High yields, low fertiliser requirements and low nitrate leaching: win it all with grass-legume mixtures

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Abstract

Grass-legume leys combine multiple agronomic benefits, several of which are associated with symbiotic di-nitrogen (N_2) fixation. However, whether significant symbiotic N inputs could lead to increased nitrate leaching is still debated. In a field experiment, we compared pure grass swards (G), grass-legume mixtures (M) and pure legume swards (L) at a fertiliser level of either 50, 150 or 450 kg N ha^{-1} $year^{-1}$ (N50, N150 and N450). The leys were frequently mown for four years before being tilled to cultivate winter wheat. The risk of nitrate leaching was determined from monitoring soil mineral N and nitrate concentration in the soil solution. Furthermore, the soil surface N balance was calculated by summing up N applied as fertiliser and N derived from symbiosis (total N input) and N in the harvested biomass (N output). During the period of intact plant cover, an increased risk for nitrate leaching was only observed for G- and M-swards fertilised at N450, and L swards at all three N levels. Despite their large N input from symbiosis, no nitrate leaching risk was revealed for M swards. After tilling, the nitrate leaching risk strongly increased until December; importantly, it was not elevated for M- compared to G-swards.

Keywords: grass-clover leys, pure swards, NO_3^- leaching, soil mineral nitrogen, soil surface balance, suction cup

Introduction

Productive mown grasslands are generally associated with a low risk for nitrate (NO_3^-) leaching to the environment. A severe risk has however been identified for high N fertiliser applications and for pure legume stands. Balanced grass-legume mixtures benefit the production of both forage (Nyfeler *et al.*, 2009) and the follow-on crop (Fox *et al.*, 2020) thanks to large N input from symbiotic N_2 fixation and positive mixing effects. However, it is not clear whether these N inputs from symbiosis are associated with an increased NO_3 leaching risk. The aim of the current study was to assess the soil surface N balance and the risk of nitrate leaching of leys as affected by legumes and N fertilisation during the two key periods, namely the ley phase for forage production and the phase after tilling for the follow-on crop.

Material and methods

The experiment included three types of swards and three levels of N fertiliser application, with a total of 54 plots arranged in a completely randomized design. The sward types were pure grass swards (G: *Lolium perenne* or *Dactylis glomerata*; *n*=4), pure legume swards (L: *Trifolium pratense* or *Trifolium repens*; *n*=4) and grass-legume mixtures (M: all four species; *n*=10). These sward types were fertilized with either 50, 150 or 450 kg N ha^{-1} $year^{-1}$ (N50, N150 and N450). In August 2002, the field (47°26′N, 8°32′ E, 491 m a. s. l.) was ploughed at 20 cm depth and the leys were sown on plots of 3 m x 6 m. Starting in 2003 (year 1), all swards were cut five times annually at 5 cm above ground surface. Annual N fertilisation was distributed equally to each regrowth. In the autumn of 2006 (year 4), leys were eradicated by glyphosate and rotary tiller application at a depth of 10 cm for successional sowing of winter wheat. Climate conditions during the period of the experiment were generally in line with the 20-year averages (1031 mm precipitation with a relatively even distribution across the year), except for an exceptionally warm and dry summer in year 1. Soil mineral nitrogen (SMN) was determined in the soil layer 0–60 cm, and nitrate concentration in the soil solution (NCSS) was measured using suction cups at 60 cm soil depth. In this short paper, the third winter period is shown to illustrate the results. Furthermore, SMN was determined at six sampling events during the autumn-winter period following sward eradication. Soil surface N balance was calculated as the difference between N input and N output from year 1 to the last harvest of year 3 (Table 1). Total N input was defined as the sum of applied fertiliser N and N input from symbiosis. N derived from symbiosis was determined by using ^{15}N-enriched mineral fertiliser and a calculation following the model of Høgh-Jensen *et al.* (2004). Total N output was defined as the amount of N harvested with forage biomass (i.e. N yield). Data was analysed by two-way ANOVAs with the level of N fertiliser application and the sward type (and their interaction). Based on significant effects in the global analysis, significant differences were revealed following the Tukey range test within each factor level (i.e. among different sward types at the same fertilisation level or vice versa). All data were analysed with the statistics software R (R Core Team, 2023).

