September 2021

BC Agricultural Climate Adaptation Research Network

Summary of Research on Management Practices for Climate Change Mitigation

Tree Fruit and Wine Grapes

SCOPE

This document is a high-level overview of recent, primarily BC-based, published research and research in progress investigating management practices with potential to mitigate climate change. Many practices are in early stages of evaluation for their impacts to carbon (C) sequestration and/or greenhouse gas emissions (primarily N_2O), and/or have not been trialled in the BC context. The objective of this research summary is to provide a brief overview of what research has been done, where it took place, and a short description of key methods and results. This review does not include an exhaustive inventory of relevant research outside of BC, specifically there is likely relevant research that has been completed in Washington and Oregon that is not included.

OVERVIEW

Land under wine grape and tree fruit (apple, cherries, other smaller-scale production) production in BC is approximately 3,900 ha and 6,900 ha, respectively. Most production occurs in the Okanagan region, with some wine grape production on Vancouver Island and in the Thompson Nicola and South Coast regions, and some tree fruit production in the Kootenay region. All BC-based BMP research to-date has occurred in the Okanagan, primarily at Agriculture and Agri-Food Canada's Summerland Research Station. Relevant management practices are listed in Table 1.

TABLE 1: MANAGEMENT PRACTICE DESCRIPTIONS and MITIGATION POTENTIAL

Management Practice Area	Description and Potential for Climate Change Mitigation
Organic amendments	Compost, manure, etc., applied in the crop row, intended to increase soil C and reduce N_2O emissions.
Nitrogen management	Type, rate, timing, and placement of nitrogen in crop rows to decrease N_2O emissions.
Cover cropping	Cover crops are typically grown in alleyways and, less frequently, in crop rows. Can be native vegetation or sown, permanent or annual, and grown in production and/or non-production seasons. Intended to increase soil C, with variable impacts to soil N_2O emissions.
Mulches	Application of a surface mulch layer in the crop row, intended to increase soil C and reduce N_2O emissions. Common mulch materials include wood chips, bark mulch or pruning residue.
Biochar	Applied to crop rows and/or alleyways, and is intended to increase soil C but likely impacts N_2O emissions as well.
Reduced tillage	Implementing reduced or no-tillage to increase soil C, but likely impacts N_2O emissions as well.
Irrigation	Type (drip, sprinkler), frequency, and volume of irrigation can impact N_2O emissions and soil C.

RESEARCH SUMMARY: HIGHLIGHTS and GAPS

RESEARCH HIGHLIGHTS

Organic amendments

- Incorporating compost into the soil did not reduce N_2O emissions compared to urea at similar rates of Plant Available Nitrogen (PAN) application (40 kg/ha) in a vineyard.
- Soil C increased soil C (along with disease suppressive bacteria) compared to fumigation when compost was incorporated pre-planting during renovation of an apple orchard.
- Compost (applied at 40 kg PAN/ha) increased soil C compared to mulch plus fertigation, surface-applied compost, and fertigation treatments in a vineyard.

Cover cropping

- Alleyway cover crop mix (cut and mulched into crop row) combined with surface-applied bark mulch and fish emulsion fertigation, and alleyway alfalfa cover crop (mowed 3x/season and mulched into crop row), both increased soil organic matter when compared to compost incorporated with monthly tillage to 10cm.

Nitrogen management

- Compost did not reduce N_2O emissions compared to urea at similar rates of PAN application (40 kg/ha), but did increase soil C when incorporated (separate study) compared to surface-applied mulch plus fertigation and just fertigation treatments in a vineyard. Surface applied compost and mulch also increased soil C compared to fertigation-only treatments.
- A reduced N application rate (64 kg N/ha) did not change N_2O emissions compared to a high N rate (127 kg N/ha) (fertigated) in an apple orchard; yield-scaled emissions were also not different.
- A global meta-analysis found nitrification inhibitors can decrease N_2O emissions compared to conventional fertilization without inhibitors in orchards

Mulch

- Surface-applied bark mulch reduced N_2O emissions (and yield-scaled N_2O emissions) compared to bare ground in crop rows in two studies (one vineyard, one apple orchard).
- Bark mulch did not increase soil C compared to fertigation-only treatments in a vineyard.
- Bark mulch did not increase soil C during apple orchard renovation compared to an untreated control or fumigation treatment.
- The use of mulches can create indirect emissions that offset N_2O emissions from mulch use in orchards.

