A Greener Revolution and a No-Regrets Carbon Capture Mechanism for New Mexico

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Part 1:
Greener Revolution
Reduced Water Holding Capacity

Soil Salinization

Soil Loss Through Wind Erosion

Pollution Through Chemical Runoff

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peak (s)oil...!
How Do We Reverse These Trends?

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Plants are no different from us as they are also outnumbered by their Microbial Counterpart and depend on them for nutrient acquisition, pathogen protection and gene regulation.
Plant Succession Ladder as a Function of Fungal:Bacterial Ratio (F:B)

- **Bacterial**
  - Bare Soil Parent Material
  - 100% Bacterial

- **Fungal**
  - Weeds (High NO₃, Lack of Oxygen)
  - Cyanobacteria, True Bacteria, Protozoa, Fungi, Nematodes
  - Early Grasses, Bromus, Bermuda
  - Mid-grasses, Vegetables
  - Late Successional Grasses, Row Crops
  - Shrubs, Vines, Bushes
  - Deciduous Trees
  - Conifer, Old Growth Forests

Increasing Ecosystem Productivity

Elaine Ingham - www.soilfoodweb.com

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The Beginning to this research path…. 

**Dairy Cow Manure**

United States Department of Agriculture (USDA) needed a composting system that allowed:

- *minimum infrastructure & labor investment*,
- *an efficient and low-cost process,*
- *a most importantly….. a superior end product.*
Johnson-Su Composting Bioreactor
Johnson/Su Static Composting Technology

• Reduces water usage by a factor of 6 times
• Reduces composting time by 66%
• Results in a low salinity compost (~2-3 mS/cm)
• Amenable to incorporation of vermicomposting after thermophilic phase (observed 10X N increase in end product)

Produces a “HIGH QUALITY” nutrient rich, fungal dominated, high-microbial-biomass & bio-diverse compost
**Biological Analysis**

**Soil**

Report prepared for:
WERC / NMSU
David C Johnson
PO Box 30001 MSC WERC
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Report Sent: 8/15/2013
Sample: 01-117115 | Submission: 01-023294
Unique ID: 130805-6
Plant: Not Indicated

Invoice Number: 0
Sample Received: 8/7/2013

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**Fungal Mass**

- **Results**
  - Dry Weight: 0.480 µg/g
  - Active Bacteria: 89.5 µg/g
  - Total Bacteria: 621 µg/g
  - Active Fungi: 82.7 µg/g
  - Total Fungi: 2682 µg/g
  - Hyphal Diameter: 2.85 µm

**Expected Range**
- Low: 0.45
- High: 0.85

- For interpretation of this report please contact:
  Earthfort Labs
  info@earthfort.com
  (541) 257-2612

Consulting fees may apply

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**Nematode Detail**

- **Classified by type and identified to genus.**
  (If section is blank, no nematodes identified.)

<table>
<thead>
<tr>
<th>Nematode Type</th>
<th>Bacterial Feeder</th>
<th>Endo</th>
<th>Ecto</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butierus</td>
<td>18.62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cephalobus</td>
<td>1.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cubicula</td>
<td>4.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diplasotrentus</td>
<td>0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diploscopter</td>
<td>7.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prodesmodora</td>
<td>2.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhabditidae</td>
<td>2.19</td>
<td></td>
<td></td>
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<tr>
<td>Fungal/Root Feeder</td>
<td>0.55</td>
<td></td>
<td></td>
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<tr>
<td>Detylenchus</td>
<td>4.38</td>
<td>Stern &amp; Bulb nematode</td>
<td></td>
</tr>
<tr>
<td>Filenchus</td>
<td>3.29</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Protozoa (Numbers/g)**

- **Flagellates**
  - Results: 28858
  - Comments: Good

- **Amoebae**
  - Results: 577176
  - Comments: High

- **Ciliates**
  - Results: 2816
  - Comments: High

- **Total Nematodes/g**
  - Results: 23.0
  - Comments: Not Ordered

**Mycorrhizal Colonization (%)**

- **ENDO**
  - Results: 10%
  - Comments: Not Ordered

- **ECTO**
  - Results: 10%
  - Comments: Not Ordered

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**Organism Biomass Ratios**

<table>
<thead>
<tr>
<th>Total Fungi to Tot.Bacteria</th>
<th>Active to Total Fungi</th>
<th>Active to Total Bacteria</th>
<th>Active Fungi to Act.Bacteria</th>
<th>Nitrogen Cycling Potential (lbs/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Results</td>
<td>4.32</td>
<td>0.03</td>
<td>0.14</td>
<td>0.92</td>
</tr>
<tr>
<td>Comments</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>300+</td>
</tr>
</tbody>
</table>