Results and discussion

Total N input of the treatments differed from 59 kg N ha^{-1} year^{-1} (G-N50) to 632 kg N ha^{-1} year^{-1} (L-N450) (Table 1). At N50 and N150, symbiotically derived N was the major N input for the L- and M-swards, amounting up to 329 kg N ha^{-1} year^{-1} (Nyfeler *et al.*, 2024). Symbiotic N depended on legume proportion, which, averaged from year 1 to 3, was 42 and 71% at N50, 32 and 73% at N150, and 21 and 80% at N450 in average across the M- and L-swards, respectively. As a result, total N input was only slightly lower in M-N50 and L-N50 than in G-N450. Increased N fertilisation significantly reduced symbiotic fixation for M- and L-swards, however, still manifesting a remarkably high N input from symbiosis at N450. This indicates that legumes only down-regulate symbiotic activity incompletely at high soil N availability. Total N output differed substantially from 113 to 495 kg N ha^{-1} year^{-1}. At all N fertiliser levels, N outputs of M- and L-swards did not differ significantly from each other, and both were significantly larger compared to G-swards (except for N450), demonstrating the much higher productivity of swards with legumes compared to swards lacking legumes. As the consequence from these results in terms of N input and output, N balance was strongly negative for G-swards and slightly negative for M-swards fertilized at N50 and N150 (Table 1). For swards fertilized at N450 and L-swards, N balance was strongly positive. As a general pattern, it shifted towards more positive values in the order G-, M- and L-swards, and was virtually identical for M-N50 and M-N150.

During the third winter period of intact plant cover, maximal SMN was found at N450 for the L- and the M-swards (>30 kg N ha^{-1}). SMN was never significantly higher for M- than for G-swards at N50 and N150 (never exceeding 16 kg N ha^{-1}). Similarly, NCSS remained very low under the M-swards at N50 and N150 (Table 1). NCSS was higher under the L- than under the M-sward even at the lowest N fertilizer application rate. After tilling the leys, SMN strongly increased until a maximum in December of winter 4, before levelling off afterwards (Nyfeler *et al.*, 2024). SMN averaged over all samplings of winter 4 did not differ significantly between G- and M-swards at the same fertilisation level (except at N150), however was significantly elevated for L- compared to M-swards (except at N450).

Conclusions

Grass-legume leys under cutting posed a very limited risk of nitrate leaching during the period of intact plant cover, as long as a substantial grass fraction was provided and the N balance (N input - N output) did not sizably exceed zero. Moreover, the nitrate leaching risk was not greater after tilling such mixtures than after tilling pure grass swards. We conclude that such grass-legume swards combine high yields, low fertiliser requirements, and low nitrate leaching better than either pure grass or pure legume swards.

Table 1. Total N input and N output in the period from years 1 to 3, nitrate concentration in the soil solution (NCSS) and amount of soil mineral N at 0–60 cm depth (SMN) averaged over all samplings of the third winter period (winter from year 3 to 4).

		Intact plant cover												After tilling		
		N input (kg N ha^{-1} $year^{-1}$)			N output (kg N ha^{-1} $year^{-1}$)			NCSS (mg NO_3^--N L^{-1})			SMN (kg N ha^{-1})			SMN (kg N ha^{-1})		
N50	G	59.3	a	α	113.0	a	α	0.0	a	α	15.2	a	α	50.4	ab	α
	M	371.9	b	α	383.3	b	α	0.1	a	α	16.0	a	α	43.4	a	α
	L	385.5	b	α	361.6	b	α	8.0	b	α	16.2	a	α	77.3	b	α
N150	G	150.2	a	β	182.5	a	α	0.2	a	α	11.9	a	α	62.5	b	α
	M	383.5	b	α	396.6	b	α	0.1	a	α	12.8	a	α	43.0	a	α
	L	449.1	c	β	387.8	b	α	11.6	b	αβ	23.1	a	αβ	77.4	b	α
N450	G	430.0	a	γ	393.3	a	β	13.1	a	β	19.6	a	α	67.8	a	α
	M	545.1	b	β	495.1	b	β	30.0	a	β	34.6	a	β	72.5	a	β
	L	631.9	c	γ	424.4	ab	α	39.1	a	β	32.0	a	β	95.4	a	α
	SE	13.58			15.26			4.04			2.79			5.08		

Means of each treatment are shown for G-, M- and L-swards fertilised at three N levels. Within a column, different letters indicate significance of Tukey range test from significant effects in the global analysis (not shown: $P \leq 0.05$). Latin script is used for comparing sward types within fertilisation levels, and Greek script for comparing fertilisation levels within sward types. SE, average of all group mean SEs.

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