Nitrogen cycling in crop rotations

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Improving nitrogen (N) use efficiency is a key strategy for mitigating climate change in the REACCH region, which is delineated by distinct environments and cropping systems. Continuous annual cropping prevails in wetter areas (> 450 mm annual precipitation), with legume crops commonly rotated with spring and winter cereals. In warmer, drier areas (< 300 mm annual precipitation), a grain-fallow rotation persists. An annual flex, or crop-crop-fallow transition zone bridges relatively wet and dry areas (300 to 450 mm annual precipitation).

IMPACT

The improvement of nitrogen use efficiency in cropping systems is a key strategy for mitigating climate change in the REACCH region. In the grain-fallow cropping system, the application of REACCH research findings has the potential to at least partially offset the effects of drought stress, low nitrogen uptake efficiency, and a shortened grain filling period predicted by some climate change models.

Along a precipitation gradient, water and N may interact in predictable ways, and so we might expect variations in N use efficiency across the REACCH region. A conceptual diagram of the relationship between annual precipitation and N use efficiency is presented as a curved line in Figure 1. In this diagram, N use efficiencies are predicted to be reduced in the grain-fallow system (< 300 mm) due to drought stress, low uptake efficiency, and a shortened grain filling period. Dry spring conditions can leave soil N "stranded" as root activity near the surface is impaired. Nitrogen use efficiency can also be diminished with increasing annual precipitation (> 600 mm) due to nitrate leaching from the root zone and denitrification. Therefore, hypothetically, N use efficiencies are thought to be maximized in the transition and drier portions of the annual cropping zones (300 to 600 mm).

However, this interpretation of N use efficiency along a rainfall gradient only considers N dynamics over a single season. It ignores the potential for N to be retained by soil organic matter, thus preventing N loss through leaching or denitrification and allowing N to be absorbed by crops during subsequent seasons. Furthermore, the hypothetical model disregards the effects of crop residues on N availability for following crops, as well as the effects of more effective timing of N fertilizer application on N use efficiency. (As annual precipitation increases, N application shifts from winter to spring.)

Rotational observations or totals for N use efficiency may be more useful when analyzing the effects of N management and cropping history on N retention and availability of the system. Rotational approaches to assessing N use efficiency include: (1) N balances; (2) N use indices; and (3) net mineralization estimates. Partial N balances calculate the difference between inputs of N (e.g., fertilizers) and N outputs (e.g., grain harvest) over the entire rotation. Rotational N use indices describe the efficiencies of the cropping system, or the sum quantity of grain that is obtained for a given rotational N supply. Finally, net N mineralization estimates the amount of inorganic N that accumulates over the entire

