Utilization of local feed resources by dairy cattle

Perspectives of environmentally balanced production systems

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Optimization of grassland production and herbage feed quality in an ecological context

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Summary

Improved grassland management and use of better cultivars of perennial ryegrass regarding feeding quality and persistency can contribute to reduction of concentrate and fertilizer inputs in grassland based dairy farming systems. Acceptable net energy production levels with minimal nitrogen losses per unit product can be achieved from grassland fertilized with c. 200 kg $N.ha^{-1}.yr^{-1}$ under integrated grazing and mowing management. Increasing N efficiency at the animal level through lowering N content in the diet is desirable, as long as the supply of aminogenic nutrients to the intestines is not hampered. In addition, roughage carbohydrate supply must be enhanced. Prospects of achieving this by increasing cell wall digestibility (CWD) are marginal, but present. Therefore, more attention is also required to increase the proportion of water soluble carbohydrates (WSC) in roughages. In the grazing situation this will not affect rumen pH. Grazing experiments with tetraploid cultivars of perennial ryegrass show promising perspectives for higher voluntary intake and milk production than from current diploid cultivars. In comparison with the diploid Wendy, the tetraploid Condesa has a higher WSC content and the tetraploid Madera has a higher fraction of potentially degradable CW. Therefore, tetraploids might gain in importance, provided their persistence is sufficient to avoid sward deterioration. Finally, excessive declines in CWD and WSC content due to ageing and stem elongation must be avoided by appropriate management and cultivar choice.

Introduction

The forage produced from grassland in the Netherlands supplied about 50% of the estimated net energy requirement of dairy cows at the end of the 1980's (Ketelaars & Van Vuuren, 1995). Around 1950 this figure was much higher (about 90%). During the last decades, three major trends have occurred in Dutch dairy farming systems. Firstly, grass and grass products have been partially replaced by maize silage and concentrates. Secondly, the application of artificial nitrogen (N) to grassland increased drastically from 50 $kg.ha^{-1}$ in 1950 to 315 $kg.ha^{-1}$ in 1985 (Van der Meer, 1991). Thirdly, the average milk yield per cow increased from a national average of 3800 $kg.cow^{-1}$ in 1950 to 7000 $kg.cow^{-1}$ in the early 1990's (LEI-CBS, 1993).

The rate of rumen fermentation of structural carbohydrates in roughages fails to support the increasing milk production potential of dairy cows. The supply of energy to grazing animals is insufficient for milk productions above 29 $kg.cow^{-1}.day^{-1}$ (Van Vuuren, 1993). Therefore, roughage diets have to be supplemented with concentrates high in nutrient and/or net energy density to support the high milk production potential. However, the production of concentrates requires large amounts of energy from fossil fuels, and the use of purchased concentrates introduces a surplus of nutrients into the system.

Enhancing rates of N application result in higher productivity of grass, primarily due to an increased rate of leaf area expansion after harvest. The grass produced contains a high proportion of the highly digestible leaf fraction, but is also high in concentration of nitrogen containing organic and inorganic compounds. Nitrogen compounds in fresh and ensiled grass are released rapidly following ingestion by ruminants (Beever, 1993). The fermentation rate of carbohydrates, in particular cell walls, by rumen microorganisms is lower. Due to this desynchronization in digestion and the high level of rumen degradable N, the N incorporation in the rumen by the microbial biomass is relatively low. This is only partly compensated by recycling of urea N to the rumen through saliva (De Visser, 1995, personal communication). Consequently, a high proportion of the ingested N is lost from the rumen as ammonia and the utilization efficiency of dietary N by cattle is low (between c. 15-30%). The level of rumen degradable N is lower in hay and artificially dried grass.

Increased environmental awareness imposes demands on management of grassland and animal production systems for optimization of fibrous feed quality in an ecological context: concentrate input has to be reduced and nutrient losses, in particular of N, must be reduced.

In this paper we will discuss the consequences of optimization (i.e. reduction) of the N input to grassland for herbage production and feeding quality, and the prospects for improving both carbohydrate supply from grass and nitrogen utilization efficiency through plant breeding.

