CLIMATE CHANGE ADAPTATION PROGRAM

Nutrient Management

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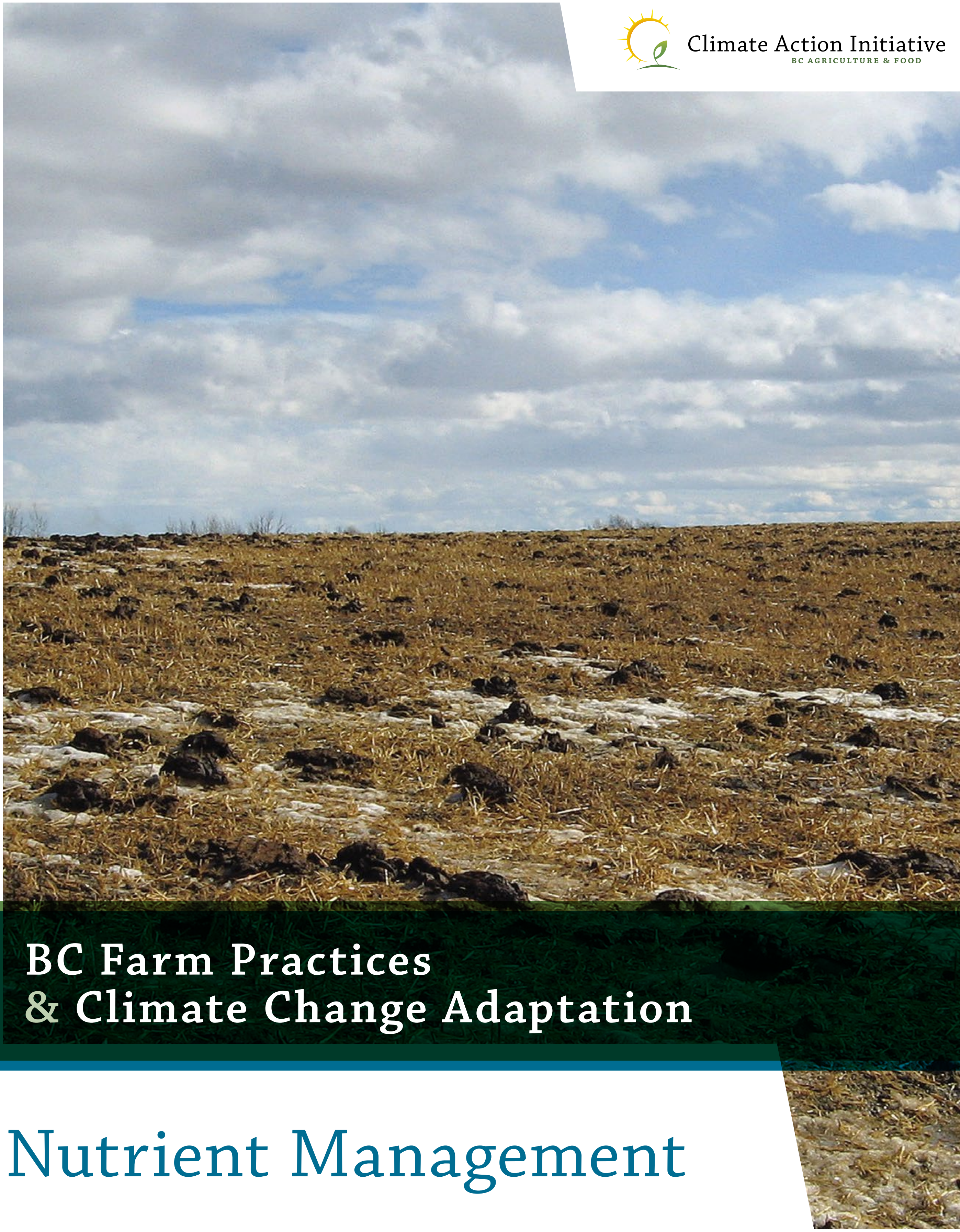

BC Farm Practices & Climate Change Adaptation

Nutrient Management

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www.BCAgClimateAction.ca

with additional thanks
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Farm Practices & Climate Change Adaptation Series

This series of six reports evaluates selected farm practices for their potential to reduce risk or increase resilience in a changing climate.

The practices selected are well known in contemporary and conservation-based agriculture. While they are not new practices, better understanding of their potential relationship to climate change may expand or alter the roles these practices play in various farming systems.

Climate change will not only shift average temperatures across the province, it will alter precipitation and hydrology patterns and increase the frequency and intensity of extreme weather events. The projected changes and anticipated impacts for agricultural systems are considered in the practice evaluations. More details regarding climate change and impacts for various production systems in five BC regions may be found in the *BC Agriculture Risk & Opportunity Assessment* at: *www.bcagclimateaction.ca/adapt/risk-opportunity*

Farming systems are dynamic, complex, and specific to the local environments in which they operate. This makes the analysis of farm practices on a provincial level particularly challenging. The approach taken for this series, is to explore the application of practices regionally and across a range of cropping systems and farm-scales. While the ratings are subjective and may not reflect suitability for a particular farm, the ratings and associated discussion help to identify both the potential, and the limitations, of selected practices on a broader scale. In some cases, the numerical ratings are expressed as a range, to reflect variation in conditions across regions and cropping systems.

The practice evaluations are informed by background research and input from agriculture producers around the province about their current use of practices. Each document includes: a practice introduction, key findings, an evaluation of suitability to help to address climate change risks, and technical practice background related to adaptation. The documents conclude with practice application examples from various regions of the province. More detailed information about the overall project may be found at: *www.bcagclimateaction.ca/adapt/farm-practices*

Like farming systems, practice applications are location specific and change over time. Continued adaptation and holistic integrated practice implementation will be required as climate conditions change. The effectiveness of most practices for mitigating climate and weather related risks will vary over a range of conditions. Ultimately, if practice adoption can reduce vulnerability and risk overall, it has some effectiveness in supporting adaptation.

This document is not intended to serve as a stand-alone technical guide. Rather, it is hoped that this evaluation supports dialogue—among producers, agricultural organizations and key government agencies—about how these and other practices may apply in a changing climate, and how to address information or resource gaps to support further adoption and adaptation.

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Introduction

Nutrient management strives to balance the withdrawal of soil nutrients from fields, pastures and orchards—by crops, livestock, and natural processes—with the addition of nutrients provided by crop residues, compost, manure or commericial fertilizers. The main objective of nutrient management is to optimize the yield and quality of crop production, while minimizing costs and negative environmental impacts. Failure to properly manage nutrients results in poor nutrient use efficiency and potentially harmful downstream environmental effects. Good nutrient management prevents the over-application of essential crop nutrients—and sustainable nutrient mangement considers the full cost associated with application, including the energy embedded in added nutrients.

