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USE OF HIGH-CARBON WASTE MATERIALS FOR SOIL RESTORATION

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USE OF HIGH-CARBON WASTE MATERIALS FOR SOIL RESTORATION

1. Purpose.

a. This PWTB provides descriptions of organic soil amendment types, recommended application rates, and the expected effects of the application.

b. This Public Works Technical Bulletin (PWTB) transmits information about management and reuse of high-carbon materials (e.g., shredded paper, composted materials, yard wastes, wood chips) for amending soils and improving vegetative growth on Army training lands.

c. All PWTBs are available electronically at the National Institute of Building Sciences' Whole Building Design Guide webpage, which is accessible through this link:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability. This PWTB applies to engineering activities of all US Army facilities.

3. References.

a. Army Regulation (AR) 200-1, "Environmental Protection and Enhancement," 21 February 1997.

b. AR 420-1, "Army Facilities Management," 12 February 2008.

c. Executive Order (EO) 13514, “Federal Leadership in Environmental, Energy and Economic Performance,” 5 October 2009.

d. Department of Defense (DoD), “Strategic Sustainability Performance Plan” (SSPP), 11 July 2011

4. Discussion.

a. AR 200-1 contains policy for implementing federal, state, and local environmental laws and DOD policies for preserving, protecting, conserving, and restoring the quality of the environment. The use of high-carbon wastes such as shredded paper, composted materials, yard wastes, wood chips, etc. can improve vegetative restoration projects by improving plant growth and response.

b. AR 420-1 contains policy for identifying and rehabilitating land disturbed by operations and real property management activities; minimizing solid waste generation and disposal; and maximizing recovery, recycling, and reuse. The use of high-carbon wastes such as shredded paper, composted materials, yard wastes, or wood chips can reduce disposal and landfill costs and improve rehabilitation of damaged lands.

c. EO 13514, Goal 2 established targets to improve water resources management and the reduction of stormwater runoff.

d. The DoD SSPP, Sub-Goal 5.2, established the goal that 50% of non-hazardous solid waste be diverted from the waste stream by 2015 and thereafter through 2020. This PWTB can assist in achieving this goal by identifying materials to divert away from the waste stream — such as much of the non-hazardous solid waste generated and collected by DoD facilities — for reuse, recycling, and/or composting.

e. In addition, this PWTB will discuss research by the US Army Corps of Engineers, Engineer Research and Development Center (ERDC-CERL) on the use of a processed, high-carbon, organic waste to promote the establishment of native grasses on US Army training lands. The research used a noncomposted, processed municipal waste byproduct, Fluff®, as a soil amendment for possible improvements to growth and distribution of native plant species at US Army installations.

f. Appendix A contains background information and an introduction to the use of high-carbon soil amendments.

g. Appendix B discusses the types of high-carbon soil amendments.

h. Appendix C discusses the application of organic soil amendments.

i. Appendix D discusses US Army Corps of Engineers research on the use of a high-carbon soil amendment for revegetation of damaged Army lands.

j. Appendix E contains references cited in this PWTB.

k. Appendix F contains a list of abbreviations used in this PWTB.

5. Points of Contact.

a. Headquarters, US Army Corps of Engineers (HQUSACE) is the proponent for this document. The point of contact (POC) at HQUSACE is Mr. Malcolm E. McLeod, CEMP-CEP, 202-761-5696, or e-mail: Malcolm.E.Mcleod@usace.army.mil.

b. Questions and/or comments regarding this subject should be directed to the technical POC:

US Army Engineer Research and Development Center (ERDC)
Construction Engineering Research Laboratory (CERL)
ATTN: CEERD-CN-N Dick L. Gebhart
2902 Newmark Drive
PO Box 9005
Champaign, IL 61826-9005
Tel. (217) 373-5847
FAX: (217) 373-7266
e-mail: Dick.L.Gebhart@usace.army.mil

FOR THE COMMANDER:

For JAMES C. DALTON, P.E., SES
Chief, Engineering and
Construction Division
Directorate of Civil Works

APPENDIX A

INTRODUCTION

The US Army manages over 12 million acres of land for military training, and these lands routinely require rehabilitation and maintenance to support training activities. Often, plant populations are greatly reduced or altered due to clearing or preparation operations, direct contact with training vehicles, and soil compaction. Soil structure is changed as vegetation is removed, topsoil is eroded, and soil horizons are mixed and compacted. Because of limited funds for land management in recent years, there is a need for low energy, cost-effective technologies to that can be applied to damaged sites to improve vegetative growth and establishment. This PWTB provides information on the use of high-carbon soil amendments to improve rehabilitation and revegetation of disturbed landscapes.

