Soil CO$_2$ Flux in Short Rotation Willow Biomass Crop Across 21-year Chronosequence as Affected by Continuous Production and Tear Out Treatments

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Overview

- Introduction
- Materials and Methods
  - Soil CO₂ flux measurement instruments
  - Site location, sampling plots lay-out
  - Procedure for CO₂ flux measurements
- Results
  - Soil CO₂ flux pattern on summer, fall, winter, and spring
  - Relationship between soil CO₂ flux and temperature and moisture
  - Accumulated soil CO₂ flux over 1 year for continuous production and tear out treatments
  - Accumulated CO₂ flux from roots over 1 year
  - Carbon balance in continuous production and tear out plots
- Conclusion
Introduction

Willow biomass crop production system:

Carbon sequestration?
Carbon neutral?
Low carbon fuel source?
Worse than fossil fuel?
Life Cycle Analysis (LCA) (Heller et al. 2003):

Willow biomass crops: low carbon fuel source
- $3.7 \text{ Mg } \text{CO}_2\text{eqv} \text{ ha}^{-1}$ emissions at the end of 7 rotations

Willow biomass crops: carbon neutral (Keoleian & Volk, 2005)
However, the previous LCA and subsequent study:

- no information available on belowground respiration (i.e. soil CO$_2$ flux) during willow production

- no estimates on CO$_2$ emissions when roots and stump were ground into soil after termination of willow plantation

major sources of CO$_2$ emissions during entire cycle of willow production; hence, important data in the life cycle analysis (LCA)
Objectives

- Compare soil CO$_2$ flux between continuous production and tear out treatments
- Determine C balance in existing willow crops (Salix dasyclados), which have been in production for 6, 13, 15, and 20 years
  - Estimate the amount of root respiration
  - Determine CO$_2$ emission and C sequestration in newly established willow plantation
Why important?

- Rates of CO$_2$ flux influence GHG fraction in atmosphere
- Need to adjust and refine previous LCA for willow biomass crops
- Inform the ongoing debate on the GHG potential of willow production system
Materials and Methods
Automated soil CO$_2$ flux monitoring equipments

LI-8100 & Multiplexer (LI-8150)

http://www.licor.com/env/products/soil_flux/

Survey Chamber

Long-Term Chamber (LI-8100-104)
Soil temperature and moisture measurements

Temperature Probe

Soil Moisture Probe
Site location

3 sites at Tully and 1 site at Lafayette, NY
Experimental Design

Randomized Complete Block Design (RCBD)
- Two treatments: continuous production and tear out
- 4 blocks (replication) for each site
- Two subsamples, randomly assigned, in each block located between two double row and within double row

For comparison of annual CO$_2$ emissions by age, we used four existing willow plantations (Salix dasyclados) sites: 6, 13, 15, and 20 years old.
We conducted field measurements on belowground biomass and SOC before treatment application:

- All four willow fields (age: 5, 12, 14, & 20) located in Tully and Lafayette
  - No significant differences in soil organic carbon (SOC) to 45 cm depth, and foliage and coarse root biomass production
- No significant differences in fine roots biomass in three sites (age 5, 14, & 20) located in Tully; Lafayette site (age 12), highest & significantly different.

- NO differences in SOC
- NO differences in biomasses and coarse roots and foliage
- NO differences in fine root biomass for Tully sites

suggest that any differences in soil CO₂ flux across the four willow field could be due to age
Treatment Application

- harvesting on early spring 2010
- Allowed to regrow (continuous production treatment)
- Ground up (tear out treatment)
Six months after treatment application......

- continuous production treatment plots
- tear out treatment plots
same age across the four willow fields because we cut them at the same time

age: 6, 13, 15, and 20 years old across four willow fields
Soil CO$_2$ flux measurement procedure

8” dia. PVC pipe as soil collars

**Root respiration = total respiration – heterothropic respiration**

**heterothropic respiration** (

i.e CO$_2$ emissions from soil fauna and microorganisms

Between 2 double rows

Within double row

(total respiration (i.e heterothropic respiration and root respiration)
Survey measurements to capture CO$_2$ flux spatial variation

Summer 2010

Tear Out Treatment

Continuous Production Treatment
...to capture spatial variation within the measurement plots

Fall 2010
Survey measurements on winter

2-3 ft deep snow in winter
2010-11
Continuous measurements to capture temporal variation of soil CO$_2$ flux

Measurements in tear out and continuous production plots on summer 2010
Measurements continued until early winter
Results and Discussion
Soil CO$_2$ flux pattern over the seasons across 4 sites
Strong relationship between soil CO$_2$ flux and soil temperature