Related Practices

- Composting
- Tillage practices
- Residue management
- Cover crops
- Manure management
- Green manure crops
- Crop rotation
- Fertilizer application
- Pest management
- Irrigation
- Grazing management
- GPS and field mapping

Since crop growth and the cycling of nutrients depend on temperature and moisture conditions, nutrient mangement could become increasingly important as an adaptive practice for minimizing the potential negative effects of climate change on farm incomes. There will likely be changes in the availability of macro-nutrients (e.g., nitrogen in nitrate form) directily affected by the water cycle. As well, changing cropping practices and increased temperature could have unpredictable effects on the nutrient balance.[1]

What Does Nutrient Management Involve?

Nutrient management can involve a number of related practices, depending on the farming system (see text box). Nutrient management is also a focus for intensive livestock operations that may not have crop production. This summary deals primarily with crop, and integrated crop and livestock, systems and addresses nutrient management as a single practice.

Nutrient management is complex and requires expert knowledge and a substantial amount of information. For this reason, nutrient management planning is essential to properly integrate related practices and maintain nutrient use efficiency over time. Field or pasture assessment, monitoring and testing are required to provide information to satisfy a basic nutrient balance equation:

> *Nutrients supplied = plant nutrient uptake – assumed nutrient losses*

The nutrients supplied come from manure, fertilizers, crop residues, soil, water, atmospheric deposition, and nitrogen fixation by legumes.

The field assessment records basic soils information, including: texture, series (if available), slope and any special concerns and problem areas. Monitoring requires periodic soil tests, field or area specific information on crop yields, crop rotation, cropping practices, timing and application of nutrient supplementation and weather records. Field mapping and spatially referenced record keeping systems can be very useful aids to nutrient management. Baseline soils information can be recorded in these systems. Monitoring helps to validate soil test information and assumptions about nutrient losses under specific soil, weather and management conditions. When all of the monitoring information is considered together, it is possible to determine if nutrients are being efficiently applied or over-applied.

The total amount of nutrients available in supplements—including manure, compost and crop residues—and soils are determined with testing. Nutrients in inorganic fertilizers are determined from their reported chemical composition or molecular structures. Appropriate soil, manure and compost testing procedures should be followed (see factsheets in the *BC Environmental Farm Plan Nutrient Management Reference Guide*).[2] It is extremely important to know the type of extraction methods used by different testing laboratories for different analyses, to properly interpret test results. Crop tissue sampling and testing may be used to help make decisions about nutrient supplementation.

Variable rate technology, or precision agriculture, is an intensive approach to nutrient management. Field mapping and soil testing are carried out on field sub-units so application can be specifically tailored to each unit with the objective of making nutrient applications even more efficient. This approach often employs GPS applications on harvesting equipment that can provide detailed yield monitoring and mapping. There is awareness of variable rate technology among producers, particularly in the grain and oilseed growing areas of the province where GPS technologies are in wide use. However, the application of precision agriculture so far is limited.

Current Adoption in BC

In BC, nutrient management has been promoted by the *BC Environmental Farm Plan Program*. A total of 147 nutrient plans were completed in the program between 2009 and 2012, with the dairy industry accounting for the highest uptake.[3] In the 2011 census of Agriculture, a relatively small proportion of farms in BC indicated they applied nutrient mangement planning, while at the same time a greater number of farms reported use of commerical fertilizer and production or use of manure (Figure 1).[4] Farmers in BC also apply a variety of related practices on their farms and ranches including the use of winter cover crops, ploughing down green crops and in-field winter feeding (Figure 2). On a comparative basis, in-field winter feeding is the most widely adopted practice of this group. It is not possible to determine from Census data how many farms that apply nutrient management planning also used the other practices. Likewise, one or more practices could be recorded for the same farm.

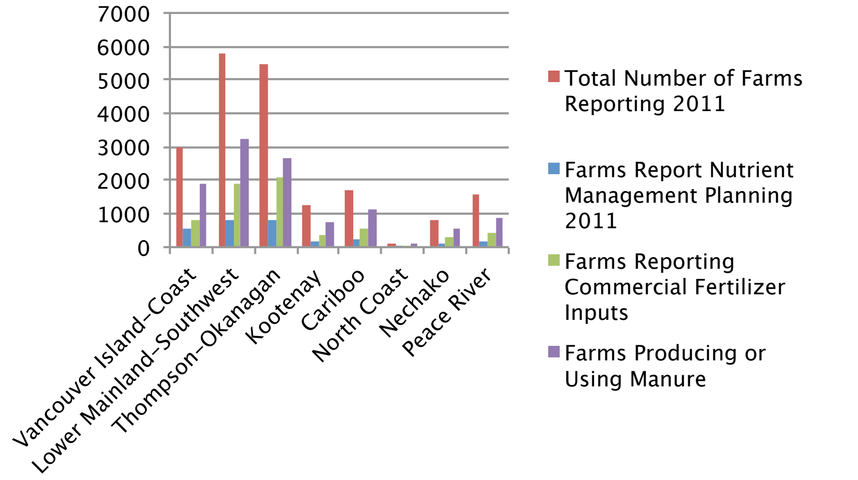


FIGURE 1 Number of farms reporting nutrient management, commercial fertilizer inputs and production or use of manure, 2011

Source: Statistics Canada, 2011 Census of Agriculture, Farm and Farm Operator Data, catalogue no. 95-640-XWE.

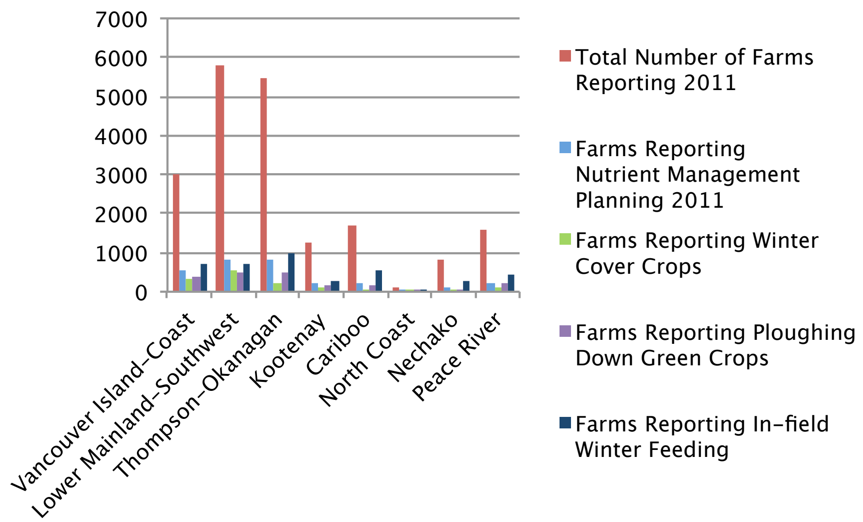


FIGURE 2 Number of farms reporting nutrient management, winter cover crops, ploughing down of green crops and in-field winter feeding

Source: Statistics Canada, 2011 Census of Agriculture, Farm and Farm Operator Data, catalogue no. 95-640-XWE.

