Summary of Research on Management Practices for Climate Change Mitigation

Forage

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. Therefore, 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. It is intended to provide an introduction to past research and research in progress.

OVERVIEW

Forage is produced in a broad range of micro-climates and includes both irrigated and dryland operations as well as a mix of perennial and annual crops. This includes tame or seeded pasture (226,000 ha), alfalfa and mixes (198,000 ha) and other tame hay and fodder crops (150,000 ha). Additionally, corn is grown for silage (17,000 ha) and there are areas devoted to growing forage for seed (15,000 ha). Production occurs in all regions of the province, but primarily in the South Coast, Cariboo Chilcotin Coast, Peace, Omenica Skeena, and Thompson Nicola regions. Grains and oilseeds also cover a substantial acreage and are primarily concentrated in the Peace region of the province (154,000 ha). BC-based published research to-date has largely occurred in the South Coast region at the Agriculture and Agri-Food Canada Agassiz Research station where research is targeted towards dairy production systems. 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
Nitrogen management	Type, rate, timing, and placement of nitrogen in crop rows to decrease N_2O emissions with impacts to soil C. Includes nitrification inhibitors, manure separation and application, and low emission application technology,
Relay / cover cropping	Fall interseeding a cover crop directly into an established first crop (typically corn). Can be cut or grazed the spring prior, and incorporated via tillage or seeded directly in the spring. Intended to increase soil C and reduce N_2O emissions.
Tillage	Implementing reduced or no-tillage to increase soil C, which impacts N_2O emissions as well.
Irrigation	Type, frequency, and volume of irrigation can impact N_2O emissions and soil C.

RESEARCH SUMMARY: HIGHLIGHTS and GAPS

RESEARCH HIGHLIGHTS

Nitrogen Management

- Integrating nitrification inhibitors, irrigation, relay cropping, early variety corn and manure separation (dairy sludge injection to corn and surface banded liquid manure to grass), did not change whole-system N_2O emissions from corn and perennial grass forage production, compared to typical management, but did moderately increase milk production. The former management practices without nitrification inhibitors or irrigation increased N_2O emissions compared to typical management.
- Separated dairy sludge injection can replace starter P fertilizer (5 to 10cm, but not 15cm at planting) in corn without yield reductions (but combined impacts to soil C and N_2O were not tested).
- Injected liquid swine manure reduced N_2O emissions from perennial grass in a clay soil, but increased emissions in a loam soil, compared to N fertilizer. There was no difference between manure treatments (raw, decanted, filtered, digested, digested/flocculated).
- Results from the use of surface banded liquid dairy manure on perennial grass have shown:
    - At low rates, surface-banded liquid dairy manure had higher nitrogen use efficiency than high manure rate and fertilizer treatments. Similarly, at high and low rates, surface-banded liquid dairy manure had similar N_2O emissions to fertilizer, but with higher yields.
    - In contrast, another study found nitrogen use efficiency to be greater with fertilizer than the use of liquid fraction at a low or high rate. The use of whole slurry at a low rate had better nitrogen use efficiency than a mid or high rate. Yields were similar between manure (all surface-banded) and fertilizer treatments.
    - High rate of surface-banded liquid dairy manure increased soil C compared to fertilizer, but low rate applications did not.
    - In contrast, another study found no difference in soil C between whole dairy slurry, liquid fraction, fertilizer, and combination slurry and fertilizer, but all treatments had higher soil C than unfertilized/unmanured control.
- Mechanically assisted infiltration reduced N_2O and NH_3 emissions of dairy manure (measured after application the following spring) compared to broadcast application.
- Dairy slurry broadcast applied to fescue (vs. bare soil) reduced N_2O emissions.
- One study found pre-sidedress soil nitrate testing could reduce fertilizer N by 90 kg N/ha/year.

Relay Cropping & Irrigation

- See the first bullet point in ‘Nitrogen Management’ above.

Tillage

- Reduced tillage in silage corn did not increase soil organic matter after 20 years compared to conventional tillage, but it did increase aggregate stability and available water capacity.

