Forage legume impact on soil fertility and N balance

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Dairy production systems in Europe are to a large extent based on ley-arable rotations. In the ley phase of such rotations nitrogen accumulation occurs as a result of (1) organic carbon accumulation in soil not disturbed by tillage operations and (2) a considerable nitrogen surplus in grasslands, particularly under grazing regimes where a large part of the N in ingested grass is recycled to soil via urine and faeces. The accumulation of N and C in grasslands starts soon after establishment, the rate asymptotically declining with age and depends on practices such as fertiliser level, animal feed composition, stocking density, length of grazing and the botanical composition of the sward. In these pasture systems, key perennial legumes are white clover (*Trifolium repens L.*) red clover **(***Trifolium pratense L.***)** and lucerne (*Medicago sativa*)**.** They are used because of their valuable contribution to production, feed quality and N inputs *via* biological fixation of atmospheric N_2 (Ledgard et al., 2010)

Grassland cultivation almost always results in a substantial residual effect and the mineralization of N often exceeds the requirement of the succeeding crop. Thus, there is a high risk of nitrate leaching following sward cultivation. Management practices to control nitrate losses include delayed ploughing until late winter or spring, the use of efficient catch crops after ploughing and a reduction in fertilizer N application to cereals after ploughing.

The objective of this paper is to illustrate by examples the importance of management for N fertility building and efficient utilization in crop rotations containing forage legumes.

Nitrogen surplus and fertility building

Nitrogen budgets for temporary pastures are influenced by sward type and use, and the N surplus is considerable for pasture grazed by dairy cows (Table 1). The residual effect of the pastures in Table 1 was investigated in the following cereal crops. In the first year there was sufficient residual effect of the grazed grasslands to obviate the need for supplementary fertilizer, but in the following years gradually more fertilizer N was required to obtain optimal yields. Comparing yields following grass-clover and a cereal history showed a residual effect (nitrogen fertilizer replacement value) of at least 115 kg N ha^{-1}. The residual effect of grazed ryegrass was 90-100 kg N ha^{-1} while for cut ryegrass it was only 25 kg N ha^{-1}. In the second year after grassland cultivation, the residual effects were 60 kg N ha^{-1} after grass-clover, 40 kg N ha^{-1} after grazed ryegrass and negative after cut ryegrass and in the third year it was either very small or non-existent. The residual effect was a combination of nitrogen and non-nitrogen effects, and the pure nitrogen effect of grass-clover was 50-70 kg N ha^{-1}. The considerable non-nitrogen effect following grassland than following cereal may be caused by a range of factors including improved soil structure and better resistance against fungal diseases.

Table 1. Annual N balance of six pasture management systems (kg N ha^{-1} yr^{-1}). Data are mean of production years 1-3 (Eriksen, 2001).

		Ryegrass-only			Clover/ryegrass		
		cut	grazed low N[1]	Grazed high N[1]	cut	Grazed low N[1]	Grazed high N[1]
Input	N fertilizer	300	300	300	0	0	0
	N_2-fixation	0	0	0	300	258	266
	Animal manure	0	222	320	0	240	326
Output	Herbage yield	287	240	292	288	271	342
Balance		13	282	328	12	227	250

[1] Grazed low and high N refers to grazing by dairy cow with 140 and 310 g N d^{-1} in supplements.

Nitrate leaching from the sward

In the early pasture phase nitrate leaching losses are usually low as much N can be accumulated in the sward, but over time the N loss depends on the equilibrium between inputs and the soil organic N pool. This equilibrium is not reached within the first years of the clover pasture and also takes longer to be reached in grass-clover compared to grass-only swards due to the self-regulatory nature of legumes. Even though nitrate leaching losses from young swards are much less than indicated by the surplus of the N budgets, losses occur depending on management of the defoliation system and N input. In terms of leaching, cutting-only systems are the most advantageous but a management system that combines cutting and grazing is preferable to a pure grazing system. In the combined system the advantages are less recycling of animal excreta and a lower N surplus because of herbage removal, both leading to less nitrate leaching. In a Danish experiment, grazing with spring application of cattle slurry showed nitrate losses dramatically higher than other managements (Fig. 1), probably because areas with N inputs from excreta had a low associated input from N_2 fixation whereas slurry N was applied uniformly. Thus N loss was increased where it coincided with excreta patches.

