EXECUTIVE SUMMARY

Pulverized Paper as a Soil Carbon Source for Degraded Training Lands

ESTCP Project RC-201416

JULY 2018

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TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 BACKGROUND/INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2.0 OBJECTIVES</td>
<td>3</td>
</tr>
<tr>
<td>3.0 TECHNOLOGY DESCRIPTION</td>
<td>5</td>
</tr>
<tr>
<td>4.0 PERFORMANCE ASSESSMENT</td>
<td>9</td>
</tr>
<tr>
<td>5.0 COST ASSESSMENT</td>
<td>13</td>
</tr>
<tr>
<td>6.0 IMPLEMENTATION ISSUES</td>
<td>15</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.</td>
<td>Flow Diagram for Technology.</td>
<td>6</td>
</tr>
<tr>
<td>Figure 2.</td>
<td>Paper Awaiting Incorporation and Seeding.</td>
<td>7</td>
</tr>
<tr>
<td>Figure 3.</td>
<td>After the First Growing Season.</td>
<td>9</td>
</tr>
<tr>
<td>Figure 4.</td>
<td>After 2 Growing Seasons.</td>
<td>10</td>
</tr>
<tr>
<td>Figure 5.</td>
<td>Highest Paper Application Rate after 2 Growing Seasons.</td>
<td>10</td>
</tr>
</tbody>
</table>
LIST OF TABLES

| Table 1. Mean Heavy Metal Concentrations of Fort Polk Pulverized Paper Samples. | 5 |

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iii
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1.0 BACKGROUND/INTRODUCTION

All DoD organizations are required to adhere to strict federal guidelines for the destruction of classified documents, compact discs, slides, Top Secret mylar communications film, and COMSEC. Further, medical records must be disposed of securely, with an option for cross-cut shredding/pulverization at the Army’s 42 hospitals. For security purposes, the majority of these organizations perform their document destruction onsite, often using industrial-sized shredders to accommodate large volumes of documents. Federal regulations require that Top Secret documents be pulverized to 0.9 x 4.2 mm, the smallest size required for classified documents. These pulverized pieces cannot be recycled by the paper industry since the fibers have been cut too short for reuse in the manufacturing of paper products. Many DoD facilities pulverize all of their documents for convenience and manpower/equipment operating efficiency, resulting in paper wastes that are often combined with other solid waste and landfilled. This adds to operational costs for the collection, transport, and disposal of pulverized paper, and directly conflicts with DoD’s aggressive sustainability policies. To resolve these issues, a successful method for reuse of this pulverized paper must be identified.

In a separate problem, DoD installations often experience significant erosion of training ranges. The primary mission for DoD is training the Warfighter, and preservation of military training lands is critical. To sustain this mission, technologies for mitigating erosion and rehabilitating degraded training lands must be validated and accepted. Disturbed military training and testing lands are almost always reseeded with native warm season perennial grasses. These grasses are adapted to nutrient-poor soils, and oversupplying nutrients is detrimental to them and often results in failure. Adequate soil restoration to reduce this overabundance of available nutrients often requires massive quantities of organic matter, but locating suitable additives is difficult and expensive. Pulverized paper is an ideal source of organic matter to rehabilitate damaged soils and support native vegetation. This material has been previously overlooked as a Carbon (C) source for degraded soils. Utilization of this material could improve sustainability initiatives implemented by DoD, by not only improving training land conditions, but by diverting a significant waste stream from landfills as well.

High C, wood-derived waste materials low in available Nitrogen (N) have been investigated thoroughly for their potential use as soil amendments to improve native vegetation establishment. In highly degraded soils lacking productivity, high C waste materials provide long lasting improvements to soil and vegetation. Alternatively, in disturbed productive soils, high C waste materials effectively immobilize N, favoring establishment of desirable perennial native vegetation. The technology demonstrated for this project is very simple: guidance does not exist for the utilization of pulverized paper for training land rehabilitation. As a readily available high C source, pulverized paper overcomes a significant hurdle to the use of high C organic amendments: the cost.

