

Research Brief

From the Southwest BC Bioregion Food System Design Project

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Nutrient Balance of a Regionalized Food System in the Southwest BC Bioregion

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Abstract

This research brief describes the roles of nitrogen and phosphorous in agricultural systems as a crop nutrient, animal waste product, and potential environmental pollutant, and introduces the concept of a nutrient balance as an effective indicator to assess the potential impact of nutrient losses from animal manures. This indicator was used in the Southwest BC Food System Design Project to assess nutrient surpluses and deficits in the baseline year (2011) and various scenarios of the food system in 2050. This brief presents results from 2011 and several future scenarios. Findings indicate that manure production in the baseline year could be managed in a way that does not exceed crop demand therefore reducing the potential of losing nutrients to the environment, and that to effectively address the nutrient balance in the future we need to consider the regional allocation of animal production and crop types to maximize the distribution of nutrients while minimizing the transport.



When nutrients are supplied beyond what the crop can use they are likely lost to the environment, contributing to climate change, air pollution, or water contamination.

Background

Nutrients are essential for producing food but can also be a consequential environmental pollutant. Plants are reliant on a number of nutrients for development, growth and productivity. Among the 16 essential nutrients crop plants require nitrogen (N) and phosphorus (P) in the greatest quantities. All nitrogen originates from the atmosphere which is 78% nitrogen gas. Nitrogen can be fixed from the atmosphere by plants through a symbiotic relationship with microbes or through the industrial Haber-Bosch process, using fossil fuels, to make synthetic fertilizers. Phosphorus originates from rock found around the world that is mined for direct application to crops or for industrial processing to make P fertilizers.

Given that the primary source of feed for agricultural animals is from plants as grain, silage or pasture, food from animals such as meat, eggs and dairy is also reliant on a wide range of nutrients, mainly N and P. Animals however do not use all of the nutrients they eat and thus transfer large quantities of N and P in their manures. These manures can be a valuable source of nutrients for crop production when farmers incorporate the manure into their fields. Manures provide N and P but also a wide range of other important nutrients and organic matter. Organic matter is important as it is key for improving and maintaining soil quality and is critical for long-term agricultural productivity.

As agricultural production has become more specialized, animals and crops are now commonly produced by different farms and the utilization of manures as a nutrient source has become more complicated and expensive. Because of the large quantity of manure required to meet the needs of crops, the cost of utilizing manure increases with the distance it is hauled. Furthermore, the nutrients in the manures are not always readily available to plants when they need it. As a result, farmers often use synthetic fertilizers to supply their crops with nutrients instead of, or in conjunction with, manure application.

As the production of animals has intensified so too has the concentration and volume of manure. In the Southwest BC Bioregion (Southwest BC), the study area of focus for the Southwest BC Bioregion Food System Design Project, this has led to a regional imbalance between the amounts of nutrients being produced relative to the amount that crops can utilize effectively. When nutrients are supplied beyond what the crop can use they are likely lost to the environment, either to the atmosphere contributing to climate change and air pollution, or as surface water run-off or leaching that contaminates drinking water and aquatic habitat. To prevent environmental degradation caused by nutrient losses it is essential to ensure that nutrient supply from manure matches the nutrient required by the crops grown in the region.

Given the importance and impact of this topic in Southwest BC, we developed an indicator of the balance of N and P to assess the potential impact of nutrient losses from animal manures in 2011 and to model potential options for managing these losses. This indicator was incorporated into the food system model developed for the Southwest BC Food System Design Project and was determined by the amount supplied by manures relative to the crop demand across the bioregion.

Methods

Food System Scenarios and Modeling

To explore the outcome of and options for regionalizing the Southwest BC food system in the future, ISFS developed two computational models to estimate current (2011) and future (2050) food production, food self-reliance, environmental impacts, and economic outcomes of various scenarios (Dorward, Smukler, and Mullinix 2016a; Dorward, Smukler, and Mullinix 2016b). The models employed two different calculation techniques based on agricultural land use allocation. In the first model (a spreadsheet model), future agricultural land use allocation followed 2011 agricultural land use patterns. In the

second model (optimization model), future agricultural land use was reallocated and prioritized to meet food need¹ in Southwest BC, with maximizing Southwest BC food self-reliance as a goal. A key feature of the optimization model is therefore that land is allocated to crops that satisfy the highest level of local food need possible. The underlying assumption in both models was that bioregional consumers choose to purchase locally produced food whenever available (that is locally produced food is first sold to the local market, excess food is for exportation). When regional production cannot satisfy regional demand, importation of that food is necessary.

