Nitrogen uptake at various fertilization levels and cutting frequencies of *Lolium* species

R. Aavola[1] and M. Kärner[2]

[1]Jõgeva Plant Breeding Institute, Aamisepa 1, 48309 Jõgeva, Estonia;
e-mail: rene.aavola@jpbi.ee
[2]Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences,
Kreutzwaldi 5, 51014 Tartu, Estonia; e-mail: malle.karner@emu.ee

Abstract. A field trial was carried out in 1999–2000 to identify optimal combinations of compound fertilizer rates and defoliation frequencies in perennial ryegrass cv. Raidi (diploid) and Raite (tetraploid) and Italian ryegrass cv. Talvike (tetraploid), to enable the nitrogen (N) requirements of dairy cows to be met. The study aimed at estimating the N utilization in the swards subjected to 6 cycles of simulated grazing or cutting 4 times for silage. N application rates were changed from 0–500 kg ha^{-1} by 100 kg in the former and from 0–400 by 80 kg ha^{-1} in the latter harvest regime. Increasing the rate of fertilizer increased the N concentrations and yields. Applying N 300 to ryegrasses defoliated at tillering to stem elongation stage allowed assuring minimum N content in the forage dry matter (2.2%) while at N 500 the upper level (2.7%) was exceeded. The ryegrass plants took up less N than was applied with the compound fertilizer. Increasing the defoliation frequency of grass had a positive effect on N content of the forage, but had inconsistent or no effect on improving N uptake from fertilizer and soil. Perennial ryegrass cultivars were more efficient than Italian ryegrass in taking up N from the soil and fertilizer at simulated grazing. Cutting 4 times a year at moderate to high fertilizer rate applications did not reveal a distinct superiority in N absorption of a particular cultivar, but Italian ryegrass had the best N uptake potential from N deficient soil.

Key words: Italian ryegrass, perennial ryegrass, nitrogen, defoliation, uptake

INTRODUCTION

Current economic and environmental concerns require the control of nitrogen (N) inputs in intensive grassland systems in order to maximize N use efficiency and to reduce harmful N losses. The environmental risks could be mitigated by limiting the N fertilizer supply or increasing the interval between defoliations to reduce N concentration of herbage (Duru & Delaby, 2003). Lowering N fertilization reduces herbage growth rate, tiller density and height and ultimately herbage mass (Wilman, 1980). Decreasing N supply leads to a reduction in grazing management flexibility, i.e. the defoliation interval ranges which are compatible with the required sward characteristics for herbage intake and protein requirements of dairy cows. Reduced fertilization has a negative effect on sward quality through decreased digestibility of organic matter that is offered to and selected by cows (Delagarde et al., 1997). Before recommending a decrease of N inputs it is necessary to assess the nutritional consequences to dairy cattle. For dairy cows grazing on low N grass, protein supply may limit milk yield as observed in the experiments of Delaby et al. (1996). Adapting the management to a grass species and variety helps to assure that herbage feeding value will not be limited by either minimum herbage mass or its N concentration. Through adaptation of the technology for a particular variety we can strive to increase animal performance and minimize the pollution risk to ground and surface waters.

For a decade, genus *Lolium* was represented in the Estonian Variety List by a single domestic perennial ryegrass cv. Raidi. Two new cultivars – perennial ryegrass Raite and Italian ryegrass Talvike were released in 2003. Prior to registration, they were evaluated under frequent and infrequent defoliation management conditions. At Jõgeva PBI (58°45' NL, 26°24' EL), these cultivars demonstrated nearly linear response in dry matter (DM) production up to N levels of 500 kg ha^{-1} (Aavola, 2005). At every increase in N rates the DM production per additional kilogram of N decreased. When quantified as crude protein production per kg N, the marginal N response was lowest at intermediate fertilization levels.

The current research was undertaken to improve knowledge about managing N that originates from mineral fertilization with respect to demand by ryegrasses. The objectives of the study were to evaluate the variation in herbage N concentration in perennial and Italian ryegrass among a range of mineral fertilization levels and to quantify the N uptake at two defoliation intervals.