RESEARCH GAPS

- Most research to-date has focused on N management (largely manure separation and application technology) in the South Coast; some results of these studies have been contradictory.
- There is a lack of studies reporting soil C, N_2O emissions, and yields together, as well as yield- or production-scaled emissions.
- Due to re-deposition of NH_3 emissions, there are challenges with only measuring N_2O emissions without measuring NH_3.
- There is limited published research on relay cropping, tillage, irrigation, or practices to increase the efficiency of cropping systems.
- Research on tillage has been limited to one long-term study in the South Coast, and N_2O emissions were not evaluated.

RESEARCH RECOMMENDATIONS

- The evaluation of promising N management practices in the South Coast can be expanded to multi-site trials, including a comprehensive set of measurements (i.e. NH_3, N_2O, soil C, yield)
- Given that nitrification inhibitors have shown promising results in one trial at AAFC, these could be evaluated further, in multi-site trials and/or under different practices and different regions.
- Trials on reduced tillage can be expanded to include a comprehensive set of measurements (N_2O, soil C, yield), and trials can be established in several different regions.
- Similarly, unpublished research data and experience from the South Coast (AAFC) and Okanagan (FAIP / BC Forage Council) should be used to inform next steps on the trials for relay crop and reduced tillage for evaluation in different regions.

TABLE 2: RESEARCH HIGHLIGHTS

Management Practice Area	Research Highlights [c]	Research Limitations
Nitrogen management **[SC, 13]** **[CC, 1*]** **[PC, 1*]**	**Agassiz research station, perennial grass and silage corn system, 2 yrs [F1]** **Dairy manure separation:** Injecting sludge manure to corn (combined with starter P fertilizer) and surface banding liquid manure to grass, increased whole-system N_2O emissions (year-round), compared to typical management of broadcasting whole manure **Relay cropping (rye grass)** [plus dairy manure separation, as described above]: Interseeding rye relay crop into early harvest corn, and cutting hay 3x (instead of 5x), increased whole-system N_2O emissions (year-round) **Nitrification inhibitor + irrigation** [plus manure separation and relay crop as described above]: did not impact N_2O emissions (year-round) from typical management **Agassiz research station, perennial grass and silage corn system, 2 yrs [F13]** **Dairy manure separation:** sludge injection to corn instead of broadcast manure plus starter P fertilizer, and surface banding liquid manure to grass instead of broadcast, moderately increased milk production **Relay cropping (rye grass)** [plus dairy manure separation, as described above]: early harvest corn variety with rye relay crop interseeded, and hay cut 3 times (instead of 5), produced moderate increase in milk production and corn crude protein compared to typical management, **Nitrification inhibitor + irrigation** [plus manure separation and relay crop as described above]: produced moderate increase in milk production and corn crude protein compared to typical management **Agassiz research station, no-till silage corn, 5 yrs [F3]** Did not measure soil C or N_2O emissions, but **separated dairy sludge injection** prior to planting, plus broadcast N fertilizer had yields similar to using starter N and P fertilizer **Agassiz research station, silage corn, 3 yrs, [F7]** Did not measure soil C or N_2O emissions, but **separated dairy sludge injected** 5 cm or 10 cm (but not 15cm) from corn at planting had yields not different from starter fertilizer **Agassiz research station, grain corn, 3 yrs [F8]** **Injected liquid swine manure** reduced N_2O emissions (production-season) in a clay soil, but increased emissions in a loam soil, compared to N fertilizer, with no difference between manure treatments (raw, decanted, filtered, digested, digested/flocculated) **Agassiz research station, perennial grass, 15 yrs [F2]**	● Lacking yield- / production-scaled N_2O emissions ● Lacking studies reporting soil C, N_2O emissions, and yields together ● Published research concentrated in the South Coast region ● Due to re-deposition of NH_3 emissions, there are challenges with only measuring N_2O emissions without NH_3 ● Limited systems research