With these computational models, numerous food system scenarios were generated. Several were selected for comparison in this research brief.

The first is the 2011 Baseline scenario (Baseline) which draws upon 2011 statistical data regarding amount of land farmed, land use for crop and animal production, population, and food need (Dorward, Smukler, and Mullinix 2016a). The Baseline scenario represents our contemporary regionalized food system situation in Southwest BC as we assume that the bioregion's population chooses to consume local products over imported products whenever possible. Therefore the amount of food production modeled in the Baseline is likely to be greater than what actually occurred, and the amount of food import to be smaller. Also important to note is an assumption that production of livestock in the bioregion was supported by imported grain feed. IE, that grain for livestock did not have to be grown in the bioregion.

In the second scenario, 2050 Business-as-Usual Food Production with Feed Imports (BAU With Feed Imports), future land use levels and the food production mix is the same as in 2011 while population increases by about 60% (Dorward, Smukler, and Mullinix 2016b). This scenario portrays the degree to which regional food need can

be satisfied by land based food production in Southwest BC under the pressure of population increases given no changes in land use, production method, and yields, and with the continued importation of livestock feed grain.

The third scenario, 2050 Business-as-Usual Food Production without Feed Imports (BAU without Feed Imports) mimics the previous scenario in all respects except for that in this scenario, the model only allowed for the production of livestock that were raised with locally grown feed.

The fourth scenario, 2050 Increase Food Self-Reliance with Feed Imports (Increase FSR with Feed Imports), represents a future in which farmable land is allocated differently; to the production of crops and livestock that satisfy regional food need and maximize food self-reliance. In this scenario, feed grain imports to support livestock production in the bioregion are allowed, and our theoretical food system becomes increasingly regionalized. Not only do consumers choose to purchase local products over imported products, the producers also aim to produce and process the types of food that would satisfy the local food need.

The fifth scenario, 2050 Increase Food Self-Reliance without Feed Imports (Increase FSR without Feed Imports), mimics the previous scenario in all respects except for that in this scenario, the model only allowed for the production of livestock that were raised with locally grown feed.

The sixth is the 2050 Expand Agricultural Land without Mitigation (Expand No Mitigation) scenario represents a future where food self-reliance is increased through reallocating production to foods that satisfy local food need, and by increasing the amount of agricultural land in production. Feed grain imports are allowed in this scenario.

Finally, the seventh, 2050 Mitigate Environmental Impacts from Agriculture (Mitigate Impacts) scenario represents a future in which we attempt to alleviate some

¹See Dorward, Smukler, and Mullinix (2016a) for method of determining food consumption or food need and a list of all foods considered in the models.

of the negative environmental impacts from agriculture. Specifically we implement a nitrogen balance to reducing nitrogen and surpluses from animal manure (described below) and enhancing wildlife habitat quantity, quality, and connectivity (via hedgerows and riparian buffers)². In this scenario, feed grain imports are allowed and the same amount of land is available for farming as in the 2011 Baseline, 2050 BAU, and 2050 Increase FSR scenarios.

While the Baseline 2011 scenario represents the current food system strategy, the other four scenarios offer a glimpse into different food system options for our 2050 future. This, however, does not mean that these are our only options. The scenarios are meant for illustrative purpose and to stimulate discussion about our preferred food system future.

As a summary, the seven food system scenarios presented in this brief and their assumptions are outlined in Table 1.

