British Columbia Manure and Crop Nutrients

A Review of Current Data and Regional Fieldwork focused on Southwest British Columbia

February 26, 2015

Prepared For:
British Columbia Ministry of Agriculture
Contract # GSAGF2-047
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Acknowledgement
This project is supported by *Growing Forward 2*, a federal-provincial-territorial initiative.

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Executive Summary

The overarching goal of this document is to provide updated manure and crop nutrient information as part of a broad set of initiatives to develop nutrient management planning tools in British Columbia (BC). A key outcome of what is reported in this document is a set of recommended reference values for manure and crop nutrients. This information is condensed as reference tables and can be found in complete form in appendices 1 and 2 of this report.

Manure nutrient analyses are required for calculating the agronomic balances and crop removal balances of fields that receive manure[1]. In addition, crop yields and nutrient analyses of harvestable portions of crops are required for calculating crop removal balances. This report includes manure and crop data from a variety of sources that have been summarized and compiled in a single dataset. The data sources included were from:

- A review of literature on manure and crop types and nutrient contents from BC, other provinces, and outside of Canada
- Field data that was collected primarily in Southwest British Columbia from June 2013 to December 2014
- Unpublished BC Ministry of Agriculture manure and crop datasets

The review provides detailed summaries of the current distribution of manure and crop types in BC, the available data on crops and manures, and an assessment of the quality of these data. In all, we reviewed a total of 148 sources including surveys, reports, personal communications, unpublished data, and peer reviewed publications from 1969 through 2014. The documents are compiled in an online bibliography here (http://www.mendeley.com/groups/4193931/bc-agricultural-nutrient-management/). We compiled data on yields, and nutrient content for 24 crops, and nutrient content of manure for 13 different manure and other soil amendment types (e.g. compost). These data will also be made available online.

Southwest British Columbia (SWBC) was the primary focus of this review and data collection because of its importance to agricultural production in the province. SWBC includes five Regional Districts: Fraser Valley, Metro Vancouver, Sunshine Coast, Squamish-Lillooet, and Powell-River Regional Districts. Decades of provincially and regionally focused research have provided baseline nutrient data for certain manures and crops, but no comprehensive or updated compilation of this information is currently available. These data could substantially enhance the development of sound strategies and nutrient management tools, particularly in SWBC, where simultaneous increases in human population, urban development, and livestock density characterize the land base pressures.

Although the findings in this literature review and preliminary fieldwork have helped develop summary values for manure and crop, more comprehensive fieldwork and a broader review could help reduce the variability of these values and contribute to a more comprehensive

[1] See the Nutrient Management Reference Guide for explanations of agronomic and crop removal balances (Poon and Schmidt, 2010. Nutrient Management Reference Guide, 2nd edition. http://www2.gov.bc.ca/gov/topic.page?id=46843E0F54024AC2A4917865F0B5C377

nutrient database that would make significant contributions to existing nutrient management planning tools. For those farms or ranches that lack records of their own manure nutrient analyses, crop nutrient analyses or crop yields, the reference or 'book' values provided in this document can be used for comparison until accurate, farm-specific values can be obtained. For the purposes of this initiative, the scope of nutrients was limited to nitrogen (N), ammonium (NH_4-N), phosphorus (P), and potassium (K).

The review is organized in two sections, which summarize our findings for manures and crops. Most of the information we found on manures indicated nitrogen content, with phosphorus and potassium information available to a lesser degree. We found crop yield data was most readily available from our sources, with the vast majority of these for forage and cereal crops. Crop nutrient content information was more limited, particularly for vegetable and fruit crops. The data we have compiled for the most part is highly variable and illustrates the challenges of collecting nutrient analyses, and the current limitations of "book" values for nutrient management.

Manure[2]

Field data on manure and compost samples from 2013 to 2014 was analyzed to develop recommended values. Dairy manure nutrient concentrations varied significantly by the moisture content of the manure, and are therefore reported by moisture ranges for solid and liquid manures. Similarly, we distinguished beef cattle manure content by moisture ranges although with fewer distinguishable categories. Manure was collected from three types of chickens: broilers, broiler breeders, and layers. We found significant differences in the nutrient contents of broiler manure sampled directly from the barns where the flock was housed (*indoor*) and that of manure that had been moved outside (*outdoor*) for storage. The reduction in nutrient content from *indoor* to *outdoor* is likely a factor of the age of the manure (*fresh* vs. *aged*) and environmental exposure. This reduction in nutrient content due to age was obvious for turkey manure. Turkey manure stored for longer than 7 weeks (*aged*) had significantly lower nutrient content than manure stored for a shorter period (*fresh*). For hog manure nutrient contents were significantly higher for solid manure (≤82% moisture) than for liquid (>82% moisture) with the exception of NH_4-N. Six other types of manure or compost were sampled but the low number of samples limited any additional categorization. For the majority of the manures and compost types sampled, the results were highly variable with coefficients of variation >33%.

Crops[3]

As part of the overall initiative to update nutrient management planning information focused on crop removal balances, in addition to reviewing the literature and compiling existing data, we carried out two seasons of fieldwork to sample select crops from 2013-2014. Crop yields from the literature and field data were compared to provincial level data produced by Statistics Canada (2015). For some crop types we found large differences in values, illustrating the challenge for providing "book values" for yields and the need, particularly for some crop types to provide regionally specific numbers. Using all of the data sources we have established nutrient

[2] Appendix 1: Manure Nutrient Values
[3] Appendix 2: Crop Nutrient Values

contents for a wide range of forage and cereal crop types and a few vegetable and fruit crop types.

Next Steps

The data collected and initial synthesis reported here are important steps in providing a set of values that can be used for managing nutrients at the field, farm or regional scale. While these efforts do aim to provide updated reference values for manure and crop nutrients for nutrient management planning in the province of BC, there are clearly some manure and crop types that lack sufficient data. Furthermore, there are a number of site-specific factors that will affect the nutrient content and accuracy of using reference values for crops and manure. While "book values" will always be less effective than current site-specific sampling, additional efforts to synthesize information on factors that affect the variability will further improve their utility. Manures could be further categorized by more detailed information on their storage and handling. More detailed information on location, soil types, crop varieties and crop management practices could improve the resolution of the reference values for crop nutrient removal. Based on our sampling and review, we have developed four recommendations:

- Targeted data collection should continue for manure and crop types that were not represented or represented in low numbers.
- A framework should be developed to continue to build this nutrient database with the goal to create a provincially comprehensive dataset. This province-wide dataset would record basic metadata of crops and manure and include specific information on the crop variety, soil type and manure storage used, bedding, feed and age.
- Additional review and quality control of unpublished crop yield information (from the Ministry of Agriculture's production insurance program) should continue in an effort to provide more accurate reference values for crop removal balances.
- As the database grows, future analysis should focus on additional categorizations of manure and crops that are focused on reduced variability in reference values. A more robust dataset on manure categories will also enable the analysis of spatial and temporal trends.

The review and compilation of nutrient management data provided in this document contribute to the development of nutrient management tools for BC. Given the limited scope of the initiative documented in this report we would suggest continued research focused on analyzing data quality and field data collection practices, as well as an assessment of the variability of manure and crop management practices at the field, farm or regional scales for comparison with the preliminary "book" values provided here.

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1. Introduction

Nutrient management has become an increasingly important component of agricultural production for improving the efficiency of operations to increase economic returns and to reduce the impact on the environment. Nutrient management may be approached at the field, farm or regional scale. At the field scale, manure nutrient inputs and nutrients removed in crops are components of nutrient balances. At the farm and regional scales, these inputs and outputs may also be components of nutrient balances. To achieve optimal agricultural production and environmental sustainability, all three approaches require an understanding of quantity of nutrients currently in the system, the nutrients entering, and the nutrients leaving the system.

The BC Ministry of Agriculture has developed numerous strategies that have targeted the long-term goal of sustainable nutrient management at the provincial level. Their Nutrient Management Plan (NMP) program was developed as a subcomponent of the Environmental Farm Plan (EFP) process. Developing a farm operation NMP is intended to help optimize nutrient usage on the farm at the field level to protect valuable soil, water, and air resources. To calculate the amount of nutrient removed from a farm field, crop yields and the amount of nutrients they have accumulated are required. To calculate the crop removal balance of the field, it is important to know the total nutrient content of the manure. A primary goal of this document is to provide an updated and comprehensive manure and crop nutrient content database to improve the efficacy of nutrient tools such as the NMP.

In this document, we provide results of our review of the existing knowledge base for manure and crop nutrient concentrations and crop yields in British Columbia (BC) with a particular focus on Southwest British Columbia (SWBC). SWBC includes five Regional Districts: Fraser Valley, Metro Vancouver, Sunshine Coast, Squamish-Lillooet, and Powell-River Regional Districts. From this review, we provide detailed summaries of the current distribution of manure and crop types in BC and SWBC, summaries of the available data, and assessments of the quality of these data. In all, we reviewed a total of 148 sources, 80 of which were from BC, including surveys, reports, personal communications, unpublished data, and peer reviewed publications from 1969 through 2014. The sources are compiled in an online bibliography here: (http://www.mendeley.com/groups/4193931/bc-agricultural-nutrient-management/).

We compiled data on nutrient contents and yields for 24 crops and nutrient content of 13 different manures and other soil amendments (e.g. compost). Sources for these data included:

- A review of literature on manure and crop types and nutrient contents from BC, other provinces, and outside of Canada
- Field data that was collected primarily in Southwest British Columbia from June 2013 to December 2014
- Unpublished BC Ministry of Agriculture manure and crop datasets

These data have been compiled in detail in a database that will be made available online and are summarized below. This is far from a comprehensive inventory of all the data available and is not a meta-analysis. Finally, from this review, we identify critical gaps in existing data and provide recommendations for prioritizing data collection and analyses to enhance nutrient management planning efforts in the future.

2. Current Understanding of Nutrient Dynamics in SWBC

Southwest British Columbia (SWBC) is one of the most important agricultural regions in British Columbia (BC) with more than 65% of BC's total farm receipts, 87% of the poultry, and 70% of the dairy cows in the province (BCMA 2012). This region is also one of the most intensively managed agricultural landscapes in the country, with more livestock per unit area than any other part of Canada (Statistics Canada 2012). Pressures to this land base are characterized by simultaneous increases in human population, urban development, and livestock density. Despite the overall strength of the livestock sector across Canada and in BC, beef, hog, and dairy farm numbers in this region were down from the 2006 to 2011 agricultural census (BCMA 2012).

Animal production makes significant contributions to the economy of the region and the province, and with its past and present viability, this agricultural sector will be at the forefront of confronting the challenges of sustaining economic success in the face of environmental impacts. Specific environmental impacts include air and water quality along with associated risks to human health. More than two decades ago, researchers began tracking surplus nutrient levels in this region from manure nitrogen (N) phosphorus (P) and potassium (K) and their impacts on the environment (Brisbin 1995, Schreier et al. 1997, Mitchell et al. 2003, Timmenga & Associates Inc. 2003, Chesnaux et al. 2007). Surplus nutrients unused by crops can be lost from farm fields through a number of pathways to either water resources or the atmosphere. In regional research documenting environmental impacts to drinking water from excess nutrients, long-term well monitoring programs have detected groundwater NO_3 concentrations in the Abbotsford Aquifer above the Canadian Drinking Water Guideline of 10 mg NO_3-N per L (Chesnaux et al. 2007). Agricultural burning, greenhouse gas emissions, odour and manure management are key air quality concerns linked with intensive agriculture in SWBC. The BC Agriculture Nutrient and Air Working Group, Ministry of Environment, and Environment Canada have contributed monitoring, assessment and best practices guides aimed to reduce negative air quality impacts associated with agricultural operations.

Regionally specific challenges to nutrient management in SWBC linked with climate include the limited duration (about four to six months per year) when manure can be land applied with low or no concerns of runoff or leaching from precipitation. Active planning and adequate storage are required for farm operations in SWBC to match manure application rates with crop demand and to meet the challenges of avoiding losses via runoff and leaching into drinking water and aquatic habitat resources.

While there have been numerous studies in the region that have examined various aspects of nutrient cycling in SWBC, including aquifer NO_3-N concentrations (Zebarth et al. 1998, Mitchell et al. 2003, Chesnaux et al. 2007), ammonia emissions (Zebarth et al. 1999), and regional nutrient balances (Brisbin 1995, Hall and Schreier 1996, Vizcarra et al. 1997, Timmenga & Associates Inc. 2003), there is a significant need for basic data required for many of the calculations used for these types of analyses. Many of the previous analyses we reviewed used the same sets of data for yield, crop nutrient content or manure nutrient content and annual animal manure production rates.

There have been a number of studies over the last 20 years that have analyzed the nutrient imbalance in SWBC, particularly for the Lower Fraser Valley (LFV), using a basic mass balance approach. The majority of these studies rely on a set of data compiled through a series of surveys that were conducted by the agricultural industry (i.e. dairy, hog, and poultry) in the early 1990s (e.g. SPFG, 1993). The first of these series of regional nutrient assessments was Brisbin (1995). The Brisbin (1995) reports provided a detailed analysis of nutrient production, use and fate in the LFV using a variety of sources and a mass balance nutrient model as part of an extensive assessment of livestock manure. The data utilized in these reports were sourced from numerous other studies conducted in the region, and the findings relied heavily on the industry surveys. Brisbin (1995) provides nutrient contents for 18 different types of animal manures that indicate wide ranges of values depending on the breed of animal. Hall and Schreier (1996) provide an analysis of the impacts of urbanization and agricultural intensification on water quality in the region. Their analysis (1996) provides typical application rates of manure (205 kg N ha^{-1} yr^{-1}, 153 kg P_20_5 ha^{-1} yr^{-1}, 158 kg K_2O ha^{-1} yr^{-1}), and fertilizer (68 kg N ha^{-1} yr^{-1}, 38 kg P_20_5 ha^{-1} yr^{-1}, 41 kg K_2O ha^{-1} yr^{-1}) that indicates substantial reliance on manures for fertilization. They also reported typical uptakes for corn and grass in this study that are far lower than typical manure and fertilizer applications rates.