The use of high-carbon soil amendments is a cost-effective in-situ process for improving the remediation of damaged sites. Organic soil amendments are commonly used to provide essential plant nutrients (e.g., nitrogen and phosphorous), to increase soil carbon content, and to improve microbial populations. Soils that have been treated with organic amendments are benefited by improved water infiltration and water-holding capacities, higher plant yields, resistance to insect pests, retention of soil nitrogen, increased biodiversity, and increased microbial activity (Pimentel et al. 2005; Hsu et al. 2009).

A wide variety of organic soil amendments is available in most regions of the United States. The most commonly used organic soil amendments are biosolids, manures, compost, digestates, paper mill sludge, and yard and wood wastes. The type and amounts of soil amendments will vary from site to site within a region, depending on soil conditions and the types of vegetation that are to be established. An effective soil amendment strategy requires an accurate assessment of existing soil conditions and knowledge of the desired soil conditions appropriate for revegetation. It is essential that potential soil amendments be characterized for all physical, chemical, and microbiological properties.

A description of the types of organic soil amendments, recommended application rates, and the expected effects are provided in the following appendices. In addition, this PWTB will discuss research by the US Army Corps of Engineers Engineer Research and Development Center (ERDC) on the use of a processed high-carbon organic waste to promote the establishment of native grasses on US Army training lands (Busby et al. 2006, 2007; Busby 2003). The research analyzed a noncomposted processed municipal waste byproduct, Fluff® (Bouldin and Lawson 2000), as a soil amendment for possible improvements to growth and distribution of native plant species at US Army installations.

APPENDIX B

TYPES OF ORGANIC SOIL AMENDMENTS

A wide variety of organic soil amendments is available in most regions of the country; however, the amount of processing and characteristics of the amendments vary considerably. Organic soil amendments for revegetation are used primarily to provide essential plant nutrients, add organic matter, and improve microorganism populations. Other benefits from the use of organic soil amendments include modifying soil pH, reducing erosion, improving hydrology, and mediating soil temperatures (Munshower 1994).

Organic soil amendments may be made of materials as diverse as paper, sewage sludge, wood chips, straw, composted municipal wastes, and manure. The most common classified types of organic soil amendments are biosolids, compost, yard wastes and mulches, paper mill sludges, and digestates. Although a discussion of paper mill sludge and biosolids is included here, these two types of organic wastes are seldom used for large revegetation projects.

Biosolids

Biosolids, also referred to as treated sludge, are the organic, solid byproducts of municipal wastewater treatment that have been treated to meet federal and state standards for land application (USEPA 2000). Municipal wastewater treatment plants in the United States generate over 6 million metric tons of biosolids per year, 55% of which is land-applied (North East Biosolids and Residuals Association 2007). Biosolids represent a sustainable nutrient and organic matter source that can also possess significant liming and sorbent properties (Power et al. 2000). Biosolids are readily available at low costs in urban areas and pose a low human environmental risk (USEPA 1993). However, real and perceived concerns for land application of biosolids are often a public concern. Issues such as odor, pathogens, attraction of pests, and aesthetics are often cited as problems that may negatively affect property values. Excessive nutrient loading is another concern (e.g., phosphorous when biosolids application rates are based on nitrogen availability). Biosolids generally contain the slow-release type of nitrogen that becomes available to plants slowly over several years after application.

The use of biosolids in the United States is regulated by state and federal environmental protection agencies that are aware of these issues. These agencies have developed risk-based criteria for land application of biosolids (USEPA 1993). However, many of these criteria are being debated due to concerns about the long-term effects of biosolids' application relating to soil qualities, the safe production of food, and protection against water pollutants.

Animal manures, another biosolid, have been applied to agricultural lands for decades and reports of its effects on soil properties are numerous (Hafez 1974; Weil and Kroontje 1979; Avnimelech and Cohen 1988; Sorenson 2001). Manure is considered an excellent source of the plant nutrients nitrogen, phosphorous, and potassium. Manure also returns organic matter and other nutrients such as magnesium and sulfur to the soil, thus improving soil quality and fertility. The nutrient content of manure varies depending on the animal type, animal diet, moisture content, and storage method.

