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The role of tactical and operational grassland management in achieving agronomic and environmental objectives; 'De Marke', a case study

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Abstract

Reduction of N losses, especially nitrate leaching, is an important objective for dairy farms in the Netherlands. So far, many strategies have focused on changes in strategic and tactical management. Little attention has been paid to operational grassland management. So a conceptual model of operational grassland management was defined, with strong interactions between N rates, realized dry matter (DM) yields, herbage N content, growing days and utilization per cut. Analysis of data from 'De Marke' and from monitoring projects shows that grassland production and utilization can be improved by changes in operational grassland management. DM yields for grazing and cutting need to be increased, grazing per paddock must be shorter and slurry must be applied as early as possible. This improved grassland management is able to partly compensate the decrease in DM production resulting from a lower N input.

Keywords: De Marke, operational grassland management, nitrate leaching, modelling.

Introduction

Restriction of nutrient losses to the environment by reducing farm nutrient surpluses is the main target of the Dutch mineral policy. To that end the so-called MINeral Accounting System (MINAS) was introduced, which aims at a reduction of the nitrate concentration in the upper groundwater to less than 50 mg l^{-1} (Van Den Brandt & Smit, 1998). In recent years, nitrate concentrations in the upper groundwater were too high (Fraters *et al.*, 1998). From literature it is known that on dairy farms fertilization and grazing have a large impact on nitrate losses (e.g. Benke *et al.*, 1992; Scholefield *et al.*, 1993; Hack-Ten Broeke *et al.*, 1996, 1997, 1999; Vertès *et al.*, 1997; Simon *et al.*, 1997). Although both factors are important, the Dutch mineral policy emphasizes a reduction of fertilizer inputs by defining a maximum N surplus per hectare (Van Den Brandt & Smit, 1998). The EU policy defines maximum values for animal N excretion per hectare, combined with adjusted fertilizer recommendations (Anon., 1991). The concept of strategic, tactical and operational management (Huirne, 1990; Kay & Edwards, 1994) assigns the reduction of fertilizer inputs to tactical management. The required code of Good Agricultural Practice (Anon., 1991) includes rules for operational management – like the timing of slurry application and the use of chemical fertilizers – that are based on legislation and the current fertilizer recommendations (Anon., 1998a).

At the experimental farm 'De Marke', choices in strategic, tactical and operational management were made in order to combine good agronomic and good environmental performance. On a tactical level, N input and grazing time were reduced, especially to reduce nitrate leaching (Aarts *et al.*, 1992).

Changes in tactical management like reduced fertilizer inputs can lead to changes in technical results and farm profits (Mandersloot *et al.*, 1998; De Haan, 2001). If operational management is improved, inputs can be reduced without changes in economic performance (Zaalmink, 1997). The effects of changes in operational management can be calculated (De Haan, 2001), but are difficult to prove experimentally. However, Rougoor *et al.*, (1999) made plausible that good operational grassland management, i.e., the management of each cut – including N rates, growing days and utilization – is important for the realization of good technical and financial results. In their study no effect of operational management on N surpluses could be determined. There are strong interactions between fertilization, grazing and cutting management (Corrall *et al.*, 1982; Doyle *et al.*, 1983; Hijink & Remmelink, 1986; Rougoor *et al.*, 1999). So all aspects should be studied in relation to one another.

Studies of operational grassland management in the UK and Denmark show that high grazing intensities lead to lower milk productions (Fisher & Dowdeswell, 1995; Fisher & Roberts, 1995; Kristensen, 1997). These results are difficult to compare with Dutch situations. In the UK and Denmark more emphasis is placed on stock building than on grazing, which means that high grazing intensities lead to low herbage allowance levels. So an evaluation of tactical and operational grassland management in Dutch farming systems is still necessary to determine viable management strategies that can meet environmental and economic goals.