	Did not measure soil C or N_2O emissions, but **low N application rate of liquid dairy manure** (200 TAN/ha) with sliding-shoe applicator, in 4 split applications, had a higher nitrogen use efficiency compared to high rate of manure, and both low and high rates of mineral fertilizer **Agassiz research station, perennial grass, 6 yrs [F4]** Whole dairy manure (high and low rates) reduced N_2O emissions (year-round) compared to fertilized control, but reduced yields compared to separated liquid manure (manure surface banded) **Separated liquid dairy manure (high and low rates)** had similar N_2O emissions (year-round) as the fertilized control plot, but had higher yields **Agassiz research station, perennial grass, 17 yrs [F6]** **High rate of liquid dairy manure** at 100 kg TAN/ha (but not low rate at 50 kg TAN/ha), surface banded in 4 split applications, increased soil C compared to mineral fertilizer (high (100) and low (50) rates) **Agassiz research station, perennial grass, 6 yrs [F9]** Did not measure N_2O emissions or soil C, but assessed nitrogen use efficiency from fertilizer / dairy manure applications, finding: fertilizer > liquid fraction (low rate) > liquid fraction (high rate), which was equal to the use of whole slurry at a low rate. Whole slurry at a low rate had greater nitrogen use efficiency than mid or high rate applications. Overall, yields were similar between manure and fertilizer treatments. **Agassiz research station, perennial grass, 6yrs [F10]** **Mechanically assisted infiltration** reduced N_2O and NH_3 emissions (measured after application to following spring) of dairy manure (decanted and whole) compared to broadcast application **Agassiz research station, perennial grass, 2 yrs [F11]** Whole dairy slurry broadcast applied to fescue reduced N_2O emissions (measured ~4 months after) compared to applications to bare soil; no difference between applications in April vs. February **Agassiz research station, perennial grass, 10 yrs [F12]** No difference in soil C between whole dairy slurry, liquid fraction, fertilizer, and combination slurry and fertilizer, but all treatments had higher soil C than unfertilized/unmanured control **South Coast (10+ sites), silage corn, 3 yrs [F14]** **Pre-sidedress soil nitrate testing** could reduce fertilizer N applications by 90 kg N/ha/year ***<u>Research in Progress:</u>*** ***Cariboo-Chilcotin and Omineca Skeena (5 sites), tame hay fields (2021 to 2023) [*F1]** Five **fertilizer N application rates** (0 to 200 kg N/ha)	

	Measuring: soil C, and forage yield and quality ***Peace (23 sites), improved pasture (2015 to 2020) [*F5]** Trialling: organic amendments, bale grazing, grazing management, nutrient management Measuring: soil organic matter, production outcomes (various) ***Other:*** ● In Switzerland, intensively managed permanent hay pastures oversown with three varieties of clover (and grazed by sheep) reduced N2O emissions compared to repeat applications of liquid slurry; yields were lower in year one, but not different in year two (after clover establishment). Yield-scaled emissions were higher from manured treatment than clover treatment.	
Relay / cover cropping **[SC, 1, 1*]** **[CC, 2*]** **[OS, 2*]** **[OK, 3*]**	**Agassiz research station, perennial grass and silage corn system, 2 yrs [F1]** **Dairy manure separation:** sludge injection to corn instead of broadcast manure plus starter P fertilizer, and surface banding liquid manure to grass instead of broadcast, increased whole-system N_2O emissions (year-round) **Relay cropping (rye grass)** [plus dairy manure separation, as described above]: early harvest corn variety with rye relay crop interseeded, and hay cut 3 times (instead of 5), increased whole-system N_2O emissions (year-round) **Nitrification inhibitor + irrigation** [plus manure separation and relay crop as described above]: did not impact N_2O emissions (year-round) from typical management ***Research in Progress:*** ***Cariboo-Chilcotin and Omineca Skeena (4 sites), pasture / tame hay fields (2019 to 2021) [*F2]** Trialling: various no-till pasture rejuvenation and cover crop strategies Measuring: soil C, and forage yield and quality ***Kootenay and Boundary (8 sites), pasture / tame hay fields (2019 to 2021) [*F3]** Trialling: frost seeding, cover crops, no-till pasture rejuvenation, management intensive grazing, legume interseeding Measuring: soil C, and forage yield and quality ***Lavington (2 sites), corn (2019 to 2022) [*F8]** Trialling: strip tillage of previous year's residues (corn residue, relay cover crop, perennial grass), and strip tillage plus relay crop Measuring: soil organic matter, soil health, yield and quality of corn and grass ***Lavington (2 sites), corn (2019 to 2022) [*F7]** Trialling: interseeding relay cover crop (rye, clover, forage brassica mix) into corn, and interseeding relay cover crops into corn with solar pathways Measuring: soil organic matter, soil health, yield and quality of corn and grass	● Limited published research in BC ● Very little research in progress in the South Coast