MATERIALS AND METHODS

The experiment was established in August 1998 on calcic luvisol with pH_{KCl} of 6.0, humus concentration 21.0, nitrogen (N) 1.4, phosphorus (P) 0.122 and potassium (K) 0.074 g kg^{-1}, respectively. The amounts of N, P and K applied before sowing were 60, 13 and 25 kg ha^{-1}, respectively. Estonian cultivars of perennial ryegrass Raidi (diploid) and Raite (tetraploid) and Italian ryegrass cv. Talvike (tetraploid) were seeded at a rate of 30 kg ha^{-1}. Plots of 5.88 m^2 were randomised in a complete block and replicated three times. Compound fertilizer Kemira Power 18 (N18 P4 K7.5 + Ca, Mg, S, B and Se) was used in order to create optimal nutrient status for the ryegrasses. The annual rates of nutrients applied in crop years 1999-2000 are shown in Table 1. These were split into five equal top-dressings at simulated grazing and into four for silage cuts.

Table 1. Annual rates (kg ha^{-1}) of plant nutrients applied to perennial and Italian ryegrass.

Grazing simulation with 6 cuts at tillering to stem elongation stage	Cutting 4 times at early heading
N0 P0 K0	N0 P0 K0
N100 P22 K42	N80 P16 K33
N200 P44 K84	N160 P36 K66
N300 P66 K126	N240 P52 K99
N400 P88 K168	N320 P68 K132
N500 P110 K210	N400 P84 K165

Two defoliation frequencies were used: simulation grazing with 6 cuts at late tillering to stem elongation stage and cutting 4 times per season at early heading. The plots were harvested by a combine harvester Hege 212. Herbage samples from three replicates were taken for determination of DM and N content (by Kjeldahl). The data were averaged over two harvest years, 1999 and 2000. The significance of differences between the means was estimated using ANOVA of the statistical package Agrobase 20. Standard deviation calculated for herbage N contents includes either 12 (2 years x 6 defoliations) or 8 (2 x 4) data points per treatment.

Weather conditions

The growing season of 1999 started in mid-April and favoured grass growth due to consistently warmer weather compared with the long-term average. Only May was colder. Water deficiency beginning in March and lasting for nearly the entire growing season in 1999 retarded the growth of ryegrasses. Winter 1999/2000 was mild. From December onwards, and throughout the whole winter, the amount of precipitation exceeded the long-term average. Sudden warmth in mid-April 2000 made the ryegrass cultivars grow rapidly. The growing season in 2000 was rainy with summer temperatures close to the long-term average. Lack of rain in September did not affect the grass growth because of earlier accumulation of moisture into the soil.

Rainfall from April to October (330 and 444 mm in 1999 and 2000, respectively) and mean air temperatures (12.3°C and 11.6°C) indicate that the first experimental year diverged from normal climatic conditions at Jõgeva. The respective averages, recorded since 1922, are 456 mm and 10.8°C. The second year of the experiment can be regarded as favourable for grass cultivation.

RESULTS AND DISCUSSION

The effects of increasing N fertilization on grass N concentration are well established (Binnie et al., 2001). In our study the average N content of herbage increased in parallel with the enhanced fertilizer rates, both at simulated grazing (r = 0.96–0.98) and cutting for silage (r = 0.98–0.99, Figs 1, 2). The concentration of N in Italian ryegrass remained lower than that in perennial ryegrass. The annual N rates exceeding 300 and 400 kg ha^{-1}, applied to the swards defoliated at tillering or heading stage, respectively, enabled attaining minimum N content in the herbage. For high-producing dairy cows that is set at 2.2–2.7% N in herbage DM (Van Vuuren, 1990). When the ryegrasses were cut 4 times per season, the N content did not attain the level measured in younger herbage. Part of the decrease can be attributed to lower fertlilization rates, compared with those applied to frequently defoliated swards. The variation of herbage N contents in cultivars Raidi, Raite and Talvike, subjected to simulated grazing on unfertilized plots and receiving 500 kg N ha^{-1}, ranged between 1.91–3.09, 1.86–3.05 and 1.73–3.03%, respectively. Italian ryegrass formed longer and stronger culms that inherently contain fewer nutrients than the leaves (Ammar et al., 1999). When the plots were defoliated 4 times at a later developmental stage, the variance comprised 1.55–2.45, 1.59–2.37 and 1.47–2.27% N. Frequent defoliation, even in unfertilized plots, enabled the enhancement of the N content of ryegrasses by a half percent. The means were 2.38 and 1.87%, when the grass was harvested at optimal stage for grazing and for silage, respectively. Kennedy et al., (2006) also stated that N content of the herbage is higher on the early-grazing treatments than on the late-grazing treatments.