**Expected Range**
- Low: 1
- High: 2
Experiment 1
Plant Growth Comparison to Eight Local Composts Using Chile Plants

<table>
<thead>
<tr>
<th>Trial Number</th>
<th>Peat Humus</th>
<th>Omni</th>
<th>Miracle Grow</th>
<th>Premium Org Potting Soil</th>
<th>Sterilized Manure</th>
<th>Composted Cow Manure</th>
<th>Organic Top Soil Top Choice</th>
<th>Potting Soil Natures Way</th>
<th>Charcoal Compost</th>
<th>Charcoal Compost (watered 4 months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Saturation</td>
<td>122</td>
<td>110</td>
<td>237</td>
<td>121</td>
<td>91.4</td>
<td>111</td>
<td>115</td>
<td>117</td>
<td>126</td>
<td>156</td>
</tr>
<tr>
<td>Calcium (meq/L)</td>
<td>96.6</td>
<td>7.48</td>
<td>7.34</td>
<td>43.6</td>
<td>5.44</td>
<td>43.7</td>
<td>72.8</td>
<td>7.59</td>
<td>6.9</td>
<td>10.1</td>
</tr>
<tr>
<td>ESP (%)</td>
<td>27.3</td>
<td>21.3</td>
<td>12.1</td>
<td>32.3</td>
<td>39.3</td>
<td>30.9</td>
<td>28.4</td>
<td>21.7</td>
<td>1</td>
<td>3.2</td>
</tr>
<tr>
<td>Copper (ppm)</td>
<td>3.96</td>
<td>9.39</td>
<td>1.8</td>
<td>4.4</td>
<td>15.29</td>
<td>9.72</td>
<td>2.77</td>
<td>5.57</td>
<td>1.43</td>
<td>1.81</td>
</tr>
<tr>
<td>EC (mmhos/cm)</td>
<td>58.1</td>
<td>15.3</td>
<td>11.7</td>
<td>40.5</td>
<td>39.9</td>
<td>66.3</td>
<td>60.3</td>
<td>6.05</td>
<td>2.92</td>
<td>3.84</td>
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<tr>
<td>Fe (ppm)</td>
<td>65.1</td>
<td>194.9</td>
<td>39.58</td>
<td>52.05</td>
<td>146.5</td>
<td>59.23</td>
<td>41.16</td>
<td>74.44</td>
<td>7.97</td>
<td>15.49</td>
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<tr>
<td>K (ppm)</td>
<td>13300</td>
<td>3640</td>
<td>4450</td>
<td>7480</td>
<td>102</td>
<td>15600</td>
<td>11700</td>
<td>975</td>
<td>945</td>
<td>1010</td>
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<tr>
<td>Mg (meq/L)</td>
<td>65.1</td>
<td>8.02</td>
<td>8.01</td>
<td>31.3</td>
<td>3.71</td>
<td>55.7</td>
<td>57.8</td>
<td>3.83</td>
<td>3.53</td>
<td>10.8</td>
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<tr>
<td>Mn (ppm)</td>
<td>5.66</td>
<td>24.19</td>
<td>45.17</td>
<td>6.74</td>
<td>13.61</td>
<td>6.26</td>
<td>7.64</td>
<td>16.4</td>
<td>12.89</td>
<td>22.16</td>
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<tr>
<td>NO3-N (ppm)</td>
<td>3052.7</td>
<td>12.2</td>
<td>30.5</td>
<td>74.7</td>
<td>1057.6</td>
<td>1971.9</td>
<td>2115.3</td>
<td>5.1</td>
<td>19.1</td>
<td>20.13</td>
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<tr>
<td>Org Matter (%)</td>
<td>21.35</td>
<td>19.23</td>
<td>38.5</td>
<td>20.98</td>
<td>15.27</td>
<td>20.05</td>
<td>18.44</td>
<td>20.1</td>
<td>14.57</td>
<td>16.54</td>
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<tr>
<td>pH</td>
<td>7.2</td>
<td>8.5</td>
<td>7.8</td>
<td>7.5</td>
<td>9.6</td>
<td>7.8</td>
<td>7.1</td>
<td>7.7</td>
<td>7.9</td>
<td>7.8</td>
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<tr>
<td>P (ppm)</td>
<td>752.6</td>
<td>482.1</td>
<td>869.4</td>
<td>957.8</td>
<td>2285.9</td>
<td>434.7</td>
<td>365.6</td>
<td>298.9</td>
<td>656.9</td>
<td>835.4</td>
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<tr>
<td>Na (meq/L)</td>
<td>237</td>
<td>53.4</td>
<td>28.2</td>
<td>203</td>
<td>95.6</td>
<td>220</td>
<td>224</td>
<td>47</td>
<td>6.21</td>
<td>10.1</td>
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<tr>
<td>SAR</td>
<td>26.36</td>
<td>19.18</td>
<td>10.18</td>
<td>33.17</td>
<td>44.7</td>
<td>31.21</td>
<td>27.72</td>
<td>19.67</td>
<td>2.72</td>
<td>3.12</td>
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<tr>
<td>Zn (ppm)</td>
<td>32.9</td>
<td>63.67</td>
<td>24.34</td>
<td>26.52</td>
<td>43.82</td>
<td>29.11</td>
<td>28.72</td>
<td>30.8</td>
<td>16.32</td>
<td>27.88</td>
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<tr>
<td>Fungal:Bacterial</td>
<td>0.027</td>
<td>0.007</td>
<td>0.031</td>
<td>0.003</td>
<td>0.067</td>
<td>0.060</td>
<td>0.194</td>
<td>0.070</td>
<td>0.404</td>
<td>0.420</td>
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<tr>
<td>Growth Volume (mL)</td>
<td>3804</td>
<td>732</td>
<td>2994</td>
<td>1680</td>
<td>1096</td>
<td>7984</td>
<td>8923</td>
<td>325</td>
<td>15626</td>
<td>17579</td>
</tr>
</tbody>
</table>