Effects of nitrogen fertilization on grass productivity and feeding quality

Recommendations of N application rates in the Netherlands are mainly based on economic cost-benefit analyses of long-term cutting trials in small plots, which at current prices leads to a marginal profitability of 7-8 kg dry matter per kg N applied. In an experiment by Deenen & Lantinga (1996) on a sandy soil the calculated economic optimum level of N input was 420 $kg.ha^{-1}.yr^{-1}$ in cutting-only plots, averaged over three years. At the same site the average N uptake from unfertilized plots was 110 $kg.ha^{-1}.yr^{-1}$. This non-fertilizer N delivery capacity of the soil is taken into account in the current N fertilization recommendations (Unwin & Vellinga, 1994).

At high levels of N input the efficiency of protein utilization by dairy cattle is relatively low, and consequently a high proportion of ingested nitrogen is excreted in urine and faeces. This leads to high N losses to the environment. The efficiency with which applied N is used in herbage production can be illustrated by the ratio between residual inorganic N in the soil at the end of the growing season and total herbage yield (Figure 1). This ratio reflects the nitrogen utilization by the crop. At its minimum value nitrogen losses per unit product are lowest. From this ecological viewpoint the optimum level of N input for integrated grazing and cutting management on the sandy soil was in the order of 200 $kg.ha^{-1}.yr^{-1}$.

The question is what the consequences of this reduced N input will be for grassland productivity and herbage quality. In the experiment of Deenen & Lantinga (1996), the response to fertilizer N was also estimated under integrated grazing and mowing management as the annual sum of herbage intake, and the amount of ensiled herbage from all the paddocks at each N level together. In Figure 2 this response curve is shown for 1988 together with the one from cutting-only plots. The figure also includes the calculated average net output from grassland of 150 dairy farms on sandy soils in relation to inorganic N input in 1988 (Daatselaar *et al.*, 1990; Van der Putten, unpublished data). It is clear from this figure that the response to N under integrated grazing and mowing management is much weaker compared to that in the cutting-only plots. The main cause for this phenomenon was sward deterioration in the grazed paddocks, which increased at higher levels of N fertilization. The 'gap' between the two response curves represents grazing losses (poached and scorched grass, losses due to senescence of grazing residues and grass removed by cleaning cuts) and conservation losses in the field during the wilting period. It may therefore be concluded that, especially on grassland soils which are susceptible to urine scorching and poaching, a reduction in N input from 300-400 kg.ha^{-1}.yr^{-1} to about 200 kg.ha^{-1}.yr^{-1} will hardly affect the total net energy yield. This may have been the reason that the grassland output on the commercial farms was surprisingly low, leaving much scope for improvement of the efficiency of applied nitrogen.

It has been postulated by Vellinga & Van Loo (1994) and Van Loo *et al.* (1995) that breeding and selection work with perennial ryegrass for better N use efficiency could lead to cultivars which would contribute to reduced nitrogen surpluses. Recovery of applied nitrogen will be highest in swards with a high tiller density, a low frequency of open patches and a high leaf expansion rate after harvest. The main criteria in grass breeding should therefore still be persistency and dry matter yield under both cutting and grazing management.