Irrigation

- Drip irrigation did not reduce N_2O emissions compared to micro-sprinklers in a vineyard, but yield-scaled N_2O emissions were not different. In a separate study, there was no difference in soil C from drip compared to micro sprinkler irrigation in a vineyard.
- Reduced irrigation frequency (every second day vs. every day) reduced N_2O emissions.

RESEARCH GAPS

- There is currently a lack of BC studies that measure yield, soil C, and N_2O emissions together.
- The data available is largely limited to the Summerland research station, and most studies have been short (2 to 3 years).
- Many studies do not indicate soil sampling depth for quantifying soil C sequestration. The soil sampling depth needs to be sufficiently deep (e.g. 1 m) for accurate measurements.
- Numerous practices, including nitrification inhibitors, biochar, pruning residue management and tillage, have not been evaluated for BC tree fruit and wine grape systems.
- There is cover cropping research in progress that will address some of the data limitations (such as measurement of C, N_2O, and yield together), but these are still relatively short studies (3 to 5 years) and are primarily taking place at a single research station.

RESEARCH RECOMMENDATIONS

Priorities for future studies include:

- Studies that report the impacts to soil C sequestration, N_2O emissions (if applicable) and production outcomes (yield, quality) together.
- Replication of treatments and measurements at different sites, over multiple years, specifically for:
    - Irrigation type (drip vs. micro sprinkler) and frequency, cover crops, compost, and mulch, which have shown promising, but sometimes contrasting outcomes.
- Evaluation of nitrification inhibitors, biochar, and pruning residue management.
- Incorporating lifecycle assessments will help capture the full implication of practices on GHG emissions.

TABLE 2: RESEARCH HIGHLIGHTS

Management Practice Area	Research Highlights [c]	Research Limitations
Organic amendments **[OK, 6, 6*] [a]**	**Summerland research station – grape – 2 yrs [O1] [c]** **Bark mulch** reduced N_2O emissions (year-round) vs. herbicide bare ground; yield-scaled N_2O emissions were also lower **Compost at 40 kg Plant Available Nitrogen (PAN)/ha** did not reduce N_2O emissions compared to urea; yield-scaled N_2O emissions were also not different **Summerland research station – grape – 3 yrs [O7]** **Compost at 40 kg PAN/ha,** incorporated to 5 cm, increased soil C compared to: mulch + N fertigation, compost (surface applied) + mulch, N fertigation, and NPKB fertigation treatments **Fertigation + 10 cm bark mulch** did not increase soil C compared to fertigation without mulch **Compost at 40 kg PAN/ha, unincorporated, on top of 10 cm bark mulch** increased soil C compared to fertigation-only treatments, but not compared to fertigation + mulch treatment **Summerland research station – apple – 2 yrs [O2]** **10 cm pine + spruce mulch** reduced N_2O emissions (year-round) vs. herbicide bare ground; yield-scaled N_2O emissions lower, but not significantly different **Also measured: soil C and nitrifier/denitrifiers [*O9], and yield [*O2]* **Summerland research station, apple (organic) – 6 yrs [O8]** **10 cm conifer bark mulch (no tillage) with alleyway cover crop mix (fescue, rye, alfalfa mix, cut and mulched onto crop row) and fertigation (12.5 kg PAN/ha) with fish emulsion** increased soil organic matter (SOM) and apple yields compared to compost (at 50 kg PAN/ha) and incorporated with monthly tillage to 10 cm **Alleyway alfalfa cover crop (mowed 3x season and mulched into crop row)** increased SOM compared to compost incorporated with monthly tillage (10cm depth) treatment, with no difference in yields **Summerland research station – apple – 2 yrs [O13]** **Pre-plant compost incorporation during orchard renovation** increased soil C and disease suppressive bacteria compared to fumigation treatment **Surface application of bark mulch** did not increase soil C compared to untreated control or fumigated treatments **Okanagan – apple – life cycle analyses [O4, O5]** Indirect GHG emissions from mulch use, including emissions from production, transportation and diverting the much from other uses, offset the N_2O emission reduction from orchard soils	• Lacking studies that measure yield, soil C, and N_2O emissions together • Largely limited to research stations • Many studies are short (2 years)