Nutrient Balance Indicator

The N and P supply for this indicator is based on our model results for the number of animals produced in the region and the estimated concentrations of N and P found in the manure of each animal type (Hofmann and Beaulieu 2006). It is assumed that not all of the N in the manure is available to plants and the availability is calculated based on what becomes available per year and what is lost to the atmosphere (Yang et al. 2011). The demand for nutrients was estimated from amount of N and P per hectare recommended to meet crop plant requirements to maximize yields multiplied by the number hectares estimated for each crop grown across the region. The balance is the difference between these two and is reported as either a surplus or deficit.

A surplus (positive number) indicates that there may be potential losses of nutrients

to the environment while a deficit (negative number) indicates nutrients from manures are insufficient to meet crop demand in the region and need to be supplemented with nitrogen fixing cover crops and/or synthetic fertilizers. It is important to recognize that this is a simplistic indicator of nutrient surplus or deficit as it does not account for imbalances of application within the region, which varies from farm to farm and can be very substantial, atmospheric deposition of N, the residual N and P in the soil that also varies greatly across the region, or the fertilizer that farmers often apply in addition to manure to ensure the crops have access to readily available forms of these nutrients when they need them. As a result, this indicator likely severely underestimates the potential surpluses in the region and associated nutrient losses compared to other more complex indicators such as the Indicator of Risk of Water Contamination by Nitrate-Nitrogen (De Jong et al. 2007) or Residual Soil Nitrogen (Drury et al. 2007) which are reliant on spatially explicit soils data.

Furthermore this indicator does not effectively account for the potential build-up of N and P in the soil. In general the ratio of N to P in animal manures is lower than that of crops and as a result P is likely to build up in the soil faster than N which is much more mobile in the environment. Over time the amount of additional P needed to meet crop requirements is likely to be reduced because of this build up in the soil and thus the surplus would be expected to increase at a faster rate than N. This simple approach to evaluating nutrient balance however enables analysis of food self-reliance using an optimization model that is not explicitly linked to spatial soils data. The food system model uses the number of animals and area of crops in production within the bioregion and provides an indicator that can be readily produced and tracked for different food system scenarios and over time.

²Compared to unfarmed areas, farmed land provides less habitat capacity for wildlife. However, if hedgerows and riparian buffers are introduced on the farms, they could provide habitat and travel corridors for wildlife. For more information on this topic, please refer to Mullinix et al. (2016).

Table 1: Summary of seven theoretical food system scenarios modeled in the Southwest BC Bioregion Food System Design Project and reported in this brief

SCENARIO	TYPE OF MODEL	FARMLAND USE	POPULATION (MILLION)	FARMLAND MODELED (MILLION HECTARES)	ENVIRONMENTAL ENHANCEMENTS	LIVESTOCK GRAIN FEED
2011 BASELINE	Spread-sheet	As Statistics Canada reported for 2011	2.7	101,000	No enhancements	With Feed Imports
2050 BUSINESS-AS-USUAL FOOD PRODUCTION WITH FEED IMPORTS	Spread-sheet	As in Baseline Scenario	4.3	101,000	No enhancements	With Feed Imports
2050 BUSINESS-AS-USUAL FOOD PRODUCTION WITH OUTFEED IMPORTS	Optimization	Reallocated according to regional food need	4.3	101,000	No enhancements	Without Feed Imports
2050 INCREASE FOOD SELF-RELIANCE WITH FEED IMPORTS	Optimization	Reallocated according to regional food need	4.3	101,000	No enhancements	With Feed Imports
2050 INCREASE FOOD SELF-RELIANCE WITHOUT FEED IMPORTS	Optimization	Reallocated according to regional food need	4.3	101,000	No enhancements	Without Feed Imports
2050 EXPAND AGRICULTURAL LAND NO MITIGATION	Optimization	Reallocated according to regional food need	4.3	165,000	No enhancements	With Feed Imports
2050 MITIGATE ENVIRONMENTAL IMPACTS FROM AGRICULTURE	Optimization	Reallocated according to regional food need	4.3	101,000	Nitrogen balance and habitat enhancements	With Feed Imports