Subsequently Vizcarra (1997) completed a similar analysis, but with the specific objectives of determining the distribution of leachable nitrogen and of estimating the nitrogen concentration in groundwater recharges. Their study utilized a water and nitrogen mass balance in five-year intervals between 1971 and 1991 and relied on a variety of data sources for application rates and concentrations (Agriculture Canada 1979; Kowalenko, 1987; Schepers & Mosier, 1991). A couple years later, Zebarth et al. (1999b) conducted an extensive analysis of the environmental outcomes of nutrient surpluses in the LFV and compared several different potential management scenarios for the region. To develop the reference scenario, Zebarth et al. (1999b) utilized 1991 Census of Agriculture data and “typical 1991” animal-and crop-production practices. Rates for animal excretion in the Zebarth et al. (1999b) study were compiled from a wide range of literature (Yeck et al.,1975; Brumm et al.,1978; Bulley & Holbek, 1982; Overcash et al., 1983; Hahn & Rosentreter, 1989). Zebarth et al. (1999) compiled estimates for inorganic fertilizer, manure and crop removal rate for N for 20 geographical districts in the LFV.

In a more recent study, Timmenga & Associates Inc. (2003) again provided a detailed assessment of manure and nutrient surpluses in the LFV based on the data produced from the industry surveys carried out in the 1990s. Their study calculated the requirement for NPK based on the crop needs as recommended in BC Ministry of Agriculture Forestry and Foods (BCMAFF) publications, used the 2001 Census of Agriculture for total animal numbers, included North Carolina production coefficients for livestock housing and production systems to estimate manure nutrient tonnage, and finally, depended on data for manure based on nutrient analysis provided by Government of British Columbia Resource Management Branch.

Other studies have provided more specific analysis of either manure or crops, but our review indicates the literature does not provide a comprehensive understanding for the broad diversity of crops grown and livestock raised in SWBC. In her Master's Thesis, Weinberg (1987) provided nutrient content and yields for silage corn, sweet corn, potatoes, alfalfa and wheat. Others have since provided data on yields and nutrient content for sweet corn (Krzic et al. 2001), forage (Bittman et al. 2000) corn, broccoli (Bowen et al. 1999), and raspberries (Dean et al. 2000). The *Soil Management Handbook for the LFV* (Bertrand et al, 1991) provides NPK values for six different manure types, and the handbook for soil management in the Okanagan and Similkameen Valleys (Gough et al. 1994) provides data for five different livestock and poultry manures and from different types of storage. Despite the breadth of this previous nutrient management research, the question remains: Is the data that has been produced over the last 40 years of manure and crop research suitable for effectively managing SWBC's current diversity and intensity of crop and livestock production? A key purpose of this nutrient management focused literature review is therefore to compile updated information on regionally tested nutrient data with the overall intent to provide a solid foundation for nutrient management planning tools for the diverse types of agricultural operations that characterize particularly SWBC and the province as a whole.

3. Data and Gaps in Current Knowledge Base

To assess the current need for nutrient content and yield data we compiled available Statistics Canada (2012) agricultural survey data for crop area and animals in production in 2011 that was reported for the SWBC and BC. We have organized this data in two main sections, *Manure* and *Crops,* which are then assessed by manure or crop types in separate subsections. In the *Manure* section, we calculate manure production for the region using the number of animals for the reported in the Statistics Canada (2012) survey for 2011 and annual animal manure production coefficients (Hofmann & Beaulieu, 2006). We then provide information about the nutrient contents of the major manure types that are land-applied. For the *Crops* section, we review the historic yields that are compiled by Statistics Canada (2015) at the provincial scale for forage and cereal crops, fruits and vegetables, and compare these to yields compiled from analysis of production specifically in SWBC. We then summarize the nutrient content and uptake by particular crops within each subsection.

3.1 Manure

In this section, we reviewed the data found for manure nutrient content by animal type (*beef and dairy, poultry, swine* and *other types of animals*). In our review, we identified 63 studies that provided data on manure in SWBC, 15 of which provided adequate data. Most of the data compiled was for manure N content, followed by P and then K.

In 2011 SWBC manure production was primarily from dairy and poultry sectors (Figure 1). While SWBC accounted for only 31% of the total estimated manure production for the province, 70% of the dairy cow manure and 80% of the poultry manure was produced in the region. Other types of animals raised in the region included: horses and ponies, goats, mink, lambs, ewes, and rams which accounted for 21% of the manure production for these animal types. Beef cattle, most of which are found outside of SWBC, produced the 34% of the calculated manure of the province. We estimate almost all of the beef cow manure (97%) is produced outside of SWBC.

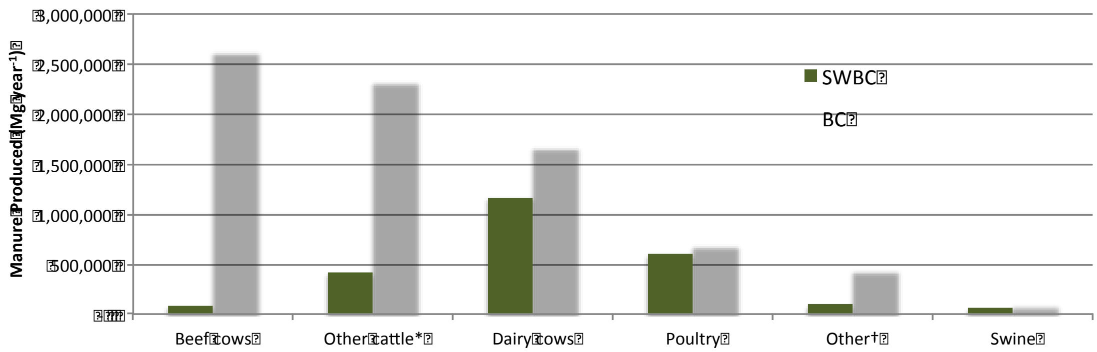

Figure 1. The distribution of total animal manures produced in Southwest British Columbia (SWBC) and British Columbia (BC) on the day of the 2011 census. Calculated using the number of animals reported (Statistics Canada 2012) and annual animal manure production coefficients (Hofmann & Beaulieu 2006). ****Other cattle* **see figure 2 for details. †*****Other*** **see figure 5 for details.**

3.1.1 Dairy and Beef Cattle

The vast majority of cattle manure produced in SWBC was from dairy production and heifers, 1 year and over while the majority of cattle manure for the province was from beef cows (Figure 2). The literature had a number of studies that included dairy manure nutrient contents and almost none that had reported values for beef manure. Of the 137 field samples of cattle manure we recorded, <20% were from beef. Statistics Canada (2012) also reports the numbers of calves under a year old, and heifers, steers and bulls over a year old, but none of the literature we identified separated nutrient values for these animal types specifically nor did we differentiate field sampling by these animal types.

Figure 2. The distribution of total cattle manure produced in Southwest British Columbia (SWBC) and British Columbia (BC) on the day of the 2011 census. Calculated using the number of animals reported (Statistics Canada 2012) and annual animal manure production coefficients (Hofmann & Beaulieu 2006)

We recorded 223 observations for dairy manure including 120 field samples. Concentrations of nutrients in dairy manure varied significantly ($p<0.001$) with the level of moisture, and are reported here by moisture content classes (Table 1). Manure with moisture content between 82-100% could be a slurry of water and manure that has separated out from the solids. Dairy manure with ≤82% moisture would be a thick slurry or solid. For all nutrients except NH_4-N values increased as moisture content decreased. Nutrient values for NH_4-N were smallest at the lowest and highest moisture contents and largest for manure with moisture ranging from 94-96%. Within each of the moisture groups, the range of values varied greatly by nutrient. Field sampling for dairy manure was consistent for the majority of samples with values found in the literature and the combined average did not differ substantially from that of the field data with the exception of N and NH_4-N values for manure <72%. In some cases the manure studies we reviewed agitated the manure before sampling but our field samples here were taken at distinct layers of the liquid or settled solid material, which may explain some of these differences. Variability for solid dairy manures was particularly high with CVs for nutrients on average >66%. Given the extent of field sampling compared to results from the literature, only the field values reported here are recommended for "book values" (Appendix 1. 1).

Table 1. Dairy manure nutrient content (as is basis) showing the average and percent coefficient of variation (CV) for total nitrogen (N), ammonium (NH4-N), phosphorus (P), potassium (K), the number of samples taken (No.) and an assessment of variability of the data based on the average CV of the four nutrients (<33% = Low, 34-66% = Medium, >67% High). Data is categorized by manure moisture ranges.

	N (%)		NH4-N (%)		NH4-N (ppm)		P (%)		K (%)			
Class	Average	CV	Average	CV	Average	CV	Average	CV	Average	CV	No.	Variability
Solid												
<72%												
Field	**0.76**	43	**0.03**	133	**317**	133	**0.20**	26	**0.43**	87	9	High
Literature	**0.13**	39	**0.06**	41	**633**	41					18	Low
72-82%												
Field	**0.39**	58	**0.08**	95	**797**	95	**0.10**	77	**0.30**	68	27	High
Literature			**0.04**		**400**		**0.39**				2	
Liquid												
82-90%												
Field	**0.36**	71	**0.12**	47	**1202**	47	**0.10**	88	**0.27**	35	19	Medium
Literature	**0.21**	123	**0.01**		**132**		**0.17**	133	**0.64**		9	Medium
90-94%												
Field	**0.28**	18	**0.13**	22	**1330**	22	**0.05**	25	**0.27**	20	23	Low
Literature	**0.02**	7	**0.01**	15	**73**	15	**0.00**	18			21	Low
94-96%												
Field	**0.23**	43	**0.14**	68	**1394**	68	**0.05**	46	**0.20**	46	15	Medium
Literature	**0.22**	4	**0.12**	24	**1233**	24	**0.04**	9			29	Low
96-98%												
Field	**0.15**	21	**0.08**	15	**757**	15	**0.03**	32	**0.14**	31	12	Low
98-100%												
Field	**0.09**	58	**0.05**	46	**497**	46	**0.02**	59	**0.12**	26	15	Medium

In total we have recorded 22 field samples of feedlot beef manure, all but two from outside of SWBC. The data therefore are not distinguished by region (Table 2). The beef cattle manure results were significantly different ($p<0.05$) by moisture class but were all highly variable, particularly for NH_4-N. Nutrient contents were highest for manures in the 72-82% moisture range with the exception of K, which was highest for ≤72%. These data are recommended for "book values" but additional sampling would likely improve the confidence (Appendix 1. 2)

Table 2. Feedlot beef cattle manure nutrient content (as is basis) showing the average and percent coefficient of variation (CV) for total nitrogen (N), ammonium (NH4-N), phosphorus (P), potassium (K), the number of samples taken (No.) and an assessment of variability of the data based on the average CV of the four nutrients (<33% = Low, 34-66% = Medium, >67% High). Data is categorized by manure moisture ranges.

	N (%)		NH4-N (%)		NH4-N (ppm)		P (%)		K (%)			
Class	Average	CV	Average	CV	Average	CV	Average	CV	Average	CV	No.	Variability
≤72%	**0.42**	43	**0.00**	60	**44**	60	**0.13**	28	**0.67**	53	6	Medium
72-82%	**0.68**	98	**0.04**	99	**368**	99	**0.15**	142	**0.30**	59	8	High
82-90%	**0.28**	30	**0.01**	175	**77**	175	**0.09**	54	**0.19**	57	8	High
All	**0.47**	93	**0.02**	159	**164**	159	**0.12**	108	**0.36**	81	22	High

3.1.2 Poultry

SWBC accounts for the majority (88%) of poultry manure production BC (Figure 3). We estimate the majority of poultry manure production in SWBC is from broilers, followed by turkeys and laying hens over 19 weeks old. In our review we found a variety of categories for recording poultry manure nutrient contents. In most cases, the studies we reviewed used only basic classes such as *poultry*, or *chicken* and *turkey*, though in some studies the type of use was identified: *breeder*, *broiler*, or *layer*. In a one study poultry was differentiated by *commercial egg*, or *hatching egg*.

