack	22.53%	35.47
	3:1 Sand		
S13	4000 kg/ha compost + 4000 kg/ha straw + tack	38.18%	2.58
S12	4000 kg/ha compost + 1000 kg/ha cellulose fiber + tack	45.26%	7.82
S14	8000 kg/ha compost + 2000 kg/ha cellulose fiber + tack	33.14%	10.21
S11	4000 kg/ha compost	30.02%	18.83
S15	25000 kg/ha compost + tack "Dry applied"	54.06%	18.03

Results seem to suggest that erosion control potential is increased when compost is mixed with straw or cellulose fiber mulch. The combination of tack and compost alone does not seem to be sufficient to provide good erosion protection at these low application rates. Previous compost research studies that showed excellent erosion control protection were based on compost depths of 100mm.

Overall, the straw with tack seems to have provided the best performance. Field observation of straw and tack indicated these materials seem to bond better than more fibrous materials.

The fact that the highest application rate of compost performed poorly was somewhat surprising in light of previous results. However, the compost used in this experiment was screened to a particle size of ¼ inch or less per CalTrans practice for application with a hydraulic seeder. This screening resulted in a decreased particle size distribution and the smaller particles were probably more easily suspended and transported off the surface. This could also account for some of the higher sediment rates observed.

Table 2. Results Ranked by Vegetation Cover, 10' Wide Plots

Plot	Treatment	Sediment Loss (Kg per 10 sm.)	Vegetation Cover (%)
	2:1 Sand		
SA16-A	4000 kg/ha compost + 4000 kg/ha straw + tack	20.96	64.74%
SA15-A	2000 kg/ha compost + 4000 kg/ha straw + tack	17.68	63.96%
SA17-A	8000 kg/ha compost + 2000 kg/ha cellulose fiber + tack	21.31	51.28%
SA18-A	25000 kg/ha compost + tack "Dry applied"	29.61	51.28%
SA15-B	2000 kg/ha compost + 4000 kg/ha straw + tack	17.68	47.58%
SA16-B	4000 kg/ha compost + 4000 kg/ha straw + tack	20.96	45.95%
SA17-B	8000 kg/ha compost + 2000 kg/ha cellulose fiber + tack	21.31	36.58%
SA18-B	25000 kg/ha compost + tack "Dry applied"	29.61	36.57%
SA14-B	4000 kg/ha compost + 1000 kg/ha cellulose fiber + tack	29.72	31.74%
SA14-A	4000 kg/ha compost + 1000 kg/ha cellulose fiber + tack	29.72	25.42%
SA13-A	4000 kg/ha compost + tack	35.47	22.83%
SA13-B	4000 kg/ha compost + tack	35.47	22.23%
	3:1 Sand		
S12-B	4000 kg/ha compost + 1000 kg/ha cellulose fiber + tack	7.82	55.69%
S15-A	25000 kg/ha compost + tack "Dry applied"	18.03	55.68%
S15-B	25000 kg/ha compost + tack "Dry applied"	18.03	52.44%
S13-A	4000 kg/ha compost + 4000 kg/ha straw + tack	2.58	38.65%
S13-B	4000 kg/ha compost + 4000 kg/ha straw + tack	2.58	37.70%
S12-A	4000 kg/ha compost + 1000 kg/ha cellulose fiber + tack	7.82	34.82%
S14-A	8000 kg/ha compost + 2000 kg/ha cellulose fiber + tack	10.21	34.01%
S14-B	8000 kg/ha compost + 2000 kg/ha cellulose fiber + tack	10.21	32.26%
S11-B	4000 kg/ha compost	18.83	30.32%
S11-A	4000 kg/ha compost	18.83	29.72%

The vegetation cover results are scattered and somewhat inconclusive. However, the numbers do suggest that the compost, particularly at the higher rates of application, does contribute to better vegetation establishment. The soil tests may help to clarify these performance data.

Table 3 shows the amount of plant material and plant litter collected in a one square meter area from each 10' wide test plot at the end of the growing season.

Table 3. Vegetation/Plant Litter per 10' wide plots

SA13-A	4000 kg/ha compost + tack	1263.97
S12-A	4000 kg/ha compost + 1000 kg/ha cellulose fiber + tack	1086.34
SA15-B	2000 kg/ha compost + 4000 kg/ha straw + tack	906.01
SA18-A	25000 kg/ha compost + tack "Dry applied"	891.06
S11-B	4000 kg/ha compost	800.30
SA15-A	2000 kg/ha compost + 4000 kg/ha straw + tack	766.78
SA14-A	4000 kg/ha compost + 1000 kg/ha cellulose fiber + tack	766.79
SA16-B	4000 kg/ha compost + 4000 kg/ha straw + tack	751.13
SA13-B	4000 kg/ha compost + tack	741.11
SA16-A	4000 kg/ha compost + 4000 kg/ha straw + tack	645.05
SA18-B	25000 kg/ha compost + tack "Dry applied"	642.13
S11-A	4000 kg/ha compost	606.12
S12-B	4000 kg/ha compost + 1000 kg/ha cellulose fiber + tack	600.10
SA17-A	8000 kg/ha compost + 2000 kg/ha cellulose fiber + tack	558.57
S15-B	25000 kg/ha compost + tack "Dry applied"	466.43
SA14-B	4000 kg/ha compost + 1000 kg/ha cellulose fiber + tack	428.14
S15-A	25000 kg/ha compost + tack "Dry applied"	370.45
SA17-B	8000 kg/ha compost + 2000 kg/ha cellulose fiber + tack	336.47
S13-A	4000 kg/ha compost + 4000 kg/ha straw + tack	301.86
S14-A	8000 kg/ha compost + 2000 kg/ha cellulose fiber + tack	227.78
S14-B	8000 kg/ha compost + 2000 kg/ha cellulose fiber + tack	223.23
S13-B	4000 kg/ha compost + 4000 kg/ha straw + tack	203.40

The plant litter numbers are less conclusive than the vegetative cover data. Particularly since several of the plots showing the greatest litter were plots with 2:1 slopes. The only environmental variable that could have possibly contributed to this scenario is that the 2:1 plots have a westerly orientation while the 3:1 plots have an easterly orientation.