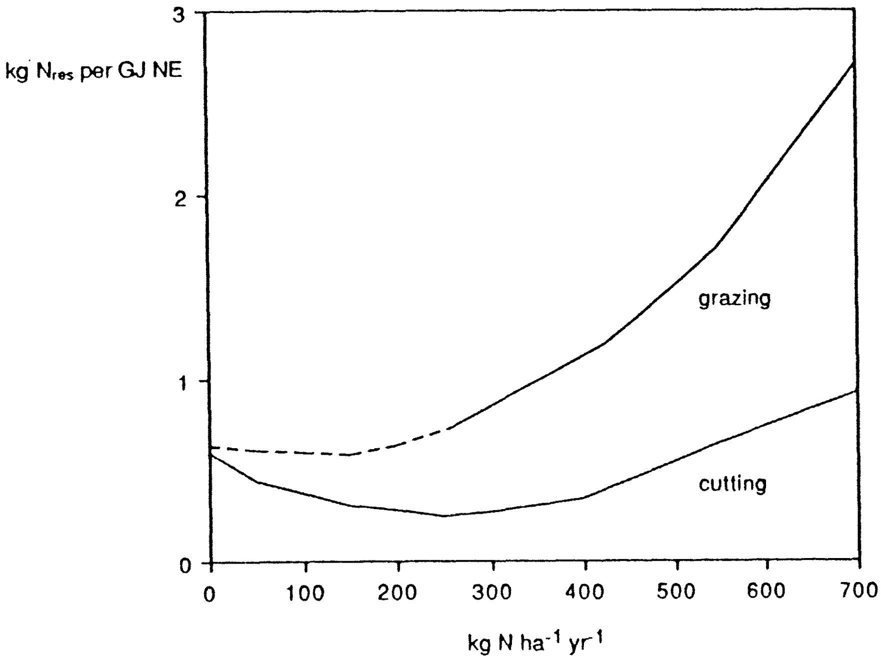

Figure 1. Relationship between fertilizer N application and the amount of residual inorganic N (kg N_{res}.ha^{-1}) in the soil profile (0-60 cm) divided by the total herbage yield expressed in GJ NE.ha^{-1} at the end of the growing season (mid-October). Data are from cut-only and grazed-only plots on a sandy soil in 1987. Sources: Deenen & Lantinga (1996); Van der Putten (unpublished data).

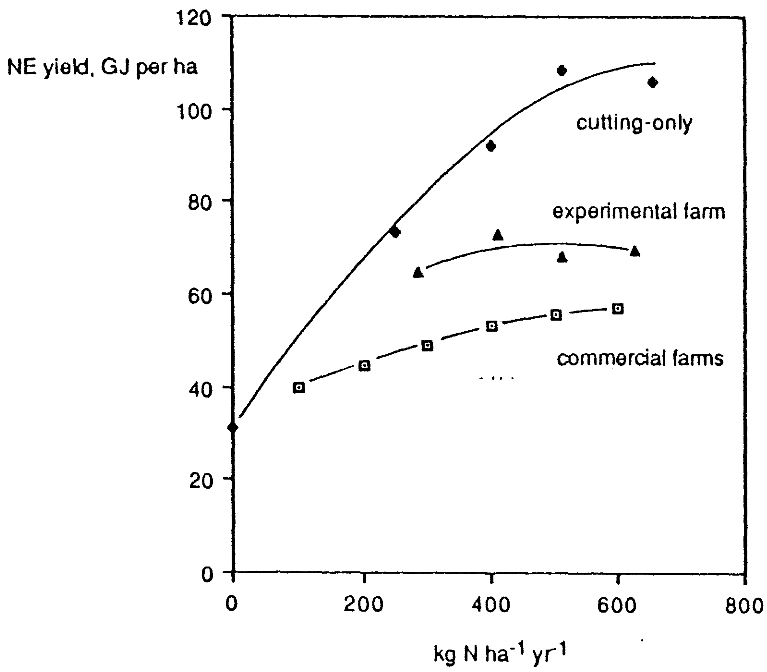

Figure 2. Relationship between inorganic N input and net energy (NE) yield on an experimental farm in cutting-only plots and in paddocks as the sum of herbage intake and ensiled herbage, and on commercial dairy farms as calculated from NE requirements of livestock. One GJ NE corresponds to about 150 kg dry matter. All data are from grasslands on sandy soils in 1988. Sources: Deenen & Lantinga (1996); Van der Putten (unpublished data).

Decreasing N fertilization and/or enhanced N use efficiency of grass will lead to reduction of N content in the dry matter. However, reduction of crude protein content in grass to levels below approximately 225 g per kg dry matter could lead to negative effects on the supply of aminogenic nutrients (Van Vuuren, 1993). This corresponds to a nitrogen content of 36 g per kg dry matter, which is still a high value. Oldham (1984) demonstrated that, in lactating cows, at least 30 g N per kg dry matter must be included in the diet to avoid negative effects on milk production. From the experiment of Deenen & Lantinga (1996) it can be derived that under integrated grazing and mowing management the average nitrogen content at a fertilizer N rate of about 200 kg.ha^{-1}.yr^{-1} will be slightly above 30 g per kg dry matter. In experiments by Deenen & Lantinga (1993) and Valk & Van Vuuren (1995) no or only small negative effects on milk production per cow were found from reducing N fertilization to 250 and 150 kg.ha^{-1}.yr^{-1}, respectively. Further reductions in N content without loss of milk yield can only be achieved if the capture of N in the rumen is improved or the level of rumen degradable N is lowered.