![Graph showing the relationship between monthly mean soil CO$_2$ flux and monthly mean soil temperature over a period from May 2010 to March 2011. The graph includes data for Tear Out (TO) and Continuous Production (CP) treatments, as well as soil temperature data for both treatments.](image-url)
No relationship between soil CO$_2$ flux and soil moisture
Cumulative amounts of soil CO$_2$ flux over 1 year based on monthly estimates

![Graph showing cumulative CO$_2$ emissions over the age of willow biomass crop.](image)
tear out plots on late fall & before heavy snowfall (7 mos. Later since treatment applied)

Exposed fine roots by frost heaving
Root respiration constitutes about 1/3 of total soil CO$_2$ emission.
Carbon Balance

Sources of C sequestration: leaves, stems, fine roots, coarse root, belowground stool

Some values for fine root turnover

- *Salix viminalis*: 4.9 to 5.8 yr\(^{-1}\) (Rytter & Rytter 1998; Rytter 1999)
- Hybrid poplar: 0.9 to 1.8 yr\(^{-1}\) (Block et al., 2006)
- Sugar maple: 2.2 yr\(^{-1}\) (Hendrick and Pregitzer, 1992)
- Pines: 0.2 to 5.0 yr\(^{-1}\) (Schoetttle and Fahey, 1994)

I used 2.5 as fine root turnover rate

<table>
<thead>
<tr>
<th>SRWC Age</th>
<th>Foliage (odt ha(^{-1}) yr(^{-1}))</th>
<th>Fine Root (odt ha(^{-1}) yr(^{-1}))</th>
<th>Total</th>
<th>CO2 Eq. (ton ha(^{-1}) yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>2.6</td>
<td>5.9 x 2.5 = 14.7</td>
<td>17.3</td>
<td>31.7</td>
</tr>
<tr>
<td>13</td>
<td>2.9</td>
<td>9.2 x 2.5 = 23.0</td>
<td>25.9</td>
<td>47.5</td>
</tr>
<tr>
<td>15</td>
<td>3.7</td>
<td>6.3 x 2.5 = 15.7</td>
<td>19.4</td>
<td>35.6</td>
</tr>
<tr>
<td>20</td>
<td>2.6</td>
<td>7.2 x 2.5 = 18.0</td>
<td>20.6</td>
<td>37.8</td>
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</table>
C Balance for continuous production

<table>
<thead>
<tr>
<th>SRWC Age</th>
<th>Measured CO₂ Emissions</th>
<th>Measured CO₂ Sequestration</th>
<th>Net CO₂ Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>32</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>38</td>
<td>47</td>
<td>-9</td>
</tr>
<tr>
<td>15</td>
<td>33</td>
<td>36</td>
<td>-3</td>
</tr>
<tr>
<td>20</td>
<td>28</td>
<td>38</td>
<td>-10</td>
</tr>
</tbody>
</table>

Fine root turnover rate of 2.3 a year to offset the accumulated CO₂ emissions on 1st yr after coppice
C Balance for tear out

<table>
<thead>
<tr>
<th>Age</th>
<th>Total CO2 Emission</th>
<th>Total CO2 Sequestration</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-yr old</td>
<td>26.99</td>
<td>0</td>
</tr>
<tr>
<td>13-yr old</td>
<td>29.51</td>
<td>0</td>
</tr>
<tr>
<td>15-yr old</td>
<td>25.02</td>
<td>0</td>
</tr>
<tr>
<td>20-yr old</td>
<td>28.6</td>
<td>0</td>
</tr>
</tbody>
</table>
Comparing tear out treatment with 1-yr old willow crop with cover crop and without cover crop

Total CO₂ Flux (ton ha⁻¹ yr⁻¹)

-6-yr old
-13-yr old
-15-yr old
-20-yr old
-1-cover crop
-1-no cover crop

-30
-20
-10
0
10
20
30
40

total CO2 emission
total CO2 sequestration
Conclusion

- One year after treatment application: higher CO$_2$ flux in continuous production than tear out
- Soil CO$_2$ flux all-year round; but, very low flux during winter
- Increased soil CO$_2$ flux at young to middle age, then stabilized at mature age
- Root respiration is about 25-30 % of total soil respiration (i.e. heterothropic and autothropic respiration)
Using fine roots and foliage as the only sources of C sink, soil CO$_2$ emissions are offset resulting in negative C balance in willow production system across 21-year chronosequence.

After willow crop termination, about 2/3 of soil CO$_2$ emissions can be offset by placing cover crop and establishment of new willow plantation.
Future Directions

- Continue data collection for the second and third growing seasons
- Field investigation of fine root turn-over rates across the 21-year short rotation willow biomass crop chronosequence
- $\text{CO}_2$ flux investigation should be expanded to other management practices (e.g. fallow and cover cropping) after SRWC plantation termination
Acknowledgment

This research is funded by USDA CSREES

Assistants:
Jacob Bakowski, Devin Mc Bride, Tyler Harvey, Gabe Kellman, and Eric Fabio
Thank You!