Key Findings

- Nutrient management focuses on nutrient relationships between livestock, plants, soil and the environment, which should enhance the opportunity to respond to climate change effects.

- The sum of all climate change effects on the processes and parameters that control plant nutrient availability is uncertain; on-going monitoring and research will be critical to achieve nutrient use efficiency.

- Nutrient stress can be expected if climate change impacts on soil factors reduce plant root growth; effects will be highly variable depending on the cropping system, site conditions, and the timing and location of the climate related impacts.

- Change in regional nutrient requirements may come through shifts in cropping systems that take advantage of altered growing conditions.

- Nutrient management planning is not widely adopted in BC, indicating potential for future adoption.

- Adoption is challenged by subject complexity and the need for outside expertise, support and extension.

- To be fully effective and efficient, objective nutrient management advice that also accounts for weather related production risk in recommendations is required.

- When plants have nutrient requirements satisfied, they are likely to have higher water use efficiency, and greater resistance to other environmental stresses.

- Where there is high level of nutrient management and planning practice in place, there is a good chance of continued optimization under a changed climate.

- Farms that adopt nutrient management principles and planning are likely to have greater resilience, and be better positioned to deal with climate change effects on crop nutrients because they are already engaged in an adaptive management practice.

- Nutrient management can provide positive economic benefits for crop and integrated crop and livestock farming systems.

Areas for Further Adaptation Research & Support

- Regionally specific research on nutrient availability and macro-nutrient cycle processes with clear linkages to weather and climatic variables.

- Education, demonstration and research related to nutrient management in all farming systems.

- Research, demonstration, and monitoring of integrated and holistic nutrient management systems/approaches for various cropping systems.

- Development of regionally specific nutrient management monitoring tools and decision aids that consider local soil characteristics and soil parent materials.

- Research and demonstration on the effectiveness and economic efficiency of nutrient management related practices, including crop residue management, composting and compost use, green manure and cover crops.

Evaluation: Adaptation & Nutrient Management

Multi-Criteria Evaluation

Agricultural research is typically undertaken to establish the efficacy of a product or practice under specific conditions. Similarly, cost-benefit analysis is valuable for assessing whether an investment is economically efficient (whether it pays to invest in a particular practice or asset). An evaluation of adaptation options for climate change needs to consider more than just effectiveness and economic efficiency to be useful for both farmers and those interested in supporting climate change adaptation. Multi-criteria evaluation provides a framework for this evaluation—enabling a set of decision-making criteria to be examined simultaneously.

Multi-criteria evaluation (MCE) can be highly structured, or, as it is applied here, more subjective and exploratory. To have value, the evaluation has to have the decision makers it aims to serve in mind. Often when MCE is employed, considerable time is spent gathering input on decision-making criteria and the needs of users. Given the limited scope of this project, it was not possible to gather user-specific input, and instead the criteria were developed by looking at other studies in the field of adaptation to climate change.[5] However, producers did provide input on the relative importance of the selected decision making criteria in a ranking exercise (27 of 29 participants). Perhaps not surprisingly, economic efficiency and effectiveness were the top ranked criteria followed by adoptability, adaptability, flexibility and independent benefits. Institutional compatibility was ranked last by the majority of farmers.

Often MCE is used to select the most desirable option from various alternatives. Ratings for each criterion are determined, and then added together to provide a total score for each alternative. The relative importance, or weight, given to a single criterion can affect the overall suitability rating for a practice. However, for this evaluation, it is the scores for individual criteria that provide insight into how a practice might be suitable for adapting to climate change, and what might need to change to make it even more suitable. The purpose of the evaluation is not to aggregate ratings and compare practices, but rather to improve understanding of how the individual practices relate to adaptation to climate change.

The evaluation takes a broad view (coarse-scale) across areas and farming systems in the regions (and production systems) where the practice might be applied or considered. The ratings were determined under the assumption that there is some basis for the application of a practice within certain farm types. For example, management-intensive grazing does not have application on a farm without livestock, and therefore it would be ineffective as an adaptive practice for that farm when compared to other alternatives.[6] If carried out at a fine-scale (individual farm level), the suitability rating of any practice could be quite different because the specific circumstances of the farm would be considered for each criterion. Likewise, ratings could vary depending on the purpose (e.g., policy formulation vs. farmer adoption), and the perspective of the individual(s) carrying out the evaluation. Even though, a broad view is taken in the evaluation, the criteria in this series are considered from an on-farm perspective.

The evaluation below assesses a farm practice through the following set of decision-making criteria: *Effectiveness*, *Economic Efficiency*, *Flexibility*, *Adaptability*, *Institutional Compatibility*, *Adoptability* and *Independent Benefits*. Each of the criteria are defined and a numerical rating (in some cases a range) has been assigned across a scale from 1–5 to reflect its potential value in adapting to climate change. The discussion that accompanies the rating captures some of the issues contemplated in determining the rating, as well as some of the variation and complexity of practice application across the province and farm systems.

Effectiveness

Whether the adaptation option reduces the risk or vulnerability, and/or enhances opportunity to respond to the effects of climate change.

RATING: 3–4
neutral to moderately effective

Effective nutrient management should integrate all nutrient-related practices on a farm — crop production, fertilizer application and winter-feeding for livestock — to optimize nutrient use in any specific farming system. Nutrient management planning is required to maintain nutrient use efficiency over time. Effectiveness of the practice for reducing risk or vulnerability to the effects of climate change will be variable and will depend, to some extent, on how well these practices are integrated.

A secondary aspect of nutrient management effectiveness, as it relates to climate change, has to do with how nutrient cycles might change under different climate conditions. Even with the substantial body of accumulated knowledge on plant physiology, plant nutrients and soils, the sum of all climate change impacts on the processes and parameters that control plant nutrient availability is uncertain. (see Table 3). However, current knowledge does suggest healthy plants that have all of the essential nutrients needed for growth will respond better, for example, to a longer, drier growing season than would plants that are deficient in an essential nutrient. Adequate nitrogen can improve water use efficiency and help plants to deal with water stress; and most of the essential nutrients play roles in water use efficiency.[7] However, nitrogen uptake by plants during dry periods can be severely restricted because absorption occurs through mass flow of the soil solution.