	***Lavington (2 sites), corn (2019 to 2023) [*F9]** Trialling: alternative winter covers/crops (to be spring harvested or grazed), including winter barley, fall rye, winter peas, and a mixture of these Measuring: crop yield and quality, and crop use parameters (i.e. ability to fill local markets) ***Agassiz research station, silage corn and grass rotation (2017 to ongoing)** Trialling: business as usual corn and perennial grass compared to improved interseeding (drill-seeded) Measuring: soil C, yield, leachates; preliminary results indicate greater cover crop yields	
Tillage **[SC, 1]** **[CC, 2*]** **[OK, 1*]** **[PC, 1*]**	**Agassiz research station, silage corn, 21 yrs [F5]** **Reduced tillage** did not increase soil organic matter compared to conventional tillage, but did increase aggregate stability and available water capacity ***Research in Progress:*** ***Cariboo-Chilcotin and Omineca Skeena (4 sites), pasture / tame hay fields (2019 to 2021) [*F2]** Trialling: various no-till pasture rejuvenation and cover crop strategies Measuring: soil C, and forage yield and quality ***Kootenay and Boundary (8 sites), pasture / tame hay fields (2019 to 2021) [*F3]** Trialling: frost seeding, cover crops, no-till pasture rejuvenation, management intensive grazing, legume interseeding Measuring: soil C, and forage yield and quality ***Lavington (2 sites), corn (2019 to 2022) [*F8]** Trialling: strip tillage of previous year's residues (corn residue, relay cover crop, perennial grass), and strip tillage plus relay crop Measuring: soil organic matter, soil health, yield and quality of corn and grass ***Peace (4 sites), improved pasture (2019 to 2021) [*F4]** Trialling: No-till pasture rejuvenation, intensive grazing, drill seeding Measuring: forage yield and quality	• Published research is limited to one study in the South Coast • Research in progress lacks inter- and intra-site replication
Irrigation management **[SC, 1]**	**Agassiz research station, perennial grass and silage corn system, 2 yrs [F1]** **Dairy manure separation:** sludge injection to corn instead of broadcast manure plus starter P fertilizer, and surface banding liquid manure to grass instead of broadcast, increased whole-system N_2O emissions (year-round) **Relay cropping (rye grass)** [plus dairy manure separation, as described above]: early harvest corn variety with rye relay crop interseeded, and hay cut 3 times (instead of 5), increased whole-system N_2O emissions (year-round) **Nitrification inhibitor + irrigation** [plus manure separation and relay crop as described above]: did not impact N_2O emissions (year-round) from typical management	• Very few research studies completed in BC

Efficiency **[OK, 1*]**	***Research in Progress:*** ***Lavington & Lumby (4 sites), corn (2019 to 2022) [*F6]** Trialling: variable rate planting Measuring: soil organic matter, soil health, grain and silage yield and quality	• Lacking studies reporting soil C, N_2O emissions, and yields together

[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 can be found in the published research and research in progress spreadsheets
* Research with an asterisk (*) is in progress or manuscripts in prep

Acknowledgements

This research summary was prepared by Amy Norgaard and the BC Agricultural Climate Adaptation Research Network (ACARN) technical working group on climate change mitigation. ACARN would like to thank those who shared information about their previous and continuing research projects.

This project was supported by the Investment Agriculture Foundation of BC, with funding provided by Agriculture and Agri-Food Canada programs.