USER GUIDE

Pulverized Paper as a Soil Carbon Source for Degraded Training Lands

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A demonstration and validation project was funded by ESTCP for the utilization of pulverized classified paper waste as a soil amendment to improve degraded training lands. Military training lands are often lacking in soil organic matter, which improves water infiltration and nutrient and moisture retention. Further, when these lands are disturbed, nutrient availability favors weed establishment and makes restoration to desirable native plant communities difficult. High carbon (C) wastes are able to alleviate these problems but due to cost and availability are often not feasible. Federal regulations require that classified paper be pulverized to very small fragments, which negates their recyclability.

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Project Summary

A demonstration and validation project was funded by ESTCP for the utilization of pulverized classified paper waste as a soil amendment to improve degraded training lands. Military training lands are often lacking in soil organic matter, which improves water infiltration and nutrient and moisture retention. Further, when these lands are disturbed, nutrient availability favors weed establishment and makes restoration to desirable native plant communities difficult. High carbon (C) wastes are able to alleviate these problems but due to cost and availability are often not feasible. Federal regulations require that classified paper be pulverized to very small fragments, which negates their recyclability. As this material is currently landfilled, a beneficial reuse of this waste material is not only advantageous to training land management but supports NetZero Waste initiatives as well.

Initial characterization of paper indicated virtually no contaminant presence and no adverse effects from land application at high rates. The demonstration sites were located at Fort Polk, LA, on two of the most common soil types occurring on military training lands. Paper was collected and stored at Fort Polk, weighed to achieve specific application rates, and applied to the demonstration sites in spring 2016. At the first site, rates of 8, 16, 24, and 32 tons acre^{-1} were applied, along with a control and a standard practice plot consisting of lime and fertilizer. Due to the difficulty in incorporating the highest two rates, the application rates were halved at the second site. Each site consisted of 4 blocks, with each respective treatment replicated in each block. Paper was incorporated into the soil, and sites were seeded with standard native warm season prairie grasses. At the end of each growing season, plant species cover and composition, standing biomass, plant and soil nutrient analysis, soil metal analysis, and soil pH and bulk density data were collected.

Paper application rate was positively correlated with native plant cover, deficient plant and soil nutrient concentrations, and soil pH, and negatively correlated with invasive plant cover and biomass and soil bulk density. Native plant cover was 45% higher at the highest paper application rates compared to controls, and most planted grass nutrient concentrations increased with increasing paper application rate. No EPA-regulated contaminants for land application of wastes increased in any capacity with increasing paper application rate.

Based on the results of this project, pulverized paper can be safely applied to degraded training lands to improve establishment of desirable vegetation without any discernable negative consequences. Due to difficulties in incorporating high rates, the recommended application rate is 16 tons acre^{-1}. When combining cost savings associated with landfill disposal of the paper with savings achieved from greater land rehabilitation success, an estimated $300 per ton of diverted paper is realized. At the recommended application rate, this results in a cost savings of approximately $4,700 per acre. At the installation level, this equates to an estimated annual costs savings of $20,000 with 70 tons of paper diverted.

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Background on Soil Impoverishment using High Carbon Waste Materials

There are two different benefits that can be provided to degraded soils from the addition of high carbon materials, based on environmental conditions: improved nutrient immobilization and improved nutrient cycling. In productive soils (often finer textured loams or clays), organic matter content is often higher, and loss of organic matter often promotes rapid mineralization of nutrients (Plaster, 1992). This mineralization favors weedy and other undesirable vegetation (Vitousek and Walker, 1987; Figure 1). In these soils, adding a carbon source with a high C:N ratio will immobilize nitrogen, providing an advantage to native plants with a high nitrogen use efficiency over weedy plants requiring greater nitrogen availability (Alpert and Maron, 2000; Paschke et al., 2000; Blumenthal et al,. 2003; Eschen et al., 2007; Perry et al. 2010; Kirkpatrick and Lubetkin, 2011; Mitchell and Baker, 2011).

