NITROGEN FIXATION IN AGRICULTURE: FORAGE LEGUMES IN SWEDEN AS AN EXAMPLE

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Perennial grasslands, managed for forage production and leys, represent the majority of cultivated land in Sweden. In northern Sweden, the leys are typically comprised of the grasses timothy, *Phleum pratense*, and meadow fescue, *Festuca pratensis*, together with red clover, *Trifolium pratense*. It is common to establish the leys as an undersowing in barley and then keep them for about 3 years in a crop rotation. Leys are normally harvested twice per year for silage, but some leys are also grazed.

Red clover has several important functions in leys (Frame et al., 1998). Red clover increases palatability of the forage, which leads to increased forage consumption and thereby increased milk production. Red clover is deep-rooted and can thus improve nutrient uptake, especially of divalent cations, from deeper soil layers. Due to its symbiosis with N_2-fixing *Rhizobium leguminosarum* bv. *Trifolii*, red clover has a great potential to increase sustainability in ley-dominated crop rotations. These rhizobia occur in high numbers in agricultural soil in northern Scandinavia. We found a large genotypic variation but only minor differences in N_2-fixation capacity among rhizobia isolated from *T. pratense* in northern Scandinavia. The rhizobia are thus well adapted to the environmental conditions in the studied soils (Duodu et al., 2007).

In spite of the widespread use of red clover in Sweden, information about its N_2 fixation activity and consequent fixed-N additions below ground is scarce. We used the ^{15}N-based ID (isotope dilution) and NA (natural abundance) methods to quantify the proportion of clover N derived from air (pNdfa) and the amount of N_2 fixed per area in a first-year ley, a second-year ley, and a third-year ley. The leys were in neighbouring fields in Umeå, northern Sweden. The so-called B value needed in the NA method was established in red clover grown in the laboratory (Carlsson et al., 2006).

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Measurements of pNdfa were made separately in leaves, stem, stubble, and in roots. pNdfa values were very high, usually ≥0.8, which is in agreement with previous results for forage legumes grown in mixture with grasses in other northern temperate/boreal areas (reviewed by Carlsson and Huss-Danell, 2003). Our measurements of pNdfa in leaves could provide useful indications of pNdfa in shoots and whole red clover plants, thus avoiding the need for time-consuming root analyses in field-grown plants (Huss-Danell and Chaia, 2005). When N_2 fixation was measured only in the herbage, (i.e., the plant parts removed at harvest), it amounted on average to 45% of whole plants at first harvest and 77% of whole plants at second harvest.

Biomass production, N content, and N_2 fixation were studied during three parts of the growing season; the start of the season until late June (first harvest), late June until mid-August (second harvest), and mid-August until early October, when first frost occurred at the site. In clover the biomass production, N content, and N_2 fixation per area was much higher in late summer than in early summer and autumn parts of the season. Grasses, on the other hand, had more similar biomass production and N content in early and late summer, but low biomass and N content in the autumn part of the season. There were none or only small effects of ley age in the studied parameters. Input of N from added fertilizer plus N_2 fixation in whole plants balanced the amount of N removed in clover and grasses in the two harvests. Nitrogen compounds in stubble and roots left in field are then used for regrowth of the plants after harvest and are decomposed in the soil. The decomposition is particularly important when the soil is ploughed for a next crop in the crop rotation. Our studies have thus highlighted that red clover consistently derives most of its N from N_2 fixation and that companion and subsequent plant species benefit from clovers.

In contrast, the influence of neighbouring species on pNdfa in clover was not known. We addressed this question in a long-term biodiversity experiment with three clover species and a varied number and composition of companion species (grasses, legumes and other forbs). Under non-fertilized conditions, the pNdfa (NA method) was always high irrespective of companion species. This is further evidence of an inherently high ability for N_2 fixation in our domesticated clovers.

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