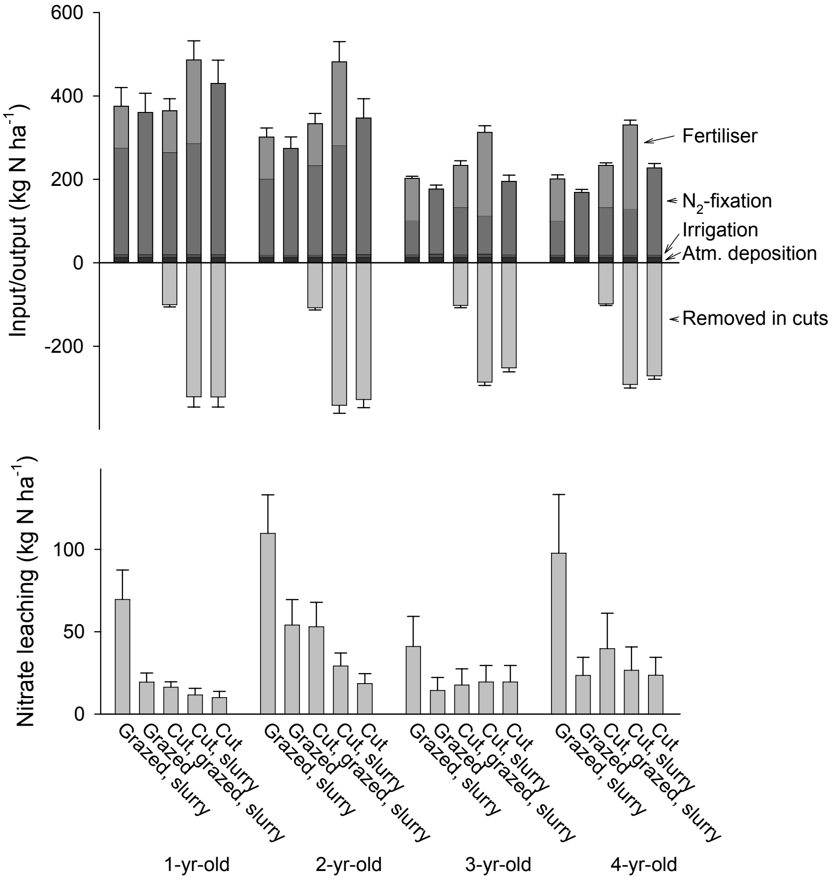

Figure 1. Nitrogen balance and nitrate leaching from grass-clover pastures with different management. In grazed grass-clover was injected slurry in the spring (100 kg total-N ha^{-1} in cattle slurry), in cut-only grass-clover an additional injection was made following a spring cut.

Nitrate leaching following cultivation

Delayed ploughing in late winter or spring can reduce nitrate leaching especially on sandy soils and where rainfall occurs early in the autumn or winter. However, this must be set against possible lower yields of spring versus winter crops. Also, it has been shown that rotary cultivation of the grass sward prior to ploughing can cause quicker availability and better synchrony between N mineralization and plant uptake (Eriksen and Jensen, 2001).

Catch crops are useful during winters in the arable phase of the crop rotation to reduce nitrate leaching, by removing soil mineral N from the soil profile before winter drainage starts. An example is given in Fig. 2, where two grass-clover swards were spring ploughed on coarse sandy soil in Denmark. Perennial ryegrass as a catch crop reduced nitrate leaching by 66-88% compared to bare soil with autumn tillage and without any yield loss. In the treatment with barley harvested green and followed by Italian ryegrass leaching was reduced by more than 90% to less than 10 kg nitrate-N per ha per year.

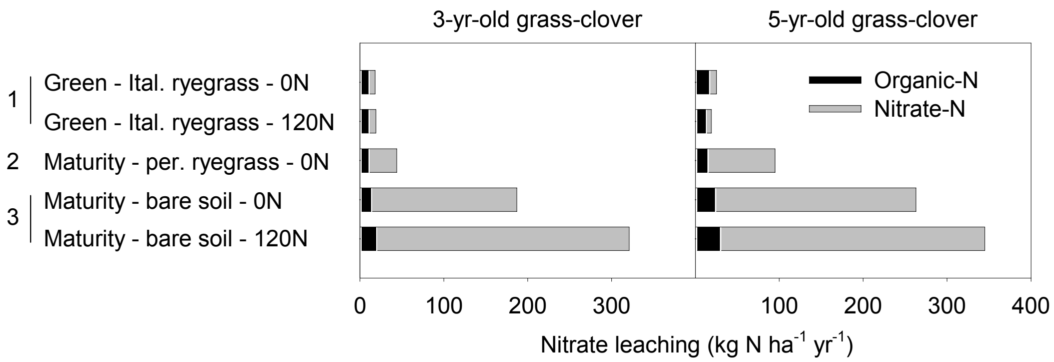

Figure 2. Leaching of nitrate and dissolved organic nitrogen in the first winter after spring cultivation of grassland followed by 1) barley harvested green with Italian ryegrass undersown, 2) barley harvested at maturity with perennial ryegrass undersown, and 3) barley harvested at maturity without catch crop. From Hansen et al. (2007).

Organizing grass-arable crop rotations

A key objective in designing grass-arable crop rotations is to optimise the grass phase, i.e. the number of grassland cultivations in relation to the length of the grass phase. For the individual farmer this depends on the requirement for feed and access to grazing. The common motivation for grassland cultivation is yield loss due to sward deterioration caused by e.g. compaction from wheel traffic and invasion of less productive natural grasses, but also the maintenance or increase of soil fertility and nutrient utilisation plays a role. Intensively grazed pasture systems markedly increase the risk of N losses to waterways and the atmosphere. Traditionally, N losses are expected to increase with the age of the sward due to the likely loss of excess N when maximum accumulation has been reached. This picture of increasing N losses with sward age and comparatively huge losses following cultivation may well describe the situation on many farms, but it is not an inherent property of grassland and grass-arable rotations. Good management of the pasture (e.g. reduced fertiliser input and reduced length of grazing) and the mixed crop rotation both during the grassland and the arable phase (e.g. delayed ploughing time and a catch crop strategy) can considerably reduce negative environmental impact of grazing (Eriksen et al., 2008).

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