Modern animal production has increased the size of production units and resulted in the generation of large volumes of animal manure and other by-products. The collectable volume of such material is estimated to be more than 55.3 million metric tons per year worldwide (Edwards and Someshwar 2000). Manures are sometimes dewatered or otherwise stabilized for use, but the majority are applied "as is" on agricultural lands as nutrient and organic matter amendments. The nitrogen content of manure is usually readily available to plants, and only a portion of the nutrient is mineralized over long periods of land application (Mallory and Griffin 2007).

A solid-waste processing technology has been developed that separates the organic fraction of garbage from the recyclable materials and sterilizes it, producing a pulp-like material called Fluff® (Bouldin & Lawson 2000). The technology not only greatly reduces waste volume, but Fluff has the potential to be used as a soil amendment to improve soil conditions in highly degraded soils. In addition, the byproduct has also been successfully utilized as potting media in the commercial horticultural industry and as a dust palliative for unpaved road surfaces.

Paper Mill Sludge

Sludge is the largest waste product of the paper and pulp industry, and disposal of the sludge has become a major solid waste problem for paper mills around the globe (Suriyanarayanan et al.

2010). Most of the sludge is landfilled, which creates serious financial and environmental concerns. A typical paper mill will produce an average of 900 tons of sludge per day at an estimated daily cost of $2,250 (Karcher and Baser 2001).

Paper mill sludge is available for use as a soil amendment on disturbed lands, but the nature of the sludge is highly variable from source to source (USEPA 2007). This variability mainly depends on the raw materials used and which unit process produced the material (Suriyanarayanan 2010). Paper mill sludge from primary treatment processes is generally composed of wood fiber, clay, and lime (O’Brien 2001). Sludge produced from some of the industrial processes from paper milling, however, may contain a mixture of contaminants, some of which may be toxic.

Paper mill sludge can be used in a variety of ways, depending on the processing and collection of the materials. Most sludge is dewatered and landfilled, usually with or without incineration or precomposting. Composted paper mill sludge has been proposed as a suitable soil amendment because of the high organic matter content and low toxicity (Suriyanarayanan 2010; Mabee and Roy 2003).

In general, paper mill sludge can provide large amounts of organic matter, but they are much lower in nitrogen and phosphorous than biosolids or composts. O’Brien (2001) reported that, when paper mill sludge was applied to corn, an increase in organic matter and phosphorous content was found after 21 days. In addition, the carbon to nitrogen ratio (C:N), salinity, and pH declined over time, while the total nitrogen concentration increased. Germination was hindered as well when the seeds were sown immediately after the application of the sludge, but germination rates were not affected if the seeds were planted 21 days post-treatment. O’Brien also reports that the addition of compost to the sludge improves the capacity of the soil to support wildflower sod production.

Many paper mills mix other processing residuals, such as fly ash or lime, with their waste sludge, which improves its potential as an organic soil amendment. Along with the high organic material found in paper mill sludge, the addition of inorganic soil conditioners may improve the soil. As supplies for traditional soil amendments such as composts, peat moss, and manures are diminishing in urban areas, opportunities for beneficial land management applications of paper mill sludge have increased.

Composts

Compost is an organic soil amendment that results from aerobic decomposition of a variety of organic materials, such as yard waste and trimmings, animal manure, and garbage. Yard trimmings and food residuals constitute approximately 25% of the waste stream in the United States (USEPA website). Nearly 60% of yard wastes and trimmings are recovered for composting, while only 3% of food wastes are recovered. The major deterrent to recovering food residuals for use in composts is the cost-prohibitive nature of residential food waste separation and collection. Many communities blend inedible food residuals into composting operations or reprocess them into animal feed. Communities near high-volume commercial or institutional food-processing plants recover large volumes of food byproducts, which saves significant transportation and disposal costs.

Animal and municipal wastes are increasingly being composted before land application so as to improve characteristics that benefit handling and spreading and to reduce odor. Repeated application of composts mixed with manure or municipal waste may increase phosphorous runoff in agricultural fields (Spargo et al. 2006). Spargo et al. compared the repeated application of composted and uncomposted organic matter (biosolids compost, poultry litter-yard waste compost, and uncomposted poultry litter) on phosphorous runoff characteristics. The addition of compost to soils and planted with cereal rye (*Secale cereal* L.) and corn (*Zea mays* L.) significantly increased soil carbon and bulk density. Compost also increased water soluble phosphorous and the degree of phosphorous saturation but showed no differences in the total dissolved phosphorous (TDP) and dissolved reactive phosphorous (DRP) concentrations. The concentrations of TDP and total phosphorous were highest in runoff from the composted sites, but the mass of DRP and TDP was not different among treatments. This was attributed to the higher infiltration and lower runoff in compost-amended soils, which improved soil physical properties to decrease loss of total phosphorous and total suspended solids.