	Research in Progress: ****Summerland research station – sweet cherry (2019 to 2023) [*O1]*** ***Soil treatments: 1. bare soil, 2. fumigation, 3. preplant agricultural waste compost, 4. surface mulch, 5. preplant compost + mulch (combined)*** *Measuring: soil C, growing season N_2O emissions, yield, plant water relations* ****Summerland research station – apple (2022 to 2025) [*O3]*** ***10 cm bark mulch** compared to bare soil* *Measuring: soil C, N_2O emissions* ****Mission Hill vineyard – (organic) grapes (2013 to 2014) [*O10]*** *Three **different compost types** at 100 kg PAN/ha compared to no mulch control* *Measuring: soil C, nematodes* ****South-east Kelowna – (organic) grapes (2018 to 2023) [*O8]*** *Three **different compost types** at 25 kg PAN/ha compared to no mulch control* *Measuring: SOM, nematodes, yield* ****South-east Kelowna (3 sites) – sweet cherries (2015 to 2017) [*012]*** ***Wood chip mulch** vs. **compost mulch** vs. no mulch (all independent of N applications)* *Measuring: soil C, yield* ****Summerland research station – grapes (2018 to 2023) [*O14]*** ***Seaweed extract and vermicompost extract (rate + frequency), vermicompost (rate),** and **compost and biochar mix*** *Measuring: soil C and nutrients, grape yield/quality, disease, cover crop establishment* ***Other:*** A global meta-analysis found mulch generally reduces N_2O emissions compared to bare soil, but the effect was not significant in orchards [O6]	
Cover cropping **[OK, 3] [a]**	**Summerland research station, apple (organic) – 6 yrs [O8]** **10 cm conifer bark mulch (no tillage) with alleyway cover crop mix (fescue, rye, alfalfa mix, cut and mulched onto crop row) and fertigation (12.5 kg PAN/ha) with fish emulsion** increased SOM and apple yields compared to compost (50 kg PAN/ha) applied and incorporated with monthly tillage to 10 cm **Alleyway alfalfa cover crop (mowed 3x season and mulched into crop row)** increased SOM compared to compost incorporated with monthly tillage (10 cm depth) treatment, with no difference in yields	• Published data limited to research station • Research in progress will address some limitations (measuring C, N_2O, and yield

	Research in Progress: ***Summerland research station – apple (2022 to 2025) [*O3]** **Alleyway cover crop mixtures**, including native and drought-tolerant species Measuring: soil C, N_2O emissions, yield ***Oliver, Summerland, West Kelowna (3 sites) – grapes (2018 to 2023) [*O13]** 15 cover crop species in alleyways, 9 cover crop species in-row (initial screening trials) 3 cover crops in alleyways, 3 cover crops in-rows (full experiments at two sites) Measuring: soil C, soil chemical properties, grape yield, quality, cover crop biomass, C and N ***Other:*** Global meta-analyses found alleyway cover crops increase soil C [O3] but generally increase N_2O emissions compared to bare soil, although the effect on N_2O emissions was not significant[O6]	together), but are still short-term (3 to 5 years) and largely at research stations
Nitrogen management **[OK, 3, 1*]** [a]	**Summerland research station – grape – 2 yrs [O1]** **Compost** at 40 kg PAN/ha did not reduce N_2O emissions (year-round) compared to urea at 40 kg N/ha; yield-scaled N_2O emissions also not different *Measuring: soil C and nitrifiers/denitrifiers [Voegel] **Summerland research station – apple – 2 yrs [O2]** **Reduced N rate** (63 kg N/ha) did not change N_2O emissions (year-round) compared to high N rate (127 kg N/ha) (fertigated); yield-scaled N_2O emissions also not different **Also measured: soil C and nitrifier/denitrifiers [*O9], and yield [*O2]* **Summerland research station – grape – 3 yrs [O7]** **Compost at 40 kg PAN/ha, incorporated to 5 cm,** increased soil C compared to: mulch + N fertigation, compost (surface applied) + mulch, N fertigation, and NPKB fertigation treatments **Compost at 40 kg PAN/ha, unincorporated, on top of 10 cm bark mulch** increased soil C compared to fertigation-only treatments, but not compared to fertigation + mulch treatment ***Research in Progress:*** **South-east Kelowna – (organic) grapes (2018 to 2023) [*O8]* *Three **different compost types** at 25 kg PAN/ha compared to no mulch control* *Measuring: SOM, nematodes, yield* ***Other:*** A global meta-analysis found nitrification inhibitors decrease N_2O emissions compared to conventional fertilization with inhibitors in orchards [O6]	• Nitrification inhibitors have not been trialed • Limited research, from short-term studies (2 to 3years) • Lacking research measuring soil C and N_2O emissions from substituting conventional fertilizer with organic amendments

