Including forage legumes in rotation with annual crops can be a useful management strategy to increase the availability of fixed nitrogen (N). Following forage legume removal, nitrogen is released to subsequent annual crops.

**Fixation of nitrogen by forage legumes**

The nitrogen fixation process involves the fixation of nitrogen from the air (N\(_2\)) into a form that is usable by plants. This process is facilitated by Rhizobium bacteria, which work together with a legume crop to form nodules on the root systems of legumes. Nitrogen is converted from N\(_2\) to ammonium (NH\(_4\)) in specialized structures called nodules.

Nitrogen fixation decreases with increasing content of soil nitrogen in plant available forms. Soil nitrate levels of approximately 33 kg N/ha will reduce symbiotic nodule formation and levels greater than 67 kg N/ha will result in little, if any, nitrogen fixation. Legumes use available nitrogen found within the soil profile, as this requires less energy than fixing nitrogen from the air.

**Amounts of nitrogen fixed**

After harvest, significantly more nitrogen is left in the residue of a forage legume compared to a non-legume annual crop (Table 1). The amount of nitrogen fixed by legumes varies substantially depending on the species, soil, and environmental conditions. Fixation rates for various legume crops are included in Table 2.

The amount of nitrogen returned to the soil by three forage legumes grown in the Black soil zone are included in Figure 1. When utilized as green manure, the sweet clover, alfalfa and red clover returned 68 to 94 kg N/ha, 41 to 101 kg N/ha, and 35 to 81 kg N/ha, respectively. Of the total nitrogen returned, the sweet clover, alfalfa and red clover roots accounted for 12 to 19%, 20 to 32%, and 21 to 29% of their respective nitrogen yields. Nitrogen content of legume roots are usually underestimated using conventional measuring techniques. If harvested and the stubble incorporated, a return of 10 kg N/ha to the soil would be expected for sweet clover, 20 kg N/ha for alfalfa and 15 kg N/ha for red clover.
Nitrogen release varies with the amount of nitrogen fixed by the legume and the mineralization rate of legume crop residues. Mineralization rate is influenced by residue amount (forage legume residue can contribute 20 to 35 kg N/tonne of forage produced), composition (carbon nitrogen ratios influence the rate of release, with lower C:N ratios resulting in greater release rates) and environmental factors (moisture, temperature and other soil conditions impact microbial activity). Mineralization rate estimates are approximately 20% of fixed nitrogen in a dry year, and can be as much as 70% in a moist year. If the crop is not removed from the field (green manure), the total nitrogen fixed by the legume stand will be mineralized and made available to following crops at the rate of the total fixed N multiplied by 0.2 – 0.4 in following years. If the crop is removed, the amount of nitrogen exported in the biomass must be subtracted initially, then multiplied by 0.2 – 0.4 for mineralization.

**Determining soil nitrogen levels**

Traditionally, fertilizer applications are based on the results of a soil test. The measurement of extractable nitrate used by many labs provides only an estimate of available nitrogen in the soil and does not account for nitrogen released from ongoing decomposition of organic matter. The PRS probe (ion exchange resin membrane), as used in commercial fertilizer recommendations, provides some indication of nutrient release from organic matter, but it only measures release of nutrients for a 24-hour period.

Some labs will measure organic matter and, along with crop history, use this value to estimate nitrogen mineralization in the model used to develop fertilizer application recommendations. This method has limitations due to difficulty in predicting environmental conditions that affect organic matter decomposition rates in the field. Therefore, predictions of available nitrogen contribution from mineralization is inexact using existing techniques that are available commercially.

**Forage Legumes in Rotation**

**Harvest**

Perennial legumes can be harvested for seed, hay, or incorporated into the soil as green manure. Crop utilization affects the levels of residual soil nitrogen available to subsequent annual crops. Nitrogen removal from perennial legume fields varies with what proportion of the legume crop is being removed.

Alfalfa seed yields average approximately 200 kg/ha in Saskatchewan, with maximum protein values of 20%. Alfalfa hay crops remove approximately 45 kg N/tonne of forage (85% dry matter basis) annually. For an unharvested forage legume, that is incorporated as green manure, it is estimated that about 65% of the nitrogen fixed by the legume crop becomes available over the next several growing seasons. Mineralization rates of green manures are expected to be slightly higher due to greater nitrogen content of the younger tissue. Fertilizer replacement values of up to 150 kg N/ha following forage legumes in rotation have been reported. Replacement values diminish over time, but increases have been detected for up to 10 years, in some cases.

