Biotic Soil Technology for Cost Effective Mine Closure Cover Systems

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Profile Products LLC
Presentation Overview

• What is **Biotic Soil Technology (BST)**?
• What goes into BST materials, how do they work, and when/where to use them?
• Engineered Soil Cover Systems (ESCS)
• Testing, Inspection and Monitoring Protocol
• Case Studies
• Discussion
What is the Most Cost-Effective form of Erosion Control?

Sustainable Vegetation!
What Is Sustainable Vegetation?

- **Vegetation** that when once established can persist through nutrient cycling in the natural environment.

- A **healthy soil is required** as the infrastructure to support and nurture vegetation.

- The **vegetation must be adapted** to the site conditions.
Key Elements of Healthy Soil

- **Minerals**
  - Carbon, macro-nutrients (N-P-K), micronutrients

- **Organic Matter**
  - Needed for microorganisms to convert or break down minerals to humus

- **Biological Activity**
  - Bacteria, fungi, protozoa, molds, nematodes, worms, etc.

- **Water**
  - Carrier of nutrients, all living things require water

- **Air**
  - Roots and many organisms require oxygen to survive
“Strive for 5%” Organic Matter

• Improves establishment and survival of vegetation
• **Improves soil structure** to better accommodate drainage and increases water retention
• **Improves erosion resistance**
  – Creation of pore spaces
  – Enhancement of soil aggregation (through microbial activity)
• **Reduces need for chemical based inputs**
  – Fertilizers, pesticides, herbicides and more
• **Improves rain/stormwater absorption and infiltration**
• For every **1% increase in organic matter, water-holding capacity increases by 16,500 to 27,000 gallons per acre** – depending on soil type (USDA NRCS 2013)
Ideal Soil Profile & Nutrient Cycling

Ideal Soil Composition

- Organic Matter: 5%
- Minerals: 45%
- Water: 25%
- Air: 25%

Carbon Sequestration!
Most projects start with “B” or “C” horizons, maybe even worse:

- Subsoils
- Saline Soils
- Mine Wastes
- Industrial Wastes
- Coal Combustible Residuals (CCR)
# Start with a Soil Test!

<table>
<thead>
<tr>
<th>Test</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water, salt and buffer pH levels</td>
<td>Soil reaction and neutralization requirements</td>
</tr>
<tr>
<td>Extractable Elements:</td>
<td></td>
</tr>
<tr>
<td>Macronutrients – Primary and Secondary (NO$_3$, P, K, Ca, Mg, SO$_4$)</td>
<td>Nutrient element availability</td>
</tr>
<tr>
<td>Micronutrients (B, Cl, Cu, Fe, Mo, Mn, Se, I, Zn)</td>
<td>Nutrient element availability</td>
</tr>
<tr>
<td>Other Elements (Al, Na)</td>
<td>Toxicity</td>
</tr>
<tr>
<td>Trace Elements and Heavy Metals (As, Cd, Co, Cr, Cu, Mn, Pb, Ni)</td>
<td>Toxicity</td>
</tr>
<tr>
<td><strong>Organic Matter Content</strong></td>
<td>Physical and chemical characteristics</td>
</tr>
<tr>
<td>Soluble Salts</td>
<td>Total salts in soil solution</td>
</tr>
</tbody>
</table>

*Agronomic Handbook Management of Crops, Soils, and Their Fertility* by J. Benton Jones, Table 11.1
Soil Texture

- Quantitative classification based on sand, silt, and clay percent composition
- Determined using a soil textural calculator & triangle
- Soil Texture can be an indicator for Cation Exchange Capacity, Buffer pH, Moisture Retention, and Erodibility
Introduction

Soil testing, interpretation of the test results, and incorporating prescriptive remedies to improve soils should be a fundamental part of any reclamation or revegetation project. Without a proper understanding of soils or substrates considered for use as growing media to establish vegetation, it is difficult to predict potential project success.

Prior to conducting and interpreting soil tests, it is important to understand test methods that are relevant for reclamation and/or vegetation establishment projects. There are various ways to extract measurable soil characteristics and analyze samples, but rarely do varying soil testing methods produce identical results. Further, it is important to properly collect and label soil samples prior to sending them to a reputable lab. Profile Products provides detailed instructions in its PS3 software program with three instructive videos that can be accessed at www.profileps3.com/video/soil-foundation-success-part-1-3. In addition, Profile has a laboratory dedicated to properly testing soils for erosion control projects at no cost to the client. Please go to www.profileps3.com and create your own account for more details.