The use of compost as a soil amendment has been shown to improve desirable soil properties, such as lower bulk density, higher plant water availability, and increased beneficial microfauna (Bulluck et al. 2002). Benefits of compost additions to soils include improved water infiltration and pH stabilization (USEPA 2000). As with other soil amendments, it is important to characterize the compost, as soil chemical composition may be affected by composition and stability of the compost. Long-term legumebased organic composts have been shown to increase organic matter and reduce nitrogen runoff (Bulluck et al. 2002).

The availability of composts is location-dependent, although it is readily available both commercially and through local municipalities in most of the country. Costs for compost are high and transportation costs may be restrictive. Composts generally contain lower nitrogen concentrations than noncomposted materials.

Yard and Wood Wastes

Yard and wood wastes (tree trimmings, garden debris, lawn clippings, etc.) are collected at many localities and made available to the public for use as mulches and as a soil conditioner. Mulches are applied to the surface of soils after seeding, which means they are not technically soil amendments like biosolids, compost, and paper mill sludge. Amendments are applied to a site prior to seeding and incorporated into the soils (Munshower 1994).

Yard and wood wastes vary greatly in stability, particle size, and composition. Local vegetation and processing differences are mainly responsible for these differences, but commercially available mulches are more uniform. Mulches are commonly made from wood and yard wastes, paper, straw, and native hay. They are applied to the surface of the soil mainly to reduce erosion, but they also provide benefits such as temperature moderation, soil moisture retention, and increased soil C. Because mulches are applied to the surface of the soils, they have limited impact on nutrient cycles or soil structure.

The application of surface mulch is an effective way to reduce wind and water erosion, to reduce impacts from raindrops, to reduce evaporation from the soil surface, and to keep temperatures at the soil surface cooler (Munshower 1994). The main benefit of mulching is to reduce soil erosion, however. Straw mulches have been shown to reduce annual soil erosion rates from 24.6 tons/ha on uncultivated bare land to 1.1 tons/ha from land covered in straw mulch on silt-loam soil at a 7 degree slope (Morgan 1994).

While it is not always possible to achieve such big differences in soil loss due to mulching, the extent to which mulch can reduce erosion potentials is generally very good (Morgan 1995). Mulches can also be incorporated into the soil. For example, one such method is the agricultural practice of incorporating “green manure,” which refers to the prior year’s biomass (stubble, groundcover, etc.), into the soil by plowing, chiseling, crimping, or tilling. When incorporated, however, mulch’s function as a true soil amendment may be limited.

Digestates

Digestates, as used in this PWTB, is a general category for organic wastes that have been partially treated via anaerobic digestion. Anaerobic digestion is useful in the treatment of both co-mingled and source-separated solid municipal wastes with the added benefit of energy recovery through the generation of methane gas (USEPA 2000). Anaerobic digestates in their basic form, however, may not be a suitable soil amendment due to odor and viscosity (Smet et al. 1998), phytotoxicity (McLachlan et al. 2004), and difficult application and handling techniques which may require expensive machinery (Tchobanoglous et al. 2002).

Digestates, therefore, often need to be “polished” via aerobic digestion to enhance their value as a fertilizer and soil amendment (Abdullahi et al. 2008). The availability of digestates depends on the location, is variable in quality, and is generally uncharacterized. Because of its variability and the difficulty and expense to apply them, digestates are not recommended for large-scale revegetation projects on Army lands.

APPENDIX C

APPLICATION OF ORGANIC SOIL AMENDMENTS

Application Rates

Application methods and rates are highly dependent on local site conditions, such as soil type, soil moisture, soil organic content, and soil chemistry. The determination of the appropriate application rate may be approached in several ways, including examination of the revegetation site, using application rates successful at other sites, and using laboratory protocols.