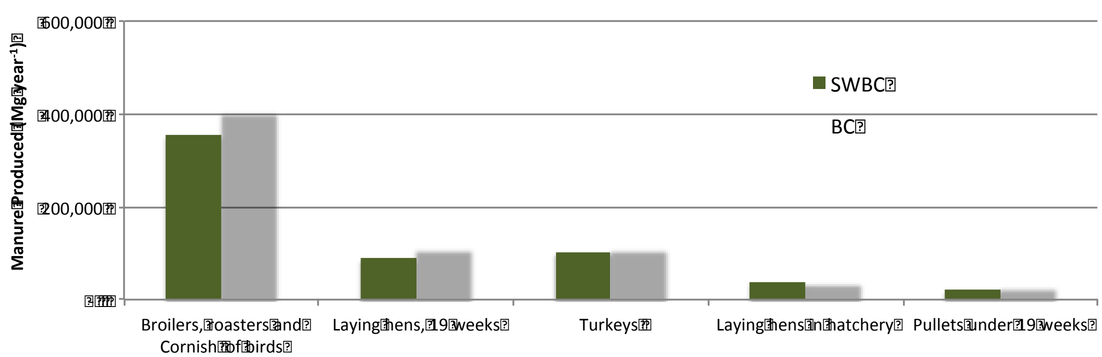

Figure 3. The distribution of total poultry manure produced in Southwest British Columbia (SWBC) and British Columbia (BC) on the day of the 2011 census. Calculated using the number of animals reported (Statistics Canada 2012) and annual animal manure production coefficients (Hofmann & Beaulieu 2006)

We recorded a total of 149 observations of poultry manure nutrient content 126 of which were from field data. The only variable that significantly differentiated poultry manures was the storage type for broilers (Table 3). Broiler manure that was sampled from *Indoor* sites would likely have been directly from the barn and is assumed to be *fresher* than sampled from *Outdoor* storage. *Indoor* manure was on average 56% higher in N ($p<0.001$) and 31% higher in P (p=0.056) but was not statistically different for NH_4-N or K. Poultry manure nutrient contents were in general fairly variable with *Outdoor* broiler having "high" variability. Our field data and the literature matched well except for *layers* and *Hatching Egg* which was not sampled. The *Layer* manure average NH_4-N was 70% higher from the data collected from the literature than our field data and was also much less variable. Future sampling should focus on providing better resolution for these two classes and for now only field data are recommended for "book values" (Appendix 1. 3).

Table 3. Chicken manure nutrient content (as is basis) showing the average and percent coefficient of variation (CV) for total nitrogen (N), ammonium (NH4-N), phosphorus (P), potassium (K), the number of samples taken (No.) and an assessment of variability of the data based on the average CV of all four nutrients (<33% = Low, 34-66% = Medium, >67% High). Data is categorized by breed and storage type. Indoor storage indicating manure is coming from poultry barns and may be fresh whereas outdoor storage is likely to be aged.

	N (%)		NH4-N (%)		NH4-N (ppm)		P (%)		K (%)			
Class	Average	CV	Average	CV	Average	CV	Average	CV	Average	CV	No.	Variability
Broiler												
Field												
Indoor (Fresh)	**2.97**	45	**0.41**	96	**4078**	96	**1.05**	40	**1.04**	47	25	Medium
Outdoor (Aged)	**1.91**	56	**0.31**	64	**3095**	64	**0.80**	60	**1.14**	87	54	High
Unknown	**2.80**	53	**0.47**	77	**4739**	77	**1.19**	67	**1.34**	79	15	High
Literature	**2.50**	40	**0.45**	40	**4490**	40	**0.97**	43	**1.06**	31	17	Medium
Broiler breeder												
Field	**1.07**	56	**0.29**	75	**2858**	75	**0.72**	77	**0.80**	49	4	Medium
Hatching egg												
Literature	**1.96**		**0.41**		**4050**		**1.31**		**1.0**		1	
Layer												
Field	**2.26**	40	**0.39**	99	**3889**	99	**1.13**	69	**1.51**	49	17	Medium
Literature	**2.31**	72	**0.66**	56	**6616**	56	**1.00**	33	**1.08**	1	16	Medium

We recorded a total of 30 observations for turkey manure, 16 of which were field data. Turkey manure nutrient contents were significantly different depending on the age of the manure when it was sampled (Table 4). N content was 100% higher (p<0.01) in *fresh* (≤7 weeks old) than in *aged* manure (>7 weeks old). This was also true of NH_4-N, which was 96% higher (p<0.001), P was 82% higher (p<0.001) and K 120% higher (p<0.001). For *aged* manure the CV ranged from 31 to 65% and for *fresh* from 19 to 67%. Although there were only four values found in the literature, they were substantially higher in value for all nutrients particularly N and NH_4-N. The differences and the relative amount of turkey manure warrant additional data collection with better resolution on the age, storage and bedding and only the *aged* and *fresh* classes are recommended as "book values" (Appendix 1. 4).

Table 4. Turkey manure nutrient content (as is basis) showing the average and percent coefficient of variation (CV) for total nitrogen (N), ammonium (NH4-N), phosphorus (P), potassium (K), the number of samples taken (No.) and an assessment of variability of the data based on the average CV of the four nutrients (<33% = Low, 34-66% = Medium, >67% High). Data is categorized by the age of the manure when sampled.

	N (%)		NH4-N (%)		NH4-N (ppm)		P (%)		K (%)			
Class	Average	CV	Average	CV	Average	CV	Average	CV	Average	CV	No.	Variability
Aged (>7 weeks old)	**0.87**	41	**0.13**	65	**1281**	65	**0.44**	31	**0.59**	64	9	Medium
Fresh (≤7 weeks old)	**1.79**	42	**0.25**	67	**2518**	67	**0.79**	29	**1.31**	19	7	Medium
Unknown	**2.86**	58	**0.61**	94	**6085**	94	**0.85**	54	**0.91**	52	10	Medium
Literature	**4.20**	23	**0.99**	44	**9938**	44	**1.24**		**1.20**		4	Medium

3.1.3 Swine

Swine in SWBC is classified into five groups which represent 65% of the swine manure production in BC. Weaner and nursing pigs are primarily found outside of SWBC (Figure 4). Roughly half of the boar manure produced in the province is in SWBC. Most of the data we found in our review was classified as generally *swine* or *hog*, representing operations that may have included multiple swine groups or stages of production. A few studies defined the manures by *farrow to finish*, *farrow to weaner*, or *grower/finisher.* We did not find any studies that included specifically *boar* manure.

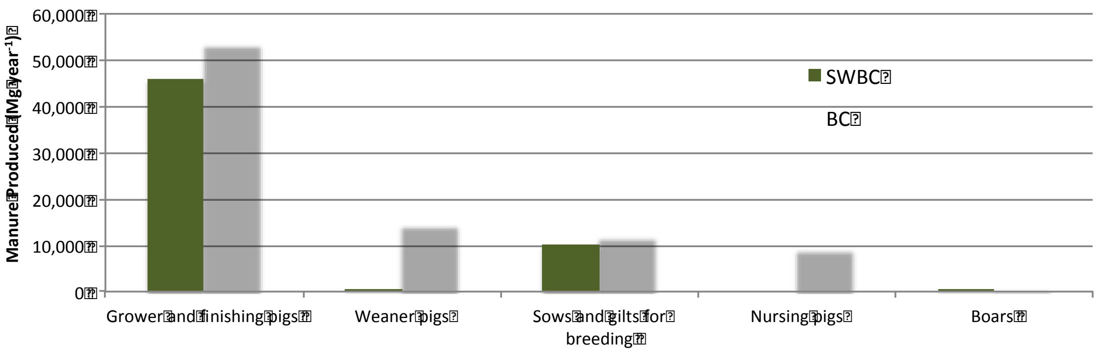

Figure 4. The distribution of total swine manure produced in Southwest British Columbia (SWBC) and British Columbia (BC) on the day of the 2011 census. Calculated using the number of animals reported (Statistics Canada 2012) and annual animal manure production coefficients (Hofmann & Beaulieu 2006)

Overall, we recorded 29 observations for swine manure, 21 of which were from field data. We found extreme differences between the nutrient concentrations of solid and liquid swine manure in the field data. N, P and K content were 2.6 ($p<0.01$), 3.7 ($p<0.05$) and 3.5 ($p<0.001$) times higher in solid manure than liquid while NH_4-N was 4.2 ($p<0.05$) times lower (Table 5). Other researchers have also differentiated swine manure by whether it was stored in a covered or uncovered pit (Gough et al. 1994) but we found no significant differences based on our data. Both the liquid and solid swine manure had high variability in nutrient values, P was by far the most variable followed by NH_4-N, K and finally N. The 8 values reported in the literature were all for liquid swine manure for different types of swine manure, farrow to finish, farrow to weaner, and grower/finisher. Field data did not differentiate by these categories and although some of the values are different we do not know the variability of the data for the literature nor the sample size. All but two observations (one from field and one from literature data) were from SWBC so there is likely no representation of the sizable *weaner* or *nursing pig* manure that is produced in the province. Future sampling of swine could help differentiate manure nutrient contents by manure storage, the age/size class of the animal and the location and for now only field data is recommended as “book values” based on solid or liquid status (Appendix 1.5).

Table 5. Hog manure nutrient content (as is basis) showing the average and percent coefficient of variation (CV) for total nitrogen (N), ammonium (NH4-N), phosphorus (P), potassium (K), the number of samples taken (No.) and an assessment of variability of the data based on the average CV of the four nutrients (<33% = Low, 34-66% = Medium, >67% High). Data is categorized by moisture content (≤82% moisture = solid, >82% moisture = liquid).

	N (%)		NH4-N (%)		NH4-N (ppm)		P (%)		K (%)			
Class	Average	CV	Average	CV	Average	CV	Average	CV	Average	CV	No.	Variability
Farrow to Finish (Liquid)												
Literature	**0.30**						**0.14**		**0.22**		1	
Farrow to Weaner (Liquid)												
Literature	**0.36**						**0.10**		**0.15**		1	
Grower/Finisher (Liquid)												
Literature	**0.57**						**0.17**		**0.25**		1	
Hog (Liquid)												
Field	**0.33**	37	**0.22**	58	**2211**	58	**0.10**	118	**0.15**	61	13	High
Literature	**0.36**	15	**0.30**	29	**2980**	29	**0.12**	29	**0.28**	75	5	Medium
Hog (Solid)												
Field	**0.86**	54	**0.05**	98	**525**	98	**0.42**	102	**0.50**	74	8	High

3.1.4 Other Animals and Compost

There are a number of other animals being raised in SWBC, but combined likely account for only ~5% of the total manure produced at the time of the 2011 census (Figure 5). This number is likely slightly larger as some of the animals raised in SWBC and elsewhere in the province do not have manure coefficients. Animals in this category that did have coefficients include horses and ponies, mink, goat, lambs, and ewes, in order of manure production. For these animals SWBC produces 21% of the total manure in the province as most of the animals of these type are raised outside of SWBC with the exception of mink, which is entirely found in the region. The "other" animals that did not have manure coefficients were small in population (<10,000 head) deer, rams, llamas and alpacas, rabbits and bison (buffalo). Also included in this section are other transformed fates of animal manures including compost and anaerobic digester products.

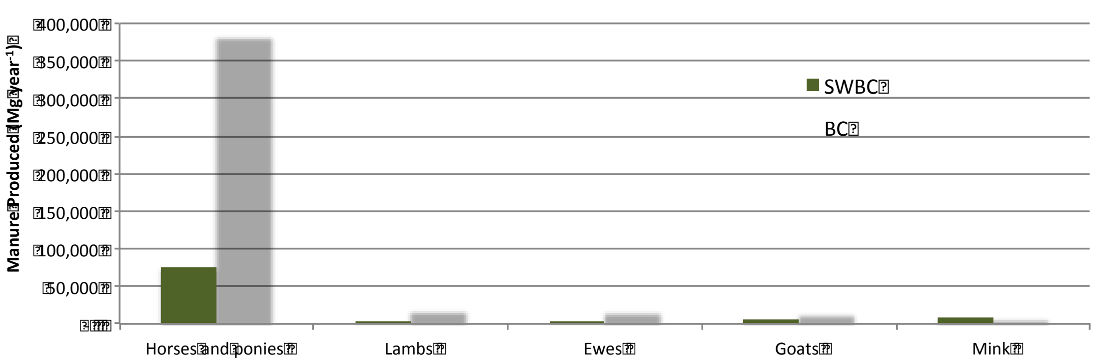

Figure 5. The distribution of total 'other' animal manure produced in Southwest British Columbia (SWBC) and British Columbia (BC) on the day of the 2011 census. Calculated using the number of animals reported (Statistics Canada 2012) and annual animal manure production coefficients (Hofmann & Beaulieu 2006)

Sample sizes for field data of the “other” category were small and limited the possibility of further differentiating the materials reported in this section and our literature review did not target these types (Table 6). Some of these materials sampled had very high nutrient contents, particularly duck and mink. The one digester sample showed high NH_4-N and very low N, P, and K suggesting the material could be an important resource for providing available nitrogen. Variability for all of these classes was high and in the case of the digester and mink, unknown, given we only had one sample of each. As composting and the use of digesters are increasing in the province getting better data for these will be important. Although the nutrient content of duck and mink manure is high, and could be a valuable manure amendment, the numbers of animals in the SWBC and the province remain relatively low. Given the limited number of samples only horse manure nutrient contents at this time can be recommended as “book values” (Appendix 1.5).

Table 6. The nutrient content of six types of manures or other soil amendments (as is basis) showing the average and percent coefficient of variation (CV) for total nitrogen (N), ammonium (NH4-N), phosphorus (P), potassium (K), the number of samples taken (No.) and an assessment of variability of the data based on the average CV of the four nutrients (<33% = Low, 34-66% = Medium, >67% High).