Whether you are utilizing the Profile Products soil testing laboratory or another facility, please refer to the methodologies listed below to ensure you are employing relevant testing protocol for erosion control projects that require vegetative establishment.

Testing Methodology

- Texture/Particle Size Analysis - Hydrometer Method
- Soil pH and Soluble Salts - 1:1 Soil/Water Slurry and Saturated Paste Extraction
- Buffer pH - Sikora Method
- Cations (Ca, K, Mg, Na) - Ammonium Acetate Extraction
- Phosphorus - Bray 1 Extraction or Olson Extraction
- Trace Elements (Zn, Mn, Cu, Fe) - DTPA Extraction
- Sulfur - Phosphate Extraction
- Boron - DTPA/Sorbitol
- Nitrate Nitrogen - Cadmium Reduction
- Salinity Evaluation - Saturated Paste Extraction
- All Soluble Nutrients - Saturated Paste Extraction

Consistency in testing methods allows for simplified and more rapid evaluations of the results. Table 1 on Page 4 of this document provides optimal ranges for various soil parameters and values where deficiencies or excesses may compromise or limit vegetative establishment - using the test methods identified above. If your soils were tested with different methods or you need assistance in reviewing soil test results from our lab, please contact Profile Products Technical Services Department at (847) 215-3464 or tech@profileproducts.com.
### General Soil Test Interpretation

<table>
<thead>
<tr>
<th>Soil Characteristic Tested</th>
<th>Unit</th>
<th>Low Value (Deficiency)</th>
<th>Optimal Range (Sufficiency)</th>
<th>High Value (Toxicity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture</td>
<td>Physical Description</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Organic Matter (OM)</td>
<td>OM mass/sample mass</td>
<td>&lt; 3%</td>
<td>3% – 5%</td>
<td>&gt; 10%</td>
</tr>
<tr>
<td>pH</td>
<td>ppm</td>
<td>&lt; 6.3</td>
<td>6.3 – 7.3</td>
<td>&gt; 7.3</td>
</tr>
<tr>
<td>HCO₃ (Bicarbonate)</td>
<td>ppm</td>
<td>n/a</td>
<td>&lt; 0.75</td>
<td>&gt; 7.0</td>
</tr>
<tr>
<td>Electrical Conductivity (EC)</td>
<td>mmhos/cm = ds/m</td>
<td>n/a</td>
<td>&lt; 480</td>
<td>&gt; 4480</td>
</tr>
<tr>
<td>Total Dissolved Solids (TDS)</td>
<td>ppm</td>
<td>n/a</td>
<td>&lt; 2.0</td>
<td>&gt; 7.0</td>
</tr>
<tr>
<td>Sodium Adsorption Ratio (SAR)</td>
<td>ppm</td>
<td>&lt; 10</td>
<td>10 – 30</td>
<td>&gt; 30</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>ppm</td>
<td>&lt; 20</td>
<td>20 – 40</td>
<td>&gt; 40</td>
</tr>
<tr>
<td>Bray 1 P (Phosphorus) pH &lt; 7.2</td>
<td>ppm</td>
<td>&lt; 10</td>
<td>10 – 25</td>
<td>&gt; 25</td>
</tr>
<tr>
<td>Olsen P (Phosphorus) pH &gt; 7.2</td>
<td>ppm</td>
<td>&lt; 150</td>
<td>150 – 250</td>
<td>&gt; 250</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>ppm</td>
<td>&lt; 60</td>
<td>60 – 300</td>
<td>&gt; 300</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>ppm</td>
<td>&lt; 400</td>
<td>&gt; 400</td>
<td>n/a</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>ppm</td>
<td>&lt; 5</td>
<td>5 – 20</td>
<td>&gt; 20</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>ppm</td>
<td>&lt; 1.0</td>
<td>1.3 – 3.0</td>
<td>&gt; 5.0</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>ppm</td>
<td>&lt; 2.5</td>
<td>4.1 – 12.0</td>
<td>&gt; 50</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>ppm</td>
<td>&lt; 1.0</td>
<td>1.0 – 2.0</td>
<td>&gt; 2.0</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>ppm</td>
<td>&lt; 4.5</td>
<td>7.1 – 20.0</td>
<td>&gt; 70</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>ppm</td>
<td>&lt; 0.5</td>
<td>1.0 – 1.5</td>
<td>&gt; 2.0</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>ppm</td>
<td>&lt; 10</td>
<td>10 – 20</td>
<td>&gt; 800</td>
</tr>
<tr>
<td>Chloride (Cl)</td>
<td>ppm</td>
<td>&lt; 5</td>
<td>10 – 30</td>
<td>&gt; 50</td>
</tr>
<tr>
<td>Cation Exchange Capacity (CEC)</td>
<td>—</td>
<td>&lt; 5</td>
<td>10 – 30</td>
<td>&gt; 50</td>
</tr>
</tbody>
</table>
How Do We Increase Organic Matter Content in Our Soil?