The standard deviations of N contents in cv. Raite and particularly in cv. Talvike slightly increased at infrequent defoliation, while in cv. Raidi these remained fairly unchanged regardless of defoliation frequency. The likely reason is that in an immature stand the varietal differences lack time to emerge due to short harvest intervals. If the grass is allowed to grow longer, divergent senescence rates of the cultivars, differences in plant morphology and root system development, influenced by diversity of soil fertility, moisture content etc. can appear across the plots.

Together with higher levels of fertilizer dressings, the N uptake of ryegrass swards defoliated 6 times increased significantly (Table 2). The amount of N removed with the forage grown on unfertilized plots gradually declined towards the end of the season. Thus nil or low rate of fertilization will inevitably result in depletion of soil N stock and is not sustainable in the long perspective. Loid (1982) found that root mass of perennial ryegrass exceeded its DM yield by 2.5–3.5 times if no N was applied. This refers to the marked nutrient uptake capacity of the species. In perennial ryegrass plots receiving 20 kg N ha^{-1} per application in our study, the amount of N absorbed exceeded the applied amount in the first crop only. In perennial ryegrasses the N removal was rather stable during the first 5 cycles of simulated grazing. The surplus N occurred in the spring growth when a single application was equivalent to 40 kg ha^{-1} or more. This will not necessarily mean that N will cause environmental pollution, as the root mass in perennial ryegrass increases under the influence of N fertilizer and is almost equal with the DM yield at 300 kg N ha^{-1} (Loid, 1982). At intermediate and high fertilization levels the amount of N fixed in every crop was rather constant, except for the last, that used the residual effect of fertilizer applied for the fifth crop. Italian ryegrass did not react to the first fertilizer dressing as clearly as Raidi and Raite. The species is ordinarily used to produce a heavy first crop around midsummer. N yield of Italian ryegrass subjected to simulated grazing was low in spring, stabilised during summer and dropped sharply at the end of season. If the cv. Talvike was defoliated 6 times at tillering to stem elongation stage, it was unable to fully utilise single N rates as low as 20 kg ha^{-1} across the season. In general, the cultivar had lower N yields, but not in the second and third cut harvested in summer.

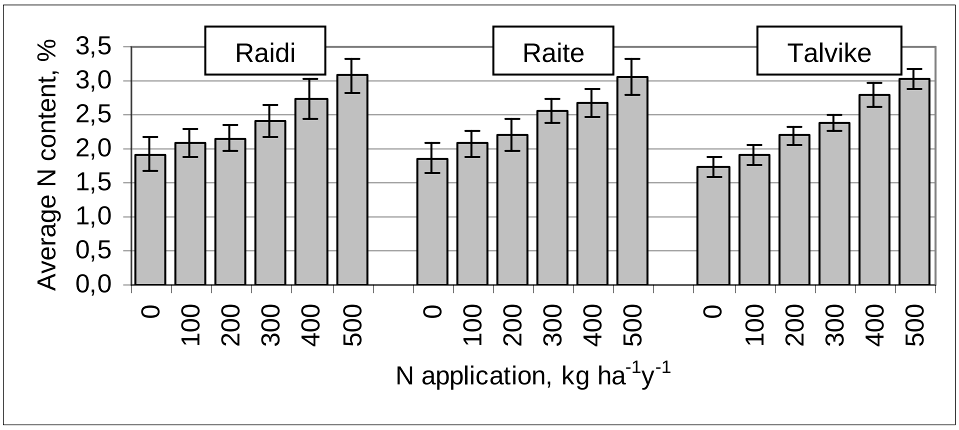

Fig. 1. Fertilization effect on the herbage N content (mean ± SD) of perennial and Italian ryegrass defoliated six times in 1999 and 2000 (in % of DM).