	N (%)		NH4-N (%)		NH4-N (ppm)		P (%)		K (%)			
Class	Average	CV	Average	CV	Average	CV	Average	CV	Average	CV	No.	Variability
Compost	**1.11**	39	**0.02**	140	**190**	140	**0.49**	67	**0.58**	82	20	High
Digester	**0.10**		**0.26**		**2,570**		**0.02**		**0.19**		1	
Duck	**2.91**	77	**0.37**	62	**3,667**	62	**1.05**	59	**1.13**	71	4	High
Horse	**0.32**	56	**0.03**	87	**268**	87	**0.09**	86	**0.25**	56	21	High
Mink	**6.78**		**1.35**		**13,500**		**3.16**		**0.79**		1	
Sheep	**0.49**	48	**0.01**	120	**137**	120	**0.07**	94	**0.56**	119	5	High

3.2 Crops

According to Statistics Canada survey data 67% of the 60,111 hectares in crop production (forage and cereal crops, vegetables, and fruit) in SWBC in 2011 was used to grow forage and cereal crops, 21% was used for fruit production, and 12% for vegetables (Figure 6). While SWBC represents only 10% of the total cropping area in BC, vegetable production in the region in 2011 accounted 74% of the vegetable production area in the province and more than 54% of the fruit production area. Although forage and cereal crops are a sizeable amount of the cropland in SWBC, this was only 7% of the total production in BC in 2011. This provincial crop distribution reflects the relatively mild maritime climate and fertile valley bottom soils found in SWBC.

In our review we found a wide range of literature on crop yield and nutrient contents, and although our search was not exhaustive there were noticeable gaps in data. Overall in our review, yield data was far more accessible than crop nutrient content. From the 27 studies that include yield data for SWBC we complied 358 observations for crop yield (most of which were for forage and cereal crops). The relative number of observations we compiled did not entirely reflect the current cropping distribution, 85% of our observations were for forage and cereal crops, 12% for vegetables and only 1% for fruit despite its land area and economic importance.

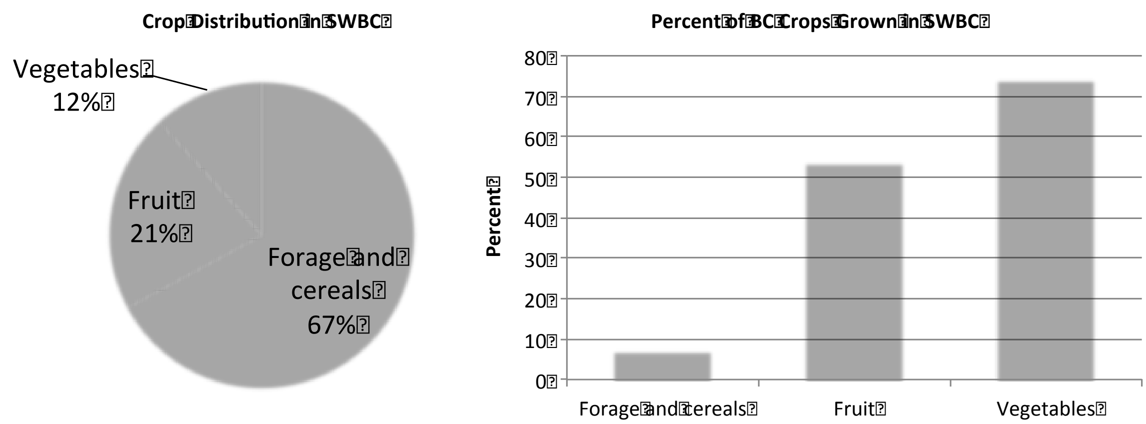

Figure 6. Distribution of crop production in the Southwest British Columbia (SWBC) by area (left) and percent of BC crop grown in SWBC (right) in 2011 by area (Statistics Canada 2012)

3.2.1 Crop Area and Yields

Two major challenges for nutrient management are targeting a feasible yield goal for a given growing season and from there, determining expected nutrient removal from the soil in the harvested biomass. Historically, the federal government has collected information on crop yields that have been reported by farmers randomly selected across the province (Statistics Canada, 2012). The yield information is then averaged for a given time period and made publically accessible. While the data collected on reported yields for the province provides a useful temporal trend, spatial variability is not accounted for, and the efficacy of disaggregating the data by region by crop type is unclear. Disaggregation of the yield data for those crops grown in different regions of the province with wide variations in soil and climate conditions, would provide a step towards nutrient management planning with feasible yield goals for those crops.

For example, potatoes and forage crops are grown in the Fraser Valley as well as in the Thompson-Nicola regional districts, yet are likely to have distinct yield averages given the differences in soil and climates between the regions. For crops with strong regional production limitations such as cranberries grown in SWBC, the provincial yield data collection and averages likely provides adequate planning information. In their study of BC crop yields, Morrison et al. (2011) uses the regional dominance of certain types of crop production to disaggregate provincial yields with varying degrees of efficacy. Here we use a similar approach to assess the validity of applying provincial yield averages specifically for SWBC and compare these data to those from found in the literature and field sampling.

In addition to compiling published and unpublished crop data we sampled select crops and feed mainly from SWBC. Crops were harvested from farmer's fields who were willing to participate in the survey. As close to harvest as possible transects were established across fields and 3-6 plots were harvested and weighed in the field. Sub-samples were taken for moisture and nutrient content analysis. Sampling of blueberry fruit was done for two cultivars *(Duke and Reka)* at two locations repeatedly throughout the season as close to the producers harvest as possible (5-6 times).

3.2.2 Forage and Cereal crops

The dominant forage and cereal crops farmed in the SWBC in terms of land use area are fodder crops for livestock. Field area devoted to tame hay and fodder crops represent 59% of the SWBC growing region but only 14% of the tame hay and fodder production area in the province (Figure 7). Silage corn in 2011 was 23% of the forage and cereal crop area in SWBC and 66% of the total production area of silage corn in the province. Alfalfa was 12% of the forage and cereal crop production area in SWBC in 2011 but this represents only 2% of the alfalfa production area of the province. The other forage and cereal crops grown in the region comprise in total only 6% of the forage and cereal crops in the area.

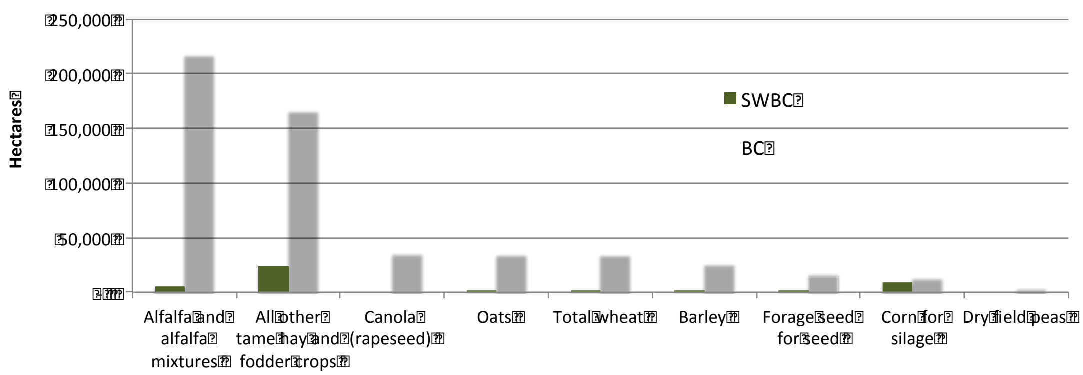

Figure 7. The area of the top 10 most prominently produced forage and cereals in British Columbia (BC) and Southwest British Columbia (SWBC) in 2011 (Statistics Canada 2012).

In terms of overall productivity, silage corn has the highest average yield (49,160 kg ha^{-1}) of all forage and cereal crops grown in the SWBC within the last 10 years (Table 7). Two crops with the highest yield variability from year-to-year were mixed grains and peas but the number of years these harvests reported were limited.

Table 7. Provincial average yields (kg ha^{-1}) for prominent forage and cereal crops grown in British Columbia from 2005 to 2014 and the average and percent coefficient of variation (CV) for that entire period (Statistics Canada 2014). Value are dry matter except when indicated with *.

					2005-14						
Crop	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average	CV (%)
Barley	3,000	2,200	2,900	2,100	2,800	1,900	2,900	3,200	3,500	2,600	2,710	19
Canola	2,100	1,100	1,700	1,600	1,700	1,000	1,600	1,700	2,200	1,700	1,640	23
Corn (silage)*	66,920	48,360	50,300	40,420	44,980	48,160	43,860	50,400	56,220	49,370	49,899	15
Mixed grains	3,300	2,800	..	1,300	..	..	..	..	2,800	2,800	2,600	29
Oats	3,100	1,900	2,700	2,100	2,800	2,000	3,100	2,300	3,000	2,600	2,560	18
Peas, dry	2,900	1,200	..	..	..	..	..	..	..	2,200	2,100	41
Tame hay	4,200	3,760	4,030	3,940	3,360	3,660	4,870	3,670	5,440	3,930	4,086	15
Wheat	3,200	1,900	3,000	1,900	2,300	1,800	3,900	3,200	4,000	2,900	2,810	29

For forage and cereal crops, the number of studies and available data for SWBC were fairly reflective of the dominance and importance of hay and fodder crops in the region. We recorded more than 250 observations for corn and grass forage. Data from field sampling, Statistics Canada and the literature were closely aligned with the exception of wheat, which was 3.5 times higher in studies reported from SWBC (Table 8). Given the massive area planted in forage and cereal crops outside of SWBC that likely contributes disproportionately to provincial yields, further spatial disaggregation for regional yields across the province would likely provide more effective nutrient management planning.

Table 8. Forage and cereal crop yield (kg ha^{-1} dry weight) average, coefficient of variation percentage (CV), minimum, maximum and number of observations in Southwest British Columbia (SWBC) reported from field sampling (field), observations found in the literature and British Columbia (BC) from Statistics Canada and the literature. CV is for the number of observations except for Statistics Canada data, which is based on 10 years of reported yields. * Provincial corn, silage was corrected for moisture content using 73% moisture from the literature.

Field crops	Location	Average	CV (%)	Min.	Max.	Count	Source
Corn, silage	SWBC	12,010	54	6,288	18,976	3	Field Data
Corn, silage	SWBC	15,068	20	8,600	20,000	40	Literature
Corn, silage*	BC	13,473	15	10,913	18,068	10	Statistics Canada
Forage grass/legume	SWBC	3,811	47	1,590	6,030	14	Literature
Orchardgrass	BC	13,856	20	10,525	17,357	16	Literature
Orchardgrass	SWBC	14,183	6	12,911	15,332	16	Literature
Tame hay	BC	4,086	15	3,360	5,440	10	Statistics Canada
Wheat	BC	5,238	37	2,900	8,100	8	Literature
Wheat	BC	2,810	29	1,800	4,000	10	Statistics Canada
Wheat	SWBC	9,838	61	4,200	21,300	13	Literature

3.2.3 Vegetable Crops

The most predominant vegetable crop grown in the SWBC is potato. The number of hectares planted to potatoes, while only 5% of the vegetable crop area in SWBC in 2011 was 66% of the potato production area of the province. Potato planting area is followed by sweet corn, which comprises 13% of the total land under vegetable crop production but accounted for 73% of the sweet corn planted across the province in 2011. Green and wax beans are the third largest vegetable crop in SWBC, with 10% of the vegetable production area and 94% of the area planted provincially. Most of the remaining vegetable crop area (44%) is comprised of a relatively equal distribution of *Other* (i.e. unspecified) vegetables, broccoli, Brussels sprouts, squash and zucchini, green peas, pumpkins, cabbage and carrots. Most of provincial area planted to these vegetables was concentrated in SWBC in 2011. For example 96% of the Brussels sprouts, 96% of Chinese cabbage, and 91% of the broccoli planted in BC was in SWBC.

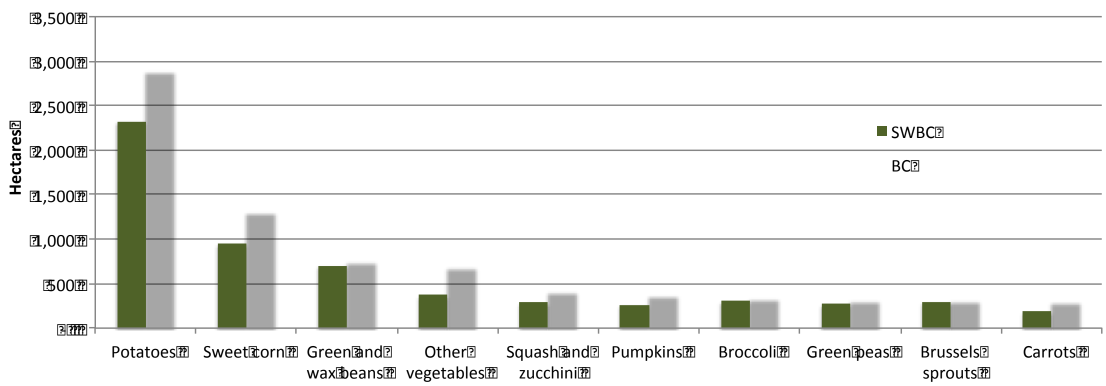

Figure 8. Area of the top 10 most prominently produced vegetables in British Columbia (BC) and Southwest British Columbia (SWBC) in 2011 (Statistics Canada 2012).

Statistics Canada data (2014) indicates fairly stable yields for most vegetable crops over a ten year period (Table 9) with the exception of Brussels sprouts and carrots. Potatoes had the most consistent yield with a CV of only 5%. Yield variability for parsnips and celery were substantially higher than other vegetables, with CVs of 64% and 53% respectively. For both of these crops as well as a number of other vegetables, yields records were not available for the entirety of the most recent 10-year period. In some cases this absence in the records was due to unreliable yields data (i.e. carrots 2009 and 2014).

In our review of yields for SWBC general, we found there was relatively little data available for vegetables. Of the studies we reviewed, the majority of the data was for sweet corn (15 observations) and broccoli (2 observations). For all other vegetables crops in SWBC, we were able to compile only one to two yield observations if any (Table 10).

Table 9. Provincial average yields (kg ha^{-1}) for vegetables of British Columbia from 2005 to 2014 and the average and percent coefficient of variation (CV) for that entire period (Statistics Canada 2012).