Greenhouse Trial

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Experiment 2
$r^2 = 0.91$
New Soil Carbon (g) & F:B Ratio

$\begin{array}{cccccc}
0.31 & 1.01 & 1.72 & 2.67 & 3.93 & 4.92 \\
\end{array}$

Beginning Soil C (%)

$\begin{array}{cccccc}
\text{New Soil C (g)} & \\
\text{F:B Ratio} & \\
\end{array}$

$\text{Fungal:Bacterial Ratio}$

$r^2 = 0.99$

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Carbon Partitions (Total New C & Plant+Root C)

- Total System New C
- Plant + Root C

>70% Carbon Flow into Soils

```
<table>
<thead>
<tr>
<th>Beginning Soil C (%)</th>
<th>Carbon (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.31</td>
<td>2.67</td>
</tr>
<tr>
<td>1.01</td>
<td>4.92</td>
</tr>
<tr>
<td>1.72</td>
<td>3.93</td>
</tr>
<tr>
<td>2.67</td>
<td>1.72</td>
</tr>
<tr>
<td>3.93</td>
<td>1.01</td>
</tr>
<tr>
<td>4.92</td>
<td>0.31</td>
</tr>
</tbody>
</table>
```

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Experiment 3
Carbon Partitioning vs. increasing F:B Ratio

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Nitrogen Partitioning vs. increasing F:B Ratio

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Field Trials of a Biologically Enhanced Agricultural Management (BEAM) Approach
Control (No Previous Covercrop Application)
Total Dry Biomass Production = 1 ton/Acre

1 Year’s Previous Covercrop Application
Total Dry Biomass Production = 5 tons/Acre
Conventional
150# Nitrogen/Acre

BEAM
Transitioning
1.5 years
What Does BEAM Offer Towards Soil Carbon Sequestration?
Shift to Fungal Dominant Soils

23 Times Increase in Fungal Mass

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Exudate Based Soil Carbon

Greater than 50% plant carbon partitioned to soil microbes

$R^2 = 0.9441$

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Higher Biomass Production

- Swamp and Marsh: 2000 g dry aboveground biomass/m²/yr
- Advanced: 4279 g dry aboveground biomass/m²/yr (37.25 mt C ha⁻¹ yr⁻¹)
- Transitional: 1980 g dry aboveground biomass/m²/yr (10.71 tons C ha⁻¹ yr⁻¹)
- Cultivated Land: 650 g dry aboveground biomass/m²/yr
- Tropical Rain Forest: 2200 g dry aboveground biomass/m²/yr

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Reduced Soil Respiration

Soil C Respiration (g C/m²/day)

Desert (0.3% C)
Control (0.6%C)
Conventional (0.6%C)
Transitional (1.52%C)
Advanced (7.6%C)

Soil C Percent (%)
Reduced Soil Respiration

Relative Respiration Rate vs. Soil Carbon Percent

- One Year Field Study
- 2012 Greenhouse
- 2013 Greenhouse

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Changes in Soil Nutrients Over a 20 Month “BEAM” Application Period