In less productive soils (often coarse textured sands), loss of organic matter reduces the ability of the disturbed soil to support the necessary vegetative cover required to control erosion (Plaster, 1992). In these soils, carbon content is often much lower, causing the soil to be susceptible to erosion and often lacking in key nutrients and moisture retention required for successful plant establishment. Adding carbon sources with a high C:N ratio to these soils improves soil structure, increases nutrient and moisture retention, and adds small amounts of nutrients that may be necessary for successful native plant establishment without promoting undesirable plants (Zink and Allen, 1998; Busby et al., 2006; Torbert et al., 2007; Watts et al., 2012a,b).

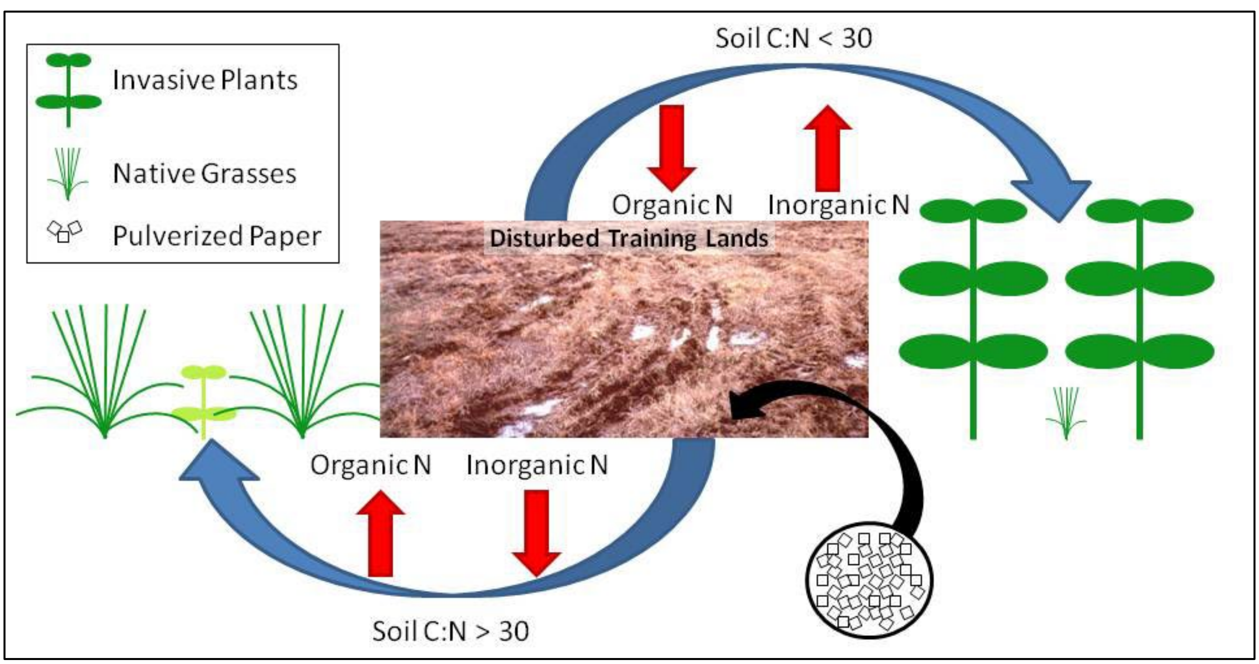

Figure 1. Soil impoverishment conceptual model. Disturbed training lands have high inorganic N concentrations that favor invasive plant dominance. Adding a high C waste such as pulverized paper stimulates microbial immobilization of inorganic N into organic N, favoring native grass dominance.

Sources of high carbon soil amendments can include sucrose (McLendon and Redente, 1992; Morgan, 1994; Paschke et al., 2000; Blumenthal et al., 2003; Kirkpatrick and Lubetkin, 2011; Mitchell and Bakker, 2011), processed municipal solid waste (Busby et al., 2006; Busby et al., 2007; Torbert et al., 2007), straw (Zink and Allen, 1998; IDOT, 2012) and cellulosic wastes (Morgan, 1994; Zink and Allen, 1998; Alpert and Maron, 2000; Blumenthal et al., 2003; Eschen et al., 2007). Each of these studies have shown that uncomposted wastes low in available nitrogen provide a suitable amendment for establishment of desirable native vegetation (Table 1).