Examine revegetation site composition

The first approach is to examine the undisturbed, healthy soil at the site to be revegetated. The total organic matter of this soil can be used as a target for application. Rates of application should, however, take into account that the organic matter will decompose in a relatively short time frame. In order to compensate for this rapid decomposition, the amount of organic soil amendment should be double the amount of the test soils. For example, if a healthy soil sample contains 2% organic matter, the application of amendment for a 4% organic matter content will help alleviate the loss of carbon through rapid decomposition (USEPA 2000).

Use successful application rates

A second approach is to use application rates that have been successful at similar sites. Application rates that are specific to the type of amendment, soil types, vegetative composition, etc., can be found in scientific literature. McConnell, Shiralipour and Smith (1993), for example, concluded that application rates of composted municipal wastes should be at least 15 tons/acre to noticeably increase organic matter in soil. Similarly, a heavily contaminated site on a barren mountainside in Pennsylvania was revegetated using a blend of 105 wet tons/acre anaerobically digested biosolids, 10 tons/acre agricultural limestone, and 52.5 tons/acre fly ash. Here, the application rates were based on the organic nitrogen content of the biosolids, then using half that amount of fly ash and twice the required amount of limestone needed to neutralize the soil (USEPA 2000).

Follow laboratory protocols

The final approach to determining the proper application rates is to follow laboratory protocols. Calculations can be made to determine the acid-base composition in soil samples, to determine moisture content, particle size, and other analytical characteristics. These protocols can be used to determine the application rate, for example, to assure that appropriate amounts of soil amendments are applied spatially at proper depths.

Amending the Soil

When incorporating organic amendments to improve the carbon content of the soil, it is important to include a mixture of nitrogen-rich materials to reduce the potential of nitrogen leaching. A bulk amendment C:N ratio between 20:1 and 40:1 is recommended (USEPA 2000), but higher carbon additions may be appropriate depending on site conditions.

In certain cases, the amount of amendments added can be a qualitative decision rather than a quantitative one. The functional A horizon is generally greater than 4 in. in depth, so the goal of the amendment application should be to create a surface layer (A horizon) that is similar to or greater than this depth.

The application of organic soil amendments can be accomplished be a number of methods. These include the use of modified manure spreaders, mechanical dry blowers, hydromulchers, or transporting and dumping the material using a dump truck and wheelbarrow. Dry blowers, while capable of dispensing large quantities of organic soil amendments in a rapid time period, are not economical on most disturbed sites because of the expense of the equipment. Manure spreaders are much more economical and can be used on small parcels of land.

APPENDIX D

ORGANIC SOIL AMENDMENT RESEARCH AT ARMY INSTALLATIONS

Background

The US Army spends an estimated $68 million annually to dispose of various forms of waste through landfills, incineration, composting, and recycling (SWARS 2008). Because of potential cost savings, efforts are being made to increase those disposal methods that have payback—such as recycling, and to involve local communities in composting materials for later use on the installation.

With more than 12 million acres of land in the United States, the US Army has the acreage to support large-scale utilization of organic soil amendments (Busby 2003). The Army is required to manage their lands to establish ecosystem sustainability, control water and air pollution, protect biological diversity, and implement reuse practices wherever possible. By revegetating damaged training lands through using organic matter from landfills as a soil amendment, the Army can simultaneously decrease landfill disposal costs, implement beneficial reuse of MSW into land management projects, and improve land rehabilitation efforts on its lands.

The US Army Corps of Engineers ERDC, along with the US Department of Agriculture (USDA), Agriculture Research Service (ARS), and National Soils Dynamics Laboratory, has conducted research to determine the applicability of using uncomposted and hydrolyzed municipal solid waste (MSW) as a soil amendment to improve the establishment of native vegetation. Studies were conducted at Fort Campbell, Tennessee, and Fort Benning, Georgia (Busby et al. 2006), to evaluate an uncomposted organic byproduct as a soil amendment for establishing native prairie grasses on disturbed Army training lands.

Analysis of Fluff®

A solid-waste processing technology has been developed that separates the organic fraction of garbage from the recyclable materials and sterilizes it to produce a pulp-like material called Fluff® (Bouldin & Lawson 2000; Figure D-1). The process grinds up the garbage, separates out ferrous metals, and uses a hydrolyzer with high temperature and pressure steam to break molecular bonds and to destroy pathogens. An end product after the completion of hydrolysis is a colorless, odorless, aggregate cellulose pulp, which is then dried and the resulting organic material (Fluff) is separated from the recyclable glass, metal, and plastic constituents by air classification. The organic byproduct from this process can be landfilled at a 30%-75% (depending upon the input materials) reduction in volume (BouldinCorp, unpublished data 2001). This technology is currently being used in Warren County, Tennessee, where a 95% recycling rate has been achieved for the county's MSW, with the bulk of the organic byproduct composted for use as a topsoil replacement in the horticultural industry (Croxton et al. 2004).