	2005-14											
Crop	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Mean	CV (%)
Asparagus	2,000	1,100	900	1,300	F	F	2,000	1,700	F	1,700	1,529	28
Beans, green or wax	7,400	9,100	9,200	7,900	6,000	5,500	6,100	6,000	7,200	7,100	7,150	18
Beets	22,100	x	21,400	20,600	F	F	29,500	24,500	26,000	16,300	22,914	18
Broccoli			5,900	5,600	5,000	4,500	5,700	7,900	7,000	5,500	5,888	18
Brussels sprouts			16,100	15,500	20,800	11,800	14,300	12,400	7,500	12,000	13,800	28
Cabbage1	24,200	21,500	19,400	17,800	26,900	21,300	18,400	17,100	23,500	20,200	21,030	15
Carrots2	28,300	x	29,000	53,200	F	28,000	34,700	26,900	F	F	33,350	30
Cauliflower	7,500	7,800	9,700	9,200	F	x	11,400	8,100	9,800	10,400	9,238	15
Celery	36,400	30,800	25,800	21,900	x	x	7,800	8,500	x	x	21,867	53
Corn, sweet	10,500	8,000	8,400	8,800	7,700	5,600	6,400	6,600	7,200	7,700	7,690	18
Cucumbers and gherkins (all varieties)	12,200	12,100	12,800	10,200	15,100	9,200	9,300	9,800	9,400	10,900	11,100	17
Garlic	2,400	2,900	3,100	F	2,500	1,700	2,800	2,500	2,500	2,800	2,578	16
Leeks			11,500	10,900	x	F	10,600	13,100	15,900	19,800	13,633	26
Lettuce3	21,300	26,900	23,300	24,500	32,100	31,700	28,400	23,500	25,800	26,400	26,390	13
Dry onions	41,600	x	33,100	23,000	F	x	33,000	35,000	F	F	33,140	20
Other melons (cantaloupes, winter melons, etcetera)	14,300	20,200	20,500	22,400	F	F	24,900	F	33,000	F	22,550	28
Parsley	12,700	15,300	11,200	13,100	15,700	F	17,700	18,900	8,600	24,200	15,267	30
Parsnips	2,400	8,600	6,400	10,000	F	F	19,400	20,000	25,000	F	13,114	64
Peas, green	5,200	3,900	4,900	4,600	4,900	4,500	3,700	5,900	6,200	5,700	4,950	17
Pumpkins			26,000	23,300	36,200	28,400	29,000	34,000	30,800	35,100	30,350	15
Shallots and green onions			14,000	15,600	20,200	20,200	14,500	17,100	16,300	11,000	16,113	19
Spinach	11,200	10,700	14,300	11,200	14,300	10,900	9,500	12,300	15,300	15,100	12,480	17
Squash and zucchinis			15,700	12,600	20,400	14,300	10,700	14,700	14,000	15,400	14,725	19
Tomatoes	15,500	17,600	21,100	17,700	17,600	20,100	23,600	23,600	19,500	19,700	19,600	13
Peppers	12,900	13,700	15,700	x	20,200	22,100	17,400	18,900	16,400	20,000	17,478	18
Potatoes	30,823	31,384	33,626	34,746	32,505	33,626	30,823	30,823	31,384	30,207	31,995	5
Radishes	13,500	13,300	14,600	13,700	17,900	13,900	15,300	13,100	12,700	19,500	14,750	15
Rhubarb	17,700	14,200	15,600	13,900	F	F	16,300	11,900	x	x	14,933	14
Rutabagas and turnips	23,900	20,400	15,600	22,800	F	19,900	20,600	13,800	25,800	29,900	21,411	23
Watermelon	14,800	16,800	15,200	9,600	15,400	F	26,800	18,900	22,000	F	17,438	30
Cabbage, Chinese (bok-choy, napa, etcetera)								..	..	10,700	10,700	
Cabbage, regular								..	..	28,900	28,900	

x - Suppressed to meet the confidentiality requirements of the Statistics Act

F - Too unreliable to be published

1. Includes Chinese cabbage and regular cabbage.

2. Includes baby carrots and regular carrots.

3. Includes leaf lettuce and head lettuce.

To convert to pounds per acre divide multiply by 0.892

Source: Statistics Canada. Table 001-0013 - Area, production and farm gate value of vegetables, annual (accessed: January 30, 2015)

The yield averages for SWBC that we did compile were in some cases far higher than the 10-year averages reported by Statistics Canada across the province. The research design and intent that formed the majority of available regional yield averages in our literature review are likely sources of these differences. Much of yield data we reviewed was from experimental studies based in this region that aimed to determine optimal crop variety, management, and/or fertilization regimes. Despite these differences, we compiled a sizable number of observations for two crops that might warrant accurate comparisons. SWBC broccoli yields were more than 1.5 times higher than provincial 10-year average while sweet corn was 41% higher than 10-year average, close to the maximum recorded during that period. Potato yields averaged from field data collected in 2013-14 for SWBC were 19% higher than the 10-year provincial average and as high as 42% greater for late season cultivars. From the data we compiled it is unclear whether provincial yields for vegetables effectively represent those for SWBC, but given the likely dominance of SWBC vegetables in the random selection of producers across the province, 10-year yield averages are probably representative for most crops with the exception of sweet corn and broccoli. Given the area of potatoes planted outside SWBC analysis of other regions and cultivars are likely to enhance nutrient management planning in other regions.

Table 10. Vegetable crop yield (kg ha^{-1}) compared for various data sources for Southwest British Columbia (SWBC), British Columbia (BC) and Washington State (WA). Yield averages, coefficient of variation percentage (CV), minimum, maximum and number of observations (No.) are illustrated. CV is calculated for the number of observations except for Statistics Canada data, which is based on 10 years of reported yields.

Vegetable Crop	Location	Average	CV	Min.	Max.	No.	Source
Beans	SWBC	10,213	21	8,243	12,465	3	Field
Beans	BC	7,150	18	5,500	9,200	10	Statistics Canada
Broccoli	SWBC	10,000	28	8,000	12,000	2	Literature
Broccoli	BC	5,888	18	4,500	7,900	8	Statistics Canada
Cabbage	SWBC	47,500	37	35,000	60,000	2	Literature
Cabbage	BC	28,900	0	28,900	28,900	1	Statistics Canada
Carrots	SWBC	21,509	30	16,031	28,621	3	Field
Carrots	SWBC	35,000	20	30,000	40,000	2	Literature
Carrots	BC	33,350	30	26,900	53,200	6	Statistics Canada
Cauliflower	SWBC	12,500	40	9,000	16,000	2	Literature
Cauliflower	BC	9,238	15	7,500	11,400	8	Statistics Canada
Corn, sweet	SWBC	10,864	72	0	22,700	15	Literature
Corn, sweet	BC	7,690	18	5,600	10,500	10	Statistics Canada
Lettuce	SWBC	50,000	28	40,000	60,000	2	Literature
Lettuce	BC	26,390	13	21,300	32,100	10	Statistics Canada
Onion	SWBC	50,000	14	45,000	55,000	2	Literature
Onions	BC	33,140	20	23,000	41,600	5	Statistics Canada
Potato	BC	31,995	5	30,207	34,746	10	Statistics Canada
Potatoes	SWBC	38,092	38	18,186	90,026	28	Field
Potatoes	SWBC	45,500	30	30,000	56,500	3	Literature
Potatoes Early	SWBC	24,737	32	18,186	33,413	3	Field
Potatoes Late	SWBC	45,603	46	26,400	90,026	9	Field
Potatoes Mid	SWBC	36,235	23	24,773	47,333	12	Field

3.2.4 Fruits, Berries and Nuts

Blueberries were by far the dominant fruit crop produced in SWBC in 2011. 65% of the total hectares in SWBC under fruit production was in blueberries (Figure 9). Cranberries and raspberries are the next most prominent crops, consisting of 19% and 13% respectively of SWBC. Provincial production of these three fruit crops is almost entirely located in SWBC. The planted area in SWBC in 2011 of blueberries represent 97%, cranberries 91%, and raspberries

92% of provincial production area. The remaining fruit types account for only 4% of the total land area in fruit production.

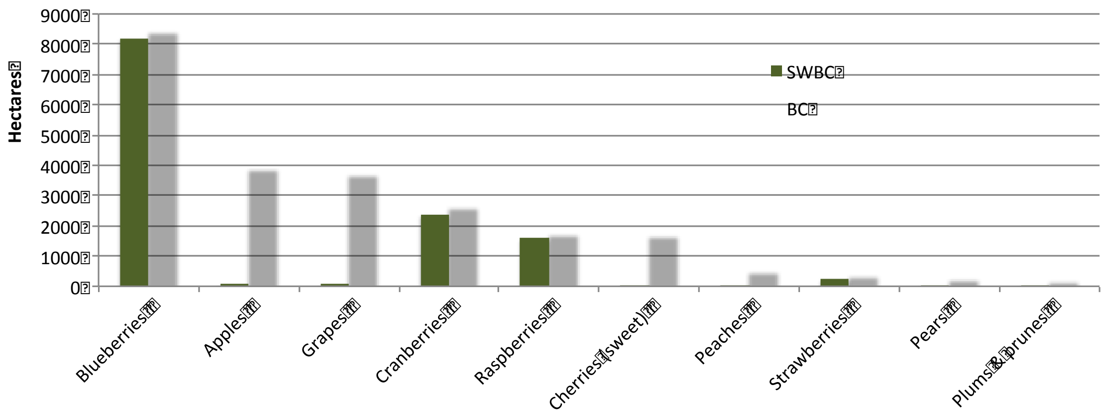

Figure 9. The area of prominently produced fruits in British Columbia (BC) and Southwest British Columbia (SWBC) in 2011 (Statistics Canada 2012).

Provincial fruit yields were determined from Statistics Canada (2014) data by dividing marketed production by total cultivated area. The calculated yield ranges from year to year were fairly stable for most fruit (Table 11). Watermelon, apricots and sweet cherries have the highest variances in their yields with CVs of 30%, 29% and 27% respectively. In contrast, raspberries and nectarines have had a fairly consistent yield between 2005 and 2014 (11% CV). There were a number of fruit crop studies reviewed for the SWBC (12), but only a few observations from the review were clearly scalable to a reliable per hectare yield and data from neighbouring Washington State (WA) have also been included for comparison (USDA 2014).

Table 11. Provincial average yields (Mg ha^{-1}) for fruit crops grown in British Columbia from 2005 to 2014 and the average and percent coefficient of variation (CV) for that entire period. Values determined from total yields divided by total production area (Statistics Canada 2012).

					2005-14							
Commodity	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average	CV (%)
Apples (1,2)	25.2	29.9	16.6	27.7	24.6	26.0	27.0	27.3	22.7	27.0	25.4	14
Apricots			5.3	5.1	9.3	6.9	4.5	6.4	4.7	8.7	6.4	29
Blueberries (3,6)	6.1	4.5	5.2	4.2	5.2	5.4	5.3	6.0	5.8	7.7	5.5	18
Cherries, sour			4.9	F	F	3.9	x	x	x	F	4.4	15
Cherries, sweet			6.1	4.6	10.1	6.9	6.9	10.0	8.0	10.5	7.9	27
Cranberries			16.0	12.7	15.1	11.3	10.4	14.0	15.7	16.4	14.0	16
Grapes (7)	5.1	5.6	5.1	5.0	4.5	4.8	5.6	6.4	5.9	6.3	5.4	12
Nectarines	9.1	10.7	9.8	10.4	7.4	11.0	10.1	10.1	8.8	10.9	9.8	11
Peaches (fresh and clingstone)	8.5	10.8	11.7	9.9	9.0	11.1	9.5	12.3	9.5	12.3	10.5	13
Pears	17.4	19.0	17.4	20.2	18.6	18.6	22.4	22.9	24.2	24.2	20.5	13
Plums and prunes	5.9	7.6	6.8	7.1	7.4	7.5	7.6	7.3	8.1	11.2	7.6	18
Raspberries (4)	5.5	5.4	5.3	7.0	6.8	6.2	6.4	6.2	5.6	7.1	6.2	11
Saskatoon berries			..	..	..	..	F	F	x	x		
Strawberries (4)	4	3.9	4.2	5.0	4.2	6.0	5.8	4.8	4.4	5.2	4.8	16
Blueberries, high bush			..	..	..	..	..	6.0	5.8	7.7	6.5	17
Watermelon	14.8	16.8	15.2	9.6	15.4	F	26.8	18.9	22	F	17.4	30

F Too unreliable to be published

E Use with caution

x Suppressed to meet the confidentiality requirements of the Statistics Act

.. Not available

1 Conversion factors used for 1 bushel of apples from 1926 to 1964 equals 45.0 pounds, 1965 equals 44.5 pounds, 1966 equals 44.0 pounds, 1967 equals 43.5 pounds, 1968 equals 43.0 pounds, 1969 equals 42.5 pounds, from 1970 on equals 42.0 pounds.

2 The value of the crop from 1984 onward is not comparable to previous years because of a change in reporting techniques for New Brunswick only.

3 Prior to 1987, total production includes figures from on-farm land and unmanaged Crown land. As of 1987, only on-farm production and value are available. Unmanaged Crown land is excluded beginning in 1987.

4 As of April 27, 1983, revisions back to 1926 in British Columbia were carried out to reflect that 1 quart equals 1.25 pounds.