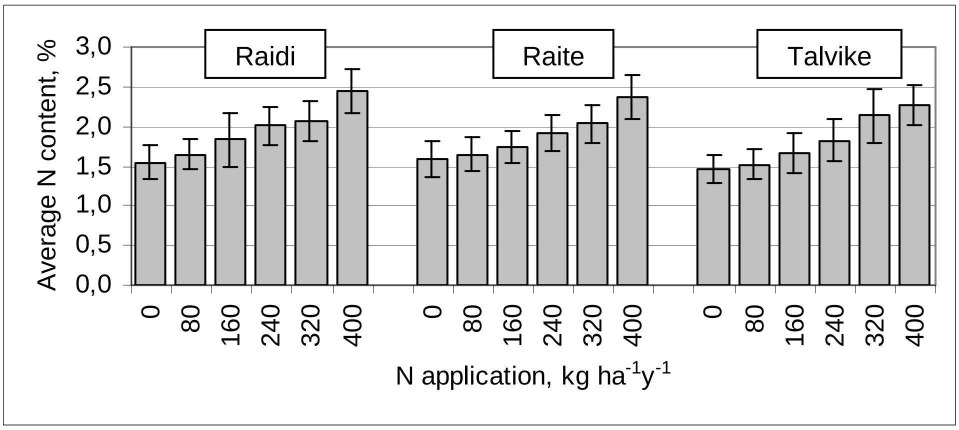

Fig. 2. Fertilization effect on the herbage N content (mean ± SD) of perennial and Italian ryegrass defoliated four times in 1999 and 2000 (in % of DM).

Table. 2. Nitrogen removal by the grass at simulated grazing, kg ha^{-1}.

Application per cut	Cut					
I to V	I	II	III	IV	V	VI
			Perennial ryegrass cv. Raidi			
0	16	9	6	6	5	2
20	25	15	12	10	12	4
40	29	23	22	17	18	14
60	39	30	33	28	35	17
80	57	45	45	46	50	27
100	64	62	60	66	64	31
$LSD_{0.05}$	5	3	3	2	4	2
			Perennial ryegrass cv. Raite			
0	13	14	8	5	6	1
20	23	16	15	11	13	6
40	27	22	24	20	26	14
60	41	39	41	38	39	20
80	51	43	49	48	47	26
100	61	57	64	61	64	29
$LSD_{0.05}$	3	4	4	3	4	3
			Italian ryegrass cv. Talvike			
0	6	7	5	4	3	5
20	12	14	12	11	11	8
40	23	26	26	21	16	11
60	31	40	39	31	30	12
80	36	48	49	52	45	20
100	34	77	58	48	53	27
$LSD_{0.05}$	5	5	3	5	4	2

Although Italian ryegrass has poorer drought tolerance than perennial ryegrass and thus suffered more in 1999, the weather conditions in 2000 allowed its full production potential. As in spring growth, increasing the N rate from 80 to 100 kg ha^{-1} in July did not cause a significant change in N uptake of cv. Talvike in the fourth cycle of simulated grazing. The quantities of N absorbed into the herbage of the fifth cut (late August or early September) especially by perennial ryegrasses, was comparable to that of the previous three defoliations. Unlike in Italian ryegrass, the greatest N removal in perennial ryegrasses was generally measured in the first cycle of simulated grazing and cutting (13–64 and 17–90 kg ha^{-1}, respectively, Tables 2, 3). An approximately two-fold drop in N quantities taken up by grass was measured in the last cycle of simulated grazing (late September–early October). Consequently, the residual effect of fertilizer was negligible. In addition, shortage of warmth and daylight during the 35 days needed as an average to grow the last pasture crop, was relatively more influential than for the last silage crop that grew for 46 days before defoliation. The longer rest periods in the latter case enabled the accumulation of similar N quantities into the perennial ryegrass crop compared with the two preceding cycles (Table 3).