Figure D-1. Fluff® is a colorless, odorless, aggregate cellulose pulp.

An additional benefit from this technology is that Fluff can be utilized as a soil amendment to improve physical and chemical conditions of the soil. Studies conducted to analyze the chemical characteristics of Fluff included extensive analysis of chemical components of environmental concern. Fluff was analyzed for nutrient components important to agriculture and found to have significant nutrient concentrations that could serve as an organic fertilizer source (Busby et al. 2006). It was also intensively analyzed for levels of 184 regulated compounds, including 11 heavy metals, 113 semi-volatile organic compounds, and 60 volatile organic compounds to determine any potential regulatory limitations. Only nine heavy metals, three semi-volatile organic compounds, and three volatile organic compounds were detected (Table D-1). The detected organic compounds (acetone, methylene chloride, toluene, di-phthalate [2-ethylhexyl], di-n-butyl phthalate, and di-n-octyl phthalate) are regulated in either the Clean Water Act or the Clean Air Act due to risks associated with workplace exposure and concentrated industrial effluent. However, due to their volatile chemical nature and rapid turnover in the environment, they pose very little risk at the concentrations found in Fluff, especially when incorporated into the topsoil; therefore, these compounds are not regulated when used for this purpose.

Land application limits for heavy metals have been established for biosolids, and these existing standards were used to assess metal loading of the byproduct in the absence of a similar compost standard (40 CFR Part 503; USEPA 1999). A comparison of heavy metal concentrations in Fluff with the USEPA biosolids limits for maximum metal concentrations, maximum annual soil metal loading, and maximum cumulative soil metal loading found that Fluff metal concentrations were at least an order of magnitude below their respective land application limits. Fluff was found to have a C:N ratio of about 30, a near-neutral pH, and studies have shown that it decomposes slowly (Busby et al. 2007).

Table D-1. Fluff® properties significant to vegetative growth.

pH	6.5
C:N	32
C (%)	39.8
N (%)	1.26
P (mg kg^{-1})	1900
K (mg kg^{-1})	2170
Ca (mg kg^{-1})	13600
Mg (mg kg^{-1})	1400
Fe (mg kg^{-1})	2460
Mn (mg kg^{-1})	130
Zn (mg kg^{-1})	234
B (mg kg^{-1})	35
Cu (mg kg^{-1})	47.7
Co (mg kg^{-1})	2.0
Na (mg kg^{-1})	5169

Because Fluff is unstabilized, concerns were raised regarding the effects of microbial decomposition on nutrient availability when the material is used as a soil amendment. Research was conducted by ERDC with the USDA-ARS National Soils Dynamics Laboratory to determine the rate of decomposition and nitrogen cycling of Fluff at increasing rates in two distinct sandy soils and to compare the results to mature municipal waste compost (Busby et al. 2007).

Fluff was obtained from WastAway, Inc. (McMinnville, Tennessee), and mature compost was obtained from the Prairieland Compost Facility (Truman, Minnesota). Soils were collected from two study sites at Fort Benning. At the first site, designated "Dove Field," a Troup loamy fine sand (loamy, kaolinitic, thermic Grossarenic Kandiudults) was collected; at the second site, designated "Borrow Pit," a highly disturbed Orangeburg loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults) was found (NRCS 2004). Incubation methods followed techniques described by Torbert et al. (1998). Experimental treatments consisted of 25 g dry weight of sieved soil samples placed in small plastic cups. Fluff or composted municipal waste was mixed into soils at the desired application rates, and the soils were moistened to 85% of field capacity by the addition of deionized water. Cups were then placed in 1.06-L jars, which were fitted with CO_2 traps and incubated in the dark at 25°C and 70% relative humidity for 90 days. Soil samples were extracted every 30 days and analyzed for ammonium (NH_4) and nitrate (NO_3).

Carbon mineralization of the Fluff was much higher than in the mature municipal waste compost. The soil with higher initial carbon and nitrogen concentrations had significantly higher rates of carbon evolution across application rates, indicating that soil type heavily influenced carbon evolution of the decomposing Fluff. This difference was most likely due to the differences in available soil nitrogen at the two sites, which could have significantly reduced microbial activity.