5 Cultivated area includes bearing and non-bearing area.

6 Includes low bush blueberries and high bush blueberries.

7 Includes table grapes and wine grapes.

Overall calculated provincial yields were lower than those reported in the literature, from USDA or field data (Table 12). The one exception was provincial cranberries yields, which were 67% larger than WA. In some cases the yield differences were small, peach yields for example were only 18% higher in WA and raspberries 19%. However, raspberry average yield found in the literature for SWBC was more than twice that of the ten-year averages reported for the province. Apple yields were more than 1.5 times higher and pears more than 2 times higher in WA. Field data for blueberries were also 2 times higher than provincial yields indicating either regional and/or cultivar variability. It may be that WA is much more productive than BC for fruit production but given the large discrepancy between other data sources, the lack of data compiled in this review, and the relative economic importance of fruit and berries, further review and additional study is recommended.

Table 12. Fruits yield (Mg ha^{-1}) compared for various data sources for Southwest British Columbia (SWBC), British Columbia (BC) and Washington State (WA). Yield averages, coefficient of variation percentage (CV), minimum, maximum and number of observations (No.) are illustrated. CV is calculated for the number of observations except for Statistics Canada data, which is based on 10 years of reported yields.

Fruit	Location	Average	CV	Min.	Max.	Count	Source
Apple	BC	25.39	14	16.57	29.85	10	Statistics Canada
Apple	Washington State	42.7					USDA
Blueberry	BC	5.53	18	4.23	7.75	10	Statistics Canada
Blueberry	Washington State	8.8	12.8	6.3	10.2	10	USDA
Blueberry	SWBC	13.51	30	8.78	18.27	12	Field
Blueberry, Duke	SWBC	9.71	6	8.78	10.59	6	Field
Blueberry, Reka	SWBC	17.31	4	16.34	18.27	6	Field
Cherries, sour	BC	4.39	15	3.93	4.86	2	Statistics Canada
Cherries, sour	Washington State	9.5					USDA
Cherries, sweet	BC	7.87	27	4.57	10.48	8	Statistics Canada
Cherries, sweet	Washington State	10.8					USDA
Cranberry	BC	13.96	16	10.40	16.38	8	Statistics Canada
Cranberry	US	8.4	10.1	7.2	9.6	10	USDA
Grapes	BC	5.42	12	4.46	6.38	10	Statistics Canada
Grapes, wine	Washington State	10.5					USDA
Peach	BC	10.46	13	8.52	12.33	10	Statistics Canada
Peach	Washington State	12.32					USDA
Pear	BC	20.49	13	17.41	24.16	10	Statistics Canada
Pear	Washington State	46.6					USDA
Raspberry	BC	6.16	11	5.34	7.14	10	Statistics Canada
Raspberry	SWBC	13.93	46	8.00	20.80	3	Literature
Raspberry	Washington State	7.3	9.1	6.4	8.3	10	USDA
Strawberry	BC	4.8	15.5	3.9	6.0	10	Statistics Canada
Strawberry	Washington State	8.9					USDA

3.3 Crop Nutrient Content

Similar to our findings of inconsistent availability of yield data in the literature across crop types, we found a sizeable amount of nutrient content data for some crops types, while for others we found little to nothing available. The vast majority of nutrient content data was for forage and cereal crops, particularly forage grass sourced from unpublished Ministry of Agriculture datasets collected over 8 years (1992-2000) from the Cariboo regional district. Far fewer nutrient content values were found for vegetables and fruits.

The nutrient content data for some forage and cereal crops was fairly consistent, while for others, there was large variability in the data (Table 13). The highest N content was found in alfalfa forage (hay and silage) and the lowest corn silage. Overall the variability for N contents were low with an average CV for all crops of 31%. Forage grass was the exception with a high range of values and a CV of 98%. High P content was found in haylage but also in alfalfa forages while freshly harvested grass had the highest K values. The variability of P and K was lower the N with an average CV of 24 and 26% respectively. The number of field samples relative to those from other datasets was small and only in a few cases (e.g. hay, alfalfa) provides additional data or increases the resolution of existing data substantially. We therefore compress the field and literature data into a single data point where there is overlap to provide a summary table (Appendix 2.1).

Table 13. Average moisture and nutrient content (% by dry weight) of forages and cereals, percent coefficient of variation (CV), and number of observations in British Columbia. Samples were taken either from the field at harvest or from storage. Values were determined from either field data (*field*) or from literature or unpublished datasets (*literature*).

		Moisture			N (%)			P (%)			K (%)		
Crop		Average	CV	No.	Average	CV	No.	Average	CV	No.	Average	CV	No.
Collected from the field													
Corn, silage													
	Field				**1.21**	15	4	**0.24**	23	4	**0.96**	19	4
	Literature	**73.21**	7	17	**2.21**	45	171	**0.15**	10	17			
Grass													
	Literature	**59.80**		1	**1.20**	98	125				**3.22**	18	36
Collected from storage													
Hay													
	Literature	**7.05**	22	5				**0.27**	39	5	**2.49**	41	5
Hay (alfalfa)													
	Field				**2.05**	7	6	**0.33**	17	6	**3.03**	13	6
	Literature				**2.80**		1						
Hay (alfalfa/grass mix)													
	Field				**2.12**	31	4	**0.30**	27	4	**2.56**	24	4
Hay (grass)													
	Field				**1.94**	38	12	**0.29**	24	12	**2.57**	27	12
	Literature	**15.68**	27	386	**1.41**	28	386	**0.18**	33	377	**1.39**	44	377
Hay (legume)													
	Literature	**15.92**	26	271	**1.96**	30	271	**0.22**	29	263	**1.83**	34	263
Hay (legume/grass)													
	Literature	**19.50**	19	5	**1.86**	39	5	**0.18**	26	5	**1.64**	25	5
Haylage													
	Literature	**57.23**	36	3				**0.35**	36	3	**2.89**	27	3
Haylage (alfalfa)													
	Literature	**49.80**		1				**0.36**		1	**3.01**		1
Haylage (grass)													
	Literature	**63.50**	2	2				**0.38**	22	2	**3.02**	11	2
Silage (alfalfa)													
	Field				**2.91**		1	**0.34**		1	**2.97**		1
Silage (cereal)													
	Literature	**57.32**	19	60	**1.57**	25	60	**0.24**	20	60	**1.63**	34	60
Silage (corn)													
	Field				**1.09**	1	2	**0.20**	8	2	**0.97**	7	2
	Literature	**70.94**	11	64	**1.34**	24	13	**0.15**	14	35	**0.98**	7	2
Silage (grass)													
	Literature	**61.83**	18	94	**1.80**	30	94	**0.24**	27	79	**1.68**	32	79
Silage (grass/legume)													
	Literature	**56.66**	26	5	**2.06**	24	5	**0.21**	29	5	**1.57**	49	5
Silage (legume)													
	Literature	**58.51**	20	196	**2.31**	25	196	**0.27**	23	186	**2.05**	27	186
Wheat													
	Literature				**2.80**		1						

In total we have compiled 50 observations for vegetable nutrient content, primarily from field samples for only 7 of the 25 vegetable crops reported grown in SWBC (Table 14). Although the sample size was small, the variability was for all vegetable crops medium to low, with an average CV for N of 48%, P 28% and K 25%. Sample sizes for sweet corn and green peas were too small to be reliable (n=1) and although carrots, beans and squash had small sample sizes CVs were for all nutrients was <35%. In 2014 three types of varieties were sampled for potatoes, *early*, *mid* and *late* season to assess differences in crop removal. While there was some variability in the nutrient content between these varieties only mid season potatoes were significantly lower in P ($p<0.001$). Although there were no significant differences in yields or moisture there were significant differences in nutrient removals. P removal from the harvest of *late* season potatoes was 60% higher ($p<0.05$) than *mid* and 100% higher than *early* season varieties (Figure 10). K removal for late season potato varieties was only higher than early season ($p<0.05$).

Table 14. Average moisture and nutrient content (% dry weight) of vegetables, percent coefficient of variation (CV), and number of observations in Southwest British Columbia.

	Moisture			N (%)			P (%)			K (%)		
Crop	Average	CV	No.	Average	CV	No.	Average	CV	No.	Average	CV	No.
Beans	**90.27**	1	4	**3.36**	27	9	**0.29**	24	4	**2.82**	15	4
Carrots	**88.24**	1	4	**1.51**	21	4	**0.28**	12	4	**2.87**	35	4
Corn (sweet)				**2.41**	58	2	**0.32**		1	**1.03**		1
Peas, green				**2.00**		1						
Potatoes	**81.71**	4	28	**1.42**	25	29	**0.24**	17	28	**2.39**	12	28
Early	**82.59**	2	3	**1.53**	4	3	**0.28**	6	3	**2.25**	10	3
Mid	**81.14**	2	12	**1.28**	23	12	**0.22**	13	12	**2.36**	10	12
Late	**80.47**	2	9	**1.30**	14	9	**0.27**	16	9	**2.45**	12	9
Squash	**90.86**	4	5	**2.14**	11	5	**0.43**	21	5	**3.52**	23	5

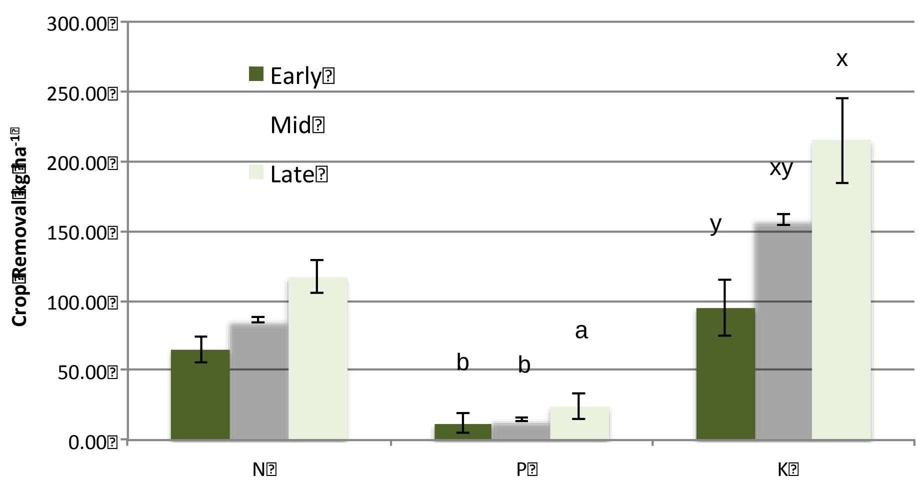

Figure 10. Potato crop nutrient removal (kg ha^{-1}) for three groups of varieties, early, mid and late season. Letters indicate significant differences ($p<0.05$).

There was little fruit nutrient content information available in the literature for the region. Some studies provided information on fruit nutrients but only a few studies provided appropriate data (Dean et al. 2000). Nutrient contents for fruit were determined by field sampling of blueberries, and blueberry leaves were sampled for additional information (Table 15).

Whereas the nutrient concentrations in the harvested fruit represent crop nutrient removals, leaf tissue content is used to guide fertilizer applications (Strik 2013) and samples ranged from 1.3 to 2.0% N but on average were below the recommended sufficiency level between of 1.76-2.0% (Strik 2013). Average values for P were however in the range of sufficiency (0.11-.4%) as was K (0.41-0.7%) (Strik 2013). Four different varieties of blueberry fruit were sampled with small variation between nutrient contents between varieties. For varieties with multiple samples (Duke and Reka) we found low variation within the samples with CVs for nutrient contents all nutrient contents <15%.

Table 15. Average moisture and nutrient content (%) of small fruit, percent coefficient of variation (CV), and number of observations in Southwest British Columbia.

	Moisture			N (%)			P (%)			K (%)		
Crop	Average	CV	No.	Average	CV	No.	Average	CV	No.	Average	CV	No.
Blueberries												
1613	**82.46**		1	**0.62**		1	**0.08**		1	**0.48**		1
Bluejay	**81.69**		1	**0.51**		1	**0.07**		1	**0.46**		1
Duke	**82.77**	1	7	**0.74**	10	7	**0.08**	9	7	**0.53**	6	7
Reka	**84.34**	1	6	**0.59**	14	6	**0.09**	6	6	**0.55**	3	6
Blueberry leaves	**59.72**	17	10	**1.55**	14	11	**0.12**	14	11	**0.69**	23	11
Raspberries												
Meeker				**1.43**	15	42						
Skeena				**1.70**	21	13						

When converting these nutrient contents to nutrients removed per harvested fruit (kg fruit Mg^{-1} wet fruit) our results fell within the range reported by Strik (2013) for N and K for both Reka and Duke varieties but were six to nine times greater for P (Table 16). There were significant differences between nutrient removed in the harvest between varieties. The estimated amount of N removed was 43% higher ($p<0.001$) in Duke than Reka, and 10% higher for K ($p<0.05$).

Table 16. Nitrogen (N), phosphorus (P) and potassium (K) content per Mg of harvested fruit (wet weight) for two blueberry varieties in Southwest British Columbia compared to data from Oregon. Letters indicate significant differences between varieties (p<0.05)

Fruit by Source	Nutrients kg Mg^{-1} wet fruit		
Strik 2013	N	P	K
Blueberry (low)	0.65	0.10	0.70
Blueberry (high)	1.35	0.15	1.10
Field Data 2014			
Reka	0.94b	0.85	0.86b
Duke	1.34a	0.85	0.94a

Nutrient content can vary enormously throughout the growing season depending on the crop. Many of the observations made here did not include the timing of the nutrient content analysis, thus limiting the utility of the data. Further analysis of the data compiled should attempt to categorize the timing of nutrient analysis and management (e.g. fertilizer application rates) if possible.