What remains to be accomplished is demonstration and validation of this technology using a readily available high C waste source in an operational environment to document cost-effective utilization and provide a means for technology transfer. This project will demonstrate and validate the use of pulverized paper for rehabilitation of degraded training lands, and identify the optimal application rate of this material in an operational setting. The performance of standard land rehabilitation plant species and techniques will be used for a direct comparison with their performance in previous investigations using other high C waste materials.
2.0 OBJECTIVES

The purpose of this project is to conduct an operational demonstration and validation to utilize pulverized paper as a source of organic matter for degraded soils, and to validate the creation of soil conditions commensurate with establishment of native vegetation on disturbed DoD training lands.

The goal of this project is to demonstrate and validate the cost-effective utilization of pulverized classified paper waste as an organic soil amendment for rehabilitation of severely disturbed training lands. Objectives include the following:

- Demonstrating improved vegetative cover and soil and plant health using pulverized paper as a soil amendment
- Validating the economic benefits of this utilization versus current practices for waste disposal and training land management
- Assessing potential paper waste contaminants to identify associated potential restrictions
- Developing user guidelines for transfer of this technology to end users

This proposed demonstration/validation project not only addresses a unique DoD problem in managing large volumes of classified paper wastes, but also addresses several high-priority Army environmental requirements in a cost-effective manner.

This project will provide a unique solution for reuse of pulverized classified documents. As DoD is the largest US producer of classified documents, providing an alternative to landfiling this pulverized paper will result in reduced operational costs while simultaneously supporting objectives and goals of the DoD Strategic Sustainability Performance Plan. This plan seeks to minimize and optimally manage solid wastes through reduced usage of printing paper, and a 50% diversion of non-hazardous solid waste from the waste stream to beneficial reuse. The successful mitigation of erosion and rehabilitation of DoD training ranges will ensure continued use for critical training, and it will maintain environmental stewardship of land assets in a cost-effective manner.
3.0 TECHNOLOGY DESCRIPTION

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 (Figure 1). This material has been previously overlooked as a C source for degraded soils, and could improve sustainability initiatives implemented by DoD, by not only improving training land conditions, but also by diverting a significant waste stream from landfills. The technology demonstrated for this project is very simple: guidance does not exist for the utilization of pulverized paper for training land rehabilitation. As a readily available high C source, pulverized paper overcomes a significant hurdle to the use of high C organic amendments: the cost.

Alternative technologies that exist for N immobilization are sucrose, sawdust, and other high C anthropogenic wastes. Advantages of the proposed technology over other technologies are availability, cost, and purity. Sucrose is the purest high C source, but its cost makes it unfeasible for large-scale utilization. Sawdust can be contaminated or pure, but its primary limitations are availability and cost. Most high C anthropogenic wastes are available and inexpensive, but contamination is high. Pulverized paper is low in contaminants (Table 1), widely available to the military, and associated costs are low. Major cost considerations are transportation to locations where it will be used and incorporation. However, because transportation costs are already incurred for removal, and current restoration activities already utilize mechanical devices to mix soil, this proposed technology can be repurposed for less cost than current disposal and rehabilitation practices.

Table 1. Mean Heavy Metal Concentrations of Fort Polk Pulverized Paper Samples.

Metals with values preceded by "<" were below detection limits for all samples; therefore, the detection limits are presented.

<table>
<thead>
<tr>
<th>Concentration (ppm)</th>
<th>Antimony</th>
<th>Arsenic</th>
<th>Cadmium</th>
<th>Chromium</th>
<th>Copper</th>
<th>Lead</th>
<th>Mercury</th>
<th>Molybdenum</th>
<th>Nickel</th>
<th>Selenium</th>
<th>Zinc</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>&lt;2.58</td>
<td>&lt;2.58</td>
<td>&lt;0.4</td>
<td>&lt;1.69</td>
<td>&lt;2.1</td>
<td>&lt;0.03</td>
<td>&lt;2.17</td>
<td>&lt;1.21</td>
<td>&lt;2.13</td>
<td>20.0</td>
<td></td>
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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.