In monitoring programmes on Dutch dairy farms, tactical management has been adjusted to reduce the N surpluses to the MINAS levels by setting targets for the fertilizer inputs per annum and – in some cases – by changing the grazing system (Beldman, 1997a; Oenema *et al.*, 2001). No explicit targets were defined in operational grassland management. At the experimental farm 'De Marke', grazing and cutting targets have been defined for tactical and operational management. Because grassland management at 'De Marke'has been intensively monitored, data to evaluate tactical and operational grassland management are available. Despite the chosen targets and the efforts in grassland management, the average nitrate concentration still exceeds 50 mg l^{-1} (Boumans *et al.*, 2001). This makes an evaluation of grassland management at 'De Marke' even more interesting as it could lead to suggestions for changes in grassland management at 'De Marke' to reduce nitrate concentrations to 50 mg l^{-1} or less. But general conclusions about grassland management could also be reached.

A framework to evaluate grassland management

Recommendations for tactical grassland management

Tactical grassland management includes decisions about fertilizer levels per hectare per annum and about the grazing system in hours per day and months per annum.

1. Because MINAS defines the N surpluses for individual farms it is important to define the N fertilizer level for grassland per annum (Van Den Brand & Smit, 1998; Bresser *et al.*, 1999). Before the introduction of MINAS, N fertilizer recommendations for grassland were based on economic optimization only, viz. a marginal dry matter (DM) response of 7.5 kg per kg N. These recommendations were defined for each cut and depended on target yield per cut, on season and on indigenous soil N supply (Unwin &Vellinga, 1994; Anon., 1998a).
2. The grazing system is often based on a combination of available pasture and personal preferences. From an economic point of view as much grazing as possible is recommended, but actual stocking rates and soil conditions define the maximum grazing opportunities (Anon., 1997). Grass production and physical bearing capacity of the soil limit grazing by dairy cows. Calves should not graze before 15 June and should be housed in September. From an environmental point of view, limited grazing is recommended in combination with a supplement of low-protein roughage (Aarts *et al.*, 1992).

A conceptual model and recommendations for operational grassland management

A conceptual model for grassland fertilization and utilization has been defined for operational grassland management. It is based on practical grassland use and on recommendations in the Netherlands (Figure 1 and Table 1). The basis of the model is the single cut in combination with the following management factors (see Figure 1):

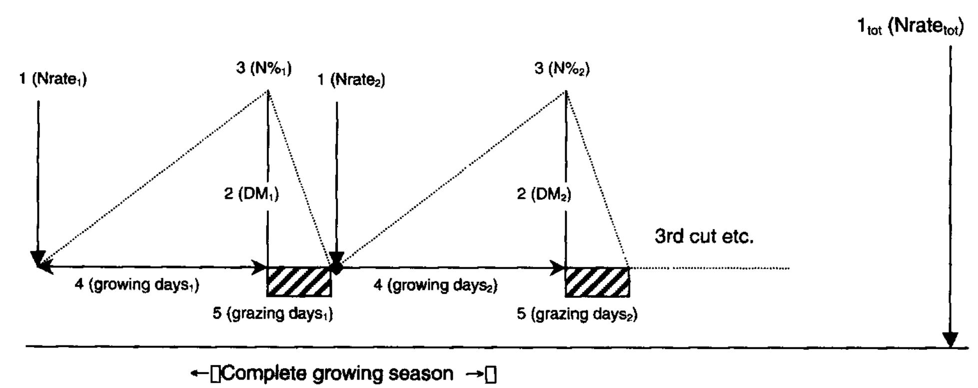

Figure 1. Scheme of grassland utilization with a rotational grazing system, where N rates per cut (1) consist of effective N from slurry and N from chemical fertilizer. DM yields per cut (2) are realized after a number of growing days (4) and are used for grazing or cutting (5). In this scheme the quality of the herbage is expressed by its N content (3). Total N rate per year (1_{tot}) is the sum of all N rates per cut.

Table 1. Recommendations for N fertilization, slurry application and grassland use in tactical and operational grassland management in the Netherlands.