Decomposition of Fluff resulted in significant nitrogen immobilization as indicated by considerably higher total inorganic nitrogen and NO_3 levels in the compost treatments than in the Fluff treatments. No changes in inorganic nitrogen concentration were observed in the Borrow Pit Fluff treatments through the 90-day incubation. However, the Dove Field Fluff treatments did increase slightly over time, with an inverse relationship between the Fluff rate and inorganic nitrogen concentration after 90 days of incubation. Ammonia concentrations in the compost treatments remained very low and relatively constant across rates and soils but decreased slightly over time. Ammonia concentrations in the Dove Field Fluff treatments peaked at day 60 and decreased to their initial levels by day 90. This indicates that net ammonification had occurred during incubation, but net nitrification had begun by the end of the 90 days. Even at the peak, however, NH_4 levels still remained at low concentrations (<11 mg kg^{-1}). The low concentrations of NH_4 indicate that potential toxicity from NH_4 buildup would not be a problem in these soils even at rates of 143 Mg ha^{-1}. In the Borrow Pit soil, neither net ammonification nor nitrification was ever indicated throughout the incubation as both NH_4 and NO_3 concentrations stayed consistently low. This consistency indicates a severe nitrogen deficiency in this soil and was probably responsible for the slower decomposition of the Fluff.

Because soils at both treatment sites were relatively infertile and both carbon and nitrogen mineralization of the Fluff were closely tied to the fertility status of the soils, it is likely that Fluff decomposition will occur at a faster rate in more fertile soils. When used in infertile soils, nitrogen immobilization will occur for an extended period due to incorporation into microbial biomass. While this may have potential negative consequences for vegetation initially, fertilization with a readily available nitrogen source may alleviate this period of immobilization. On the other hand, slower degradation of the material may provide the best long-term benefit since leaching losses would be minimized and nitrogen inputs would more closely resemble natural soils. Claassen and Carey (2004) found similar results in yard waste compost that initially led to net immobilization.

The mature compost would work well for vegetation that requires significant nitrogen inputs since it provided a steady and significant amount of nitrogen throughout the 90 days. In settings where available nitrogen could be detrimental, such as native plant restorations or where weed pressure is undesirable and detrimental, Fluff application could be a simple way to decrease available nitrogen in the short term. In addition, it would most likely provide a slowly available source over the longer term. Restoration of late-seral plant communities has been achieved using high C:N organic soil amendments that limit available nitrogen, such as sucrose and sawdust (Sulmon et al. 2007; Paschke et al. 2000). Additionally, any increase in the organic carbon content of soil will provide significant benefits, especially in degraded soils with sparse vegetative cover.

Comparison of these data with other studies using raw household waste indicates that Fluff has a much lower rate of carbon mineralization than the unprocessed waste (e.g., Bernal et al. 1998). The processing must have a significant effect on Fluff’s degradation rate because it had such a low rate of carbon mineralization relative to the raw waste. The increase in soil carbon and decrease in soil nitrogen from Fluff amendment indicates that it would be best suited for highly degraded soils, where establishment of native perennial communities adapted to nitrogen limitation is desired.

APPENDIX E

VEGETATION ESTABLISHMENT AND GROWTH

A potential problem with noncomposted organic material, as previously noted, is the high C:N ratio, which could create a soil environment with low nitrogen availability. However, the creation of low nitrogen availability may be an advantage for establishing native vegetation adapted to nutrient limited soils and that would benefit greatly from a reduction in weed competition for nitrogen (Paschke et al. 2000; Wilson and Gerry 1995; McLendon and Redente 1992). Perennial warm season grasses are well adapted to harsh environmental conditions, including low nitrogen availability, which gives them a competitive advantage in poor soils (Jung et al. 1988; Skeel and Gibson 1996). These grasses are advantageous to vegetative reclamation projects because they develop extensive root systems that penetrate deep into soils to provide a very effective safeguard against erosion (Drake 1980). Even though these species are well suited to reclamation plantings, establishment in nitrogen-rich soils may be impeded by weedy species that easily out-compete them and cause failure (Warnes and Newell 1998; Brejda, et al. 2000).

In addition to the incubation study, researchers conducted a vegetation establishment study at Fort Benning to evaluate the use of Fluff as a soil amendment to rehabilitate damaged military training lands. Such damaged land often lacks sufficient topsoil, organic matter, and nutrients required for successful rehabilitation (Busby et al. 2006).