Nonetheless, the opportunity to respond to climate change effects should be enhanced with nutrient management. For example, the reduced yield brought about by a sustained dry period on a non-irrigated crop could result in substantial nutrient carry over into the next year. If this effect was accounted for through nutrient management planning there would be a positive impact on the operation, because nutrient supplements could be reduced in the following year.[8]

Related practices that are adopted as a result of nutrient management need separate evaluation to assess their effectiveness. For example, the use of winter cover crops would likely be rated as moderate to very effective as a measure to reduce nutrient loss from translocation and soil erosion (brought about by increased winter precipitation falling as rain). On balance, nutrient management should be neutral to moderately effective in reducing the risk or vulnerability to the effects of climate change, depending on the level of application.

Economic Efficiency

The economic benefits relative to the economic costs that are assumed in implementing the adaptation option.

RATING: 4
moderately efficient

The economic efficiency of nutrient management is likely to be variable, depending on how the practice is applied. An economic analysis of nutrient management plans provided under the

BC Environmental Farm Plan Program suggested the completion of a nutrient management plan had a positive net benefit for the average farm with crop, over a wide range of discount rates (0–8%).[9] However, increased crop yields and lower fertilizer costs could not be captured by farms that did not have crop production, resulting in very minor negative net present values on those farms. A 2007 multi-province study of Beneficial Management Practices (BMP), which used 2006 data and an economic modelling approach, reported that without subsidy, nutrient management planning resulted in a net positive increase in the estimated net revenue after implementation.[10] The study also concluded that variable rate technology was less profitable. BC farms were not included in the analysis; however, the work has some relevance to grain oil-seed production in the Peace Region.

Both the regulatory environment, and how nutrient planning expertise is delivered, are likely to affect economic efficiency. A study of nutrient planning in Maryland found there was a systematic bias among independent consultants and fertilizer companies when it came to nutrient recommendations.[11] When farmers prepared their own plans, they more often recommended fertilizer reductions. The observation made by these researchers suggests that "the fear of yield losses dominates independent crop consultants nutrient management planning."[12]

The possibility that independent consultants may have a bias could be seen as a substantial limitation for the design of programs to support further nutrient management adoption. This example however, highlights the findings of only one study, and in a different institutional and regulatory environment from that of BC. Yet it does point to the potential for bias and the value in focusing on supporting farmer knowledge development and education. This would enable producers to feel confident in adjusting their nutrient management practices to address weather-related risk factors that may affect production and returns.[13]

Other studies have reported net benefits associated with nutrient management planning; however, most appear to focus on intensive livestock operations that are affected by nutrient control regulations.[14] Although there can be considerable cost associated with nutrient planning, there can also be considerable cost-savings if nutrient use efficiency is increased. Overall, nutrient management is judged to be moderately economically efficient.

Flexibility

The ability of an option to function under a wide range of climate change conditions. An option that reduces income loss under specific conditions, and has no effect under other conditions, would be considered inflexible.

RATING: 4
moderately flexible

As an integrated and adaptive management practice, one objective of nutrient management is to maintain nutrient use efficiency under a wide range of weather conditions. For example, increased nutrient loss from more frequent and intense precipitation events should be accounted for. Likewise, over-application of nutrients after drought can be avoided. Nutrient management would be considered moderately flexible.

Adaptability

Whether a practice can be built upon to suit future conditions and allows further adaptation.

RATING: 5
very adaptable

Practices like nutrient management that include a monitoring component are very adaptable. Internal monitoring creates a feedback response to management so that change can be initiated as conditions warrant. The timing, placement, type and amount of nutrients supplied can be adjusted on an on-going basis.

Institutional compatibility

Compatibility of the adaptation option with existing institutional and legal structures.

RATING: 5
very compatible

Current institutional structures are highly supportive of nutrient management as a practice. The public benefits associated with reduced risks to environmental quality when nutrients are not over-applied, or are applied in sub-optimal conditions, are substantial. Nutrient use efficiency for the purposes of greenhouse gas emissions reduction and energy conservation is also valued, and therefore institutional compatibility and support will continue in the future.

Adoptability

The ease with which farms can implement the practice under existing management practices, values and resource conditions.

RATING: 1–2
very low adoptability to moderately low adoptability

Significant knowledge and management inputs are required for implementation of integrated nutrient management. Adoption appears to require education and support from external agents. Adoption of the cost-shared nutrient management plan BMP under the *BC Environmental Farm Plan Program* had widest adoption among dairy producers (57 of 147) from 2009–2012. Overall adoption under this program has been concentrated in the Fraser Valley and the Thompson-Okanagan regions.[15] The Statistics Canada 2011 Census of Agriculture data shows a somewhat broader distribution of adoption of nutrient management planning in general, but adoption is still low. Overall adoptability is considered very low to moderately low.

Independent Benefits

The potential for a practice to produce benefits independent of climate change. For example, a practice that reduces income loss regardless of climate change effects, would be rated high.

RATING: 4
moderate independent benefits.

The potential for nutrient management to produce benefits independent of climate change is moderate. Nutrient processes are intricately linked to temperature and precipitation. Where there is a high level of nutrient management in place, there is a good chance of optimizing the yield and quality of crop production while minimizing costs and negative environmental impacts, regardless of the expected climate change effects.

TABLE 1 Nutrient management evaluation summary

Evaluation Criteria	Rating	Meaning
Effectiveness	3–4	Neutral to moderately effective
Economic Efficiency	4	Moderately efficient
Flexibility	4	Moderately flexible
Adaptability	5	Very adaptable
Institutional Compatibility	5	Very compatible
Adoptability	1–2	Very low adoptability to moderately low adoptable
Independent Benefits	4	Moderate independent benefits

Nutrient Management Background Information

Plant Nutrient Basics

All plants require essential nutrients for growth. Three important nutrients—carbon, hydrogen and oxygen—are supplied from air. The remaining nutrients come from the soil in the form of inorganic salts, and are taken up by plant roots (Table 2). Generally speaking, organic forms of plant nutrients need to be converted to inorganic forms before uptake. Legumes provide an exception, in that they contain rhizobia bacteria in their root nodules that allow atmospheric nitrogen to be converted into a form of nitrogen that is eventually useable by plants.

Soil properties, including parent material, structure, texture and pH, all affect how and in what quantity soil nutrients are made available to plants. The type and amount of organic matter in the soil and the biotic or living components also determine nutrient availability and the overall productivity of soil.

