GROWING FORAGE LEGUMES IN ROTATION WITH ANNUAL CROPS

The Impact of Biologically Fixed Nitrogen on Crop Yields

Sask Forage Council

Nitrogen is usually the most limiting nutrient for annual crop production. It is supplied to crops by mineralization of soil organic matter, commercial fertilizers, and atmospheric nitrogen fixed by legumes and rhizobia. Because biologically fixed nitrogen may cost less than commercial fertilizers, maximizing the proportion of fixed nitrogen in cropping systems reduces costs. Forage legumes are grown on approximately 3.9 million acres in Saskatchewan (Statistics Canada, 2006).

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

Nitrogen fixation is a complex, symbiotic process in which *Rhizobium* bacteria work together with a legume crop to take nitrogen from the soil air (N_2) and convert it to ammonium (NH_4), a form that is useable by plants. The process takes place in specialized structures called nodules that are formed by the bacteria on the root systems of legumes.

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).*

Table 1. Amounts of nitrogen in residue after harvest of wheat and forage legumes at two sites in North Dakota

Treatments	1984		1985	
	Fargo	Prosper	Fargo	Prosper
	N (kg/ha)			
wheat straw and chaff	28	11	16	16
Vernal alfalfa	51	89	82	58
sweet clover	74	86	63	84
Arlington red clover	66	78	41	33
hairy vetch	-	-	57	26

(Badaruddin and Meyer, 1989)

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.*

Table 2. Nitrogen fixation of legume crops

Legume	Plant N derived from atmosphere (%)	N fixed symbiotically (kg/ha)
alfalfa	80	114-300
sweet clover	90	5-250
fababean	90	178-300
field pea	80	2-200
lentil	80	10-150
chickpea	70	24-120
dry bean	50	2-70

(Knight, 2005: Adapted from Heichel, 1987 & Green and Biederbeck 1995)

In grass-legume forage mixtures, as much as one-third of the nitrogen fixed by a forage legume may be transferred to the grass.

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.

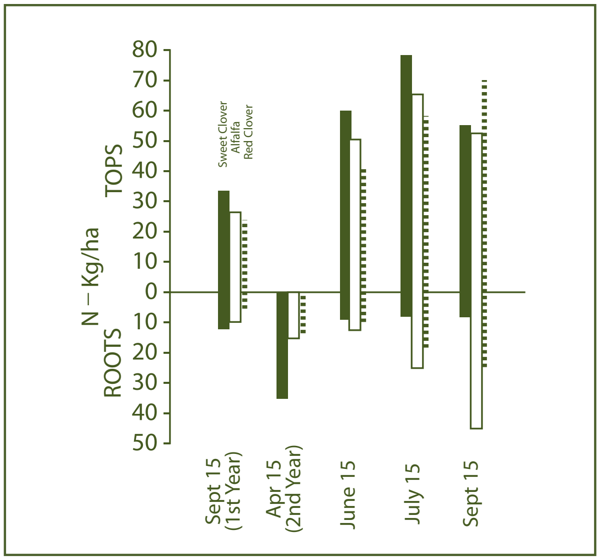

Figure 1. Average production of N (kg/ha) by three legumes at Melfort and White Fox, Saskatchewan (Bowren, 1969)

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 be 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:

Photo Credit: Martin Entz - University of Manitoba

Organic flax following alfalfa in rotation (2003) late seeding (May 27) on the left; early seeding (May 15) on the right

Photo Credit: Martin Entz - University of Manitoba

Organic flax without alfalfa in rotation (2003)

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.

Alfalfa roots with nodules

At Winnipeg and Portage la Prairie, Manitoba, (Kelner et al., 1997), studies determined that nitrogen fixation rates of alfalfa increased from 174 kg/ha in year one to 466 kg/ha in the third year of the stand, and the net soil nitrogen balance increased from 84 kg/ha to 137 kg/ha from year one to three.

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

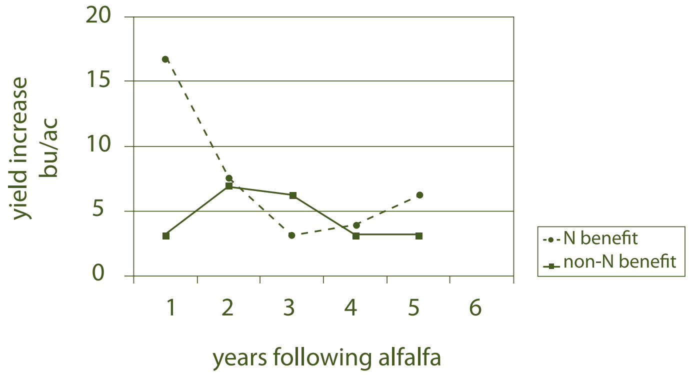

Figure 2. Nitrogen and non-nitrogen caused yield (bu/ac) increases in wheat following alfalfa (Adapted from Forster, 1998)

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.

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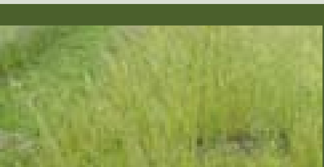
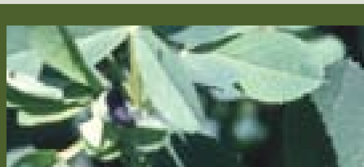
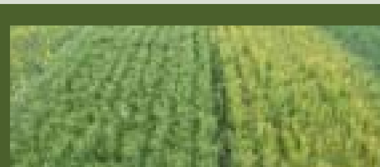
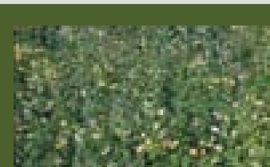


PROJECT PARTNERS

Sask Forage Council

University of Saskatchewan

Saskatchewan Ministry of Agriculture

University of Manitoba

Agriculture and Agri-Food Canada / Agriculture et Agroalimentaire Canada

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

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