THE UNIVERSITY OF BRITISH COLUMBIA

Improving Farm Profitability and Reducing Greenhouse Gas Emissions with 4R Nutrient Stewardship

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The 4R Nutrient Stewardship framework **—** **R**ight source, **R**ight rate, **R**ight time, and **R**ight place — provides an approach to improving nitrogen use efficiency (NUE) while optimizing yield and minimizing environmental impacts. By minimizing nitrogen (N) losses, it also serves as an effective emissions reduction strategy. In Canada, widespread adoption of these practices could reduce GHG emissions by 6.3 million tonnes of CO_2 equivalents annually by 2030, contributing 3% toward the national Paris Accord target. While applicable across diverse agricultural settings, this brief focuses on implementing the 4R's in intensive vegetable production systems, where overapplication and N loss are common due to shallow-rooted crops, high N demand over short periods, and frequent irrigation, which can contribute to significant N loss. Further contributing to these issues, limited data on nutrient application rates reduces the capacity to make informed recommendations that maximize yields while minimizing environmental losses. For these reasons, 4R Nutrient Stewardship is a key approach to minimizing N loss, improving farm profitability, and mitigating GHG emissions.

Choosing the right nutrient sources is essential to: (1) ensure N is in plant-available forms, (2) match crop nutrient requirements, and (3) complement existing nutrient sources. Synthetic fertilizers typically provide plant-available forms of nutrients, making them easier for farmers to apply effectively, but they must be sourced elsewhere and have high costs and large carbon footprints. Alternatively, organic sources, like manures, plant residues, and compost, release nutrients slowly. Waste products like manure are typically inexpensive and may also help lower costs. Incorporating leguminous cover crops (clover, peas, etc.) enhances biological N fixation, builds organic matter content, and promotes microbial communities. Cover crops also reduce erosion and nutrient leaching, both of which can improve NUE. This can be directly translated into increased yields, as seen in a multi-year processing tomato study based in Ontario. Plots with cover crops consistently outperformed bare control plots in yield, with **partial profit margins up to $1,320/ha with oilseed radish** and **$960/ha with oats**. Growing leguminous cash crops (lentils, chickpeas, etc.) or forage crops (alfalfa, vetch, etc.) can also achieve these outcomes while acting as a source of profit. Alternatively, investing in nitrification inhibitors or slow-release fertilizers can improve NUE, while **reducing N_2O emissions by 20-40% per unit of N applied**.

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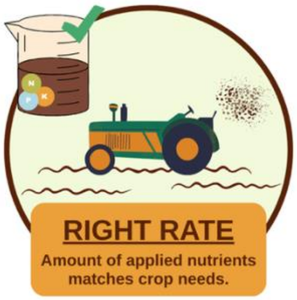
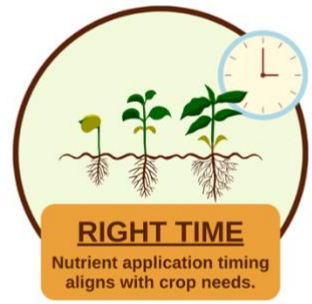


Optimizing nutrient application rates through nutrient management planning helps prevent overuse, reduce environmental harm, and sustain or improve yields. Effective planning aligns application rates with crop requirements and accounts for existing nutrient sources, including those from previous crop residues. On top of this, timely, affordable, and accurate nutrient testing, especially annual soil tests, is key to informed decision-making and avoiding overapplication. In cucurbits, for example, excess N can promote vegetative growth at the expense of fruit development, reducing marketable yield. A multi-site study on butternut squash in southwestern Ontario found that at **64% of field sites**, the **provincially recommended N rates were unnecessarily high –** failing to improve yields and adding avoidable input costs. Similar results were found in a study conducted in the Lower Mainland of British Columbia on potato production, where a **cost-benefit analysis reported that the increase in yield from 90 to 120 kg N ha^{-1} did not significantly outweigh the additional fertilizer costs**. However, in this case, provincial guidelines of **70 kg N ha^{-1}** are often surpassed by farmers in the area, with application rates reported as high as **112 kg N ha^{-1}.** These results underscore the economic and agronomic importance of adjusting fertilizer rates to actual crop and soil conditions prior to application to avoid waste, additional costs, and, in some cases, yield penalties. Without this information, growers are likely to overapply N to mitigate the risk of lower yields.



Timing N applications to align with crop demands over the growing season reduces N losses and maximizes uptake, improving NUE. Utilizing tools such as sensors, field observations, tissue testing, and forecasting models can facilitate dynamic responses to weather and guide split applications to better align with plant needs. In a modelling study focused on corn in Ontario, the findings suggested that **split N application** with rate adjustments may **increase profits by 15-19% in dry conditions** and **1-15% in wet conditions**, while reducing nitrate leaching and indirect N_2O emissions.

Nutrient placement affects both crop uptake and N losses. Applying N near the root zone during key growth stages—through incorporation, injection, banding, or side-dressing—can enhance NUE and reduce volatilization and leaching. However, these methods have trade-offs: surface applications increase NH_3 volatilization and indirect N_2O emissions, while injection may raise direct N_2O emissions by creating denitrification hotspots. Subsurface placement is often recommended, but its impact on emissions is uncertain. As such, investing in new systems may not be cost-effective if farms have suitable application methods. Instead, focusing on **localized placement,** like shallow incorporation or banding near the root zone, can improve NUE while minimizing emissions.

Key Takeaways

Considering both the costs and the potential climate and environmental impacts of on-farm nitrogen application, targeted N applications through 4R Stewardship is a key management strategy to reduce GHG emissions and improve farm profitability.

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