Management factor	Source	Recommendation
N rates per year	Van Den Brand & Smit, 1998; Bresser *et al.*, 1999	N surplus = 140 kg ha^{-1}
	Anon., 1998a	N rate = 250–350 kg ha^{-1}
N rates per cut	Anon., 1998a	See table, part of GAP[1]
	Sheldrick *et al.*, 1994	Within 1 week in new cut
	Van Loo, 1993	
Effective N from slurry	Anon., 1998a	4 cuts after application
Timing slurry application	Anon., 1998a	Not from 1/9–1/2, part of GAP
		Within 1 week in new cut
Grazing system	Anon., 1997	Grazing as much as possible
	Aarts *et al.*, 1992	Limited grazing, supplementation
DM yields	Anon., 1997	Grazing 1700 kg DM ha^{-1}, max. 4 weeks
		Cutting 3000 kg DM ha^{-1}, max. 6 weeks
Herbage N content	Anon., 1998b	See Figure 5
Growing periods	Anon., 1997	See Table 2
Utilization	Anon., 1997	Grazing max. 4 days
		Cutting 2 days

[1] Good Agricultural Practice.

(1) fertilization, in kg N ha^{-1}, originating from slurry and chemical fertilizers, (2) DM yield in kg ha^{-1}, (3) herbage N content in g kg^{-1} DM, (4) growing period in days, (5) utilization period, grazing or cutting, in days. Three to ten cuts are realized per annum. The actual fertilizer level and DM yield per annum are the result of N rates and DM yields per cut.

N fertilization

The grassland N fertilization per cut is based on the tactical target of the N fertilizer level per annum. Slurry is applied two to three times per annum, but the effective N is expressed per cut (Anon., 1998a). Chemical fertilizer is applied for every cut. The total N rate per cut is the sum of effective N from slurry and N from chemical fertilizer. There is a strong relationship between recommended N rates and target yields for grazing and cutting. Slurry and chemical fertilizer should be applied within a few days after growth is resumed (Sheldrick *et al.*, 1994). Applications later than one week will hardly contribute to increased growth but do lead to higher herbage N contents (Van Loo, 1993).

Dry matter yield

Although recommended N rates correspond with a wide range of DM yields, recommended DM yields for grazing and cutting are 1700 and 3000 kg ha^{-1} respectively. Moreover, growing periods should not last longer than 4 and 6 weeks, respectively (Anon., 1997). This means that the target yields cannot be realized during dry spells or at the end of the growing season. In these cases reduced N rates are recommended. The recommended DM yields are based more on practical experience of extension workers than on scientific evidence.

Table 2. Average number of growing days needed to realize target yields of 1300, 1700 and 3000 kg DM ha^{-1} on sandy soils with a good moisture holding capacity, at an annual N rate of 250 kg ha^{-1}.

DM yield at grazing (kg ha^{-1})	Date of use						
	May II[1]	June I	June II	July I	July II	Aug. I	Aug. II
1300	20	21	21	22	23	26	28
1700	23	24	24	25	26	30	33
3000	30	32	33	34	36	40	45

[1] First (I) or second (II) half of the month.
Source: Anon., 1997.

Herbage N content
There is a good relationship between N rate, DM yield and herbage N content. If target yields are not realized, the N rate may have been too high, which leads to a lower N recovery per cut (Vellinga *et al.*, 2001), a higher herbage N content and reduced N utilization by the grazing animal. So herbage N content is a useful indicator to examine whether fertilizer rate per cut and realized yield are matching. Standard values are based on calculations (Figure 5, Anon., 1998b).

Growing period
The length of the growing period for cuts is an indicator that must be used in combination with N rate and realized DM yield to see whether growing conditions were less than perfect, e.g. because of drought, or when the growing periods were too short. Average values have been defined for growing periods in relation to growing season and to recommended N rates and DM yields per cut (Table 2).

Utilization period
In general, the utilization period for cuts should be as short a possible. In practice this is defined as a two-day wilting period, with cutting and tedding on the first day, and windrowing and ensilage on the second. Short periods are also preferred for grazing, with a maximum of 4 days (Anon., 1997). Grazing at low DM yields to realize short grazing periods is not recommended.

The factors of tactical and operational grassland management and the recommendations are summarized in Table 1. Only the N rates per cut and the slurry application are part of the code of Good Agricultural Practice.