Table. 3. Nitrogen removal by the grass harvested for silage, kg ha^{-1}.

Application per cut	Cut I	Cut II	Cut III	Cut IV
Perennial ryegrass cv. Raidi				
0	17	5	3	2
20	25	14	7	7
40	35	22	19	24
60	47	32	30	34
80	74	40	40	47
100	90	61	59	55
$LSD_{0.05}$	5	6	3	4
Perennial ryegrass cv. Raite				
0	20	6	4	4
20	24	14	10	9
40	37	23	22	26
60	41	35	31	33
80	69	46	46	52
100	85	57	65	61
$LSD_{0.05}$	8	5	4	3
Italian ryegrass cv. Talvike				
0	13	11	16	6
20	23	19	25	13
40	27	21	24	19
60	40	35	36	28
80	48	54	58	46
100	60	73	60	51
$LSD_{0.05}$	4	3	5	3

The continuously rising N content of cv. Raidi and Raite during the season, attaining a peak in the last cut (2.12 and 2.23% at unfertilized to 3.17 and 3.15% at 400 kg N ha^{-1}) had a role in this. The uptake of N by Italian ryegrass did not surpass that of the second and third cut, although the N concentration in the autumn-grown herbage was higher (1.88 at unfertilized to 3.04% at 400 kg N ha^{-1}) than in summer. At prolonged rest periods between the harvests the concentration of N in the forage declined, but the N recovery percentages and thus yields obtained at the only coinciding N level (400 kg ha^{-1}) did not differ from the swards cut 6 times (Table 4).

The pattern of N accumulation at the silage harvest regime was similar to that observed in frequently defoliated grass. In perennial ryegrasses however, the uptake of N peaked more clearly at the beginning of the season because the most vigorous spring growth of the grass was not interrupted by early defoliation.When 20 kg N ha^{-1} was applied for spring growth, all the ryegrasses removed more N than was applied. At a single application of at least 40 kg of N, perennial, unlike Italian ryegrass, absorbed most of it into the first crop, while in regrowths remarkable quantities remained unused. N uptake in Italian ryegrass was restricted at the beginning of the season but was stabilized thereafter. Hindered growth of the Italian ryegrass in spring did not allow assimilating a remarkable portion of the applied N: between 8 (at N 20) and 66 kg ha^{-1} at early (Table 2) and between 13 (at N 40) and 40 kg ha^{-1} at postponed first defoliation (Table 3). Unlike in perennial ryegrasses, N yields of cv. Talvike declined at the end of the season though not as sharply as in frequently cut swards. At intermediate fertilizer rates the cv. Raidi and Raite took up more N into the last silage crop than in summer. Almost each ascendant fertilizer rate caused a significant increase in the N amount taken up by the grass. Yet spring application of 20 and 60 kg N ha^{-1} to Raite as well as 40 kg N ha^{-1} for Talvike in summer did not produce significant differences.

Cultivation of ryegrasses in unfertilized field is not reasonable: the forage produced has insufficient N content and low yield (Aavola, 2005). Application of 20 kg N ha^{-1} to perennial ryegrasses for the spring growth and to Italian ryegrass for the first three silage cuts demonstrated higher N uptake potential during these periods. This particular rate is insufficient for covering the N requirements of the ryegrasses at their most intensive growth stage. Therefore soil N reserves will be utilized.

N surplus increased in parallel with the increased fertilization rates (Fig. 3). Thus the described grazing system with concurrent high mineral fertilizer rates is not sustainable for long-term prevention of N leaching. Declining grass growth before the last cycle in autumn is associated with the accumulation of excessive N in the roots and soil. The proportions of N in the herbage of Raidi, Raite and Talvike, defoliated 6 times a year, accounted for 60–77, 66–84 and 59–68% of the N applied by mineral fertilizer (Table 4). Maximum nutrient application to grass grown for silage was lower. In this case the respective percentages of N, recovered in the herbage of tested varieties, were 60–66, 58–72 and 56–99, although higher nutrient use efficiency of a plant may be expected at limited fertilizer application levels (Levins & Schmitt, 1995). Italian ryegrass absorbed nearly the same amount (99%) of N that was applied by modest (80 kg N ha^{-1}) fertilizer rate. However, cv. Talvike possessed the least efficiency in N uptake (56–64%) at higher N treatments.