Macronutrients

The macro-nutrients N, P, K and S are used by plants in the highest quantity and are usually the focus of nutrient management for agronomic purposes. Nitrogen and P, however receive special attention

TABLE 2 Essential plant nutrients

Supplied from Air and Water	Supplied from Soil, Organic Matter and Fertilizer	
	Macronutrients	**Micronutrients**
Carbon (C)	Nitrogen (N)	Zinc (Zn)
Hydrogen (H)	Phosphorus (P)	Copper (Cu)
Oxygen (O)	Potassium (K)	Iron (Fe)
	Sulphur (S)	Manganese (Mn)
	Calcium (Ca)	Boron (B)
	Magnesium (Mg)	Chlorine (Cl)
		Molybdenum (Mo)
		Cobalt (Co)

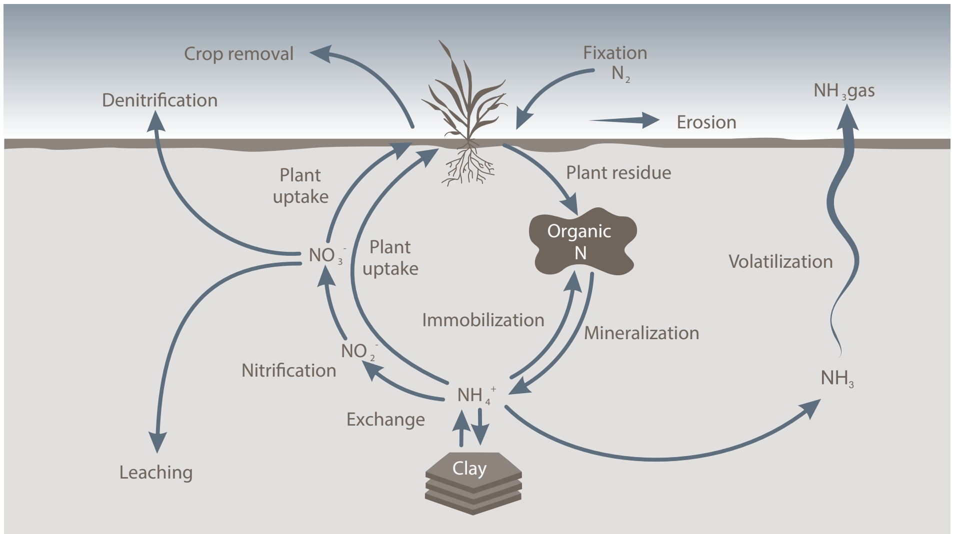


FIGURE 3 Simplified agricultural nitrogen cycle

Source: Nutrient Management Guide, Alberta Agriculture and Food, 2007.[19]
Note: Nitrogen additions from manure and other supplements also interact with this cycle.

because of their negative effects on the environment when they are over-supplied.

There are organic and inorganic forms of N in the soil. The inorganic forms used by plants include ammonium (NH_4^+), ammonia (NH_3^+), nitrate (NO_3^-) and nitrite (NO_2^-), and are 2–5% of total nitrogen in the soil.[16] Nitrogen is most available to plants as ammonium or nitrate. Ammonium is found in soil, manure, compost and fertilizer and can temporarily bind to soil particles. Ammonium becomes available to plants when it is released into the soil solution, but it can also be lost to the atmosphere when it is converted to ammonia gas, through a process called volatilization. Nitrate is highly mobile and readily moves with soil water, and can be lost through leaching and runoff. Nitrate can also be lost from the soil under low oxygen (water-logged) conditions, through a process called denitrification, where microbial activity converts NO_3^- to N_2O or N_2.

Organic nitrogen is a much larger part of total nitrogen in the soil. As organic matter is broken down by microbial action, nitrogen is converted to ammonium and nitrate in a process called mineralization. Nitrogen can be returned to the soil pool as soil organic matter in the form of plant material or soil microbial biomass. A graphical representation of the agricultural nitrogen cycle is shown in Figure 3.

Phosphorus can also exist in the soil in organic and inorganic forms. Both types have labile (available) and non-labile (unavailable) forms. The availability of phosphorus is determined by the rate at which useable forms of P (orthophosphates $H_2PO_4^-$, HPO_4^{-2}) are released into the soil solution. Recent research has shown P is bound more than twice as tightly in Fraser Valley soils than in Okanagan soils.[17] Understanding the soil P interaction in different soils and under different climatic conditions is critical for successful nutrient management, and for surface and groundwater protection.

Unlike N and P, potassium (K) is not an integral part of any plant structure, but is important in enzymatic reactions, water transport, photosynthesis, stomatal activity and protein and starch synthesis. Potassium is similar to phosphorus in that it exists as different pools in the soil. Plants absorb only K^+ ions and as they are taken up additional ions are released into the soil solution from the exchangeable pool. If the concentration in the soil solution is greater than in the exchangeable pool, K will adsorb to the exchange sites. At this time there are limited concerns about K leaching into water sources, but K toxicity may be a concern for livestock that are fed forage from fields with long histories of manure supplementation. Forages may take up K far in excess of plant requirements when there are high concentrations of K in the soil solution.[18]

Sulphur is essential for the conversion of NO_3^- to NH_4^+ in plants, and for the synthesis of plant proteins. It is also integral to nitrogen fixation in legumes, synthesis and functioning of chlorophyll, and oil formation in canola.[19] Sulphur is available to plants as SO_4^{-2}, while most of the S in the soil is in organic matter. The mineralization of S from organic compounds is an important source of S for plants. The plant available sulphate sulphur (SO_4^{-2}) is mobile and can move with groundwater and be leeched from coarse textured soils. It can also be lost from solution with precipitation of Mg or Ca, or through adsorption to aluminium or iron oxides on clay particles.

More Information

Additional information on plant and soil nutrient basics, and nutrient cycles in cropping environments can be found in:

- David Poon et al., Nutrient management reference guide ([Vancouver, B.C.]: BC Agricultural Research and Development Corporation, 2010), *http://www.llbc.leg.bc.ca/public/pubdocs/bcdocs2011_2/499368/nutrientmgmt_refguide.pdf* .
- Alberta Agriculture and Food, Nutrient Management Planning Guide (Alberta Agriculture and Rural Development, 2007), *http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw11920/$FILE/nutrient-management-planning-guide.pdf* .

Micronutrients

The availability of micronutrients is determined largely by the mineral composition of soil parent materials, but also by soil properties and management practices. The need to supplement micronutrients usually occurs because of natural deficiencies or because of poor availability.

Plant Nutrient Processes & Climate Change

How climate change may affect nutrient cycles and plant growth is somewhat uncertain. Plant physiologists, soil scientists and other researchers have begun to investigate various theories about how these processes might change, and what might be done to make crop growth more efficient under future climate conditions.