Material and methods

'De Marke' experimental farm

'De Marke' is located on a drought-sensitive, light, sandy soil in the eastern part of the Netherlands. The farm area consists of 55 ha of reclaimed moor land with a top-soil containing on average 4.8% organic matter, overlying a layer of sand free from organic matter. 55% of the area consists of grassland, partly permanent pasture and partly leys. The remainder is used for growing silage maize and triticale (Aarts *et al.*, 1999). To create a phosphate buffer in the soil that can be used by the maize following the ley, the amounts of slurry applied on the leys are larger than those on the permanent grassland (Aarts *et al.*, 1999). To maintain a high sward quality, permanent grassland is regularly renovated (D.Z. Van Der Vegte, pers. comm.).

Tactical targets
Fertilizer N rates have been lowered to reduce nitrate leaching, but at the same time they are maintained at levels that just guarantee a sufficient supply of roughage from the farm. Total N fertilization on grassland is planned at 250 kg N ha^{-1} per annum (Aarts *et al.*, 1999). Grazing time per day has been reduced to 8 hours; it is supplemented with energy-rich, low-protein roughage during the period indoors. Reduced grazing is managed as a so-called 'siesta system', i.e., grazing from about 8 to 12 a.m. and from 6 to10 p.m. to balance protein and energy supply during the whole day (Aarts *et al.*, 1992). Grazing time per day has gradually been reduced from 8 hours in 1997 and 1998 to 6 hours in 1999 and 4 hours in 2000. Dairy cows graze until 1 October. Heifers are grazing day and night and as long as possible during the growing season. Calves are grazing day and night from 15 June till 1 September (Aarts *et al.*, 2001).

Operational targets
Nitrogen fertilizing ceases in late summer instead of in autumn. The target yield for grazing was 1300–1500 kg DM ha^{-1}, and for cutting 2500–3000 kg DM ha^{-1} (D.Z. Van Der Vegte, pers. comm.). The grazing period per paddock was planned at 4 days with a leader-follower system, i.e., 2 days grazing by dairy cows followed by 2 days grazing by heifers.

Analysis of operational and tactical management

The analysis of grassland management is based on a comparison of the five management factors mentioned above for 'De Marke', with norms that partly belong to Good Agricultural Practice. Because application of slurry and chemical fertilizer stops after 1 August, only the cuts from before this date will be analysed. Data were collected in the period 1997–2000.

Data collection

Tactical management
The total N rate per annum was calculated as the sum of the N rates per single cut. Farm management recorded the grazing system and the grazing period per cut during the growing season. Total grazing period was based on these data.

Operational management
Data were collected on the application (rate and timing) of slurry and chemical fer-

tilizer per paddock and per cut. The amount of slurry applied was measured by weighing each load. It was assumed that the loads were partitioned proportionally over the paddocks where slurry was applied. The amount of chemical fertilizer was measured for each paddock by weighing before and after fertilizer spreading.

DM silage yields per cut were measured by weighing each load. DM grazing yields per cut were estimated visually by the farm manager. The visual estimates were calibrated regularly by cutting and weighing strips.

N content of the grazed herbage and the wilted grass before ensilage was measured at each harvest, by Near Infrared Spectrometry (Williams & Norris, 1987).

The number of growing days between consecutive cuts was calculated. The growing period for a cut starts after the animals have been moved to another paddock or when the wilted grass has been removed. It ends when the grass is grazed or cut again. For split paddocks, growing days were calculated from the average starting date of both parts.

Grassland use covers the complete scheme of grazing and cutting for each paddock, including the type of animals (dairy cows, young stock) and the number of grazing days, as recorded by farm management. Total number of grazing days per cut was calculated. Two to three days after they had started grazing, the dairy cows were transferred to another paddock. Heifers then grazed the remaining herbage. Duration of the grazing period for each cut refers to the sum of grazing days for both dairy cows and heifers. For split paddocks, where both parts are grazed, length of the grazing period refers to the average of both parts.

Calculation of nitrate concentrations in upper groundwater

The model Nitrogen, URine and Pastures (NURP) is used to look for ways to reduce nitrate leaching on 'De Marke' (Vellinga *et al.*, 2001). NURP describes the effects of strategic, tactical and some operational management factors like stocking rate, milk production level, N rate per annum, and grazing system including monthly supplementation, on the nitrate concentration in the upper groundwater. NURP is based on the same conceptual model as shown in Figure 1. Operational management is carried out according to the recommendations and standards as shown in Table 1.