<table>
<thead>
<tr>
<th>Macro Nutrients</th>
<th>Polynomial/GLM Model</th>
<th>R²</th>
<th>% Increase/Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Kjeldhal Nitrogen (TKN)</td>
<td>y = 1.0585x² - 2.8141x + 658.59</td>
<td>0.84</td>
<td>58.30%</td>
</tr>
<tr>
<td>Nitrate (NO3-N)</td>
<td>y = 0.105x + 1.4887</td>
<td>0.91</td>
<td>111.70%</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>y = 0.2783x + 8.468</td>
<td>0.46</td>
<td>64.70%</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>y = 0.6847x + 29.027</td>
<td>0.87</td>
<td>44.80%</td>
</tr>
<tr>
<td>Meso and Micro-nutrients</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>y = 0.025x² - 0.2805x + 3.8998</td>
<td>0.94</td>
<td>144.40%</td>
</tr>
<tr>
<td>Copper</td>
<td>y = 0.0353x + 0.9988</td>
<td>0.66</td>
<td>65%</td>
</tr>
<tr>
<td>Iron</td>
<td>y = 2.297x</td>
<td>0.72</td>
<td>800%</td>
</tr>
<tr>
<td>Magnesium</td>
<td>y = 0.0697x + 0.458</td>
<td>0.49</td>
<td>214.80%</td>
</tr>
<tr>
<td>Manganese</td>
<td>y = 0.2005x² - 2.0596x + 4.4929</td>
<td>0.97</td>
<td>900%</td>
</tr>
<tr>
<td>Zinc</td>
<td>y = 0.0213x + 0.4654</td>
<td>0.67</td>
<td>83.30%</td>
</tr>
</tbody>
</table>

5 sampling periods

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Practicing a Biologically Enhanced Agriculture Management (BEAM) Approach Offers:

- Faster and Greater Biomass Growth (>10 tons C/Hectare/year with potential to 37 tons C/Hectare/year).
- More efficient transfer of carbon from plant photosynthates to soil microbes as exudates (bypassing a plant signature carbon vehicle).
- Greater populations of microbial biomass plus a shift from plant signature to a longer duration fungal dominant soil carbon.
- Reduced soil respiration rates as soil fertility along with soil carbon increases.
- Increased soil fertility in macro-, meso- and micro-nutrient profiles.
What Impact Does Our Current Agricultural Approach Have on the Environment?

• Each year, **agriculture emits** 10 to 12 percent of the total estimated GHG emissions, some **1.4 to 1.7 Gt C per year**. (Smith, et al. 2007, Bellarby, et al. 2008)

• Conversion from plough to no-till in 67 long term field experiments **captured 0.570 ± 0.140 tons C ha\(^{-1}\) yr\(^{-1}\)** (West 2002)
Current Viewpoint on Carbon Capture Capability of Agriculture

- Arable and permanent cropping systems can capture $0.2 \text{ t C ha}^{-1} \text{ yr}^{-1}$ and pasture systems $0.1 \text{ t C ha}^{-1} \text{ yr}^{-1}$ (Niggli 2009)

- Global SOC capture potential of 0.4-1.2 Pg C yr$^{-1}$ or 5-15% of global fossil fuel emissions or about $0.7 \text{ tons C ha}^{-1} \text{ yr}^{-1}$ (Lal 2004)
BEAM Results

Using **BEAM approaches** for the previous 4.5 years on beginning soils (0.43% C increase/year) ISAR has averaged soil C increases of **10.71 tons C ha\(^{-1}\) yr\(^{-1}\)**

This rate is from **20 to 50 times** soil C capture rates observed by other agriculture management methods.
Part 2:
No-Regrets Carbon Capture in New Mexico
EPA’s Rule 111(d)

- Requires a ~30% reduction in electrical power plant CO$_2$ emissions beginning 2020 to 2050.
- Approximately 6 million tons CO$_2$/year reduction required in NM.
- Individual States and Power Companies are responsible and liable for these reductions.
- The language in Rule 111(d) promotes implementation of Carbon Capture and Storage (CCS) technologies; however, the costs are high.
Rule 111(d) Allows:

- Outside the fence solutions for atmospheric carbon reduction.
- Adoption of currently existing mechanisms being used for carbon reduction.
- Assistance from the U.S. Department of Agriculture for agricultural solutions towards carbon reduction.
CAPEX Costs of CCS Pilot Power Plants