A summary of climate change impacts on the processes and parameters that control nutrient availability is presented in Table 3. Climate change impacts could affect the amount of nutrients in the soil solution, how nutrients move through the soil, and how plants take up nutrients. Most of the potential changes are driven by increased temperature and changes in the patterns of precipitation; both of these conditions are expected in BC. Nutrient stress can be expected if climate change impacts on soil factors reduce plant root growth. Impacts will be highly variable depending on the cropping system, site conditions, and the timing and location of the climate related effects. The more substantial change in regional nutrient requirements, however, may come through shifts in cropping systems that take advantage of altered growing conditions.[20]

Most of the nitrogen needed for plant growth reaches the plant through mass flow—where the dissolved nutrients move with water to the plant roots where they are absorbed. Nutrient movement by mass flow is reduced in dry conditions and at lower temperatures, because rates of transpiration are lower. Phosphorus and potassium move to the plant roots primarily by diffusion—where nutrients move from areas of higher concentration to areas of lower concentration (see Table 4). Diffusion may

TABLE 3 Impact of climate change on process and parameters controlling nutrient availability

Nutrient Availability Attribute	Soil/Plant Controls	Controller Parameters	Potential Global Climate Effects
Nutrients in Soil Solution	▪ Adsorption/desorption ▪ Mineralization, immobilization, ▪ Fertilization	▪ Buffer power, temperature, pH, soil moisture, solution ionic strength ▪ Soil moisture, temperature, organic matter quality/quantity, microbial activity ▪ Source, timing, rate, placement	▪ Increased temperature may increase process rates; increased CO_2 may enhance root exudates that alter buffer power, enhanced fine root growth, and turnover ▪ Changes in soil moisture caused by rainfall patterns may enhance or depress processes ▪ Increased temperature may enhance volatilization of surface-applied N fertilizer; changes in rainfall patterns may enhance or depress volatilization, and leaching losses of nutrients
Nutrient Movement	▪ Mass flow ▪ Diffusion	▪ Soil moisture, soil physical properties, including bulk density and hydraulic conductivity, soil solution concentration and water influx rate into roots. ▪ Soil moisture, tortuosity (interactive with soil moisture and physical properties), temperature, buffer power, and nutrient uptake	▪ Increased CO_2 may reduce transpiration, depressing nutrient movement to the root through mass flow, but may increase root exudation and fine root growth enhancing buffer power, soil solution concentration and nutrient movement through diffusion. ▪ Increased temperature will enhance diffusion; changes in soil moisture caused by changes in rainfall may enhance or depress mass flow and/or diffusion
Nutrient Uptake	▪ Morphology and architecture ▪ Kinetics	▪ Length, diameter, surface area, branching and spatial distribution, distance between roots, root hairs and specialized structures ▪ Transporter capacity, affinity, and efficiency (minimum soil solution concentration at which net uptake can still occur	▪ Enhanced CO_2 may enhance fine root development. If temperature is sub-optimal increased temperature will enhance root surface area development; changes in soil moisture caused by changes in rainfall patterns may enhance or depress mass flow and/or diffusion.

Source: Adapted from Brouder and Volenec 2008.[20]

TABLE 4 Relative Percentage Contributions of Root Interception, Mass Flow and Diffusion in Nutrient Transport to Corn Roots

Nutrient	Root Inter-ception	Mass Flow	Diffusion
N	1	99	0
P	2	4	94
K	2	20	78
S	4	94	2

Source: Adapted from Havlin et al. (2005) in the Nutrient Management Guide, Alberta Agriculture and Food, 2007.[21]

be enhanced by increased temperatures, because transpiration may be increased. Relatively minor amounts of nutrients are taken up as result of root interception—where as a result of plant growth, roots incidentally come into contact with nutrients.

Nutrient management needs to be responsive to weather and climate conditions in order to be effective. Increased winter and spring precipitation could increase the amount of nutrients lost from the soil profile, making the use of cover crops, crop residue management and other conservation practices more important. Reduced yields caused by an extended dry period in the growing season in non-irrigated crops could mean crop nutrients go unused (e.g., residual soil nitrate), and could be available for plant growth in the following growing season. This example highlights why annual nutrient management planning is needed to prevent over-application and nutrient loss. Where there is a high level of nutrient management and planning practice in place, there is a good chance of continued optimization under a changed climate.[22]

Nutrient Supplements

In farming systems, plant nutrients are converted into useable forms as edible crops or livestock products. As production is intensified, nutrients may not be replaced as rapidly as they are removed, reducing crop or forage production. Nutrients are usually supplemented with inorganic (commercial fertilizer) or organic (e.g., manure, green manure, compost, bio-solids) sources. The nutrients provided by inorganic sources are determined directly from the chemical composition of the specific fertilizer being applied. Organic sources will vary considerably in the amount of nutrients they provide per unit of weight, and may need to be tested. The Reference Guide for the *BC Environmental Farm Plan Program* provides information on the management of different nutrient sources and lists legislation applicable to their use.

The *law of minimum* is an important concept in plant nutrition and in nutrient management. It essentially states that crop production is limited by the nutrient that is in shortest supply. A deficiency in one nutrient cannot be corrected by the addition of a different nutrient.[23] However, where there are environmental concerns about the oversupply of nutrients (e.g., for intensive livestock operations) nitrogen and/or phosphorus will be the main focus for nutrient management. The application of supplemental nutrients for crop production is an integral part of nutrient management and planning, and can be guided by what are known as the four Rs:[24]

- Right nutrients—matching the right nutrient source with soil properties and crop needs
- Right amount—matching the rate of application with crop requirements and soil available nutrients
- Right place—placing nutrients so they can be accessed by the crops, and so that losses are minimized, to improve nutrient use efficiency
- Right time—making the nutrients available so they match plant growth stages and demand

The right application will vary with the farming system, location, crop and weather conditions and should rely on information from a farm-specific nutrient management plan.

Livestock Based Systems

In livestock based systems, manure management is critical, especially when the amount of nutrients brought on to the farm in the form of animal feed is greater than the amount of nutrients harvested and marketed in crops, forage and livestock products.

Various methods of storing and handling manure, in both solid and liquid forms, are used on intensive livestock operations. Timing, quantity, placement and method of application are critical to avoid nutrient loss and contamination of surface and groundwater. Manure has an unbalanced nutrient profile relative to what most crops require, and this can lead to over or under-supply of crop nutrients. For this reason, nutrient management plans that involve manure application are often geared to manage the nutrient that is oversupplied in the system (often phosphorus).

In more extensive cow/calf beef operations the distribution of manure may be managed through winter feeding operations and grazing management. Greater numbers of beef producers are using in-field winter feeding systems like swath and bale-grazing (Figure 4). Within these types of systems it is important that the concentration of manure nutrients does not exceed future crop requirements in any specific area. More detailed information can be found in the Reference Guide for the *BC Environmental Farm Plan Program*.