Limitations of the technology include the need to store the material in an enclosure that prevents wind transportation, as well as the requirement that applications occur on more or less calm days. Volume availability also limits the applicability of the technology. Volumes produced by most installations will likely only allow annual treatment of a small area (likely in the range of 2-8 hectares (ha) (5-20 acre)) of highly disturbed sites at the highest application rates. A larger area (likely in the range of 8-32 ha (20-80 ac)) can be treated at lower application rates. This demonstration/validation will indicate what levels of change are observed across the range of application rates. This will allow end user utilization in the most effective manner given volume constraints. A further limitation is the seasonal effectiveness of the technology. To prevent offsite migration of the material, sites of application should be prepared by mechanical mixing of the soil. Frozen soil will prevent utilization in winter months. In climates where soil does not freeze, application of the material could be achieved during winter months, but decomposition of the material and nutrient immobilization could occur on a timescale that does not provide the greatest benefit to desirable native warm season perennial grasses if vegetation is not seeded and germinates soon after the material is applied.

Due to multiple sources of pulverized paper across Fort Polk producing varying volumes of material, two separate collection efforts were conducted. Large sources of paper that were stored in dumpsters at their respective sources were collected using a 20 cubic yard rolloff container placed at the edge of a parking lot. Instead of emptying these dumpsters in garbage trucks for transport to the landfill, waste management contractors instead emptied the paper dumpsters in the rolloff container. A cover was kept over the rolloff container to prevent moisture entry.
This container held approximately three tons of paper. Smaller sources of pulverized paper were collected by a recycling contractor. This contractor collected recycled material from collection sites across Fort Polk. The small batches of pulverized paper were placed into plastic bags and separated from other recyclable materials.

![Image of paper spread on a field](image)

**Figure 2. Paper Awaiting Incorporation and Seeding.**

Paper stored in the rolloff container was bagged and placed with the other paper stored in plastic bags. Because of the necessity for specific paper weights to be applied at the demonstration sites, storage in bags was necessary for accurate weighing and separation into different application rates. However, in full implementation where paper is to be applied in a similar manner, the requirement for storage in plastic bags is not necessary and is likely an impediment to efficient transportation and application to soils.

Approval for conducting this demonstration at Fort Polk, LA, was required at the state and installation levels. The Louisiana Department of Agriculture and Forestry issued a permit based on best management practices for application of the material to the soil. Fort Polk issued approval based on completion of Records of Environmental Concern for each of the two demonstration sites (Briley [32 tons acre\(^{-1}\)] and Eastwood [16 tons acre\(^{-1}\)]).

To obtain exact application rates for the demonstration, all paper was bagged in plastic bags and weighed to allow for accurate placement on field plots. Bags were weighed with a benchtop 400 pound capacity postal scale, weights were recorded on a piece of duct tape placed on the bags, and all bag weights were recorded to document total mass of paper cumulatively. Paper was then transported to the sites in a moving truck and spread by hand, disked, and seeded (Figure 2).
Paper application rates above 16 tons acre\(^{-1}\) did not incorporate into the soil and created a thick mulch on the soil surface that restricted plant growth and retained significant amounts of moisture (Figures 3-5). Due to this impediment, paper application rates at the second demonstration site were halved compared to the first site to ensure all application rates could be incorporated.
4.0 PERFORMANCE ASSESSMENT

A positive correlation was observed between paper application rate and native plant cover at both sites. A negative correlation was also observed between paper application rate and invasive plant cover at both sites. At the Briley site, native plant cover at the 32 tons acre\(^{-1}\) paper application rate was 42% higher than the control treatment. At the Eastwood site, native plant cover at the 16 tons acre\(^{-1}\) paper application rate was 48% higher than the control treatment.