Results and Discussion

2011 Baseline

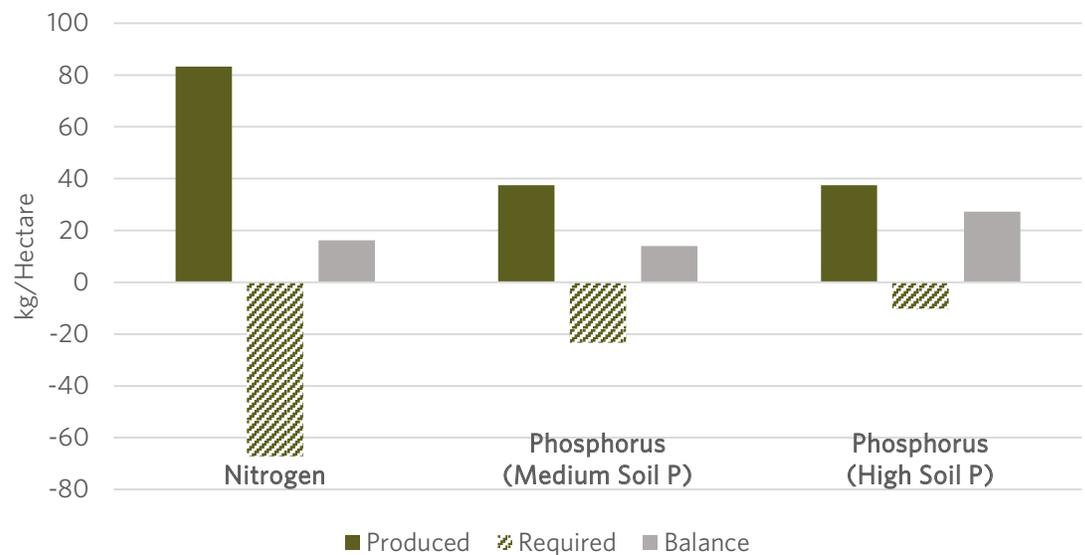
In 2011, based on the number and types of animals, and acreage and types of crops produced, there was a modest surplus of N and P produced from manures across the bioregion. The surplus of N was 16 kg N/ha/yr and of P was 14 kg P/ha/yr (Figure 1). While these values suggest that manure production and crop requirements are nearly in balance, they actually indicate, given the concentration of the animal production within some parts of the bioregion and the amount of fertilizers that are likely being applied, that there are probably large quantities of nutrients being lost to the environment. Berka et al. (Berka, Schreier, and Hall 2001), when including estimated fertilizer applications along with manure, found large areas in the Fraser Valley had surplus N in excess of 120 kg N/ha/yr and in some areas as high as 300 kg N/ha/yr which is far higher than the 100 kg N/ha/yr they suggest is the upper limit for minimizing water quality impacts. It should also be considered that there are areas within the bioregion that require more nutrient additions to achieve target yields such as fields with low organic matter soils, while others already have high concentrations of soil P and likely require far less than what has been modeled here.

While the P requirements for the region were based on soil P concentrations considered “Moderate” to “High” (20 to 50 ppm Bray P) a recent study in the Fraser Valley indicates that much of the soils in the region have soil P concentrations that are considered “High” to “Very High” (50 to 70+ ppm) and therefore should require little additional P fertilization (Sullivan and Poon 2012). When the model is run assuming “High” soil P concentrations the surplus jumps to 27 kg P/ha/yr from the 14 kg P/ha/yr modeled based on a “Medium” concentration of soil P. The comparison of “Medium” to “High” P concentration in the soil the model illustrates how risk of nutrient loss will vary spatially. It also illustrates how P surpluses are likely change after repeated applications of manures and fertilizers.

2050 Scenarios

In the Increase FSR with Feed Imports scenario, where land use is allocated to optimize the food system for local food self-reliance in 2050, food self-reliance could double that of the BAU with Feed Imports scenario. This doubling of food self-reliance would largely be accomplished by increasing the production of eggs, dairy and pork (see Dorward et al (2016b)). This scenario however results in a surplus of N

Figure 1: The annual average nitrogen and phosphorus (kg/ha) produced in animal manures in southwest British Columbia in 2011, the amount required by crops planted in the region and the balance between the two. Phosphorus values are based on medium and high estimates of initial soil phosphorus concentrations.



almost five times that of the BAU scenario and the amount of P surplus by three times (Figure 2). Clearly, increasing production to meet local food demands given the current land base would mean an increased risk of nutrient pollution.