Table 1. Summary of soil impoverishment benefits to soil and vegetation.

Date	Summary	Source
1992	480 g C m^{-2} sucrose increased perennial plant cover 51% in sagebrush steppe	McLendon et al., 1992
1998	wood waste 3 cm thick increased sagebrush seedling survival 40% in sagebrush steppe	Zink and Allen, 1998
2000	600 g C m^{-2} sawdust decreased invasive plant biomass 40% in coastal grassland	Alpert and Maron 2000
2000	640 g C m^{-2} sucrose decreased invasive plant biomass 60% in shortgrass steppe	Paschke et al., 2000
2003	3346 g C m^{-2} sawdust increased prairie species 700%, decreased invasive plants 54% in tallgrass prairie	Blumenthal et al., 2003
2006	5691 g C m^{-2} MSW byproduct increased seeded grass biomass 2225% on degraded training lands	Busby et al., 2006
2007	5691 g C m^{-2} MSW byproduct decreased soil bulk density, increased pH, and increased soil C and N in degraded training land soils	Torbert et al., 2007
2007	220 g C m^{-2} sawdust and sucrose increased seeded plant cover 11% in European fields	Eschen et al., 2007
2007	high C waste materials immobilize N greater than 90 days in sandy soils	Busby et al., 2007
2010	1433 g C m^{-2} MSW byproduct increased cover of planted grasses 48% on degraded training lands	Busby et al., 2010
2011	1000 g C m^{-2} sucrose reduced cover of invasive plants 45% in Puget prairie	Kirkpatrick and Lubetkin, 2011
2012	effects of MSW byproduct on vegetation improvements persist greater than 5 years on degraded training lands	Watts et al., 2012a
2012	effects of MSW byproduct on soil physical and chemical properties persists greater than 5 years on degraded training lands	Watts et al., 2012b

Disturbed military training and testing lands are almost always reseeded with perennial native vegetation. Over the long term, this vegetation is most effective at mitigating erosion and providing suitable wildlife habitat. However, they are difficult to establish in the short term because they are slow growing and susceptible to competition with weedy plant species. Because native perennial vegetation is adapted to nutrient poor soils, oversupplying nutrients is detrimental to them and often results in failure. Adequate soil restoration often requires massive quantities of organic matter, but locating suitable additives is difficult and expensive. Further, many materials are unsuitable, as they have high nitrogen concentrations that encourage weed growth. The carbon:nitrogen (C:N) ratio of the material is important in determining suitability. Poultry litter, yard wastes, biosolids, and manures have C:N ratios less than 30, which results in an oversupply of nitrogen that encourages weed growth. Others, with high C:N ratios such as wood wastes, straw, high carbon anthropogenic wastes, and sucrose can immobilize enough nitrogen to allow native vegetation to dominate reseeded sites. Pulverized paper, with a C:N ratio of around 200, is an ideal source of organic matter to rehabilitate damaged soils and support native vegetation. This material has been previously overlooked as a carbon source for degraded soils, and could improve sustainability initiatives implemented by DoD by not only improving training land conditions, but by diverting a significant waste stream from landfills.

Overview of Process for Amending Soils with Pulverized Paper

The following lists the key steps required for implementing this technology, along with key questions that should be asked in each step. All parts are discussed in detail in this Guide.

Preparation- prior to paper collection

Permitting- What is required to legally apply pulverized paper to training lands?

Paper Stream Characterization- How much paper is produced? Where is it produced? How often is it currently collected? How is it collected?

Initiation- collection and storage of paper for utilization on training lands

Collection and Storage- How should paper be collected? Where should it be stored? How do I know how much paper is stored?

Transport- What is the best process for moving paper to and from the storage site?

Implementation- applying paper to training lands

Paper Application and Incorporation- How much paper do I have/need to apply? How best do I move it? Where am I putting it? How am I spreading it?

Seeding- Do I have enough of the right type of seed? How is it being applied?

Monitoring- How successful is my seeding over the short and long term?