Results

Tactical management

N rate per annum

Average annual N rate on grassland at 'De Marke' is 250 kg ha^{-1}, which is exactly the same as the target value. On permanent grassland 230 kg N per ha^{-1} is applied, on temporary grassland 260 kg ha^{-1} (Table 3). In some paddocks white clover is present. The contribution of clover to DM production and N uptake is assumed to be small (Baan Hofman, 1994).

For the soil and management conditions of 'De Marke', application of the eco-

Table 3. N rates (kg ha^{-1}) for a farm economic optimum on drought sensitive soils at 'De Marke', and calculated values for grassland farms with a MINAS N surplus of 140 kg ha^{-1} per year.

Situation	Permanent grassland (Soil N supply =140)	Leys (Soil N supply =100)
Economic optimum level		
Irrigated	320	340
Non-irrigated	270	290
Fertilization 'De Marke'	232	263
Calculated level at MINAS-N surplus = 140 kg (100% grassland)		
Irrigated	205	
Non-irrigated	170	

nomically optimal recommendations would lead to N rates of 270–290 kg ha^{-1} without irrigation, and to 320–340 kg ha^{-1} with irrigation (Table 3). Actual N application rates at 'De Marke' are 30–90 kg ha^{-1} lower.

Realizing the MINAS target level of 140 kg N surplus per hectare, yields N rates of 170 and 205 kg N ha^{-1} per annum for non-irrigated and irrigated situations, respectively (Willems *et al.*, 2000) (Table 3). These quantities are 80–45 kg N ha^{-1} lower than current rates at 'De Marke'.

Grazing system and grazing season
Grazing time per day has gradually been reduced from 8 hours in 1997 and 1998 to 6 hours in 1999, and to 4 hours in 2000, which is in good agreement with the targets. Heifers and calves have been grazing day and night in all years.

In the years 1997–2000, dairy cows started grazing on 30, 8, 15 and 19 April, respectively. Heifers started grazing at about the same time, because they follow the dairy cows. Calves started grazing at the end of May, or in the first week of June.

In the years 1997–2000, dairy cows were housed on 20, 1 and 1 October and on 15 September, respectively. In the same years heifers grazed till 20,14 and 14 November and 15 September. Calves grazed till 12, 19 and 11 August in the years 1997, 1998 and 1999 respectively, but remained indoors in 2000.

Compared with the targets, grazing by dairy cows in1997 and by heifers in the period 1997–1999 lasted too long.

Operational management

N rates per cut for grazing and cutting
Average N rate for grazing cuts was 33–45 kg N ha^{-1} (Table 4). Different groups of N rates can be distinguished (Figure 2). The first group refers to the first cut, which received high N rates (three points at top left in Figure 2). This is in agreement with the fertilizer recommendations based on a total annual application of 250 kg N ha^{-1}. In 1999, N rates for the first cut were the same in all grazing paddocks. In other years, N rates for the first cut were differentiated between paddocks. The second group received high N rates during the growing season, varying from 45 to 75 kg N

Table 4. Details of grazing cuts for dairy cows (leader-follower system with heifers) at 'De Marke' over the period 1997–2000. Data are averages over all cuts starting before 1 August.

Year	Growing days	Grazing days	DM yield at start of grazing (kg ha^{-1})	N rate (kg ha^{-1})	Herbage N content (g kg^{-1})
1997	19	4.3	1219	38	33.7
1998	23	4.8	1207	34	32.8
1999	21	6.0	1341	45	33.4
2000	23	6.7	1481	33	–

ha^{-1}. These cuts were planned for silage, but due to shortage of grass, they were used for grazing. So the N rates were far too high. The third group consists of cuts with N rates of about 35 kg N ha^{-1}. These cuts were planned and used as grazing cuts. The N rates for planned grazing in the years 1997–2000 were 35, 25, 35 and 30 kg N ha^{-1}, respectively. Recommended N rates for grazing cuts of between 1000 and 1500 kg DM ha^{-1} were on average 27 kg N ha^{-1} (Anon., 1997; 1998a). So in 1997 and 1999 the N rate was far too high, in 2000 slightly too high, and in 1998 it was in good agreement with the recommendations.