Table 4. Percentages of nitrogen recovery in the herbage of perennial ryegrass cv. Raidi and Raite and Italian ryegrass cv. Talvike.

	Simulated grazing				
N kg ha^{-1}	100	200	300	400	500
Raidi	77	62	60	67	70
Raite	84	67	73	66	67
Talvike	68	62	62	63	59
	Cutting for silage				
N kg ha^{-1}	80	160	240	320	400
Raidi	66	63	60	63	66
Raite	72	67	58	67	67
Talvike	99	56	58	64	61

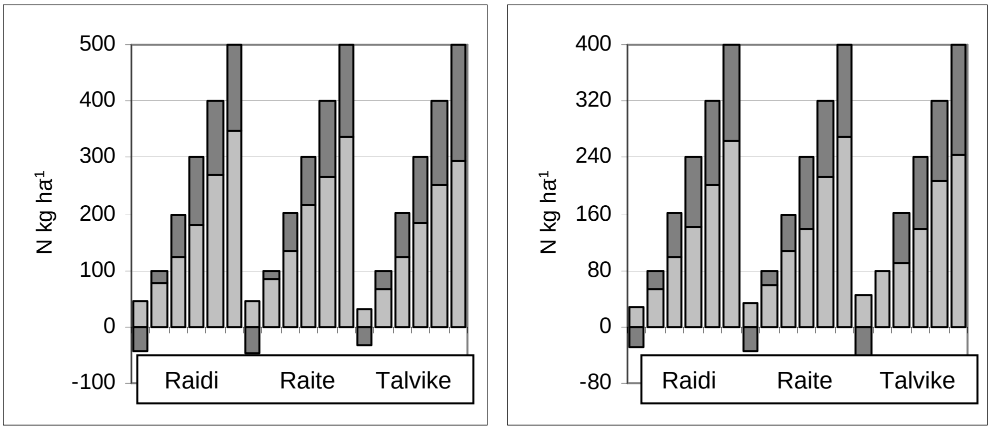

Fig. 3. Allocation of annual rates of N applied as a compound fertilizer Kemira Power 18. Light bars – quantity absorbed into the forage, dark – not used by the crop. Raidi and Raite – *Lolium perenne*, Talvike – *L. multiflorum*. Left – simulated grazing, right – cutting for silage.

In both infrequent and frequent defoliation regimes, the highest N recovery was obtained at the lowest annual mineral fertilizer rates – either 80 or 100 kg N ha^{-1}. A common and thus comparable fertilizer rate for both management systems was equal to 400 kg N ha^{-1}. There was no difference in the proportion of N removal with the grass crop using this particular treatment. In the case of cutting for silage the produced forage comprised 66, 67 and 61% of the N applied to the swards of Raidi, Raite and Talvike, respectively. At reduced harvest intervals 67, 66 and 63% of the fertilizer N amounts together with the soil N was taken up by the plants. These quantities account for 244–268 (four cuts) and 252–268 kg N (six cuts) on a hectare basis. Binnie et al.

(2001) found that in general there is a decrease in response to N with increasing N rate. In the present experiment the recovery of high N rates in the herbage was occasionally better than that at intermediate levels. Still the steady increase in the non-harvested portion of N concurred with the increase in N application rates.

CONCLUSIONS

1. Increased N rates led to higher herbage N contents. As for forage quality, early defoliation of grasslands seeded with *Lolium* species would be recommended, so that grasses require less N to reach a minimum crude protein level.

2. The minimum interval between defoliations on the pasture swards consisting of ryegrasses that received 500 kg ha^{-1} N annually should be increased to aim at an upper threshold of 2.7% N in forage DM. The length of the harvest interval is more influential upon the N recovery percentage in the herbage of poorly fertilized ryegrasses than at sufficient fertilization levels.