Improving carbohydrate supply from grass

Concentrate feeding to high producing animals and losses of N from the rumen can be reduced by improving the supply of carbohydrates from roughage. Grass and other roughages contain water soluble carbohydrates (WSC) and structural, polymerized carbohydrates laid down in cell walls (CW). WSC are released into the rumen after disruption of the cell, e.g. through mastication by the ruminant. The sugars are assumed to be fermented rapidly by rumen microorganisms. CW are more resistant to microbial attack. The CW fraction is not completely degradable, and the rate of degradation may be too low to assure carbohydrate supply for microbial growth and N utilization at a desired high level. Potential avenues for improvement of the fermentation of carbohydrate and the synchronization with N digestion would be to increase CW digestibility and/or WSC content.

Many researchers have argued that improvement of CW digestibility (CWD) of perennial ryegrass through breeding would enhance animal performance and reduce concentrate requirement (e.g. Vellinga & Van Loo, 1994), regarding the high correlation between CWD and organic matter digestibility (Deinum *et al.*, 1996). However, contrary to maize, prospects for improvement of CWD of perennial ryegrass through breeding are limited. Cell wall content (CWC) in modern grass cultivars is relatively low (below 50% in the DM) and CWD is generally already high (around 80%). These characteristics have automatically developed in breeding programmes for higher DM production. A possible improvement might be found by increasing CWC in organs with fully-degradable CW, for example laid down in parenchymatic tissue in grass leaves. This is unlikely to be achieved, since CWC and CWD are negatively correlated (Deinum *et al.*, 1996). Furthermore, extra production of energetically expensive CW (see e.g. Thornley & Johnson, 1991) would inevitably reduce grass productivity, which would imply a step backwards in grass breeding. Is there then any possible advantage from increased CW degradation rates? Hageman *et al.* (1992) observed large variations in CW degradation rates between cultivars of perennial ryegrass and throughout the season (approximately 3.5-8 $\%.h^{-1}$). However, no correlation at all with herbage intake, milk production and composition was found. Tamminga & Van Vuuren (1996) also postulate that effective clearance from the rumen (degradation and passage) is virtually independent of rate of CW degradation. This would make the scope for improvements in CW degradation rate limited.

Higher proportions of degradable carbohydrates can also be obtained when the proportion of easily fermentable WSC is increased. Additionally, this could contribute to a more balanced C/N ratio in the rumen following ingestion of the feed. This approach is advocated by Beever (1993) and Beever & Reynolds (1994). In infusion experiments, Rooke *et al.* (1987) observed higher microbial N synthesis and non- ammonia nitrogen flow to the small intestine and a decline in the ammonia concentration in the rumen of about 50%, as a result of continuous supply of glucose syrup. This is ascribed to the improved synchronization of release of C and N compounds.

Ingested WSC are rapidly fermented in the rumen (cf. pulse dose), which could lead to accumulation of VFA and possibly a decline in pH (Van Vuuren, 1993). This could impair rumen function (Tamminga & Van Vuuren, 1996) and reduce intake and ruminal outflow of organic matter, as shown by Henning *et al.* (1993) and Mansfield *et al.* (1994) after pulse dosing of carbohydrates into either the rumen or continuous culture fermenters. In the grazing situation, Van Vuuren *et al.* (1986) observed a sharp decrease in rumen pH during the evening hours. This was associated with a 'bulking period' around late-afternoon/early-evening, when animals grazed for three hours or longer with short or no resting periods. It was remarkable in this experiment that the pattern of ruminal pH values was not influenced by the level of concentrate supplementation (1 vs. 7 $kg.cow^{-1}.d^{-1}$) nor by intake of easily degradable carbohydrates. In the experiment of Hageman *et al.* (1992), only marginal differences in the average values and diurnal patterns of rumen pH were observed between three grass cultivars. This was also the case in autumn, when a marked difference in WSC content occurred (100 g.kg^{-1} DM in Wendy and Madera, compared to 150 in Condesa). This leads us to the conclusion that fluctuations in rumen pH may be more correlated with ingestion rates than with level of WSC intake per se.

WSC content and CWD rapidly decline when stem elongation starts, especially in periods of high temperatures. In order to shorten the period of stem elongation it may be a wise decision either not to use cultivars in mixtures which differ too much in heading date, or to simply use monocultures. Besides, stem elongation can be suppressed under intensive continuous grazing. Since growing conditions and feeding quality of the herbage produced are best in late spring it is advisable to use cultivars with a rapid early spring growth. By using such cultivars a high quality first cut silage with a good yield can be obtained more easily than is the case with late cultivars. In addition, it may be of interest to investigate whether there are differences between cultivars in the length of the period of stem elongation.

