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Summary of Research on Management Practices for Climate Change Mitigation

Field Vegetables

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

The total area of BC's agricultural land under field vegetable production is 8,250 ha. The largest production area is dedicated to potatoes in the South Coast region. Field vegetables are grown in almost all production areas of the province with a concentration of production in the South Coast region (69%), as well as considerable production in the Okanagan (14%) and Vancouver Island regions (12%). BC-based research to-date has largely occurred in the South Coast at UBC Farm, Delta and the Fraser Valley. Relevant management practices are listed in Table 1. The share of vegetable production acreage and location of sites with published data for GHG mitigation are shown in Figure 1.

FIGURE 1: TOP VEGETABLE PRODUCING REGIONS & LOCATION of RESEARCH SITES

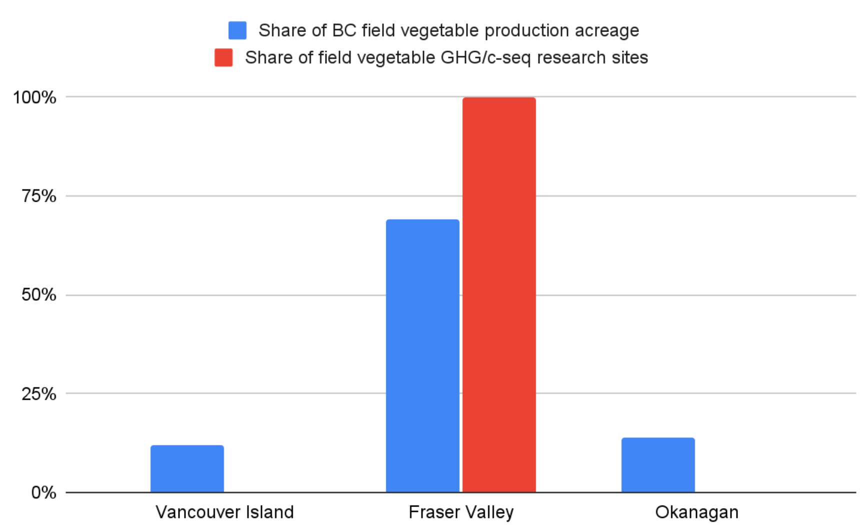

TABLE 1: MANAGEMENT PRACTICE DESCRIPTIONS and MITIGATION POTENTIAL

Management Practice Area	Description and Potential for Climate Change Mitigation
Nitrogen management / Organic amendments	Type, rate, timing, and placement of nitrogen in crop rows to decrease N_2O emissions with impacts to soil C. Includes nitrification inhibitors, split applications, manure separation and application, and low emission application technology.
Cover cropping	Fall cover crops planted directly after, or interseeded into, a main summer crop. Intended to increase soil C with impacts to N_2O emissions as well.
Grassland set-asides	Removing a field from agricultural production and seeding it with grass / legume mixes, typical for 2+ years, could increase soil C.
Drainage management	Installation of sub-surface drainage with or without pumps to reduce the length of time a soil is saturated could reduce N_2O emissions, but with impacts to C sequestration as well.
Tillage	Implementing reduced or no-tillage to increase soil C, but likely impacts N_2O emissions.

RESEARCH SUMMARY: HIGHLIGHTS and GAPS

RESEARCH HIGHLIGHTS

Nitrogen management / Organic amendments

- Reducing the N application rate to 90 from 120 kg N/ha in potatoes did not reduce soil CO_2e emissions, but did reduce N_2O emissions while not affecting yields.
- In a comparison of four different nutrient management strategies, cumulative N_2O emissions were higher with manure than a hybrid (low compost plus organic N fertiliser). The hybrid had greater emissions than the high compost treatment. Lowest emissions were recorded for the low compost treatment. Yields were similar for the manure, high compost and hybrid treatments. Yields varied between years/crop types for the low compost treatment. No differences in soil C was found after two years of treatments.
- Fall-applied poultry manure produced ~5x higher N_2O emissions compared to fall-applied horse manure but the poultry manure resulted in higher spaghetti squash yields.
- A field scale study of annual C sequestration and N2O and CH4 emissions in potatoes and peas on Westham Island with conventional levels of fertilizer application found that CH4 emissions are a negligible component in NGHGB for both crops

Cover cropping

- Annual rye-grass (seeded mid-August) increased soil C the following spring compared to a bare soil control.
- Fall rye numerically, but not significantly, increased soil C. Spring barley cover crop winter killed.
- In a 16-week field incubation, hairy vetch released the most available N, followed by crimson clover mixes (with winter wheat, fall rye, or annual rye grass). Crimson clover by itself had highly variable N release, and grasses on their own tended to immobilize N.