Finally, Figure 2 shows the cuts starting in September and October. These cuts received no chemical fertilizer, but some N from previously applied slurry was still effective.

Average N rate per silage cut was 59–71 kg N ha^{-1} (Table 5) with rates for the first

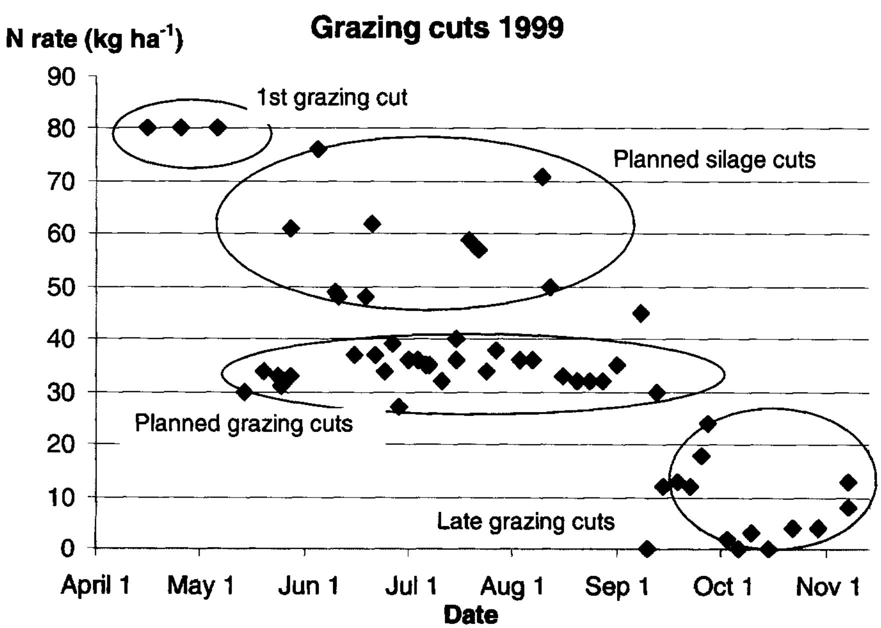

Figure 2. Fertilizer N rates for grazing cuts in 1999 at 'De Marke'.

Table 5. Details of silage cuts at 'De Marke' over the period 1997–2000. Data are averages over all cuts starting before 1 August.

Year	Growing days	DM yield (kg ha^{-1})	N rate (kg ha^{-1})	Herbage N content (g kg^{-1})
1997	29	2585	60	28.6
1998	35	2732	64	28.9
1999	32	2640	71	30.4
2000	36	2849	59	–

cut of about 100 kg N ha^{-1}, and for later cuts of about 50 kg ha^{-1} (Figure 3). N rates for silage cuts were in good agreement with the fertilizer recommendations.

Chemical fertilizer is applied within 3 days from the start of the growing period.