In contrast, in the BAU without Feed Imports and Increase FSR without Feed Imports scenarios, the balance is reversed. Instead of a sizable surplus we would expect a severe deficit largely for the N needed for producing the grain to feed these locally produced animals. This deficit would be ~30% greater for both N and P in the Increase FSR without Feed Imports scenario than the BAU without Feed Imports scenario. The difference in the balance based on local vs. imported feed illustrates the large quantities of nutrients that are currently being imported into the region from areas where feed is being produced.

To maintain a nutrient balance, it is critical that there is sufficient land base to utilize animal manures. If the area of land in agricultural production decreased due to conversion of farmland to urban or industrial uses, we could expect to see nutrient surplus increase as the same amount of manure would be produced on a smaller land base. Alternatively, in the Expand No Mitigation scenario where some

of the underutilized land in Southwest BC is brought into agricultural production, we could expect to see a 62% reduction in N surplus and a 43% reduction in P surplus compared to the Increase FSR scenario.

In the scenario in which a nitrogen balance is imposed on the currently farmed land base (Mitigate Impacts), the nitrogen balance would be zero and the phosphorus near zero with only a 12% loss in food self-reliance. This would be achieved by a substantial shift from meat production to vegetables.

Conclusions

The analysis of the nutrient balance between animal manure and crop production indicates two important possibilities for the SWBC Bioregion. First, given the balance in the baseline is relative close, there is the possibility that much of regional crop nutrient demand could be supplied by the animal manure produced within the region which would reduce farmer reliance on synthetic fertilizer and improve soil quality as organic materials in the manure are added to the soil. Secondly, it is possible that manure production across the region could be managed in a way the does not exceed crop demand therefore reducing the potential of losing nutrients to the environment.

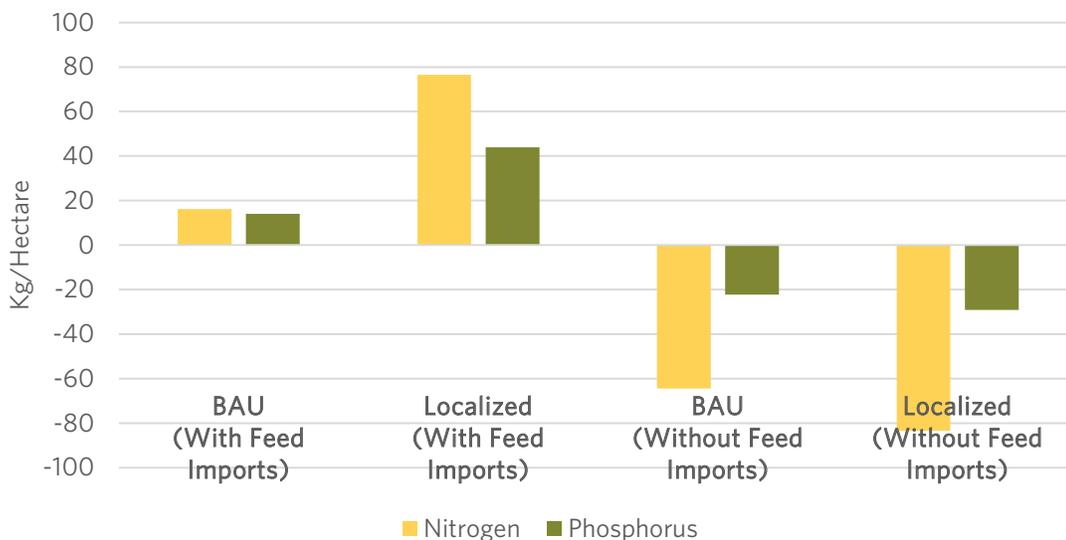
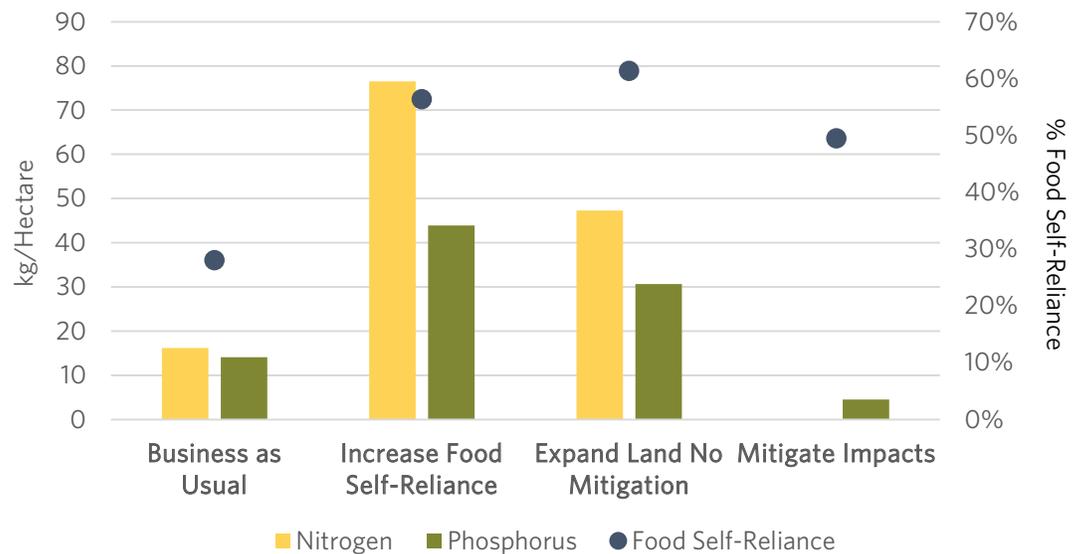