The TxDOT performance standards for erosion control materials on sand are:

Site Conditions	Maximum Sediment Loss (kg/10 square meters)	Minimum Vegetation Density (% cover)
2:1 Sand	26.84	70%
3:1 Sand	12.20	70%

The plots had a final average vegetative cover of 41.68% for the 2:1 test plots and 40.13% for the 3:1 test plots. These percentages of cover do not meet the TxDOT minimum performance standards for products to be placed on the Approved Product List (APL). The University of California Davis will perform additional analysis of vegetation litter, soil and the compost materials used in the test. These findings may further clarify performance of yard compost with respect to vegetation establishment.

Three of the 2:1 and three of the 3:1 test plots met the TxDOT Standards for Sediment Loss. However, to achieve inclusion on the APL, the product must meet both Sediment Loss and Vegetation Density requirements.

CONCLUSION

Although none of the application rates met TxDOT standards in order to warrant a place on the TxDOT Approved Product List, there is indication that erosion control potential increases when compost is mixed with straw or cellulose fiber mulch. This material appears to offer the best sediment reduction when compared with yard waste compost not containing straw or cellulose fiber mulch. Furthermore, heavier applications of yard compost appear to assist in better vegetation establishment, but sediment losses were higher than expected for these applications.

Increasingly, rolled erosion control materials (blankets and mats) are being specified to mitigate surface erosion and assist in establishing permanent vegetation. These materials represent a substantial project cost when compared to other natural materials such as yard compost or straw.

Recent research by TTI and reported field trials suggests that yard waste compost and composted sludge are effective erosion control materials in terms of cost and performance. While compost may assist with establishing and maintaining a permanent vegetation cover, it might also improve soil properties. This would be a significant added benefit not offered by most rolled erosion control products. However, research literature provides little that would allow quantification of the actual soil improvement benefit.

Appendix F. Analysis of source of variation in compost sampling.

Table 14. Variation in extractable N content, including ammonium (XNH4) and nitrate (XNO3) extraction, anaerobic mineralizable N (XminNH4), % total N, 2 hour autoclave (XAC2), 6 hour autoclave (XAC6), and 18 hour autoclave (XAC18). Means are listed in mg N/kg, followed by percentages above and below the mean.

Table 3 CE30e compost N release and variability confidence intervals (CI).

			XNH4mg/kg			XNO3mg/kg			XminNH4			% tot N		
			90%CI	80%CI	67%CI	90%CI	80%CI	67%CI	90%CI	80%CI	67%CI			
green waste compost	YWC 1-24	X	277.1			112.5			83.2			1.3		
		% ± X type	33.2	25.8	19.5	86.4	67.3	50.9	57.6	44.9	33.9	6.8	5.3	4.0
		% ± X prod	26.0	20.3	15.3	37.0	28.8	21.8	72.4	56.4	42.6			
		% ± X bag	3.5	2.7	2.1	18.4	14.4	10.9	17.4	13.6	10.2			
biosolids compost	CCM 100's	X	2725.5			423.3			353.5			1.9		
		% ± X type	36.8	28.6	21.6	42.4	33.0	24.9	103.3	80.5	60.8	18.0	14.0	10.6
		% ± X prod	19.8	15.4	11.6	64.2	50.0	37.8	101.8	79.3	59.9			
		% ± X bag	7.5	5.9	4.4	25.3	19.7	14.9	27.9	21.7	16.4			
ag manure compost	AGC 200's	X	951.1			26.2			511.2			1.5		
		% ± X type	58.2	45.4	34.3	124.6	97.1	73.3	42.6	33.2	25.1	36.5	28.5	21.5
		% ± X prod	19.2	15.0	11.3	91.7	71.4	53.9	26.1	20.4	15.4			
		% ± X bag	2.9	2.2	1.7	55.9	43.6	32.9	23.7	18.4	13.9			

			XAC2mg/kg			XAC6mg/kg			XAC18mg/kg		
			90%CI	80%CI	67%CI	90%CI	80%CI	67%CI	90%CI	80%CI	67%CI
green waste compost	YWC 1-24	X	308.3			437.1			636.2		
		% ± X type	33.1	25.8	19.5	23.6	18.4	13.9	18.7	14.6	11.0
		% ± X prod	20.4	15.9	12.0	12.7	9.9	7.5	8.3	6.5	4.9
		% ± X bag	2.1	1.6	1.2	2.4	1.9	1.4	2.3	1.8	1.3
biosolids compost	CCM 100's	X	3320.9			3759.2			4327.8		
		% ± X type	35.4	27.6	20.9	21.8	17.0	12.9	35.9	28.0	21.1
		% ± X prod	26.8	20.9	15.8	18.2	14.2	10.7	20.3	15.8	12.0
		% ± X bag	3.5	2.7	2.1	3.7	2.9	2.2	4.1	3.2	2.4
ag manure compost	AGC 200's	X	1345.6			1600.3			1977.4		
		% ± X type	61.2	47.7	36.0	51.7	40.3	30.4	49.7	38.7	29.2
		% ± X prod	16.2	12.6	9.6	13.9	10.8	8.2	11.0	8.6	6.5
		% ± X bag	3.0	2.3	1.8	5.5	4.3	3.2	4.5	3.5	2.7