- Topsoil
- Compost
- Peat
- Manure or biosolids
- Wood chips, sawdust, straw, etc.
Ideally – We Would Place 4-8 in. (10-20 cm) of Biologically Active, Organic Rich Topsoil Over Every Project

However,

• There is not enough quality topsoil available.
• Even if available, topsoil may be too wet or frozen to dig or transport.
• Topsoil cannot be effectively placed on steep slopes and can actually increase erosion potential.
• Stockpiled topsoil results in mostly “top dirt” since only the surface material remains biologically active after only a few weeks of storage.
• Costs of obtaining, hauling and placing topsoil can be significant.
• Borrow Areas must then also be reclaimed!
Stockpiling of Onsite Topsoil

Do you think there will be much biological activity within the pile within a few weeks?

Is your topsoil simply “The Dirt that lies on Top?”
Biotic Soil Technology (BST)

• Generic term to describe manufactured growth media or “engineered soils” containing recycled biodegradable fibers, biostimulants, biological inoculants and other amendments
• Designed to promote regeneration of denuded soils and accelerate sustainable vegetative establishment
• Why import “topsoil” when you can build a soil in place?
Mixing and Application

- **Pre-packaged bales** mixed with water, seed, fertilizer, amendments and other components
- **Applied below** hydraulically-applied or rolled erosion control products, blown straw or **even sod**
- **Complements performance** of hydraulically-applied erosion control products such as Flexible Growth Medium
One-Step Approach

More convenient/uniform application using standard equipment

Biotic Soil Media, Biostimulant, Seed, and Fertilizer Application

< 1.5 tank loads/acre with a 3,000 gallon hydromulcher

Safety!

Caltrans
Hwy 133 & 241 Toll Roads
Some Common BST Components

• Bark and Wood, Straw, Flax, Fibers – *phyto-sanitized* to provide organic matter, erosion resistance and high moisture retention *without weed seeds and pathogens*

• **Soil Building Components:**
  
  o *Porous Ceramics and Biochar* – stable, porous particles that demonstrate a high CEC, ability to hold water/nutrients & act as habitat (“coral reef”) for beneficial bacteria and fungi
  
  o **Beneficial Bacteria** – colonize “fresh” substrates and essential for soil processes, Nitrogen fixation, aggregation of soil particles, and maintenance of soil nutrients

  o **Endomycorrhizae** – symbiotic association of a *fungus* and plant roots to facilitate nutrient and water uptake that improves drought, disease and salinity resistance

  o **Humic Acid** – principal component of humic substances, which are the major organic constituents of soil (humus), peat and coal produced by biodegradation of dead organic matter

  o **Seaweed Extract (cytokinins)** – plant growth substances (phyto-hormones) that promote cell division or cytokinesis in plant roots and shoots

• **Cross-linked Polysaccharide Biopolymers/Flocculants** — increase water-holding capacity, viscosity, bond strength and “*shoot-ability*” of the media matrix
How Do BST Work to Build Soils?

- BST improves soil **chemistry** – which later improves soil **structure/texture** with increased organic matter and biological **activity** combined with plant establishment and subsequent nutrient cycling.

- Helps O & A horizons to regenerate faster by creating a **“revegetation platform”**.

- While the soil chemistry is improving, the media provides a more ideal growing **environment**.

- Provides rapid growth establishment and sustains long-term vegetation.

Five Weeks After BST Installation
Developing an “Engineered O Horizon”
# Typical BST Application Rates

<table>
<thead>
<tr>
<th>% Organic Matter</th>
<th>lb/ac</th>
<th>kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.75</td>
<td>5,000</td>
<td>5,600</td>
</tr>
<tr>
<td>≥0.75 to &lt;1.5</td>
<td>4,500</td>
<td>5,040</td>
</tr>
<tr>
<td>≥1.5 to &lt;2.0</td>
<td>4,000</td>
<td>4,480</td>
</tr>
<tr>
<td>≥2.0 to &lt;5.0</td>
<td>3,500</td>
<td>3,920</td>
</tr>
</tbody>
</table>