- Fall-planted wheat and rye cover crops reached critical maturation growth stage (i.e. for best N management) when soil water content was too high for soil to be worked by tillage. Authors suggest terminating cover crops with mowing or spraying to minimize soil compaction. Spring barley winter killed.
- In a litterbag study, the highest N release was from vetch and a rye, vetch and chicory mix. Compared to N release from rye alone, the mix had lower N release than the no cover crop control. N release from chicory was not different than the control. The vetch and rye combination had higher N release than the control and rye alone.

Grassland set-asides

- In one study, 2-4 year grassland set-asides did not increase soil C, compared to continuously cropped fields, but another study found moderately increased soil C at the 30-45 cm depth after 4 year grassland set asides. Another study, which did not measure soil C, did find increased aggregate stability and decreased bulk density from 2-year grassland set-asides.
- A 2-year grassland set-aside incorporated with 100 kg N/ha fertilizer had the highest cumulative N_2O emissions (year-round) compared to both 2-year grassland set-aside without fertilizer N and the continuously cropped treatment with the same fertilizer N. Yields were variable, but in general the set-asides increased yields in paired comparisons, where grassland set-asides plus N fertilizer had higher yields than paired continuously cropped fields with N fertilizer. Similarly, grassland set-asides incorporated without N fertilizer had higher yields than continuously cropped fields without N fertilizer.

Drainage management

- There is no BC data on N_2O or soil C, but one study found that the number of days of ponding was not reduced with subsurface drainage (drains plus pumps and drains alone were tested) compared to controls without drainage installed.

Tillage

- There is no published BC data on tillage impacts on emissions in vegetable systems.

RESEARCH GAPS

- In general, fewer BC data are available, and lacking studies reporting impacts to soil C, emissions, and production (i.e. yields) together. No published data available for drainage and tillage.
- Many nutrient management studies to-date and in-progress are in organic farming systems. Future studies could evaluate these regenerative farming practices in a conventional context, in addition to trialling simple practices that have not been tested in BC, but have shown promise in other places or other sectors, (i.e. nitrification inhibitors, split applications).
- Despite studies elsewhere finding increased soil C after grassland set asides, two studies in Delta did not. Future research could consider under what climates, soils, and other conditions (i.e. set-aside management, years in set-aside) grassland set-asides might be beneficial in the BC context. Evaluations should also consider N_2O emissions.
- Cover crop research is limited to field experiments in Delta and incubation/litterbag experiments, and with simple monocultures and blends. This could expand to include more advanced cover crop varieties and seeding methods (i.e. interseeding, living mulch). Studies need to consider impacts to N_2O emissions in addition to soil C.

TABLE 2: RESEARCH HIGHLIGHTS

Management Practice Area	Research Highlights [c]	Research Limitations
Nitrogen management / Organic amendments [SC, 3, 4*] [VI, 3*] [KT, 1*]	**Delta (1 site), potatoes, 1 yr [V3]** No difference in (growing season) did not reduce soil CO_2e emissions or N_2O emissions between low vs. high N application rates (90 vs. 120 kg N/ha); yields were also not different between application rates **UBC Farm, beets and fennel, 2 yrs [V7]** Compared four different nutrient management strategies, and in terms of cumulative N_2O emissions (measured June to April), found: manure > hybrid (low compost plus organic N fertiliser) > high compost > low compost. But for yields: manure ~ high compost ~ hybrid > low compost; yields varied between years/crop types. No difference in soil C after two years of treatments. UBC Farm, spaghetti squash, 1 yr [V8] Fall-applied poultry manure (@ ~105 kg PAN/ha) produced ~5x higher N_2O emissions (measured October to April) compared to fall-applied horse manure (@~80 kg PAN/ha), but also higher yields; both treatments received municipal compost (@~150 kg PAN/ha) in the spring prior to squash planting, and incorporated with cover crop. ***<u>Research in Progress:</u>*** ***UBC Farm and one Vancouver Island farm, potatoes and broccoli and cauliflower, 3 yrs [*V1]** Treatments: 1. Compost targeting N requirements, 2. Compost plus organic N fertilizer targeting N and P requirements, 3. Typical amendments used by the farm, 4. Control (no N or P added) Measuring: soil C, yield, and N_2O, CO_2, and CH_4 emissions (year-round) (emissions at one site) ***UBC Farm and one Vancouver Island farm, beets, fennel, beans, 2 yrs [*V2]** Treatments: Split-plot design with main plot nutrient treatments: 1. Compost targeting N requirements, 2. Compost plus organic N fertilizer targeting N and P requirements, 3. Typical amendments used by the farm, 4. Control (no N or P added), and split-plot cover treatments: 1. Winter cover cropping, 2. Plastic mulch (tarp) winter cover Measuring: soil C, yield, and N_2O, CO_2, and CH_4 emissions (year-round) (emissions at one site) ***Vancouver Island, Fraser Valley, Kootenays (14 sites), 2 yrs [*V3]** Treatments: Split-plot design with main plot nutrient treatments: 1. Compost targeting N requirements, 2. Compost plus organic N fertilizer targeting N and P requirements, 3. Typical amendments used by the farm, 4.	- Limited BC research, with two organic studies and only one conventional study; research in progress is similar - Lacking long-term, BC studies on organic amendment applications and soil C - Many N management practices have not been validated in BC vegetable production