The overall process includes understanding your installation's unique pulverized paper stream and requirements and developing the most effective plan to collect, store, and utilize the pulverized paper. Because each installation is different, no single approach for establishing this process is provided. However, learning specifics about the pulverized paper stream and putting some thought into the process for collection and storage will ensure that implementation of this technology will be a success.

Preparation

Permitting

A permit of some type will likely be required for land application of pulverized paper waste in most locales. The starting point for determining what is required should be the installation Environmental Directorate, as they will be knowledgeable on any required installation permits and probably any others as well. Contacting a state department of agriculture, environmental quality, or natural resources office may be necessary as well to obtain a state permit. Because permitting can take months for approval, this should be the initial action for preparing to implement a pulverized paper diversion program. While the permitting process is occurring, all other initiation activities can likely be completed, and implementation will occur more quickly.

Because of the novel nature of the paper material, a baseline chemical characterization may be required to alleviate concerns over contamination. Because no regulations exist for land application of pulverized paper, along with most other materials, guidelines established for land application of biosolids will likely be utilized for quality assurance (Table 2). Of these regulated metals, only copper (< 2 mg kg^{-1}) and zinc (20 mg kg^{-1}) were detected in paper samples, both of which are plant micronutrients that can be deficient in soils. However, certain states may have

Table 2. EPA ceiling concentrations for land application of biosolids[1]

Pollutant	Ceiling concentration (milligrams per kilogram)[1]
Arsenic	75
Cadmium	85
Copper	4300
Lead	840
Mercury	57
Molybdenum	75
Nickel	420
Selenium	100
Zinc	7500

1 From CFR 40 Part 503

different requirements and more stringent regulations. Concerns arose over additional contaminants in the paper stream from mylar films (phthalates), thermal paper (bisphenol A) and compact and digital video discs (antimony and bisphenol A). However, extensive analysis did not detect any phthalates or antimony, even in samples spiked with contaminants.

Bisphenol A was detected in most samples at low concentrations (parts per billion range). However, it is considered a readily biodegradable compound that does not persist in the environment. Thus, the low amounts applied to the soil with the paper are not likely to persist more than a few hours up to a few days, and pose no hazard to the environment (Klecka et al. 2001). Grab-bag sample collection can be sent to an EPA-certified laboratory for analysis if required by a permitting agency. An important consideration if this is required is to ensure all contaminants of concern are analyzed for to prevent delays and additional sample submission while minimizing costly analyses for compounds that are not required.

Paper Stream Characterization

Knowledge of installation source locations and production rates of pulverized paper will be necessary to formulate a collection and storage plan. Unfortunately, there is no centralized facility or plan in place to manage all of the pulverized paper produced across an installation. Most installations handle pulverized paper waste differently, and most sources of this material within each installation have their own mechanisms for management. Many offices possess their own cross-cut shredders and will produce small quantities of pulverized paper on an intermittent basis. These batches are often disposed of similar to garbage. Other entities that handle large amounts of classified documents or personally identifiable information, such as post hospitals, produce large amounts of pulverized paper wastes. These larger producers might have their own shredding facility or separate contract for the collection, shredding, and disposal of the paper. Identifying all of these sources, the amounts produced, the intervals in which they are managed, locations of storage receptacles, and existing management mechanisms will ensure that beneficial reuse is maximized and performed in an efficient manner.

Initiation

Collection and Storage

Collection of the paper material in an efficient manner will be the greatest challenge to successful implementation of a pulverized paper diversion program. Because of the variable nature of pulverized paper production, a system must be initiated to collect all of the pulverized paper material in a timely manner once it is produced, including small batches in garbage bags up to large batches in dumpsters. This system requires timely communication with multiple locales so that paper is collected in a timely manner upon production. Due to the variable production of pulverized paper on an intermittent basis, establishing a collection and storage mechanism will allow the amount of paper to grow over time until it reaches a volume where it is feasible for land application. This will likely take months, which provides ample time to identify application sites and logistics for application once the collection and storage is implemented and has begun to occur.