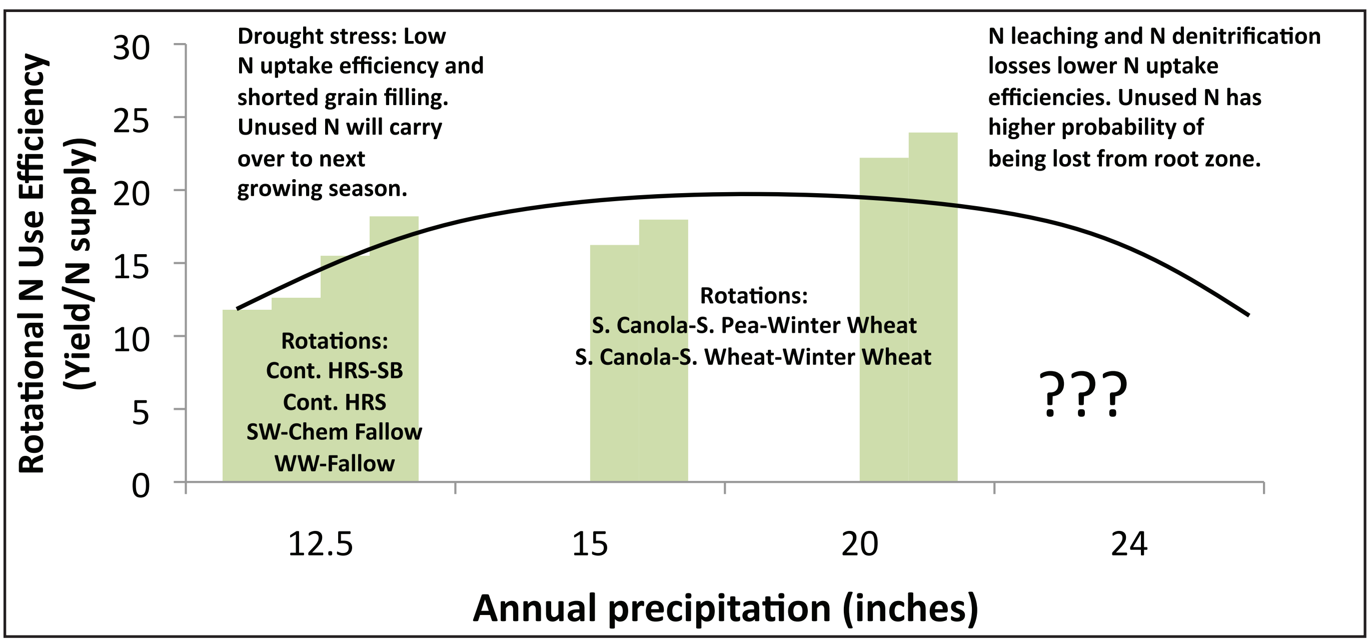

Figure 1. *Nitrogen use efficiencies for alternative wheat crop rotations in different rainfall zones of the inland Pacific Northwest. Adapted from a conceptual relationship between nitrogen use efficiency and rainfall zones. Cont. = Continuous cropping. HRS = Hard red spring wheat. SB = Spring barley. Chem Fallow = Chemical fallow. WW = Winter wheat. S = Spring.*