	Control (no N or P added), and split-plot cover treatments: 1. Winter cover cropping, 2. Plastic mulch (tarp) winter cover Measuring: soil C, yield, other soil chemical properties ***Delta (1 site), vegetable and forage rotation, 1 to 2 yrs [*V4]** Treatments: Split plot design with main plot tillage treatments: 1. Reduced tillage, 3. Conventional tillage, 4. Conventional tillage + herbicide, with split plot nutrient treatments: 1. Organic nutrient management (compost + feathermeal), 2. Synthetic nutrient management (NPK blend), 3. Control (no applications) Measuring: soil C, yield, N_2O, CO_2, and CH_4 emissions (year-round) ***<u>Other:</u>*** ● A review looking at emissions from horticultural systems in Canada indicated that studies to-date have generally found that: reduced N application rates, delayed N applications, use of nitrification inhibitors and slow release fertilizers, and broadcast and incorporation of fertilizer (vs. banding) can reduce N_2O emissions [V1] ● In a long-term experiment at Rothamsted Research Station, United Kingdom, large applications of farm yard manure (35 t/ha wet weight) increased soil organic C by 0.69 t/ha/year and 1 t/ha/year for the first 20 years, in winter wheat and spring barley production systems, respectively. Rate of soil C increase began to decrease after the first 20 years. [V11] ● In a global meta-analysis of organic farming practices, use of organic (carbon-based) amendments increased soil C. [V13] ● In a two-year field experiment in Fredericton, New Brunswick, a split N application reduced cumulative N_2O emissions (production season), but only in year two of the trials, which had substantial precipitation between planting and hilling (versus drier spring conditions in year one, where no differences were found). Yields were not different between full vs. split application treatments. [V16]	
Cover cropping [SC, 4, 3*] [VI, 2*] [KT, 1*]	**UBC Farm (litterbag study), various cover crops, 1 yr [V6]** Did not measure soil C or N_2O emissions, but found: highest N release from vetch and rye + vetch + chicory mix, compared to N release from rye alone was less than the no cover crop control; N release from chicory was not different than the control, and rye + vetch mixture was higher than control and rye, but not different from the others. **Delta (2 sites), various cover crops, 2 yrs [V19]** Did not measure soil C or N_2O emissions, but found that fall-planted wheat and rye cover crops reached critical maturation growth stage (i.e. for best N management) when the soil water content was too high for soil to be workable by tillage. Authors suggest terminating cover crops with mowing or spraying to minimize soil compaction. Spring barley winter killed.	- Lacking data on impacts to N_2O emissions, especially studies reporting soil C, emissions, and yield together - Lacking data on long-term impacts of cover crops to soil C

	Delta (1 site), various cover crops, 1 yr [V20] Annual ryegrass seeded mid-August increased soil C (measured in the following spring) compared to a bare control without cover crop. Fall rye numerically but not significantly increased soil C as well, and spring barley cover crop winter killed. **Delta (1 site), field incubation, 1 yr [V21]** Did not measure soil C or N_2O emissions, but in a 16 week field incubation including winter wheat, fall rye, annual rye grass, three crimson clover plus grass mixes, and a winter wheat plus hairy vetch mix, the hairy vetch released the most available N, followed by crimson clover mixes. Crimson clover N release was highly variable, and grasses on their own tended to immobilize N. ***<u>Research in Progress:</u>*** ***UBC Farm and one Vancouver Island farm, beets, fennel, beans, 2 yrs [*V2]** Treatments: Split-plot design with main plot nutrient treatments: 1. Compost targeting N requirements, 2. Compost plus organic N fertilizer targeting N and P requirements, 3. Typical amendments used by the farm, 4. Control (no N or P added), and split-plot cover treatments: 1. Winter cover cropping, 2. Plastic mulch (tarp) winter cover Measuring: soil C, yield, and N_2O, CO_2, and CH_4 emissions (year-round) (emissions at one site) ***Vancouver Island, Fraser Valley, Kootenays (14 sites), 2 yrs [*V3]** Treatments: Split-plot design with main plot nutrient treatments: 1. Compost targeting N requirements, 2. Compost plus organic N fertilizer targeting N and P requirements, 3. Typical amendments used by the farm, 4. Control (no N or P added), and split-plot cover treatments: 1. Winter cover cropping, 2. Plastic mulch (tarp) winter cover Measuring: soil C, yield, other soil chemical properties ***Delta (26 sites), various annual cropping systems [*V5]** Treatments: No formal treatments. This is an observational study using historical management practice data and soil samples from fields in 2018. Generally observing impacts of cover cropping, grassland set asides, and hedgerows. Measuring: soil C and assessing soil workability thresholds ***<u>Other:</u>*** ● A review looking at emissions from horticultural systems in Canada indicated that studies to-date have generally found variable impacts from cover crops on N_2O emissions, depending on type, planting and termination dates, seeding rate, climate, and soil type. In general, early planted cover crops tended to reduce N_2O emissions. [V1]	- Studies to-date are concentrated in Delta