- Always conduct a soil test to determine agronomic needs.
- Soils with organic matter ≥5% typically do not require BST.
- Depending on the test results, it is typically advisable to apply fertilizer, pH neutralizers and/or additional biostimulants with BST.
Biotic Soil Technology (BST)

Descriptors or Categories include:

- Biotic Soil Amendment (BSA)
- Biotic Soil Media (BSM)
- Engineered Soil Media (ESM)
- Hydraulic Growth Medium (HGM)
- Hydraulic Biotic Soil Amendment (HBSA)
- Organic Fiber Matrix (OFM)
Coal Ash Closure Capping System

Engineered Capping System

- Topsoil layer
- Protective soil layer
- Vegetation

18"

4" - 8"

18"
“Traditional Cover System”

18” Cover Soil and ~6” Topsoil
Engineered Soil Cover System (ESCS)

A Side by Side Comparison

Traditional Cover System

Engineered Soil Cover System

1. Waste
2. Barrier
3. Drainage
4. Cover Soil
5. Topsoil
6. Erosion Control Material

4–8”

18”
### Volume Based Topsoil and/or Compost

#### MATERIAL COST

<table>
<thead>
<tr>
<th>Material</th>
<th>Depth in Inches</th>
<th>Cubic Yards Needed</th>
<th>Cost Per Cubic Yard</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topsoil</td>
<td>6</td>
<td>242,000</td>
<td>$10.00</td>
<td>$2,420,000.00</td>
</tr>
<tr>
<td>Compost/Other</td>
<td>0</td>
<td>0</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td><strong>Total Material</strong></td>
<td>6</td>
<td><strong>242,000</strong></td>
<td></td>
<td><strong>$2,420,000.00</strong></td>
</tr>
</tbody>
</table>

#### TRANSPORTATION & INSTALLATION COST

<table>
<thead>
<tr>
<th>Truck Size</th>
<th>Cubic Yards</th>
<th>Total Truckloads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22</td>
<td>11,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material Hauling</th>
<th>Number Of Truckloads</th>
<th>Miles to Job Site</th>
<th>Cost Per Mile¹</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topsoil</td>
<td>11,000</td>
<td>0</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Compost</td>
<td>0.0</td>
<td>0</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td><strong>Installation</strong></td>
<td><strong>242,000</strong></td>
<td></td>
<td><strong>$8.00</strong></td>
<td><strong>$1,936,000.00</strong></td>
</tr>
</tbody>
</table>

| Total Transportation & Installation Cost | **$1,936,000.00** |
| Total Cost                              | **$4,356,000.00** |
### Cost Comparison Calculator

<table>
<thead>
<tr>
<th>Material</th>
<th>Application Rate (lb/ac)</th>
<th># Bags Needed</th>
<th>Cost Per Bag</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biotic Soil Media</td>
<td>3,500</td>
<td>46,297</td>
<td>$45.00</td>
<td>$2,083,370.08</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transportation</th>
<th>Number Of Pallets²</th>
<th>Cost Per Pallet³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biotic Soil Media</td>
<td>1,157.4</td>
<td>$0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Installation⁴</th>
<th>Acres</th>
<th>Cost per Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biotic Soil Media</td>
<td>300</td>
<td>$2,000.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total BSM Cost</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$2,683,370.08</td>
</tr>
</tbody>
</table>

**BSM Cost Savings:** 38.4% $1,672,629.92
BSM Application on Cover System over Dirt Fill
Three Weeks Later!
Cripple Creek and Victor Gold Mine

• Famous gold mining district in Rocky Mountains of Colorado
• Elevation is 2,927 m (9,600 feet) in elevation
• Site receives snow in winter with summer rains, < 750 mm/year (30 in/year)
• Biotic Soil Technology was first applied in summer of 2014
• Topped with Flexible Growth Medium - FGM
1. **VLF Chemical Closure:** Following gold recovery, CC&V will rinse the spent ore with water over a period of several years to meet State water quality standards.

2. **VLF Final Reclamation:** Following chemical closure activities, the VLF liner will be punctured and the slopes will be regraded to an erosionally-stable shape, topsoil will be placed, and the area will be revegetated to meet post-mining land use goals.
Remote Placement of Biotic Soil Tech
Flexible Growth Medium
Applied Over BST
Hydroseeder w/Remote Hoses
October 2014 -
Good growth for 1st
Growing Season in
High and Dry Climate
Degraded Mine Site
Southeastern US – March 2016