The Eastwood site alone exhibited a positive correlation between planted grass biomass and paper application rate. A negative correlation was observed between paper application rate and invasive plant biomass. At the Briley site, native plant biomass at the 32 tons acre\(^{-1}\) paper application rate was 71% lower than the control treatment, due to the high rate of paper forming a thick mulch on the soil surface. However, at the Eastwood site, native plant biomass at the 16 tons acre\(^{-1}\) paper application rate was 90% higher than the control treatment. Although our target of a 50% increase in native plant biomass in the highest paper application rates relative to controls was not achieved (10% average across sites), we exceeded our target at one site (90% at Eastwood). Because of the difficulties in incorporating the high application rates into the soil, when using 16 tons acre\(^{-1}\) across both sites, an average of 74% is achieved, which exceeds our target.

Figure 3. After the First Growing Season.
Figure 4. After 2 Growing Seasons.

Figure 5. Highest Paper Application Rate after 2 Growing Seasons.
Plant concentrations of Ca and Mo were moderately correlated with paper application rate while P and S were weakly correlated at both sites. We achieved our target of positive correlation between application rate and a deficient plant nutrient concentration for both Ca and Mo across both sites. Soil Ca concentration was also correlated with paper application rate. As Ca content in the paper was high while being deficient in the soil, this is understandable.

Soil pH was positively correlated with paper application rate at both the Briley (Pearson correlation coefficient = 0.73, \(p < 0.001\)) and Eastwood (Pearson correlation coefficient = 0.55, \(p = 0.01\)) sites. For bulk density, paper application rate was moderately negatively correlated with bulk density (Pearson correlation coefficient = -0.60, \(p = 0.005\)) at the Briley site, while no correlation was observed at the Eastwood site (Pearson correlation coefficient = -0.07, \(p = 0.78\)). This was likely a result of utilizing paper application rates at this site that were half of what was planned due to incorporation difficulties at the higher rates.

Contaminant concentrations for EPA-regulated heavy metals were analyzed, with the expectation that no contaminant would be increased by more than 50% at the highest application rate. No contaminant reached a level even close to that number. In fact, no significant increase was observed for any regulated metal in the highest application rates versus control treatments, and no discernible increases could be attributed to paper application rates at any level for any regulated heavy metal. Because most EPA-regulated heavy metals were not detected in analyzed paper samples, a very conservative calculation of application limits is presented here based on detection limits of the analytical equipment. Using detection limits, the limiting contaminant would be molybdenum. This is based solely on its concentration limitation by the EPA in relation to the detection limits of the analytical instrument used to quantify concentrations, and in no way reflects its concentration in the paper. But using this estimate, and assuming an annual application of the recommended 16 tons of pulverized paper over the same acre of land every year, the cumulative EPA loading limit would be reached in 231 years.

However, if using heavy metals that were actually detected in the paper, copper and zinc (both of which are plant micronutrients), then zinc is the limiting factor. At an annual paper application rate of 16 tons, our recommended pulverized paper application rate, the cumulative EPA loading limit would be reached in 3,900 years.
5.0 COST ASSESSMENT

Fort Polk paper disposal costs for landfill placement run at $175 per ton. Collection and storage of the paper from small batch sources did not incur an additional cost as it was included in a contract for collection of all recyclable materials from the same collection locations. Storage of the larger batches of paper required rental of a rolloff container. The 20 cubic yard rolloff cost $114 per month, with a one-time charge of $250 for dropoff and pickup. This rental was required due to our bagging and weighing for exact application rates and would not be necessary for full implementation. Thus, this cost was not included in the final cost calculations. However, if storage in a rolloff(s) container is deemed desirable, purchasing or acquiring an excess container would be cost effective. Because storage occurred in unused buildings, the storage cost for paper was $0. Outside storage could be an option if blowing paper deposition in the area immediately surrounding the storage location is acceptable. Wetting the paper a single time causes the paper particles to stick together, which significantly reduces wind movement. Storage of paper in this way in an empty lot with a water hydrant would likely be most cost effective and easiest to store and load bulk paper material. Transport of bulk materials costs $0.40 per ton per mile at Fort Polk. Our overall cost estimate used this number and an average distance of 15 miles for collection and disposal at a training land, giving an overall paper disposal cost of $6.00 per ton.

