EFFECT OF IRRIGATION PRACTICES ON SOIL NITROGEN CYCLING MICROBIAL POPULATIONS AND NITROUS OXIDE EMISSIONS IN A MERLOT VINEYARD IN THE OKANAGAN VALLEY OF BRITISH COLUMBIA

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Objectives of This Presentation

• AGGP1
  • Does irrigation source affect abundance of N-cycling soil microbial populations, N$_2$O emissions and soil physico-chemical properties in a Merlot vineyard in the Okanagan Valley?
  • Are N$_2$O emissions correlated with changes in abundance of nitrifying or denitrifying populations?

• AGGP2
  • Overview of regional scale project
  • Progress to date
Climate of the Okanagan Valley

- Characterized by hot dry summers and crisp, overcast winters with air temperatures below freezing for about ten weeks
  - Average summer temperatures high 20’s
  - Most rain falls between April and June, little rain over the summer months
- Irrigation changes the plant productivity dramatically and allows a range of crops to be grown, predominantly apples, cherries and grapes
- In AGGP1 we studied how irrigation source (micro-sprinkler or drip) affected the abundance of the N-cycling soil microbial populations in a Merlot grape vineyard
Major Soil Microbial Processes Contributing to Nitrous Oxide Emissions and Genes Measured

- **Nitrification** – aerobic autotrophic bacteria and archaea
  
  \[
  \begin{align*}
  \text{NH}_4^+/\text{NH}_3 & \rightarrow \text{NH}_2\text{OH} \\
  & \rightarrow \text{NO}_2^- \\
  & \rightarrow \text{NO}_3^-
  \end{align*}
  \]

  - **AmoA**: ammonium monooxygenase

- **Denitrification** – anaerobic heterotrophs
  
  \[
  \begin{align*}
  \text{NO}_3^- & \rightarrow \text{NO}_2^- \\
  & \rightarrow \text{NO} \\
  & \rightarrow \text{N}_2\text{O} \\
  & \rightarrow \text{N}_2
  \end{align*}
  \]

  - **NirS**: nitrite reductase
  - **NosZ**: nitrous oxide reductase

- We also measured *16SrRNA*, a measure of the total soil bacterial abundance
Methodology

• Merlot/SO4 vineyard, established 2011
• Sandy loam soil
• pH 6.2 - 6.5
• Two irrigation treatments: drip or micro-sprinkler
  • Delivered 100% of water lost previous day to evapotranspiration
  • Randomized complete block, split plots
• Soils were sampled from 5-10 cm depth, 20 cm from irrigation source in 2013 and 2014
• Sampled in February (Thaw), in May after irrigation start (Irrig), in June after fertilization (Fert), and in September (Fall)
  • Standard soil analyses conducted by BC Ministry of Environment
• N₂O flux measured regularly during irrigation, fertigation and winter months
  • Using non-flow-through, non-steady-state chambers and Bruker 456 GC
Methodology

- Total soil DNA was extracted using MoBio Power Soil kits
- Gene abundance determined using quantitative real-time PCR on a BioRad CFX cycler with Sybr Green
  - Linearized plasmids as standards
  - Standard primer pairs and cycling conditions
    - amoA1F-amoA2R
    - nirSCd3aF-nirSR3cd
    - nosZ1F-nosZ1R
    - BACT1369F-PROK1492R (16SrRNA)
  - Efficiencies ranged from 91-102%
- Data averaged over 2 years
N$_2$O Emissions 2013-2015
Effect of Irrigation Type on Gene Abundances

16SrRNA

amoA

nirS

nosZ
Effect of Irrigation Source on Soil Physicochemical Properties

• Soil NH$_4^+$-N content was higher under micro-sprinkler (3.34 mg/kg) than in drip-irrigated plots (1.68 mg/kg) at the onset of irrigation only.

• There were no significant effects of irrigation source at any of the sample times on:
  • % total N
  • NO$_3^-$-N
  • % total C
  • % organic matter
  • Water-filled pore space (WFPS)*
  • pH

*ratio of volumetric soil water content to total soil porosity
## Correlations between Gene Abundances, N₂O Emissions and Environmental Variables

<table>
<thead>
<tr>
<th>Gene Abundance</th>
<th>Temp P-value</th>
<th>WFPS*</th>
<th>NO₃-N</th>
<th>NH₄-N</th>
<th>pH</th>
<th>N₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>16SrRNA P-value</td>
<td>&lt; 0.001</td>
<td>ns</td>
<td>0.018</td>
<td>&lt;0.001</td>
<td>0.007</td>
<td>ns</td>
</tr>
<tr>
<td>amoA P-value</td>
<td>&lt; 0.001</td>
<td>0.001</td>
<td>0.004</td>
<td>ns</td>
<td>0.04</td>
<td>ns</td>
</tr>
<tr>
<td>nirS P-value</td>
<td>0.001</td>
<td>&lt;0.001</td>
<td>ns</td>
<td>ns</td>
<td>0.005</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>nosZ P-value</td>
<td>&lt; 0.001</td>
<td>ns</td>
<td>&lt;0.001</td>
<td>ns</td>
<td>ns</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

ns=not significant

- Nitrifier abundance was negatively correlated with WFPS
- *nirS* abundance was positively correlated with WFPS
- N₂O emissions were negatively correlated with denitrification gene abundances