Due to multiple sources of pulverized paper across Fort Polk producing varying volumes of material, 2 separate collection efforts were initiated. For locations that produced large volumes of paper that were stored on-site, waste disposal drivers were instructed to empty dumpsters devoted to paper collection into a 20 cubic yard rolloff container that was rented specifically for paper centralization, rather than emptying dumpsters into garbage trucks for transport to the landfill. A cover was kept over the rolloff container to prevent moisture entry (Figure 2). Smaller sources of pulverized paper were treated as another recyclable material: collected in plastic bags, and placed at installation recycling collection sites at multiple locations. A recycling contractor collected recycled material from collection sites across Fort Polk, and separated the pulverized paper and delivered it to the centralized collection facility in garbage bags(Figures 3 and 4).

Issues that occurred with this method included having to empty the roll-off routinely when it became full (which required communicating with source locations to determine when paper was being disposed of) and having immense piles of plastic bags full of paper to contend with (Figure 5). Multiple roll-off containers could reduce this problem, but the added rental expense and increased area requirements would be detrimental. To reduce the proliferation of plastic bags for collection and transport of small batches of paper, cardboard boxes or plastic bins could be utilized where they are dumped at a centralized facility and returned to each collection site.

Figure 2. Approximately 1 ton of pulverized paper in a rented 20 cubic yard rolloff container.

Figure 3. Batch-collected paper collected by a contractor. This batch was from multiple locations across Fort Polk and dropped off at the storage location when other recyclable materials were collected.

Paper storage should be in a location where it is easily accessible with large equipment for drop off and pick up. An open-air pile would negate the use of plastic bags for storage and multiple roll-offs or other large volume containers. However, the risk exists for blowing of the paper into the surrounding area. Although this poses no hazard, it could create an eyesore and end up in areas where it is not desired. Wetting the pulverized paper causes it to stick together. This can be utilized to create a crust over open air piles to prevent movement. However, too much moisture would be detrimental, as the paper would be too sticky to easily spread, would weigh much more, and would begin to decompose and give off a musty smell. The best option for storage would be to utilize an existing bulk material bin or shelter similar to how construction materials and road salt are stored. This way the material is protected from moisture and wind and is accessible by large equipment. Covering paper piles with tarps could also be employed. However, any protected location where blowing paper can be contained and exposure to moisture could be minimized and managed would be suitable. Keeping a record of estimated paper mass or conceiving a means to estimate accumulated mass would be useful for future determinations of coverage for soil application and logistics.

Figure 4. Close-up of a small batch-collected waste paper source.

Figure 5. Bagged and weighed paper. Paper was stored in a greenhouse prior to transport to the field sites.

Transport

Because of the low density of pulverized paper (700 pounds or 1/3 ton per cubic yard), moving large masses requires large volumes of space. Dump trucks are the most efficient way to move paper from storage to application sites. The amount of paper held in trucks depends on the type of truck, and this information should be determined prior to implementation to determine number of loads, truck and driver availability, etc. A tandem axle dump truck holds 10 to 14 cubic yards of material. For pulverized paper, this would be 3.5 to 4.9 tons per truck. To apply paper to 1 acre at the recommended 16 ton per acre rate, approximately 4 tandem dump truck loads would be required. Most truck drivers will be able to quickly determine the dump angle and speed to apply a desired rate of paper over the application site (approximately 1 inch of paper in depth), although excessive moisture in the paper or a rough application site could make application from a dump bed difficult. In most situations, the truck will be able to directly deliver the paper to the application site and spread it. However, some training areas may not be easily accessible or conditions at the site may prevent direct deposition by the truck. In these situations, a loader of some type might be necessary for final placement. Ideally, the dump truck used for paper delivery and application will have a cover. However, if a cover is lacking, application of water over the surface of a loaded truck will cause the exposed layer of paper to stick and prevent blowing during transport. As the bulk of the paper will remain dry, this should not impede the application of paper from the dump truck.