Because site preparation with a disk is not performed at every location, this additional cost of site preparation was included, although at other locations this will likely not be the case. Because most installation land management departments already own a disk, acquisition costs are not included. Tractor operation costs for disking average close to $8 per acre nationwide, with an additional $21 labor cost per acre for disking ($42 per hour labor at a disking rate of 2 acres per hour). No other site preparation costs are required to incorporate pulverized paper into disturbed training lands undergoing rehabilitation.

At the recommended 16 tons per acre rate (and a cost of $96 for incorporation on 1 acre of land), the benefits will include an average reduction in bulk density of 5%, a 20% increase in pH (1 unit), a 40% increase in soil carbon, a 10% increase in basal cover of planted grasses, a 25% decrease in weed basal cover, and more than double the biomass of native warm season grasses.

Current estimates indicate that costs associated with Army land rehabilitation are $2,000 per acre ($4940 ha⁻¹) and 50% of all rehabilitation activities on these lands fail. This assessment is supported by the literature, where published analyses indicate that only 52% of restoration goals are achieved (Lockwood and Pimm, 1999). An additional analysis of 82 published reports and a global survey indicates that for year-old restorations in unprotected sites the success rate is 50%, but drops to 25% after 3 years (Godefroid et al., 2011). Assuming that half of all land rehabilitation actions currently must be repeated after 1 year and 3/4 must be repeated after 3 years, a 3-year life cycle cost for current practices is twice the estimated per unit cost. This number is based on half of the original sites requiring additional rehabilitation in year 2, while a quarter of the original sites require additional rehabilitation in year 3 along with half of the re-rehabilitated sites from year 2. Assuming 50% of failures are overcome with the addition of paper, the cost savings on a per acre basis amount to $2000 per acre.
The most important consideration for cost is paper movement. This single consideration will ultimately determine the cost effectiveness of technology implementation. Collection of paper from multiple sources and variable production rates will differ significantly both within and between installations. Smaller batches require greater collection times, removal from plastic bags, and disposal of plastic bags. Bulk materials can be collected and dumped easily from bulk containers, but requires larger equipment. Storage in an area that can be accessed by loaders and dump trucks will make paper utilization much more cost effective.

Current costs for disposal are $175 per ton. Current land rehabilitation costs are $4000 per acre when factoring in repeated efforts due to failure. Paper transportation costs $0.40 per ton per mile using a tandem axle dump truck with 10 to 14 cubic yard capacity. Site preparation costs $8 to disk paper in and $21 in labor to operate, with an overall cost of $29. Assuming an average distance from the paper source to the incorporation site of 15 miles, and utilizing a rate of 16 tons of paper per acre, the average acre will cost $96 to transport paper and $29 to incorporate it, for a grand total of $125 per acre, or approximately $8 per ton. This alone saves approximately $167 per ton compared to landfill disposal. Assuming the addition of paper reduces rehabilitation failures by 50%, this results in a cost savings of $2000 per acre, or $125 per ton of paper. Overall, the cost savings realized from diversion of pulverized paper waste from landfills to degraded training lands is $4,672 per acre, or $292 per ton of paper diverted. As the average installation likely disposes pulverized paper at a rate of 70 tons per year (based on populations of installations relative to Fort Polk and an assumption of similar per capita paper production rates), this could result in cost savings of $20,000 per installation per year, and a diversion of 70 tons of paper from the waste stream. At the Service level, a cost savings greater than $1 million per year could be realized.
6.0 IMPLEMENTATION ISSUES

Implementation required a permit from the Louisiana Department of Agriculture and Forestry for land application of the paper. Most states likely require a similar permit, but specific details will probably vary. Due to the novelty of the paper material, the exact permit that was applicable was not known. This caused a one-year delay in implementation as initially it was decided that no permit was required, but later the permit was requested. Land application of wastes are often required to adhere to 40 CFR Part 503 (Land Application of Sewage Sludge) at a minimum, and states may have more stringent requirements for one or all regulated contaminants.

A primary concern raised during site selection was the creation of an eyesore with paper material covering the soil surface. Due to this concern, our demonstration sites were moved from areas near highly traversed roadways to less frequented areas.