Kemper County Coal
Mississippi
$6.1 Billion
3 Mtpa
$81.33/ton CO₂
+ Financing (2.4 X Capex)
+Parasitic Load Costs ($24-40/t)
+O&M ($9.51/MWh)

SaskPower- Boundary Dam
$1.467 Billion
1 Mtpa
$58.68/ton CO₂
+ Financing (2.4 X Capex)
+Parasitic Load Costs ($24-40/t)
+O&M ($9.51/MWh)

Petra Nova-Texas
$6 Billion
3 Mtpa
$80.00/ton CO₂
+ Financing (2.4 X Capex)
+Parasitic Load Costs($24-40/t)
+O&M($9.51/MWh)

Estimated Upfront Costs of $180-$234/ton CO₂
**Costs of CCS**

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>High</th>
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</thead>
<tbody>
<tr>
<td>Transportation and Storage</td>
<td>$22</td>
<td>$36</td>
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<tr>
<td>Overhead and Maintenance</td>
<td>$22</td>
<td>$22</td>
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<tr>
<td>Parasitic Loads</td>
<td>$90</td>
<td>$90</td>
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<tr>
<td>Financing</td>
<td>$84</td>
<td>$116</td>
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<tr>
<td>CAPEX</td>
<td>$59</td>
<td>$81</td>
</tr>
</tbody>
</table>

**Total Cost/Ton CO₂**

- Low: $276
- High: $345

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2 The Costs of CO₂ Capture, Transport and Storage, Post-demonstration CCS in the EU, www.zerosemissionsplatform.edu
CO₂ Sequestration Costs

Power Company Energy Efficiencies
- High: $155
- Low: $155

Photovoltaics
- High: $131
- Low: $131

CCS (Geologic)
- High: $336
- Low: $336

CCS (EOR)

Renewable Energy Credits
- High: $29
- Low: $18

BEAM
- High: $22
- Low: $17

No Net CO₂ Sequestered!
CCS Liabilities

- Migration of injected CO2,
- Unintended leaks,
- Seismic activity,
- Acidification of aquifers driving up contaminant concentrations, and
- Long term monitoring
- No Measurable Co-Benefits!

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CCS Liabilities

• Civil Liabilities where third parties have suffered harm and seek compensation.
• Administrative liability where authorities are given powers to serve some form of enforcement or clean-up order.
• Emissions trading liability where an emissions trading regime provides a benefit for CO$_2$ storage and an accounting mechanisms is in place should there be a subsequent leakage.
BEAM Liabilities and Co-Benefits

Few Liabilities and Multiple Co-Benefits

• Increases
  – Soil fertility.
  – Water Storage in soils
  – Plant water use efficiencies
  – Soil nutrient availability

• Reduces
  – Plowing and heavy tillage
  – Fertilizer Application
  – Downstream pollution of streams, rivers, lakes, aquifers, estuaries, oceans and coral reefs

Allows farmers to transition to a Sustainable and Ecosystem-friendly agricultural approach.
Pair Soil Carbon Capture with a Voluntary Carbon Market in New Mexico

• Money goes directly to participating farmers.
• Improves New Mexico’s farm and ranch communities.
• Money stays and recirculates in New Mexico.
• Promotes satellite businesses for seed production, farm equipment and other support industries.
• Brings in out-of–state revenue for energy produced in New Mexico being shipped to other states.

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Cost to Accomplish Reduction of the World’s Annual GHG Emissions = $617 Billion/year

- Agricultural Subsidies: $281 Billion Annual
- Energy Subsidies: $500 Billion Annual
- Health Related Damages: $1.43 Trillion/year

Potential Loss From Stranded Energy Assets: $4 Trillion

$1.4 Trillion/Year for Next Two Decades

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Legislative Efforts Needed to Recognize Soil Carbon as a Carbon Offset

• States must submit their implementation plans for reducing carbon dioxide emissions by June 2016
• As of April 20th, Utah is the only state that has signed a law (Resolution 8) recognizing soil carbon increases in range, farm and forestry lands for carbon offsets in a carbon market
• New Mexico’s Senator Sapien introduced a similar bill (SB630) in the 2015 Legislature and the action was postponed indefinitely.

Legal recognition of soil carbon in NM is necessary for industry participation in a carbon market!
Employing BEAM on NM farmlands will help the State of New Mexico and energy producers comply with EPA 111(d) in an economically feasible way while greatly improving New Mexico’s economy, agricultural lands and farmers livelihoods.
Align your self with nature!

Tao Te Ching

Questions?