Specialty Crop Block Grant Reporting  
Final Report

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Development of Poplar Plantations for Food Processing Wastewaters

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PROJECT TITLE: Development of poplar plantations for food processing wastewaters

PROJECT SUMMARY

The specialty crop industry in Michigan relies on the economic and environmental sustainability of food processing. Many fruit, vegetable, and other specialty crop processors in Michigan rely on land application to treat high strength, high flow processing wastewater. While properly operating fields can assimilate wastewater through biodegradation of carbon and biochemical oxygen demand (BOD), excess application of wastewaters rapidly contributes to environmental deterioration by mobilizing metals like iron, manganese, and arsenic. At multiple sites in Michigan, elevated groundwater concentrations of iron, manganese, and arsenic have been attributed to land application of processing wastewaters. Metal contamination of groundwater prompts aesthetic concerns and can adversely affect human health. For many processors, conventional wastewater treatment plants are cost-prohibitive and few alternatives to land application exist. Development of low-cost, effective treatment systems for these wastewaters is crucial to economic viability of specialty crops in Michigan because many processors are facing either closure or substantial increases in costs to meet environmental regulations. Poplar plantations have great potential to inexpensively increase treatment at land application sites and are a well-developed technology for phytoremediation. However, research is needed to develop poplar plantations into reliable, effective, and low-cost treatment systems for processing wastewaters.

The purpose of the research was to evaluate the effects of poplar tree growth on metal mobility and wastewater treatment under land application conditions in both column and field studies to demonstrate the technology while developing a design tool to provide processors with site-specific design recommendation and cost estimates. The research is expected to develop a low-cost, effective treatment technology for processing wastewaters within 5 years.

PROJECT APPROACH

The funds from SCBGP were used to complement funds from MSU project GREEEN in order to build towards overall project objectives. The project used both column and field studies to meet the objectives. In column studies, 12 columns were constructed, in triplicates of two poplar varieties, a willow variety, and no plant controls. Synthetic food processing wastewater that represented the actual wastewater was applied to all columns, leachate collected and analyzed for pH, chemical oxygen demand, and metals. In addition, the columns were instrumented with 16 oxidation-reduction probes in 8 columns, 36 moisture sensors in 12 columns and 12 temperature sensors in 3 columns and redox potential of column soil at two depths, moisture in three depths and temperature in four depths were continuously monitored. The results showed no effects of plant in metal mobilization. However, anaerobic conditions were formed in the columns and we expect that these differences will become more apparent as the columns continue to be treated with synthetic wastewater, establishing long-term anaerobic conditions.
Field installation was delayed after the first food processor who had agreed to participate withdrew their offer after approximately three months of effort. In field studies, a second field site suitable to the research needs was chosen. Poplars were planted in two of the four sub-plots and required instrumentation to monitor the deep drainage, rainfall, temperature and soil moisture was installed. Leachate water and ground water will be analyzed for metals, pH, cations and anions.

GOALS AND OUTCOMES ACHIEVED

Objective 1: Evaluate metal mobility in planted and unplanted columns

To quantify the effects of poplar trees on metal mobility, three plant varieties (tall shade poplar, shade poplar and willow) were planted in sandy loam soil (76.9 % sand, 11 % silt, 12.1 % clay) in triplicate each along with no plant controls (12 columns in total) (Figure 1, 2). Instrumentation to assess oxidation-reduction potential at two different depths (1.5 ft and 3 ft) below soil surface in 8 columns (Figure 1), temperature at four different depths (surface, 1.5 ft, 3 ft and 4.5 ft) in 3 columns and soil moisture at three different depths (1.5, 3, 4.5 ft) in all columns was completed in November, 2010. Continuous data from the above instrumentation has been collected since November until August 2011 when the columns were reconstructed. Also, an irrigation system with main source tank and distribution pipes in each column was built and used to apply wastewater to the columns.

Figure 1 Layout of columns showing 8 columns with oxidation-reduction probes (not to scale)
Synthetic wastewater was designed to mimic a representative food processor’s wastewater sample (Table 1). Synthetic wastewater was applied daily at the rate of 16,000 gal/ac/day since March 2011 until August 2011. Leachate water samples were collected weekly and pH and COD was monitored since March 2011 (temperature permitting). Additionally, leachate water samples have been analyzed for Fe II and Fe III, Mn, Co, Cu, Zn, Ni, Ca, Mg, F, Cl, NO₃, SO₄, and PO₄.

The oxidation-reduction potential (ORP), temperature, and soil moisture in the columns has been measured since November 2010. Figure 1 depicts the ORP (corrected for platinum and silver/silver chloride electrode) at the top and bottom ports of the soil columns from November 2010 until the columns were reconstructed in August 2011.
As shown in Figure 3, the trends in ORP were relatively similar for the top and bottom of the columns. With the exception of willow, no statistical difference between treatments was observed (p>0.05). Willow plants were different from other treatments as one of the replicate ORP was consistently higher. There were visibly distinct dryer pattern in the willow column that had higher ORP. However, a substantial decrease in ORP was noticed in June 2011, indicating that anaerobic conditions were reached. These results will guide research next summer, indicating that we need to add more COD to quickly reach anaerobic conditions conducive to metal leaching.