Implementation

Paper Application and Incorporation

The ideal application rate for soils has been determined at 16 tons per acre from an incorporation standpoint utilizing a disk. This amounts to an average paper depth on the soil surface of about an inch. Most truck drivers will be able to quickly determine the dump angle and speed to apply a desired rate of paper over the application site. However, higher rates could be applied with the use of a rotary tiller or moldboard plow, since they will mix and turn the soil more effectively. Lower rates will not result in provision of a high level of benefits such as nutrient immobilization, pH increases, and lower bulk density, but they will still provide benefits, will still add organic carbon to the soil (Table 3), and will still result in landfill diversion and associated cost savings. The average installation is estimated to produce around 70 tons of pulverized paper per year. This amount would cover a little over 4 acres at the recommended application rate, or 1/3 of an acre per month assuming a consistent paper stream.

Table 3. Properties of pulverized paper.

				Plant Macronutrients (mg kg^{-1})						Plant Micronutrients (mg kg^{-1})				
Density (g ml^{-1})	C:N	C (%)	Na (mg kg^{-1})	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
0.4	202	37.9	1716	1900	5.8	155	56000	1400	880	3	1.8	1562	15	20

Paper can be applied to unworked or worked soils. Worked soils have the benefit of higher surface moisture and increased micro-topography (ridges, clods, and furrows), which both aid in preventing airborne movement of the paper (Figures 6 and 7). However, paper should always be worked into the soil using an implement described in the previous paragraph (Figures 8 and 9). The paper will not completely disappear into the soil and will still be visible on the soil surface (Figures 10-15). However, the paper remaining on the surface does not readily blow around once the incorporation has been completed.

Figure 6. Initial site preparation.

Figure 7. Prepared site ready for paper application.

Figure 8. Paper is spread evenly over plots. Plots contained varying application rates.

Figure 9. Paper incorporation using a compact tractor with disk.

Figure 10. Pulverized paper demonstration plots. Plots consisted of a control, 8, 16, 24, and 32 tons per acre of paper application. The 2 highest application rates did not incorporate into the soil, but residual paper remained on the soil surface for all application rates.

Figure 11. One month after incorporation of paper. Paper did not move from the locations where it was applied.

Figure 12. Three months after incorporation of paper and seeding.

Figure 13. Paper application after 1 growing season. The paper is still visible in 24 and 32 tons per acre application rates. Areas where paper is not visible received paper application rates of 16 tons per acre or less.

Figure 14. Vegetation establishment on paper application plots after 2 growing seasons.

Figure 15. 32 tons per acre paper application rate after 2 growing seasons. The rate was too high to effectively incorporate into the soil, resulting in a thick soil covering that prevented plant growth.

Seeding

One of the primary benefits of applying pulverized paper to disturbed soils is the advantage it provides to establishing desirable vegetation. Many native plants, particularly native perennial warm season grasses, are slow to establish and have high nitrogen use efficiency. This means that they are adapted to nutrient poor conditions and are not capable of taking advantage of excess soil nutrients. Many species are, however, and are often the undesirable weeds that take over disturbed soils and outcompete any desirable vegetation that is present because of their ability to utilize the excess nutrients to increase their growth rates and biomass. Pulverized paper addition to soil is one of many high carbon materials that has been utilized to decrease the availability of soil nutrients to aid in the establishment of desirable vegetation, also known as soil impoverishment.

To take full advantage of this benefit, seed perennial native vegetation, especially C_4 grasses. These species are long-lived, have very deep and dense root systems, and are resilient to a variety of environmental stresses. Most installations already utilize the best adapted native grasses for their particular environment for land rehabilitation and maintenance, so development of new seed mixes is not necessary in most locations. However, the need for herbicides, mowing, or other activities to ensure establishment will not be necessary when paper is incorporated into the soil at the recommended rate. Standard seeding practices already utilized for seeding this type of vegetation can be utilized, to include rangeland drill seeding and broadcast seeding. Broadcast seeding should be followed by cultipacking or harrowing to improve seed-soil contact for surface applied seeds.

Monitoring

Visual inspection of the site following seeding is not necessary, but occasional checkups to ensure that flooding or other natural phenomena have not moved the paper from the site are advised. The first year following seeding, plants will be small in stature and difficult to identify. However, in subsequent years the seeded plants will dominate and be easily identifiable. Comparing rehabilitated sites amended with paper to sites without the addition of paper over the long term is recommended to document the benefits that are provided.

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