4. Conclusion and Recommendations

The data that we have compiled here is highly variable for some manure and crop types both in terms of the coverage of the data and the results. The literature in general is dominated by data for forage and cereal crops, and fruit and vegetable data is not as readily available. We have used broad categorizations of both manure and crop data to provide averages and the associated variability. There are certainly gaps in what we have compiled (e.g. limited fruit and vegetable data) and it is likely that additional data on both manure and crops does exist.

Manure data compiled here was highly variable and in some cases too limited to provide conclusive estimates for particular animals or finer categories (e.g. by moisture contents). Manure nutrient contents vary greatly as there are a large number of factors that impact nutrients in the final product. These factors include the animal breed, feed quality and type, methods to collect and store the manure, climate, the duration of storage, and the mechanisms and timing for applying the manure (Chastain et al. 2003). To further complicate predicting manure nutrient content, sample values can vary substantially by the sampling and laboratory methods. In a statewide survey of manure in Colorado, Davis et al. (2002) estimated based on the variability in the data they collected, that 25 sub-samples would be required to assess manure nutrients with a 10% margin of error. Based on this analysis, Davis et al. (2002) argued for building a database of manure nutrient content for the state. The data compiled here clearly support such an effort.

From the data from the literature we compiled, it is unclear whether provincial yields for vegetables effectively represent those for SWBC. This review suggests, however, that 10-year yield averages are probably representative for most vegetable crops with the potential exception of sweet corn and broccoli. Given the limited yield data compiled for this review and the relative economic importance of fruit and berries, further review and additional field studies are recommended, with the caveat that, given the dominance of SWBC production of blueberries and cranberries, documented provincial yields may also be representative of those of the region.

What is noticeably missing from forage and cereal crop data was information on alfalfa production, which represents 12% of the forage and cereal crop production area in SWBC. The few yield reports we found indicated that yields local to SWBC could be much higher than the averages for reported at the provincial scale. While several nutrient management studies in SWBC have included the cooperation of area potato growers, returning crop yield data for those nutrient management focused projects was not a priority of the initiatives (e.g. Temple, Lewis & Bomke, 2010; Kowalenko et al., 2007). Filling in and updating this yield information for SWBC growers was a targeted component of this study and results suggest there are substantial differences between regional and provincial yields.

Crop nutrient content information compiled in this review are limited and variable. Plant nutrient uptake can vary substantially depending on the genetics of the variety, climate, soils and management, all of which interact to impact plant nutrition and ultimately crop yields and nutrient removal (Jones 2009). Assessing plant nutrients can be challenging as the content changes throughout the growing season. The small number of samples limited our ability to further categorize the crop types by any of the factors (e.g. fertilizer application rates) that may characterize content and crop removal. Our field data, which targeted potatoes in SWBC did show significant differences in crop nutrient removal for different varieties, specifically for P and K. Our analysis of blueberry nutrient contents also show that there are significant differences in varieties in terms of the nutrients removed in the harvested fruit. While the utility of nutrient removal information for fruit crops may be limited for field and farm level management these numbers would enhance regional nutrient analysis. There remains a clear gap in nutrient content and removal data for fruit crops, particularly blueberries and cranberries that will likely require future field sampling.

Numerous institutions have long recognized the limitations of “book values” for fertility management, and the consensus recommendation is that site-specific analysis of soil, manure and crop is best for developing management plans (Davis et al. 2002, Chastain et al. 2003). Developing collective datasets at a regional scale can help in the effort to optimize crop production for multiple outcomes, including income, ease of operation and environmental sustainability. There are a number of examples where institutions have developed online databases to enhance this process. For example the *Crop Composition Database v4.2* developed by the International Life Sciences Institute provides a global database of the nutritional composition for various crops, primarily to aid in health planning, but could be a model for livestock nutrition. The Manitoba Agriculture, Food and Rural Development (MAFRD) designed the Manure Application Rate Calculator (MARC) 2008 software to help with manure management for Manitoba. These platforms serve as examples of various approaches that could be used to enhance farmer’s nutrient management planning but a provincially specific software would need to be designed to address the crop mix and associated nutrient demands of BC. Such software would enable users to develop multiple plans for multiple operations by accessing an extensive database of nutrient analyses.

Ensuring a planning tool will enhance farmer’s efficiency is critical to maximize adoption and utility for farm operations. It is clear that dairy farmers in BC are actively analyzing their feed (personal communication, 2013) to optimize production. It is unclear however, how much and of what quality, sampling is being done on manures before application. Developing a system that provides farmers with enhanced planning capabilities that simultaneously generates data that can be analyzed with enough spatial and temporal resolution, could effectively increase the BC Ministry of Agriculture’s capacity to provide accurate planning information. The data compiled in this review can serve as a starting point for developing a comprehensive nutrient database. There are certainly other historical datasets that may be added, and what has been collected could be further reviewed for key information, e.g. manure handling and storage and greater resolution for manure and crop values. Specifically, our recommendations are:

- Targeted data collection should continue for manure and crop types that were not represented or represented in low numbers.
- A framework should be developed to continue to build this nutrient database with the goal to create a provincially comprehensive dataset. This province-wide dataset would record basic metadata of crops and manure and include specific information on the crop variety, soil type and manure storage used, bedding, feed and age.
- Additional review and quality control of unpublished crop yield information should continue in an effort to provide more accurate reference values for crop removal balances.

As the database grows, future analysis should focus on additional categorizations of manure and crops that are focused on reduced variability in reference values. A more robust dataset on manure categories will also enable the analysis of spatial and temporal trends. An important next step may be to assess the sensitivity of management options at the field, farm or regional scale to determine to variations in “book values” to determine the importance of future sampling efforts.

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Appendix 1: Manure Nutrient Values

Appendix 1. 1.Dairy manure nutrient content (as is basis) showing the average and percent coefficient of variation (CV) for total nitrogen (N), ammonium (NH4-N), phosphorus (P), potassium (K), the number of samples taken (No.) and an assessment of variability of the data based on the average CV of the four nutrients (<33% = Low, 34-66% = Medium, >67% High). Data is categorized by manure moisture ranges.

	N (%)		NH4-N (%)		NH4-N (ppm)		P (%)		K (%)			
Class	Average	CV	Average	CV	Average	CV	Average	CV	Average	CV	No.	Variability
Solid												
<72%	**0.76**	43	**0.03**	133	**317**	133	**0.20**	26	**0.43**	87	9	High
72-82%	**0.39**	58	**0.08**	95	**797**	95	**0.10**	77	**0.30**	68	27	High
Liquid												
82-90%	**0.36**	71	**0.12**	47	**1202**	47	**0.10**	88	**0.27**	35	19	Medium
90-94%	**0.28**	18	**0.13**	22	**1330**	22	**0.05**	25	**0.27**	20	23	Low
94-96%	**0.23**	43	**0.14**	68	**1394**	68	**0.05**	46	**0.20**	46	15	Medium
96-98%	**0.15**	21	**0.08**	15	**757**	15	**0.03**	32	**0.14**	31	12	Low
98-100%	**0.09**	58	**0.05**	46	**497**	46	**0.02**	59	**0.12**	26	15	Medium

Appendix 1. 2. Feedlot beef cattle manure nutrient content (as is basis) showing the average and percent coefficient of variation (CV) for total nitrogen (N), ammonium (NH4-N), phosphorus (P), potassium (K), the number of samples taken (No.) and an assessment of variability of the data based on the average CV of the four nutrients (<33% = Low, 34-66% = Medium, >67% High). Data is categorized by manure moisture ranges.

	N (%)		NH4-N (%)		NH4-N (ppm)		P (%)		K (%)			
Class	Average	CV	Average	CV	Average	CV	Average	CV	Average	CV	No.	Variability
≤72%	**0.42**	43	**0.00**	60	**44**	60	**0.13**	28	**0.67**	53	6	Medium
72-82%	**0.68**	98	**0.04**	99	**368**	99	**0.15**	142	**0.30**	59	8	High
82-90%	**0.28**	30	**0.01**	175	**77**	175	**0.09**	54	**0.19**	57	8	High
All	**0.47**	93	**0.02**	159	**164**	159	**0.12**	108	**0.36**	81	22	High

Appendix 1. 3. Chicken manure nutrient content (as is basis) showing the average and percent coefficient of variation (CV) for total nitrogen (N), ammonium (NH4-N), phosphorus (P), potassium (K), the number of samples taken (No.) and an assessment of variability of the data based on the average CV of all four nutrients (<33% = Low, 34-66% = Medium, >67% High). Data is categorized by breed and storage type. Indoor storage indicating manure is coming from poultry barns and may be fresh whereas outdoor storage is likely to be aged.

	N (%)		NH4-N (%)		NH4-N (ppm)		P (%)		K (%)			
Class	Average	CV	Average	CV	Average	CV	Average	CV	Average	CV	No.	Variability
Broiler	**2.26**	56	**0.34**	76	**3423**	76	**0.91**	59	**1.14**	79	94	High
Indoor (Fresh)	**2.97**	45	**0.41**	96	**4078**	96	**1.05**	40	**1.04**	47	25	Medium
Outdoor (Aged)	**1.91**	56	**0.31**	64	**3095**	64	**0.80**	60	**1.14**	87	54	High
Unknown	**2.80**	53	**0.47**	77	**4739**	77	**1.19**	67	**1.34**	79	15	High
Broiler breeder	**1.07**	56	**0.29**	75	**2858**	75	**0.72**	77	**0.80**	49	4	Medium
Hatching egg	**1.96**		**0.41**		**4050**		**1.31**		**5.36**		1	
Layer	**2.26**	40	**0.39**	99	**3889**	99	**1.13**	69	**1.51**	49	17	Medium

Appendix 1. 4. Turkey manure nutrient content (as is basis) showing the average and percent coefficient of variation (CV) for total nitrogen (N), ammonium (NH4-N), phosphorus (P), potassium (K), the number of samples taken (No.) and an assessment of variability of the data based on the average CV of the four nutrients (<33% = Low, 34-66% = Medium, >67% High). Data is categorized by the age of the manure when sampled.

	N (%)		NH4-N (%)		NH4-N (ppm)		P (%)		K (%)			
Class	Average	CV	Average	CV	Average	CV	Average	CV	Average	CV	No.	Variability
Aged (≤7 weeks old	**0.87**	41	**0.13**	65	**1281**	65	**0.44**	31	**0.59**	64	9	Medium
Fresh (>7 weeks old	**1.79**	42	**0.25**	67	**2518**	67	**0.79**	29	**1.31**	19	7	Medium

Appendix 1. 5. Hog and horse manure nutrient content (as is basis) showing the average and percent coefficient of variation (CV) for total nitrogen (N), ammonium (NH4-N), phosphorus (P), potassium (K), the number of samples taken (No.) and an assessment of variability of the data based on the average CV of the four nutrients (<33% = Low, 34-66% = Medium, >67% High). Data is categorized by moisture content.

	N (%)		NH4-N (%)		NH4-N (ppm)		P (%)		K (%)			
Class	Average	CV	Average	CV	Average	CV	Average	CV	Average	CV	No.	Variability
Hog Liquid (> 82% moisture)	**0.33**	37	**0.22**	58	**2211**	58	**0.10**	118	**0.15**	61	13	High
Hog Solid (≤ 82% moisture)	**0.86**	54	**0.05**	98	**525**	98	**0.42**	102	**0.50**	74	8	High
Horse Solid (≤ 82% moisture)	**0.32**	56	**0.03**	87	**268**	87	**0.09**	86	**0.25**	56	21	High

Appendix 1. 6. Annual total manure, and nitrogen (N), phosphorus (P), and potassium (K) production by livestock type (kg animal^{-1} year-^{1})

	Agriculture Canada 1980			BCMAF 1982			Brisbin 1995			Hofmann & Beaulieu 2006		
Row Labels	N	P	K	N	P	K	N	P	K	N	P	Total
Cattle												
Beef							78.0	13.5	39.8	78.8	21.3	13,444
Beef bulls							112.0	20.1	76.4			
Beef calves							20.0	21.9	14.9			
Beef feeder	28.1	5.7	27.6									
Beef heifer	28.1	5.7	27.6				44.0	14.4	33.2			
Beef steers							50.0	16.2	36.5			
Bulls										90.1	24.4	15,364
Calves										25.3	6.9	4,321
Dairy	62.8	13.1	61.8	116.0	13.0	97.0	116.0	13.1	97.1	122.0	26.8	22,706
Dairy bulls							112.0	20.1	76.4			
Dairy calves							20.0	21.9	14.9			
Dairy heifers							42.0	47.2	37.4			
Heifers										52.2	14.1	8,904
Steers										56.3	15.2	9,603
Poultry												
Broilers, roasters and Cornish hens										0.4	0.1	28
Chicken							0.6	0.2	0.3			
Layer	0.5	0.2	0.2	0.8	0.2	0.3	0.8	0.2	0.3	0.6	0.2	42
Other							0.6	0.2	0.3			
Pullets							0.3	0.1	0.1	0.4	0.1	28
Turkey							0.9	0.3	0.4	1.5	0.6	117
Swine												
Boars							24.3	7.5	9.5	9.9	3.3	1,358
Feeder				11.8	2.9	3.5						
Grower and finishing pigs										8.5	3.2	1,287
Hogs												
Nursing and weaner pigs										3.5	1.4	613
Other							7.2	2.4	4.6			
Sows							18.3	5.6	7.1			
Sows and gifts										9.6	3.1	1,358
Swine	11.7	2.9	3.3									
Weaners												
Other												
Ewes	7.3	1.1	5.2				11.0	1.6	8.0			
Lambs							4.4	0.6	3.2			
Rams							11.0	1.6	8.0			
Sheep and lambs										7.0	1.4	662
Goats							11.0	1.6	8.0	10.5	2.6	958
Horse	44.5	8.0	27.6				45.5	7.6	28.4	49.3	11.7	8,377