The two experimental sites at Fort Benning, previously described in Appendix D, were (1) Dove Field, which was moderately degraded sandy loam soil, and (2) the Borrow Pit site, which was highly degraded fine-loamy soil (Busby et al. 2006). At each site, treatments consisted of a control, revegetation-only treatment, and revegetation with application of Fluff at rates varying from 0–143 Mg ha^{-1}. Three native C4 grasses species (big bluestem - *Andropogon gerardii*; switchgrass - *Panicum virgatum*; and indiangrass - *Sorghastrum nutans*) and one C3 grass (Virginia Wildrye - *Elymus virginicus*) were planted. Plant biomass, plant species composition, and vegetative basal cover were measured at the end of each of two growing seasons. Plant biomass collections consisted of composite samples of all species present.

E-1. The “before” photo of the Borrow Pit site at Fort Benning, GA (ERDC-CERL 2003).

E-2. The “after” photo of the Borrow Pit site at Fort Benning, GA (ERDC-CERL 2005).

A total of 21 species were sampled in the research plots over 2 years. Planted grass species were 98.2% of the total species composition of the Borrow Pit and 87.3% of the Dove Field plots. Switchgrass dominated all seeded sites and was the highest relative percentage composition and basal cover of all species present. It also responded the most favorably to Fluff application as basal cover increased significantly with an increasing application rate at both sites. It became an even larger component of total vegetation with an increasing application rate at Dove Field. Application rate had no effect on percent composition of total planted grasses at either site.

Big bluestem appeared to be unaffected by application rate at the Dove Field site, but basal cover increased significantly with an increasing application rate at the Borrow Pit. Indiangrass performed well in Dove Field initially, but remained only a minor vegetation component at the Borrow Pit. Also, it diminished over time and in response to increased Fluff, while the other two dominant species increased. Indiangrass was not able to effectively compete with switchgrass and big bluestem at either site in the presence of Fluff-amended soil.

Above-ground biomass increased significantly over time at both sites (Table E-1). Biomass was much higher at the Dove Field site than at the Borrow Pit for all treatments, but both sites responded very well to increased Fluff application. Furthermore, biomass at the Dove Field site remained relatively constant in the unseeded control at less than 300 g m^{-2} but almost doubled in the 143 Mg ha^{-1} treatment (from 539 to 1059 g m^{-2}) from Year 1 to Year 2. In the Borrow Pit, the unseeded control failed to produce any biomass, but the biomass for the 143 Mg ha^{-1} treatment increased from 345 to 582 g m^{-2} over time.

Table E-1. Biomass yields as affected by Fluff® application for the Dove Field and Borrow Pit study sites.

Fluff® Rate (Mg ha-1)	Dove Field ($g\ m^{-2}$)		Borrow Pit ($g\ m^{-2}$)	
	2003	**2004**	**2003**	**2004**
Unseeded Control	243	291	0	0
0	269	392	18	14
18	344	617	46	90
64	428	613	73	122
72	468	749	202	403
143	539	1059	345	582

The increases in switchgrass and big bluestem cover show that the application of Fluff has a positive effect on these native grasses. Planted grass species constituted almost all vegetation in the seeded plots (98% in the Borrow Pit and 87% in the Dove Field) with mean basal cover values of 7.5% and 12.2%, respectively. Because of these positive effects of Fluff application at both sites, the establishment of a native grass community was considered successful.

APPENDIX F

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APPENDIX G

ACRONYMS AND ABBREVIATIONS

Term	Spellout
AR	Army Regulation
CECW	Directorate of Civil Works, United States Army Corps of Engineers
CEMP-CE	Directorate of Military Programs, United States Army Corps of Engineers
CERL	Construction Engineering Research Laboratory
CFR	Code of the Federal Regulations
DRP	Dissolved reactive phosphorous
EPA	Environmental Protection Agency; also USEPA
ERDC	Engineer Research and Development Center
HQUSACE	Headquarters, United States Army Corps of Engineers
MSW	Municipal solid waste
POC	point of contact
PWTB	Public Works Technical Bulletin
TDP	Total dissolved phosphorous
USACE	United States Army Corps of Engineers
USDA-ARS	United States Department of Agriculture, Agriculture Research Service
USEPA	United States Environmental Protection Agency