*Water Filled Pore Space*
Conclusions

• Nitrification was likely the major N₂O-generating process during the growing season
  • Coarse textured soil and irrigation method which supplied only the water lost to evapotranspiration led to low WFPS during the irrigation period (Irrg, Fert, Fall)
  • WFPS averaged 63% across all treatments – aerobic conditions
  • Negative correlation between N₂O emission and nirS abundance
• At Irrig (May) sampling irrigation method significantly affected gene abundance
  • With Drip irrigation amoA and nosZ were lower and nirS higher than for micro-sprinkler
  • Water released by drip is under higher pressure which may cause greater displacement of soil nutrients – NH₄⁺-N decreased significantly under drip
• Less N₂O was emitted under micro-sprinkler than under drip during the growing season (Fentabil et al 2016)
  • Likely related to lower nirS and higher nosZ abundance under micro-sprinkler leading to complete denitrification to N₂
AGGP2

• Understanding the impact of irrigation on soil C and N storage, and associated greenhouse gas emissions at a regional scale
  • Melanie Jones, Louise Nelson, Nathan Pelletier (UBCO)
    • 2 research associates (Andy Midwood and Tanja Voegel), 4 grad students, 2 research assistants, undergraduate students
  • Collaborators
    • Denise Neilsen, Tom Forge, Scott Smith, Kirsten Hannam (AAFC)
    • Anna Warwick-Sears (Ok. Basin Water Board)
    • Rob Birtles (Interior Health)
    • David Poon (BC Ministry of Agriculture)
    • Pete Millard (Landcare NZ)
Objective and Major Activities

• Develop recommendations for the conditions under which irrigation can be used to increase soil C storage without stimulating loss of N through N\textsubscript{2}O efflux
  • Conduct meta-analysis of existing research on changes in C and N pools in response to irrigation
  • Use the diverse cropping systems and soil types in the Okanagan Valley to conduct an extensive survey of irrigated and non-irrigated sites that vary in their long-term management regimes
    • Collect data on stored soil C and N pools
    • Measure CO\textsubscript{2} and N\textsubscript{2}O emissions on a subset of these sites representing a range of soil types, cropping systems and management practices
Major Activities (continued)

- Use molecular tools to identify the major N$_2$O-generating pathways and soil-related drivers of N$_2$O emissions
  - Develop novel droplet digital PCR methods to assess nitrification and denitrification gene abundances
  - Apply to field and laboratory microcosm studies
- Conduct lab studies to quantify contribution of bicarbonates in irrigation water to CO$_2$ efflux
- Conduct environmental life cycle assessment of organic amendments and delivery of irrigation water
Okanagan Valley – A Living Laboratory

- Irrigation is widely used throughout the Okanagan Valley
- Different crops, types of irrigation and different soils
- Excellent location to study the impact of irrigation on soil carbon and nitrogen levels and emissions

Carbon and Nitrogen

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Carbon and Nitrogen
Soil Sampling Plan

• Sampling five different soil series/groups: Glenmore, Osoyoos, Penticton, Rutland and Armstrong
• Contrasting textural and organic C contents
• Represent about 50% of the total area across the valley
• Three depths, alleys and rows for apples, cherries and grapes
Crops and Irrigation Types

- Apples irrigated by drip and micro-spray
- Cherries irrigated by micro-spray
- Grapes irrigated by drip
- Forage irrigated by various systems: traveling gun, hand-line and wheel-line
## Summary of Sites

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>Crop</th>
<th>Sites Required</th>
<th>Soil Types</th>
<th>Soil Samples 3 x depths (row and alley, or spatial)</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
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<td>none</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>75</td>
</tr>
<tr>
<td>Gun, wheel-line, hand-line</td>
<td>pasture forage</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>75</td>
</tr>
<tr>
<td>drip</td>
<td>apple</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>150</td>
</tr>
<tr>
<td>drip</td>
<td>grape</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>150</td>
</tr>
<tr>
<td>Micro-spray</td>
<td>apple</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>150</td>
</tr>
<tr>
<td>Micro-spray</td>
<td>cherry</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>150</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>750</td>
</tr>
</tbody>
</table>

Theoretical maximum number of sites: 150
Progress to Date

- Literature review meta-analysis in progress
- Field soil sampling underway
  - Experimental design, soils, crops and irrigation methods finalized
  - Sites selected, field protocols finalized and tested
  - Grower questionnaire developed and delivered
  - 94 soils sampled to date
  - Database of growers and sites developed
- Personnel recruited
- Soil N-cycling studies in progress
  - Novel molecular methods for detection of nitrifying and denitrifying microbial populations optimized and manuscript ready to submit
  - Soil microcosm studies to determine soil physico-chemical properties influencing N-cycling initiated
- Life cycle assessment of net greenhouse gas emissions associated with alternative uses of wood chips and mulch underway
Acknowledgements

- Agriculture and Agri-Food Canada, Agricultural Greenhouse Gases Program
- AAFC Summerland Research and Development Centre
- BC Ministry of Agriculture
- BC Wine Grape Council
- BC Tree Fruits
- Andy Midwood and Kirsten Hannam
- Numerous growers, vineyard managers and orchardists who allowed us to come onto their properties and take soil samples