Crop Based Systems

Most crop-based systems will require nutrient additions that come from off-farm. Typically with these operations, there is a net export of nutrients from the farm in the form of harvested crops. The amount of imported off-farm nutrients can be reduced with the use of green cover crops (that can add nutrients but also reduce nutrient loss from run-off) and the retention of harvested crop residues. Crop residues of all kinds can make a substantial contribution to the nutrient pool for future crop growth. Chipped orchard prunings, and grass clippings are a valuable resource, however some attention should be given to the carbon-nitrogen ratio (C:N, see inset page 17). Nutrient availability from these sources depends on the C:N, time, temperature, moisture, soil properties, and mineralization rates (e.g., microbial activity).

Table 55 and Table 6 illustrate the value of straw and chaff of four field crops that are commonly grown in the Peace River region. There is a wide range in the actual nutrient content of crop residues, and these should be established with testing. Although this

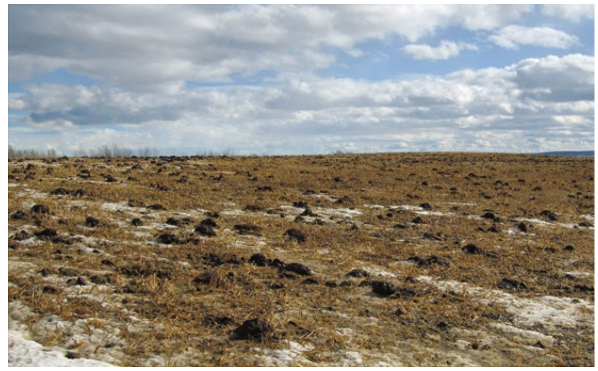


FIGURE 4 Manure accumulation after swath grazing—a form of in-field winter feeding in the Peace River region

This nutrient addition should be accounted for in planning for the next year's growing season. The nutrients available for a future crop on this area would be lower if the forage had been removed and fed in a contained area.

TABLE 5 Average nutrient contents in the straw of selected field crops

Crop Straw	kg N/ tonne	kg P_2O_5/ tonne	kg K_2O/ tonne	kg S/ tonne	Total $/ tonne
Wheat	4.9	1.5	12.3	1.2	$26.56
Barley	6.2	1.7	16.9	1.2	$33.86
Oats	5.8	1.7	17.7	1.4	$33.86
Peas	9.9	1.9	12.3	2.1	$38.70

TABLE 6 Average nutrient content in the chaff of selected field crops

Crop Straw	kg N/ tonne	kg P_2O_5/ tonne	kg K_2O/ tonne	kg S/ tonne	Total $/ tonne
Wheat	7.4	1.9	9.9	1.5	$30.72
Barley	8.2	2.5	14.8	1.5	$38.50
Oats	8.2	1.9	14.8	1.6	$37.19
Peas	14.0	4.4	9.9	2.1	$51.37

Tables 4 and 5 are based on straw with 10 per cent moisture; and the total $/tonne is based on fertilizer prices of $2.18/kg N, $2.43/kg P_2O_5, $0.93/kg K_2O, and $0.53/kg S.

Source: Hartman, 2008.

specific data was produced in Alberta, it is a useful example for illustrating the potential nutrient value of crop residue. It should also be noted, that these tables report the value of the total nutrients contained in each kind of residue, based on the equivalent fertilizer costs of those nutrients. Actual nutrient availability will depend on the nutrient processes mentioned above, and amounts lost to leaching (N and S), denitrification (N), immobilization (N, P, K and S) and fixation (P and K).[25]

The amount of crop residue produced in any given year will vary with weather conditions, crop kind, variety, the level of nutrients supplied and soil type. As an example reference, in the Black soil zone on the Prairies, it is estimated there are 20.4 kg of harvestable straw and 2.6–4.5 kg. of chaff for each bushel of barley produced (assumes 80% of the total material harvestable).[26] Average residue production based on crop yields is also presented in the Soil Factsheet *Estimating Crop Residue for Soil Erosion Control*.[27] If this material were baled and removed from fields after grain is harvested, it would represent a considerable loss in terms of nutrients, and its value for erosion control, and moisture capture and retention.

Carbon to Nitrogen (C:N) Ratio: Organic Matter Cycling & Nutrient Release

The C:N ratio in soils and residues has a significant impact on decomposition and nutrient release. The C:N ratio in soils is about 10:1. Adding organic residues to the soil changes the C:N ratio. Decomposition is slowed when C:N ratio is high (greater than 30:1) and rapid when C:N ratio is low (less than 20:1). Generally, N is released when C:N is less than 20:1, and N is immobilized when C:N is greater than 30:1. (Source: Nutrient Management Guide, Alberta Agriculture and Food, 2007.)[17]

Special Nutrient Formulations

The use of high-wheel sprayers fitted with GIS auto-steer capabilities allows efficient application of low volume foliar nutrients, with essentially no crop damage from off-tracking. Here a wheat field has been sprayed with a special nutrient formulation (see photo right). Copper can also be applied as an annual foliar application on soils where it is found to be deficient. Producers should be aware of possible biases when nutrient supplementation advice is delivered by product sales representatives. Nutrient deficiencies should be diagnosed with assistance from independent sources.

FIGURE 5

Environmental aspects of nutrient management are important in the Fraser Valley, where intensive livestock production and crop agriculture take place over important groundwater aquifers, and near important fish habitat.

FIGURE 6

Solid manure is spread on a field in the Cowichan Valley, Vancouver Island.

Some Benefits & Payoffs of Nutrient Management

Potential benefits associated with nutrient management include:

- Better nutrient use efficiency
- Identification of surplus and deficient nutrients
- Improved crop yield and quality
- Reduced fertilizer costs
- Improved animal and plant health[28]
- Better pest and disease control
- Reduced environmental risks and improved environmental quality
- Certainty in meeting legislated requirements related to agricultural waste

Some Costs & Trade-offs of Nutrient Management

Potential costs and trade-offs associated nutrient management include:

- Costs of knowledge acquisition, plan development and on-going expert input
- Increased labour and management inputs
- Costs for testing plant tissues, soils, manure and compost
- Potential bias created when nutrient management expertise is delivered by nutrient suppliers