Summary results of the leachate analyses collected in 2011 are shown below for COD (Figure 4), transition metals (Figure 5 and 6), and nitrates (Figure 7). Points represent means of three columns. COD concentrations were reduced from approximately 1,000 – 2,500 mg/L to 69.6 – 105 mg/L, a reduction in average by 94.65%. As yet, there is no statistical significant difference in COD concentrations in the leachate of the columns; however, this is likely due to the ability of the soil ecosystem in the control columns to assimilate the wastes. This ability is expected to decrease as the study progresses.

Table 1 Synthetic Wastewater Characteristics and Composition

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Wastewater strength, mg/L</th>
<th>Compound</th>
<th>Molecular Weight</th>
<th>Synthetic wastewater composition, mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 COD</td>
<td>1438.5</td>
<td>Sucrose C_{12}H_{22}O_{11}</td>
<td>342.3</td>
<td>1282.287891</td>
</tr>
<tr>
<td></td>
<td>205.5</td>
<td>Starch C_{6}H_{10}O_{5}</td>
<td>162.15</td>
<td>173.5511719</td>
</tr>
<tr>
<td>2 Ca</td>
<td>66.8</td>
<td>Calcium chloride CaCl2</td>
<td>110.98</td>
<td>184.975897</td>
</tr>
<tr>
<td>3 Mg</td>
<td>24.9</td>
<td>Magnesium sulfate MgSO4</td>
<td>120.366</td>
<td>123.2872645</td>
</tr>
<tr>
<td>4 K</td>
<td>476.9</td>
<td>Potassium sulfate K_{2}SO_{4}</td>
<td>174.26</td>
<td>1062.718593</td>
</tr>
<tr>
<td>5 Na</td>
<td>35.3</td>
<td>Sodium bicarbonate NaHCO_{3}</td>
<td>84.01</td>
<td>128.937087</td>
</tr>
<tr>
<td>6 Fe</td>
<td>2.4</td>
<td>Ferric chloride FeCl_{3}.6H_{2}O</td>
<td>162.21</td>
<td>7.112783878</td>
</tr>
<tr>
<td>7 Mn</td>
<td>0.1</td>
<td>Manganese sulfate MnSO_{4}.H_{2}O</td>
<td>187</td>
<td>0.350911036</td>
</tr>
<tr>
<td>8 NH_{4}-N</td>
<td>19.7</td>
<td>Ammonium sulfate (NH_{4})<em>{2}SO</em>{4}</td>
<td>132.14</td>
<td>72.30994444</td>
</tr>
<tr>
<td>9 Zn</td>
<td>0.2</td>
<td>Zinc sulfate ZnSO_{4}.7H_{2}O</td>
<td>287.58</td>
<td>0.879718568</td>
</tr>
<tr>
<td>10 Cu</td>
<td>0.1</td>
<td>Cupric chloride CuCl_{2}.2H_{2}O</td>
<td>170.47</td>
<td>0.268262361</td>
</tr>
<tr>
<td>11 Co</td>
<td>0.02</td>
<td>Cobalt chloride CoCl_{2}</td>
<td>129.84</td>
<td>0.044063598</td>
</tr>
<tr>
<td>12 B</td>
<td>0.01</td>
<td>Sodium borate Na_{2}B_{4}O_{7}.10H_{2}O</td>
<td>381.37</td>
<td>0.35279371</td>
</tr>
<tr>
<td>13 Mo</td>
<td>0.01</td>
<td>Sodium molybdate Na_{2}MoO_{4}.2H_{2}O</td>
<td>241.95</td>
<td>0.025218361</td>
</tr>
<tr>
<td>14 Ni</td>
<td>0.07</td>
<td>Nickel nitrate NiNO_{3}.6H_{2}O</td>
<td>290.81</td>
<td>0.346851252</td>
</tr>
</tbody>
</table>
Figure 4 COD concentrations in influent and effluent of columns planted with tall shade poplars, shade poplars, willows, and no trees (control).