<table>
<tr>
<td>Irrigation

[OK, 3, 3*] [a]</td>
<td>Summerland research station – grape – 2 yrs [O1]
Drip irrigation did not reduce N2O emissions (year-round) compared to sprinklers; yield-scaled N_2O emissions also not different

Summerland research station – apple – 2 yrs [O2]
Reduced irrigation frequency (every second day) reduced N_2O emissions (year-round) compared to watering every day; yield-scaled N_2O emissions lower, but not significantly different
*Also measured: soil C and nitrifier/denitrifiers [*O9], and yield [*O2]

Summerland research station – grape – 3 yrs [O7]
Micro sprinklers did not increase soil C compared to drip irrigation
*Also measured: nitrifier/denitrifiers [*O10]

<u>Research in Progress:</u>
*Summerland research station – sweet cherry (2019 to 2023) [*O1]
Micro sprinklers vs. drip irrigation
Measuring: soil C, growing season N2O emissions, yield, plant water relations
*Mission Hill vineyard – (organic) grape (2013 to 2014) [*O11]
Micro sprinklers vs. drip irrigation
Measuring: soil C and nematodes
*South-east Kelowna (3 sites) – sweet cherries (2015 to 2017) [*O12]
Post-harvest deficit irrigation vs. full irrigation
Measuring: soil C, yield

<u>Other:</u>
● A global meta-analysis found sprinkler irrigation increases soil C (especially below 10 cm depths) compared to drip irrigation [O9]
● A global meta-analysis also found micro sprinklers and subsurface drip decreases N_2O emissions compared to surface drip in orchards [O6]
● In contrast, a global meta-analysis found drip irrigation reduces N_2O emissions vs. sprinkler irrigation [O10]</td>
<td>● Limited to short-term studies (2 to 4 years)

● Lacking studies that measure yield, soil C, and N2O emissions together

● Meta-analyses have found increased soil C from micro sprinklers, but conflicting impacts on N2O emissions</td>
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<td>Biochar

[OK, 1*]</td>
<td><u>Research in Progress:</u>
*Summerland research station – grapes (2018 to 2023) [*O14]
Seaweed extract and vermicompost extract (rate + frequency), vermicompost (rate), and compost and biochar mix
Measuring: soil C and nutrients, grape yield/quality, disease, cover crop establishment</td>
<td>● Minimal research in BC
● Lacking research looking at biochar alone vs. industry standard</td>
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	***Other*:** ● A global meta-analysis found that applying biochar in vineyards increased soil C [O3] ● Biochar could increase soil C while reducing N2O emissions by adsorbing mineral N [H7]	● Lacking both soil C and N2O emissions from biochar applications
Pruning residues **[0]**	No known, published BC data ***Other*:** A global meta-analysis found that retaining pruning residues in vineyards increased soil C [O3]	● Lacking BC data
No-tillage **[0]**	No known, published BC data ***Other*:** A global meta-analysis found that reducing tillage in vineyards increased soil C [O3]	● Lacking BC data

[a] [Agricultural region [b], number of studies in the region]
[b] BC Agricultural Regions: Vancouver Island/Coast (VC), South Coast (SC), Cariboo Chilcotin Coast (CC), Thompson Nicola (TN), Okanagan (OK), Kootenay (KT), Omenica Skeena (OS), and Peace (PC)
[c] References include both peer-reviewed publications and Master's theses, and are referenced using an alpha-numeric system, where the letter indicates the can be found in the published research and research in progress spreadsheets
* Research with an asterisk (*) is in progress or manuscripts in prep

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