Some Nutrient Supplement Practice Considerations

Compost

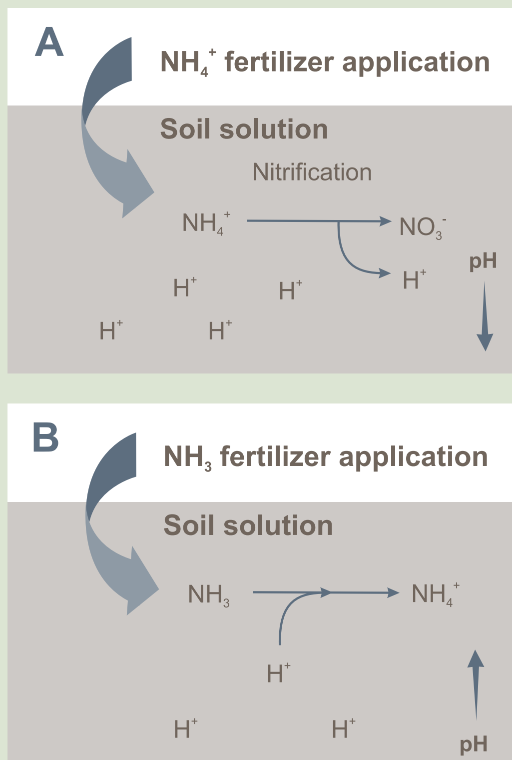
Manure composting produces a stable and odorless soil amendment that is used both as soil conditioner and a fertilizer. It introduces living soil microbes as well as valuable nutrients, but usually with less available N than manure sources. Under the right conditions composting can also kill pathogens and weed seeds. It has better handling characteristics than manure, because of its reduced volume and weight.

The positive effects of compost amendments for plant growth and soil health have been documented in a wide range of cropping systems including grains, vegetables and tree fruits. The economic advantage of compost over other alternatives varies with production scale, and the value of the crops produced.

Compost operations may require additional equipment for aeration, like this farm-scale windrow compost mixer used on a large mixed grain farm and feedlot in the Peace River region (see photo below). Other costs include the loss of some nutrients in the composting process, additional labour, and land required for storage. Composting can be a suitable nutrient management practice for integrated crop and livestock operations. In this case, most of this compost was applied to forage crops.

Fertilizer & Acidification

The addition of inorganic and organic fertilizer sources can alter soil pH. This is yet another reason why over-application of fertilizer should be avoided. Under certain conditions when ammonium forms of nitrogen are added to the soil, they are converted to nitrate under certain conditions. This process releases positive hydrogen ions, increasing soil hydrogen concentration, decreasing soil pH. Ammonia ions can accept a single hydrogen ion, neutralizing the affect slightly. The overall balance of these two processes determines the level of the acidifying effect. The effect can be beneficial on basic soils. Of the commonly used inorganic fertilizers, anhydrous ammonia produces the greatest acidification effect.



Source: Nutrient Management Guide, Alberta Agriculture and Food, 2007.[17]

Nutrient Management Examples

Green Manure & Crop Rotation *(Thompson-Okanagan region)*

On this medium-scale organic vegetable farm, green manure and crop rotation are used to fix nitrogen and add organic matter. The green manure crop—with nitrogen fixing legumes—is planted in June following a fall-rye cover crop seeded after the vegetable harvest in mid-September. The green manure crop is allowed to grow through the summer, and a portion is worked down in October for garlic planting and early spring crops. Most of the cover crop area is left to go through the winter, and is worked in the following spring. Roughly half the farm's cropland is in cover crop at any given time. Some compost is also used on the farm to build up soils in spots that might be less productive, and therefore produce less cover crop residue.

> "*Well, my favorite [cover crop] is peas, oats and hairy vetch. I've got it growing out right along the road there… I've tried a few different things but I keep coming back to that one. It's the one that seems to work best. Hairy vetch is one of the biggest nitrogen fixers. So that's one of the big reasons I use it and the other thing I like about it, is it kind of takes over. If it's established, you're just not going to have any weeds… Nothing gets by it… if I can get a good start to it, and not have too many weeds to start off with, I pretty much am guaranteed weed free into the fall and actually let it winter kill.*

Highlights

- → Green manure
- → Winter cover crop
- → Weed control
- → Crop rotation
- → Compost

A vigorous cover crop of predominantly hairy vetch and oats. Hairy vetch is an annual-biennial cool season agronomic legume. It is highly valued as a nitrogen fixing winter cover crop.

Integrated Orchard Floor Compost & Mulch, and Beef Cattle
(Thompson-Okanagan region)

This cherry and peach orchard in the southern Okanagan has a highly integrated approach to nutrient management. Compost applications began after gaining experience with turkey manure additions on vegetable crops, and seeing the benefits of compost after helping a local organic grower establish a new cherry orchard. Purchased compost was expensive, so small a cattle herd was purchased to produce manure for composting. Yard waste with a higher carbon:nitrogen ratio is obtained from the Regional District to balance the compost. Moisture is added with drip irrigation to speed up microbe activity through the dry summer. Mixing is accomplished with a custom-hired Bobcat loader, and the compost is spread in the orchard using an old solid manure spreader. This how some of benefits were characterized:

> *I don't use anywhere near the amount of chemical fertilizers [compared to the typical production model]. My pest management… I don't spray my peaches. They don't get aphids, because the nitrogen generated by compost comes in a different form [organic form] and it doesn't attract aphids. You put chemical nitrogen on, and they love it, they love the smell of it. It's a real attractant for aphids.*

Reduced chemical inputs have also provided some price premium for the peach crop. The effects of nutrient management practices in the orchard have been been monitored by engaging various experts and researchers.

Highlights

- Nutrient management with compost soil amendment
- Mulching for added organic matter and moisture retention
- Pest management
- Monitoring

Composting windrow of beef cattle manure and yard waste obtained from the Regional District.

A specialized side-delivery mower for managing the orchard floor.

With this equipment, grass clippings are delivered from the centre alley right to the base of the fruit trees.

Endnotes

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3 Amy Kitchen, Patrick Kitchen, and Ryan Trenholm, *Social, Economic and Environmental Evaluation of Beneficial Management Practices* (The Sustainable Agriculture Management Branch, BC Ministry of Agriculture (AGRI), 2013).

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5 See: A.H. Dolan et al., *Adaptation to Climate Change in Agriculture: Evaluation of Options* (University of Guelph, Department of Geography, 2001), *http://www.uoguelph.ca/gecg/images/userimages/Dolan%20et%20al.%20(2001).pdf*

6 Enterprise diversification may in fact be a suitable adaptive strategy to minimize the effects of climate change; however, it is not among the practices evaluated in this series.

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11 C. Lawley, E. Lichtenberg, and D. Parker, "Biases in Nutrient Management Planning," *Land Economics* 85, no. 1 (2009): 186–200.

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14 L. S. VanDyke et al., "Nutrient management planning on four Virginia livestock farms: Impacts on net income and nutrient losses," *Journal of Soil and Water Conservation* 54, no. 2 (April 1, 1999): 499–505.

15 Kitchen, Kitchen, and Trenholm, *Social, Economic and Environmental Evaluation of Beneficial Management Practices*.

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28 See Macro-nutrients – Potassium.