**Impacts on yield and quality of following annual crops**

**Mechanism of nitrogen transfer**

Fixed nitrogen can be returned to the soil or neighbouring plants from forage legumes via a number of below and aboveground pathways. Belowground pathways for nitrogen transfer consist of:
1. Excretion of nitrogen into the legume rhizosphere;
2. Decomposition of roots and nodules;
3. Transfer of nitrogen by mycorrhizal fungi and fauna found within the soil profile.

Above ground transfer occurs by:
1. Decomposition of plant material on the soil surface;
2. Leaching;
3. Ammonia losses from the soil surface that are reabsorbed by foliage.

**Crop and soil responses to forage legumes in rotation**

In a study examining the effects of legumes grown in rotation at McLennan, Alberta, Hoyt (1990) found wheat yields following alfalfa during a 15 year period were increased for nearly 12 years, compared to a fallow-wheat rotation with no supplemental nitrogen fertilizer. Wheat yields following alfalfa were from 66 to 114% greater than those following fallow for the first eight years. In years eight to 12, yield differences were less, but were still greater on the alfalfa-wheat, compared to the fallow-wheat treatment. The total yield of all wheat crops following alfalfa was 7.3 tonne/ha greater than the wheat yields that followed the fallow control.

In a long-term experiment at Indian Head, Saskatchewan (Zentner et al., 1987), wheat yields in a three-year rotation following a legume increased as compared to unfertilized fallow by 15-24% and unfertilized stubble by 33-71%.

A study conducted in Manitoba by Forster (1998) separated the nitrogen based and non-nitrogen based yield benefits of an alfalfa hay crop on successive wheat crops. After a second grain crop, rotational yield benefits from alfalfa were similar for nitrogen and non-nitrogen factors (Figure 2).

In the Brown and Dark Brown soil zones, forage legumes may have negative effects on yields of following crops due to the depletion of soil moisture reserves. A study in the Dark Brown soil zone near Saskatoon, found that wheat yields following legumes were decreased, compared to wheat grown in a fallow system. Kilcher and Anderson (1963) found that in the Brown soil zone of Saskatchewan, spring wheat yields following a forage legume crop were reduced compared to a wheat-fallow rotation.

**Rotation length and frequency**

Rotating forage legumes with annual crops can provide many benefits to following crops such as increased grain yields and quality, shifting weed populations, and improved soil quality. Alfalfa productivity can begin to decline after five years, due to stand thinning, disease, winter injury, weeds, rodents, and nutrient deficiencies. To maximize the benefits of perennial forages in an extended rotation with annual crops, fields should be removed after approximately five years. Nearly any environmental factor that negatively influences the growth of the legume plant will reduce nitrogen fixation.

**Conclusions**

Residual soil nitrogen can be available to subsequent crops when a legume stand is removed. The harvest method of the legume has an impact on residual soil nitrogen. Green manure provides the greatest residual soil nitrogen. In dry conditions, benefits of residual soil nitrogen can be offset by reduced soil moisture following a legume crop. Including perennial legumes in a crop rotation with annual crops can result in yield increases in the annual crop due to residual soil nitrogen, with the greatest potential for fixation and yield increases in higher moisture areas, including the Black soil zone.
REFERENCES


Knight, J.D., 2005. Enhancing soil fertility with green manures. Proceedings of the Saskatchewan Soil Conservation Association Workshop. 2 December, 2005, University of Saskatchewan, Saskatoon, SK.


FURTHER READINGS

Project Technical Review Committee
Janice Bruynooghe, PAg – Saskatchewan Forage Council
Dr. Bruce Coulman – University of Saskatchewan
Dr. Martin Entz – University of Manitoba
Dr. J. Diane Knight – University of Saskatchewan
Dr. Sukhdev Malhi – Agriculture and Agri-Food Canada
Barry Marquette – Saskatchewan Forage Council
Elaine Moats, PAg – Saskatchewan Ministry of Agriculture
Dr. Jeff Schoenau, PAg – University of Saskatchewan
Michel Tremblay, PAg – Saskatchewan Ministry of Agriculture

Content Compilation
Shanda Sedgwick, BSA - Elrose, Saskatchewan
Michel Tremblay, PAg - Saskatchewan Ministry of Agriculture

Printing & Design
Orylix Media Group, Saskatoon, Saskatchewan

Front and back cover photo credits: Dr. Martin Entz - University of Manitoba, Manitoba Agriculture, Food and Rural Initiatives.