Possibilities for improved intake and milk production

Promising results have been obtained from experiments comparing diploid and tetraploid cultivars of perennial ryegrass (Hageman *et al.*, 1992, 1993). Tetraploid cultivars of perennial ryegrass are superior to diploids in terms of animal performance (Castle & Watson, 1971; Vipond *et al.*, 1993). In a grazing experiment, the tetraploid cultivars Condesa and Madera and one of the most palatable diploids (Wendy) were compared. Herbage intake tended to be higher for the tetraploids at a herbage allowance of more than 30 kg OM.cow^{-1}.d^{-1}, and a concentrate supplementation of 1-3 kg.cow^{-1}.d^{-1} (Table 1). Although differences in intake were not significant in this grazing experiment, they were reflected in a higher concentration of volatile fatty acids and the lower pH in the rumen for the tetraploids (see Robinson *et al.*, 1986). Intake differences might also explain the observed higher FPCM (fat and protein corrected milk) production on the tetraploids. In the spring of 1990, with a concentrate supplementation of 3 kg.cow^{-1}.d^{-1}, there was a difference between the tetraploids and the diploid of about 2 kg FPCM.cow^{-1}.d^{-1}.

The reasons for the higher intake and milk production from tetraploids are still not fully understood. It has often been postulated that tetraploids are more palatable than diploids because of a higher content of WSC in the ingested herbage. However, there were no differences at all in WSC content on a dry matter basis between the tetraploid Madera and the diploid Wendy (Table 1). In the fresh material the content of WSC was even lowest in Madera due to a higher water content. Despite this, palatability tests in cultivar evaluations (free choice as in a 'cafeteria') always show a significant preference for the tetraploids. An alternative explanation might be the lower resistance to physical breakdown during chewing of tetraploids compared to diploids (Hageman *et al.*, 1992). The rate of mastication has been identified as an important factor influencing voluntary intake (Moseley & Antuna Manendez, 1989). Notably, in the tetraploid Madera the fraction of potentially degradable cell walls was higher than in Wendy. Taking into account that between 86-89% of the potentially degradable CW is always digested (Tamminga & Van Vuuren, 1996), this might indicate that in fact the NE content or VEM value of tetraploid perennial ryegrass is somewhat higher than derived from standard *in vitro* analyses with an incubation period of 48 hours. These cultivar differences in potentially degradable CW demonstrate that there is some scope for improving CW digestibility through breeding.

Table 1. *The mean daily herbage allowance and intake (kg OM.cow⁻¹.d⁻¹), fat and protein corrected milk yield (FPCM; kg.cow⁻¹.d⁻¹), milk protein content (%), rumen fermentation characteristics (VFA; mmol.l⁻¹ and pH), in-vitro digestibility of OM (DOM; %), potentially degradable CW (PDCW; %) and WSC (% in DM) in a grazing experiment with three cultivars of perennial ryegrass. D=diploid; T=tetraploid; VFA=volatile fatty acids. Average values for three 4-weekly grazing periods in spring, summer and autumn 1990. DOM, PDCW and WSC refer to ingested grass. Source: Hageman et al. (1992, 1993).*

Cultivar	Allowance	Intake	FPCM	Milk protein	VFA	pH	DOM	PDCW	WSC
Wendy D	35.2	17.1	28.4	3.39	129.0	6.02	83.0	88.5	9.9
Condesa T	33.5	17.6	29.6[a]	3.48	138.7	5.81	83.0	90.4	12.1[a]
Madera T	34.3	17.7	29.3[a]	3.44	133.9	5.87	83.6	92.7[a]	9.9

[a] Significantly higher than Wendy.

A weak point of the tetraploids is that they generally have a lower tiller density than diploid cultivars. In Condesa this is also associated with a lower persistency (Neuteboom *et al.*, 1993). However, based on recent cultivar evaluations (Neuteboom *et al.*, 1992; Anonymous, 1995), the tetraploid Madera can be seen as a representative of a new generation of tetraploids, combining high herbage intake with good persistency. Condesa is no longer present on the Dutch recommended variety list for agricultural crops (Anonymous, 1995).

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