Figure 5 Concentrations of ferrous iron (Fe II) and ferric iron (Fe III) in leachate samples.
Iron was detected both as ferrous and ferric iron in the leachate. Iron reduction occurs in the range of 0-100 mV redox potential and manganese reduction occurs from 100-250 mV. The observed ORP ranges in the soil columns indicate several periods of iron reducing redox potential and longer manganese reduction periods. As ferrous iron was a component of the synthetic wastewater, iron leaching from the columns could have come from the synthetic wastewater (and not from metal mobilization in the soil). However, with the exception of June 2011, manganese was not a major component of the synthetic wastewater. As seen in Figure 6, leaching of manganese in concentrations greater than the influent concentrations was observed in all columns, an expected phenomenon considering the values of ORP. As with COD and ORP, statistically significant differences in treatments are not yet observed for transition metals. We expect that these differences will become more apparent as the columns continue to be treated with synthetic wastewater, establishing long-term anaerobic conditions.
As supported by the ORP measurements, aerobic conditions persisted in the soil columns until at least May 2011. During this time, reduced nitrogen in the synthetic wastewater was oxidized to nitrate within the columns. Concentrations of nitrate were lower in columns planted in with trees than in controls, indicating that tree growth prevented leaching of nitrate. This result may have important implications as food processors address the problems of metal mobilization associated with land application of wastewaters. One recommendation to decrease metal mobilization is to rest fields between applications to allow for drying and re-establishment of aerobic conditions. While this will likely decrease metal mobilization, our results indicate that it will also increase the probability of nitrate leaching into groundwater, creating risk to human health.

Columns were reconstructed in August and September 2012. The soil mixture in three columns was changed from sandy loam to silt loam and these columns were planted with poplars. Three additional columns were constructed with a silt loam soil mixture and were not planted to serve as no-tree controls.

**Objective 2: Assess transpiration of poplars under land application conditions**

The originally constructed columns could not be prevented from leaking. Therefore, starting August 2011, the columns were reconstructed. A PVC sheet was attached to the bottom of the column and sealed by roof sealing to prevent leakage from bottom. All instrumentation ports were sealed from inside and the instrumentation wires run from the top of the column. Utilizing funding from MSU GREEEN, the rates of evapotranspiration will be calculated for each treatment during summer 2012.

**Objective 3: Establish field site to evaluate benefits of poplar plantings at land application sites**

We have designed and installed at field site at western Michigan food processor. The site plan for the field site is shown in Figure 8. Trees were planted in August 2011 and field instrumentation, including 4 drain gauges, 12 lysimeters, 4 Enviroscan water content probes, 24 TDR (water content) sensors, 2 rain gauges, and 2 temperature sensors were installed in November to December 2011. All the sensor data are collected in two dataloggers powered with solar panel each (Figure 9).
Experiment plot consists of 580 ft × 70 ft plot, divided into four sub-plots of 145 ft × 70 ft each (figure 8). Two sub-plots are planted and two are controls (no plants) as shown in figure 8. A data logger is placed between planted and control sub-plots which is connected to raingage, temperature sensor, draingage, enviroscan sensor and TDR sensors. The locations of each of the sensors are shown in figure 10.

![Diagram](image)

Figure 9 Layout of instrumentation in the half of the field. Green dots represent plants at the spacing of 10ft ×10ft. The dimensions are in ft. TDR represent time domain reflectrometry.

![Image](image)

Figure 10 Plants in the field
Utilizing MSU GREEEN funding, we will monitor the field site in summer of 2012. We are also in the process of applying for additional funding from USDA to continue this research.

BENEFICIARIES

The immediate beneficiary of the project is the food processor of the field site and 1 graduate and 2 undergraduate students working in the project. Students working on the project gained hand on experience with field project, including planting, installation and monitoring of sensor and analysis of data. The project’s future outcomes will benefit all food processors who rely on land application to treat their waste. After the completion of the overall project, the food processors will benefit from the site specific design recommendations that will be provided by the project. The outcome of the project will help increase the profitability of special crop industry while also minimizing health risks from groundwater. In this sense, the beneficiaries of the project would be food processors as well as general public. Moreover, increased profitability of the special crop industry in turn could lead to secondary benefits including more jobs.

LESSONS LEARNED

The project team had to go through several delays and hindrances. Several instruments were backordered. Field site had to be chosen twice as first food processor pulled out of the commitment after months of work. During field installation, digging holes up to 13 ft below ground was a problem, provided that drainage needed to be installed in relatively undisturbed soil. Digging a manual hole would too greatly disturb the soil and digging the hole by well-drilling truck was problematic as the heavy truck got stuck in the wet field. These problems were resolved by the conclusion of the grant period.

In column project, early and long winter in 2010/11 posed a challenge. Column design utilized sealant to seal the bottom of the column and the instrumentation ports. However, lack of sealant that works in wet, cold conditions and high pressure posed a great problem. This prevented us from quantifying evapotranspiration of poplar trees. It would have been better to not have holes at the sides for the instruments in the column. Also, alternate thawing and freezing helped break seal due to differential thermal expansion of sealant material and column material. We have corrected this problem by reconstructing a column and will utilize MSU GREEEN funding to fulfill objective 2 during Summer 2012.

CONTACT PERSON

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ADDITIONAL INFORMATION
The project progress has been shared in professional meetings. Following publications are directly out of the project:

1. Aryal, N.; Gammans, M. T.; Reinhold, D. 2011. Poplar plantations for treating food processing wastewater. 1\textsuperscript{st} annual engineering graduate research symposium, Michigan State University, East Lansing, MI, Nov. 3.