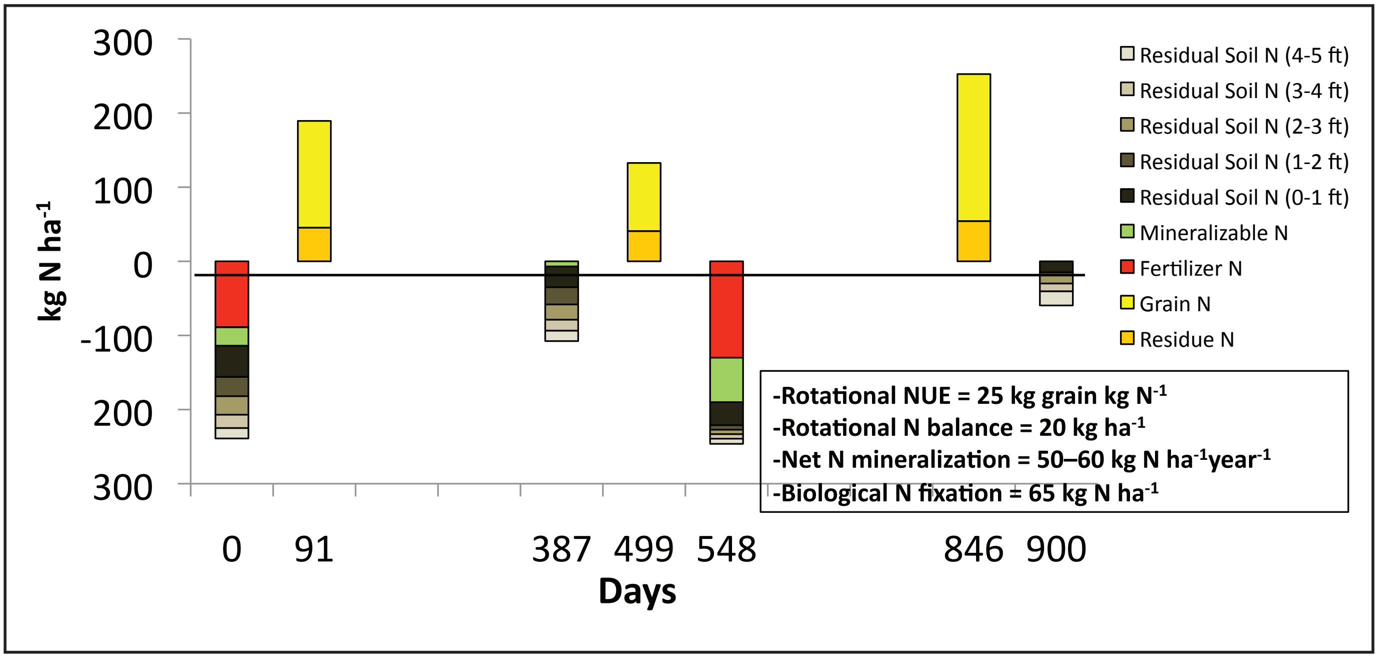

Figure 2. *Changes in grain, crop residue, and plant-available soil nitrogen (N) during a 3-year rotation of spring canola/spring pea/winter wheat in the high precipitation zone. Estimates are provided for crop sequence nitrogen use efficiency (NUE), rotational N balances, and biological N fixation (BNF). NUE = total yields/total N supplied. Rotational N balances = (N fertilizer + N mineralization + biological N fixation) – (total grain N exports + residual soil inorganic N). BNF = (plant N – change in soil N relative to an unfertilized spring wheat reference crop).*

rotation. Internal N cycling may enhance N use efficiencies over multiple years under increasing precipitation (Figure 1). We aim to incorporate REACCH data from replicated field sites to corroborate this hypothesis in the upcoming year.

Our team has adopted a multiple-year N budget approach to track N dynamics over 3-year cropping sequences (e.g., spring canola-spring pea-winter wheat; spring pea-spring wheat-winter wheat) in the annual cropping and crop-fallow transition zones. In the spring canola-spring pea-winter wheat cropping sequence, our N budgets indicate that spring canola, like winter wheat, is an effective N scavenger (Figure 2). After both canola and winter wheat crops, residual nitrate is less than 50 kg N/ha in the top 4 feet of soil, compared to more than 60 kg N/ha following spring peas. While the soil N supply (e.g., inputs of N fertilizer, pre-plant soil N, and net N mineralization) often exceed grain N exports for the entire rotation, the amount of N remaining in crop residues after harvest accounts for 8 to 40% of the total N inputs and is not subject to immediate loss. Furthermore, residual inorganic N remaining after canola and winter wheat represents 10 to 33% of the total N supplied to the crops.

Including field peas in rotation can enhance N outputs by 15 to 50 kg N/ha, as compared to the reference rotation with wheat, presumably due to biological N fixation. However, more residual and leachable inorganic N remains after pea harvest. This N is readily available to the following winter wheat crop, amounting to approximately half of the pre-plant N supply.

Nitrogen use indices show that winter wheat is a more efficient overall N user than canola, but has a relatively greater dependence on fertilizer N. Peas reduce the overall reliance on fertilizer through biological N fixation, while residual inorganic N is able to satisfy a greater proportion of canola's N requirement at yield-optimizing fertilizer rates.

In this rotation, the proceeding crop species and N fertilization resulted in apparent differences in net N mineralization, or the accumulation of inorganic N, of 20 kg N/ha or less in soil cores (0 to 6 inches) collected from the field (data not shown). Soil organic matter plays an important role in N cycling, primarily through mediating N mineralization and immobilization (e.g., release/absorption) of inorganic N. Soil organic matter content is enriched with nitrogenous compounds, and can serve as an important potential sink for fertilizer N. Based on knowledge of soil organic matter turnover, we would expect a net release ranging from less than 20 kg N/ha in a soil that has 1% organic matter under reduced tillage to 55 kg N/ha in a soil with 3% organic matter.

The addition of fresh organic sources, such as plant residues, is known to enhance or reduce N availability, depending on residue quality and decomposability. A rule of thumb is that net mineralization, or release, of N occurs when C:N ratios of fresh plant material are less than 25:1, with a net release of N over a season expected for residues ranging from 10:1 to 24:1. However, cereal crop residues tend to have C:N ratios well above 25:1, and a greater quantity of residue can remain after winter crop harvests. Dissimilarities in crop residue quality and quantity could contribute to differences in short-term N cycling following one crop compared to another. In the long term, continual additions of crop residues help maintain soil organic matter, sustain N cycling from fertilizer and crop residue sources, and prevent fertilizer N losses from the cropping system.