Erosion Over 10 Year Period
3 Failed Reclamation Attempts
Mine Location

Site
## Results of Initial Soil Tests

<table>
<thead>
<tr>
<th>Sandy Clay Loam</th>
<th>December 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic Matter</td>
<td>- 0.4%</td>
</tr>
<tr>
<td>pH</td>
<td>- 5.0</td>
</tr>
<tr>
<td>Nutrients</td>
<td>Very low</td>
</tr>
</tbody>
</table>
## Typical BSM Application Rates

<table>
<thead>
<tr>
<th>% Organic Matter</th>
<th>lb/ac</th>
<th>kg/ha</th>
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<tr>
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<td>5,600</td>
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<tr>
<td>&gt;1.5 to &lt;2.0</td>
<td>4,000</td>
<td>4,480</td>
</tr>
<tr>
<td>&gt;2.0 to &lt;5.0</td>
<td>3,500</td>
<td>3,920</td>
</tr>
</tbody>
</table>

- Always conduct a soil test to determine agronomic needs.
- Soils with organic matter >5% typically do not require BST.
- Depending on the test results, it is typically advisable to apply fertilizer, pH neutralizers and/or additional biostimulants with BSM.
April 25, 2016

Per soil test recommendations installed:
- 5,600 kg/ha (5,000 lb/ac) of BST
- 3,920 kg/ha (3,500 lb/ac) of HP-FGM
- Fast-Acting Lime
- Slow-Release and Fast-Acting Biostimulant Additives

Slopes were cat tracked to:
- Increase soil roughness
- Reduce erosion potential
- Create pockets for germination
April 25, 2016

- Site after Tropical Storm Colin dumped 150 mm (6 in) of rain on June 5-6
- No soil loss into lake

Drone shot of applications over 2 hectare (5 ac) site
Day After Tropical Storm Colin
Field Data – Follow-up Visits

- Soil erosion
- Vegetation establishment
  - Basal Cover
  - Biomass
  - Species diversity
- Functional longevity
- Precipitation and weather data
Mine Reclamation Complete

October 2016

**Project Summary**

- Initiated/Completed Final Design Jan/Feb 2016
- Completed Grading & re-Contouring & Application by end of April 2016
- Site inspection mid-August 2016 by Regulatory Agency
- Achieved Bond Release on September 1, 2016
- < 4 Months from Time of Installation until Release
Field Soil Properties

- Ongoing testing of representative site soils conducted by an accredited laboratory
- Determine agronomic potential
- Monitor key parameters such as:
  - pH, texture, percent OM, availability of macro- and micro-nutrients, CEC, and TDS
- Subsequent tests over the first few growing seasons
- Document changes in soil make up and chemistry
## Mine Site Soil Test Results

<table>
<thead>
<tr>
<th>December 2015</th>
<th>December 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sandy Clay Loam</strong></td>
<td><strong>Sandy Clay Loam</strong></td>
</tr>
<tr>
<td>- Organic Matter – 0.4%</td>
<td>- Organic Matter – 2.0%</td>
</tr>
<tr>
<td>- pH – 4.8</td>
<td>- pH – 5.3</td>
</tr>
</tbody>
</table>

Background Organic Matter is 1.5%
Soil Respiration

<table>
<thead>
<tr>
<th>Condition</th>
<th>Average C-CO₂ (ppm)/100g/day</th>
<th>% Increase in Soil Respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated Soil</td>
<td>17.4</td>
<td>n/a</td>
</tr>
<tr>
<td>BST Treated Soil</td>
<td>47.1</td>
<td>271%</td>
</tr>
</tbody>
</table>

- Significant increase in soil respiration with BST treated soil compared to untreated area after 18 months
- Indicator BST treated soil is improving soil health
## Bacteria/Fungal Counts

<table>
<thead>
<tr>
<th>Condition</th>
<th>Bacteria (cells/g soil)</th>
<th>% Increase in Bacteria</th>
<th>Fungi (cells/g soil)</th>
<th>% Increase in Fungi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated Soil</td>
<td>6.7E+09</td>
<td>n/a</td>
<td>1.1E+07</td>
<td>n/a</td>
</tr>
<tr>
<td>BST Treated Soil</td>
<td>2.3E+10</td>
<td>345%</td>
<td>1.6E+07</td>
<td>142%</td>
</tr>
</tbody>
</table>

- Significant increase in both bacteria and fungal counts in BST treated soil compared to untreated area after 18 months
- Indicator BST treated soil is improving soil health
“The Five Fundamentals”

Create Optimal Soil Conditions

Pick the Right Plant Species

Select the Correct Erosion Control Materials

Ensure Proper Installation

Inspection and Maintenance
Biotic Soil Technology

“Spray it, Don’t Spread it!”