3. Annual N treatments of at least 80 kg ha^{-1} prevent N depletion from the soil.

4. Excessive mineral fertilization rates should be avoided as the unused nutrient amounts prone to leaching increase with the elevated fertilizer rates. If the N application exceeds 100 kg ha^{-1} approximately 1/3 of the nutrient will not contribute to the formation of the harvestable part of the biomass.

5. The cultivars of perennial and Italian ryegrass responded differently among the tested management intensities. Tetraploid cv. of perennial ryegrass Raite showed higher N uptake potential at simulated grazing when up to 300 kg N ha^{-1} were applied, diploid cv. Raidi thereafter. When cut for silage, cv. Talvike took up more N than the perennial ryegrasses if the swards were not fertilized or received 80 kg N ha^{-1}. Italian ryegrass is better adapted to infrequent defoliation. At 160 kg N ha^{-1} or more the differences between the cultivars were smaller.

6. The most appropriate way to increase the N utilization by ryegrass crops would be to use high nutrient levels to promote the spring growth of perennial ryegrass and reduce or neglect the last fertilization of grassland. The spring application of N to Italian ryegrass should be somewhat less than for perennial ryegrass.

REFERENCES

Aavola, R. 2005. The yield potential of Estonian perennial ryegrass (Lolium perenne L.) cultivars at different mineral fertilization levels and cutting frequencies. In Lillak, R., Viiralt, R., Linke, A. & Geherman, V. (eds): *Integrating Efficient Grassland Farming and Biodiversity. Gr. Sc. in Europe, vol. 10.* EGS, Tartu, pp. 449–453.

Ammar, H., Lopez, S., Bochi-Brum, O., Garcia, R. & Ranilla, M.J. 1999. Composition and in vitro digestibility of leaves and stems of grasses and legumes harvested from permanent mountain meadows at different stages of maturity. *J. Anim. and Feed Sc.* **8** 4), 599–610.

Binnie, R.C., Mayne, C.S. & Laidlaw, A.S. 2001. The effects of rate and timing of application of fertilizer nitrogen in late summer on herbage mass and chemical composition of perennial ryegrass swards over the winter period in Northern Ireland. *Grass and Forage Sc.* **56** (1), 46–56.

Delaby, L., Peyraud, J.L., Verite R. & Marquis, B. 1996. Effects of protein content in the concentrate and level of nitrogen fertilization on the performance of dairy cows in pasture. *Ann. Zootech.* **45** (4), 327–341.

Delagarde, R., Peyraud, J.L. & Delaby, L. 1997. The effect of nitrogen fertilization level and protein supplementation on herbage intake, feeding behaviour and digestion in grazing dairy cows. *Anim. Feed Sci. Tech.* **66** (1–4), 165–180.

Duru, M. & Delaby, L. 2003. The use of herbage nitrogen status to optimize herbage composition and intake and to minimize nitrogen excretion: an assessment of grazing management flexibility for dairy cows. *Grass and Forage Sc.* **58** (4), 350–361.

Kennedy, E., O'Donovan, M., Murphy, J. P., O'Mara, F. P. & Delaby, L. 2006. The effect of initial spring grazing date and subsequent stocking rate on the grazing management, grass dry matter intake and milk production of dairy cows in summer. *Grass and Forage Sc*. **61** (4), 375–384.

Levins, R.A. & Schmitt, M.A. 1995. Green programs: a Corn Belt example of one way to reduce nitrogen use. *The Magazine of Food, Farm, and Resources Issues*, **2**, 24–26.

Loid, H. 1982. Content and balance of nutrients at intensive fertilization of perennial ryegrass. In: *Research on biology and yield improvement of crop plants. Transactions of Est. Acric. Acad*. *133,* Tartu, pp. 47–55 (in Russian).

Van Vuuren, A.M. 1990. Nutritional quality of herbage in relation to animal production. In: *Fodder crops breeding: achievements, novel strategies and biotechnology. 16th Meeting of EUCARPIA Fodder Crops Section*. Wageningen, pp. 161–165.

Wilman, D. 1980. Early spring and late autumn response to applied nitrogen in four grasses. 1. Yield, number of tillers and chemical composition. *J. Agric. Sci.* **94**, 425–442.