Figure 2: The annual average nitrogen and phosphorus (kg/ha) balance in southwest British Columbia, by scenario

Figure 3: The annual average nitrogen and phosphorus (kg/ha) balance (left axis) and food self-reliance (FSR right axis) in Southwest BC, by Scenario



These two possibilities have important implication for the economic and environmental sustainability of farms in the region. The challenge however is that manure is costly to move and is highly concentrated in some areas of the region. Thus getting the manure to where it is required is likely to incur expensive, emissions producing, transport. Furthermore, the nutrient balance indicator does not take into account the vast amount of nutrients required by the crops and animal feed grown elsewhere that are imported into the region or the fate of those nutrients as a large percentage of them are ultimately consumed by people and end up in the municipal wastewater system.

The scenario analysis for 2050 suggests that food self-reliance can be improved by increasing production on the agricultural land reserve but potentially with substantial increases in nutrient surpluses. Alternatively, the nutrient balance could be improved drastically by carefully selecting a crop and livestock mix but would likely result in some trade-off in terms of food self-reliance.

To effectively address the nutrient balance within the bioregion we need to begin to think about the regional allocation of animal production and crop types to maximize the distribution of nutrients while minimizing the transport. Addressing the import of nutrients in feed and their ultimate post-consumer fate will require further analysis and the development of creative new solutions.

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About ISFS

The Institute for Sustainable Food Systems (ISFS) is an applied research and extension unit at Kwantlen Polytechnic University that investigates and supports regional food systems as key elements of sustainable communities. We focus predominantly on British Columbia but also extend our programming to other regions.

About the Southwest BC Bioregion Food System Design Project

The Southwest BC Bioregion Food System Design project was conceptualized at ISFS in 2012 and concluded in 2016. The project was conceived as a “research project within a research project,” with the broad goals of developing a method to delineate the interconnected economic, food self-reliance, and environmental stewardship potentials of a bioregional food system and applying the method to the Southwest BC bioregion. To our knowledge, this project is the first of its kind. Project research briefs are one means used to present project findings. They are intended to report detailed, topic specific project methods and results. For other research briefs from the project, as well as the project report and summary, and peer-reviewed publications, please visit kpu.ca/isfs.

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