Appendix 1. 7 Bibliography of manure nutrient content indicating the number of observations from each sources

Author Date	Title	N	NH4-N	P	K
BCMOA unpublished	EFP Manure Nutrients	162	98	164	164
Bertrand et al. 1991	Soil management handbook for the Lower Fraser Valley	6		6	6
Bhandral et al. 2008	Emissions of nitrous oxide after application of dairy slurry on bare soil and perennial grass in a maritime climate				
Bittman and Kowalenko 1999	Surface-Banded and Broadcast Dairy Manure Effects on Tall Fescue Yield and Nitrogen Uptake	18	18		
Bittman et al. 2006	Starter Phosphorous and Broadcast Nutrients on Corn with Contrasting Colonization by Mycorrhizae	3	3	3	
Bittman et al. 2007	Agronomic effects of multi-year surface-banding of dairy slurry on grass	2	1		
Bittman et al. 2012	Precision Placement of Separated Dairy Sludge Improves Early Phosphorus Nutrition and Growth in Corn (Zea mays L.)	3	3	3	
Bomke and Lowe 1991	Trace Element Uptake by Two British Columbia Forages as affected by Poultry Manure Application				
Dean et al. 2000	Poultry Manure Effects on Soil Nitrogen Processes and Nitrogen Accumulation in Red Raspberry	3	3		
Gough et al. 1994	Soil Management Handbook for the Okanagan and Similkameen Valleys		7	7	
Khan 1986	Effects of Rates and Methods of Swine Slurry Application on Crop N Uptake and N Distribution in the Soil	3	3	3	
Lau et al. 2008	Development of ammonia emission factors for the land application of poultry manure in the Lower Fraser Valley of British Columbia	3	3		
Nolan 2002	Poultry Manure and Composted Yard Trimmings for Organic Vegetable Production in Delta, B.C.	1	1		
Smukler et al. 2015	BC Nutrient Database Field Data	170	170	176	176
Sustainable Poultry Farming Group 2004	Sustainable Poultry Farming Group Fact Sheet	4	4	4	4
Timmenga and Associates Inc. 2003	Evaluation of Options for Fraser Valley Poultry Manure Utilization	2		2	2
Zebarth et al. 1996	Influence of the Time and Rate of Liquid-Manure Application on Yield and Nitrogen Utilisation of Silage Corn in South Coastal British Columbia				
	Total	**380**	**314**	**368**	**352**

Appendix 2: Crop Nutrient Values

Appendix 2. 1. Average moisture and nutrient content (% by dry weight) of forages and cereals, percent coefficient of variation (CV), and number of observations in British Columbia. Samples were taken either from the field at harvest or from storage.

	Moisture			N (%)			P (%)			K (%)		
Crop	Average	CV	No.	Average	CV	No.	Average	CV	No.	Average	CV	No.
Collected from the field												
Corn, silage	73.21	7	17	**2.19**	46	175	**0.17**	28	21	**0.96**	19	4
Grass	59.80		1	**1.20**	98	125				**3.22**	18	36
Collected from storage												
Hay	7.05	22	5				**0.27**	39	5	**2.49**	41	5
Hay (alfalfa)				**2.16**	14	7	**0.33**	17	6	**3.03**	13	6
Hay (alfalfa/grass mix)				**2.12**	31	4	**0.30**	27	4	**2.56**	24	4
Hay (grass)	15.89	32	388	**1.42**	29	398	**0.18**	34	389	**1.42**	45	389
Hay (legume)	15.92	26	271	**1.96**	30	271	**0.22**	29	263	**1.83**	34	263
Hay (legume/grass)	19.50	19	5	**1.86**	39	5	**0.18**	26	5	**1.64**	25	5
Haylage	57.23	36	3				**0.35**	36	3	**2.89**	27	3
Haylage (alfalfa)	49.80		1				**0.36**		1	**3.01**		1
Haylage (grass)	63.50	2	2				**0.38**	22	2	**3.02**	11	2
Silage (alfalfa)				**2.91**		1	**0.34**		1	**2.97**		1
Silage (cereal)	57.32	19	60	**1.57**	25	60	**0.24**	20	60	**1.63**	34	60
Silage (corn)	70.94	11	64	**1.31**	24	15	**0.15**	16	37	**0.98**	6	4
Silage (grass)	61.83	18	94	**1.80**	30	94	**0.24**	27	79	**1.68**	32	79
Silage (grass/legume)	56.66	26	5	**2.06**	24	5	**0.21**	29	5	**1.57**	49	5
Silage (legume)	58.51	20	196	**2.31**	25	196	**0.27**	23	186	**2.05**	27	186
Wheat				**2.80**		1						

Appendix 2. 2. Average moisture and nutrient content (% dry weight) of vegetables, percent coefficient of variation (CV), and number of observations in Southwest British Columbia.

	Moisture			N (%)			P (%)			K (%)		
Crop	Average	CV	No.	Average	CV	No.	Average	CV	No.	Average	CV	No.
Beans	**90.27**	1	4	**3.36**	27	9	**0.29**	24	4	**2.82**	15	4
Carrots	**88.24**	1	4	**1.51**	21	4	**0.28**	12	4	**2.87**	35	4
Corn (sweet)				**2.41**	58	2	**0.32**		1	**1.03**		1
Peas, green				**2.00**		1						
Potatoes	**81.71**	4	28	**1.42**	25	29	**0.24**	17	28	**2.39**	12	28
Early	**82.59**	2	3	**1.53**	4	3	**0.28**	6	3	**2.25**	10	3
Mid	**81.14**	2	12	**1.28**	23	12	**0.22**	13	12	**2.36**	10	12
Late	**80.47**	2	9	**1.30**	14	9	**0.27**	16	9	**2.45**	12	9
Squash	**90.86**	4	5	**2.14**	11	5	**0.43**	21	5	**3.52**	23	5

Appendix 2. 3. Bibliography of crop yield and nutrient content indicating sources of information

Author Date	Title	Yield	N content	P content	K content
BCMOA 2003	Overview of Vegetable Production in BC	1	0	0	0
BCMOA unpublished	Feed analysis data	0	1	1	1
Bhandral et al. 2008	Emissions of nitrous oxide after application of dairy slurry on bare soil and perennial grass in a maritime climate	1	1	0	0
Bittaman and Kowalenko 2000	Within-Season Grass Herbage Crude-Protein- and Nitrate-N Concentrations as Affected by Rates and Seasonal Distribution of Fertiliser Nitrogen in a High Yearly Rainfall Climate	0	1	0	0
Bittman 2012	Reduced Tillage in the Fraser Valley	1	0	0	0
Bittman and Kowalenko 1998	Whole-season Grass Response to and Recovery of Nitrogen Applied at Various Rates and Distributions in a High Rainfall Environment	1	1	0	0
Bittman and Kowalenko 1999	Within-season Grass Herbage Crude-Protein and Nitrate-N Concentrations as Affected by Rates and Seasonal Distribution of Fertilizer Nitrogen in a High Yearly Rainfall Climate	0	1	0	0
Bittman et al. 1999	Advanced Forage Management - A production guide for coastal British Columbia and the Pacific Northwest	1	0	0	0
Bittman et al. 1999	Surface-Banded and Broadcast Dairy Manure Effects on Tall Fescue Yield and Nitrogen Uptake	1	0	0	0
Bittman et al. 2000	Phosphorous Deficiency in Seedling Corn - Crop Rotation Considerations	1	0	1	0
Bittman et al. 2000	Phosphorus Deficiency in Seedling Corn: Crop Rotation Considerations	1	0	0	0
Bittman et al. 2004	Season of Year Effect on Response of Orchgardgrass to N fertilizer in a Maritime Climate	1	1	0	0
Bittman et al. 2005	Cheam-VR Orchardgrass	1	0	0	0
Bittman et al. 2006	Chilliwack-VR Orchardgrass	1	0	0	0
Bittman et al. 2006	Haida-VR Orchardgrass	1	0	0	0
Bittman et al. 2006	Starter Phosphorous and Broadcast Nutrients on Corn with Contrasting Colonization by Mycorrhizae	1	0	1	0
Bittman et al. 2007	Agronomic effects of multi-year surface-banding of dairy slurry on grass	1	0	0	0
Bittman et al. 2012	Precision Placement of Separated Dairy Sludge Improves Early Phosphorus Nutrition and Growth in Corn (Zea mays L.)	1	0	1	0
Bomke and Bertrand 1983	Response of an Orchard Grass-Perennial Ryegrass Sward to Rate and Method of Urea and Ammonium Nitrate Application	1	0	0	0
Bomke and Lowe 1991	Trace Element Uptake by Two British Columbia Forages as affected by Poultry Manure Application	1	0	0	0
Bomke and Temple 1994	Winter Wheat Growth and Nitrogen Demand in South Coastal BC	1	0	0	0
Bowen et al. 1998	Dynamics of nitrogen and dry-matter partitioning and accumulation in broccoli (Brassica oleracea var. italica) in relation to extractable soil inorganic nitrogen	1	1	0	0
Dean et al. 2000	Poultry Manure Effects on Soil Nitrogen Processes and Nitrogen Accumulation in Red Raspberry	1	1	0	0
Dyck et al. 2004	Agronomic Performance of Hard Red Spring Wheat Isolines Sensitive and Insensitive to Photoperiod	1	0	0	0
Fairey 1982	Influence of Population-Density and Hybrid Maturity on Productivity and Quality of Forage Maize	1	1	0	0
Fairey 1985	Productivity and Quality of Perennial and Hybrid Ryegrass, Orchardgrass, and Reed Canarygrass Grown in the Lower Mainland of British Columbia	1	0	0	0
Fairey 1985	Productivity, Quality and Persistence of Perennial Ryegrass as Influenced by Cutting/Fertility Management and Ploidy	1	1	0	0
Fisher et al. 1993	A comparison of tall fescue and orchardgrass silages for lactating cows	0	0	1	1

Author Date	Title	Yield	N content	P content	K content
Gaye and Maurer 1991	Modified Transplant Production Techniques to Increase Yield and Improve Earliness of Brussels-Sprouts	1	0	0	0
Grant et al. 2012	Crop yield and nitrogen concentration with controlled release urea and split applications of nitrogen as compared to non-coated urea applied seeding	1	1	0	0
Guthrie and Bomke 1980	Nitrification Inhibition by N-Serve and ATC in Soils of Varying Texture	1	1	0	0
Khan 1986	Effects of Rates and Methods of Swine Slurry Application on Crop N Uptake and N Distribution in the Soil	1	0	0	0
Kowalenko 2000	Nitrogen pools and processes in agricultural systems of Coastal British Columbia — A review of published research	1	0	0	0
Krzic and Bomke 1996	Zero Till Seeding of Corn into Winter Cover Crops in the Western Fraser Valley	1	1	0	0
Krzic et al. 2001	Sweet Corn Tillage-Planting Systems in a Humid Maritime Climate of British Columbia	1	0	0	0
Kuchta 1999	The effect of nitrogen, water and alley management strategies on nitrate and water loss from the root zone in perennial raspberry	1	0	0	0
Ma et al. 2004	Corn Growth and Development (Chapter 7: Advanced Silage Corn Management)	1	0	0	0
Maynard and Bomke 1980	The Response of a Grass-Legume Sward to Poultry Manure	0	1	0	1
Neilsen et al. 2009	Organic fruit production in British Columbia	1	0	0	0
Nolan 2002	Poultry Manure and Composted Yard Trimmings for Organic Vegetable Production in Delta, B.C.	0	1	0	0
Ritchie Smith Feeds, Inc. 2013	Forage Analysis - Ritchie Smith Feeds, Inc	0	0	1	1
Ritchie Smith Feeds, Inc. 2014	Forage Analysis - Ritchie Smith Feeds, Inc	0	0	1	1
Schmidt 2008	Assessment of nutrient management Benefical Management Practices (BMPS) for poultry manure on high fertility fields in the Fraser Valley	1	0	0	0
Smukler et al. 2015	BC Nutrient Database Field Data	1	1	1	1
Thompson 2013	Yield and Nutritive Value of Irrigated Tall Fescue Compared with Orchardgrass: in Monocultures or Mixed with Alfalfa	1	0	0	0
Tucker et al. 2012	Effects of Livestock Grazing on Forage Production, Forage Quality and Soils Properties at Six Sites in the Southern Interior	1	0	0	0
van Dalfsen and Gaye 1999	Yield from Hand and Mechanical Harvesting of Highbush Blueberries in British Columbia	1	0	0	0
Weinberg 1987	Improving nitrogen fertilizer recommendations for arable crops in the Lower Faser Valley	1	1	0	0
Wilkeem et al. 1993	An overview of the forage resource and beef production on Crown land in British Columbia	1	0	0	0
Zebarth et al. 1995	Influence of Nitrogen Fertilisation on Broccoli yield, Nitrogen Accumulation and Apparent Fertiliser-Nitrogen Recovery	1	0	0	0
Zebarth et al. 1996	Influence of the Time and Rate of Liquid-Manure Application on Yield and Nitrogen Utilisation of Silage Corn in South Coastal British Columbia	1	0	0	0
Zebarth et al. 2001	Fertilizer nitrogen recommendations for silage corn in high-fertility environment based on pre-sidedress soil nitrate test	1	0	0	0
	Total	**44**	**17**	**8**	**6**