	● In a global meta-analysis of organic farming practices, cover cropping increased soil C, but only after 5 years of continual use. [V13]	
Grassland set-asides [SC, 5, 1*]	**Delta (4 sites), 2-6 yr grassland set-asides – annual crop production [V2]** Compared to continuously cropped fields, grassland set-asides did not increase soil C after 2-4 years set-aside Delta (5 sites), 4-yr grassland set-asides – annual field crops [V18] Grassland set-asides moderately increased soil C at the 30-45cm depth, but not in any other depth, compared to paired fields with continuous annual cropping. **Delta (4 site pairs), 3 yr grassland set-asides – annual crop production [V4]** Did not measure soil C or N_2O emissions, but found variable impacts to soil available N, with increased N in year one, but decreased N in year two, compared to control fields with continuous annual cropping and no set-aside. Incorporating composted chicken manure (100 kg N/ha) resulted in similar available N compared to no GLSA control. **Delta (8 site pairs), 2 yr grassland set-asides – annual crop production [V5]** Did not measure soil C or N_2O emissions, but found increased aggregate stability and aeration porosity and decreased bulk density compared to continuous annual cropping. **Delta (2 sites), 2-3 yr grassland set-asides – potatoes [V9]** The 2-year grassland set-aside incorporated with 100 kg N/ha fertilizer had the highest cumulative N_2O emissions (year-round) compared to both 2-year grassland set-aside without fertilizer N and the continuously cropped treatment. Yields were variable, but in general the set-asides increased yields in paired comparisons, with grassland set-asides plus N fertilizer having higher yields than continuously cropped fields plus N fertilizer. Similarly, grassland set-asides incorporated without N fertilizer had higher yields continuously cropped fields without N fertilizer. ***Research in Progress:*** ***Delta (26 sites), various annual cropping systems [*V5]** Treatments: No formal treatments. This is an observational study using historical management practice data and soil samples from fields in 2018. Generally observing impacts of cover cropping, grassland set-asides, and hedgerows. Measuring: soil C and assessing soil workability thresholds ***Other:*** ● In a long-term experiment at Rothamsted Research Station, United Kingdom, grassland set-asides ranging from (1 to 8 years) increased soil C when used in rotation with various arable crops. [V11]	Research concentrated in Delta; lacking research in other climates, soil types

	● In a long-term experiment near Winnipeg, Manitoba, a 4-year grassland set-aside (alfalfa/grass mixes) reduced the cropping system's net C loss (measured by eddy covariance) when included in an 11-year cycle of annual field crops (corn, faba, spring wheat, rapeseed, barley, soybean). [V12]	
Drainage management [SC, 1]	**Delta (15 sites), annual vegetable fields, 2 yrs [V17]** Soil C and N_2O emissions were not measured, but the number of days of ponding was not reduced with subsurface drainage (drains plus pumps or drains only) compared to controls without drainage installed.	No BC research regarding impacts to N_2O emissions or soil C
Tillage [SC, 1*]	***Other:*** In a global meta-analysis of organic farming practices, conservation tillage generally increased soil C. [V13] ***Research in Progress:*** ***Delta (1 site), vegetable and forage rotation, 1 to 2 yrs [*V4]** Treatments: Split plot design with main plot tillage treatments: 1. Reduced tillage, 3. Conventional tillage, 4. Conventional tillage + herbicide, with split plot nutrient treatments: 1. Organic nutrient management (compost + feathermeal), 2. Synthetic nutrient management (NPK blend), 3. Control (no applications) Measuring: soil C, yield, N_2O, CO_2, and CH_4 emissions (year-round)	No BC research regarding impacts to N_2O emissions or soil C
[Agricultural region [b], number of studies in the region] 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) 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		

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