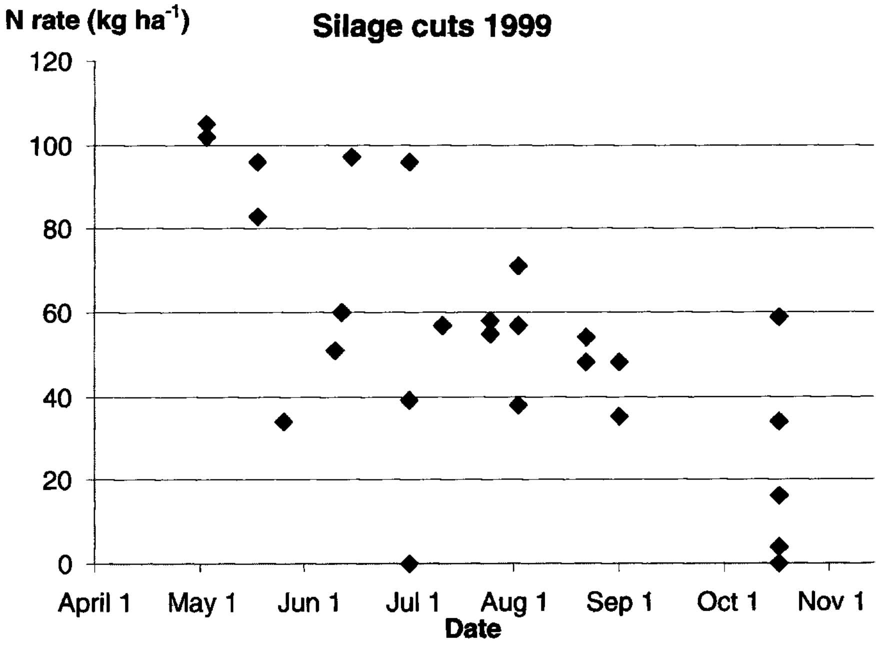

Figure 3. Fertilizer N rates for silage cuts in 1999 at 'De Marke'.

Slurry application

The average amount of slurry applied on leys was 78 m^3 ha^{-1} and on permanent grassland 52 m^3 ha^{-1} (Table 6).

The annual amounts on leys were split into 4 portions, the last of which was applied in the first half of August (Table 6). Of the total amount of about 2,500 m^3 of slurry applied on the farm, 200–400 m^3 (more than 10%) was applied after 1 August. The low amount in August 1997 is the result of large applications on 31 July.

Table 6. Details of slurry application on permanent grassland and leys at 'De Marke'.

Year	Permanent grassland			Leys		
	Amount (m^3 ha^{-1})	Effective N (kg ha^{-1})	Total after 1 Aug. (m^3 ha^{-1})	Amount (m^3 ha^{-1})	Effective N (kg ha^{-1})	Total after 1 Aug. (m^3 ha^{-1})
1997	49	88	0	79	145	43
1998	45	74	0	69	116	415
1999	55	95	0	84	148	375
2000	58	99	27	80	137	225

N from slurry is effective in four cuts after application (Anon., 1998a), which corresponds with a period of 3.5–4 months. Consequently, slurry applications after 1 August lead to fertilizer effects till the end of November. The relatively high grass production in late autumn required late silage cuts to remove the grass. Although these late cuts are important for efficient N utilization, still 5 to 10 kg slurry N ha^{-1} is not used for herbage production and remains in the soil-plant-system during winter. Although the slurry applications are in agreement with the recommendations and with Good Agricultural Practice, part of the N is not utilized.

Contractors carry out the application of slurry. To work efficiently they always combine applications for a group of paddocks. Consequently, slurry sometimes was applied more than 10 days after the grass had resumed growth, which actually is too late.

DM yield per cut

Table 4 presents information on grazing cuts from before 1 August. The data show that the average yield for grazing was 1200–1400 kg DM ha^{-1}. These yields did not fully meet the targets set by 'De Marke'. The difference is about 100 kg DM ha^{-1}. However, considering the drought-prone conditions of 'De Marke', it is a satisfactory result. The average target yield for grazing was only realized in 2000 when rainfall conditions were favourable. Although 1300–1500 kg DM ha^{-1} was the target value for the start of grazing during the entire growing season, many grazing cuts yielded less (Figure 4). Low DM yields were very common for grazing calves, but also dairy cows started grazing at DM yields of 1000 kg ha^{-1} or less. At the end of the season, i.e., for cuts starting after 1 August, DM yields for grazing that exceeded 1000 kg ha^{-1} were not realized anymore in the unfertilized cuts. The situation in 1999 is representative for the entire period 1997–2000. The average DM yield for grazing at 'De Marke' is 300–500 kg ha^{-1} below the recommended target yield of 1700 kg ha^{-1}.

The target DM yield for cutting is 2500–3000 kg ha^{-1}, which was realized in all years that were analysed (Table 5). Yields were lower for silage cuts at the end of the growing season, mainly because of less favourable growing conditions and reduced N applications. In 2000, which was characterized by a relatively wet summer, DM yields of silage cuts were higher. The recommended DM yield for cutting is 3000 kg ha^{-1}, which is only slightly higher than the targets.

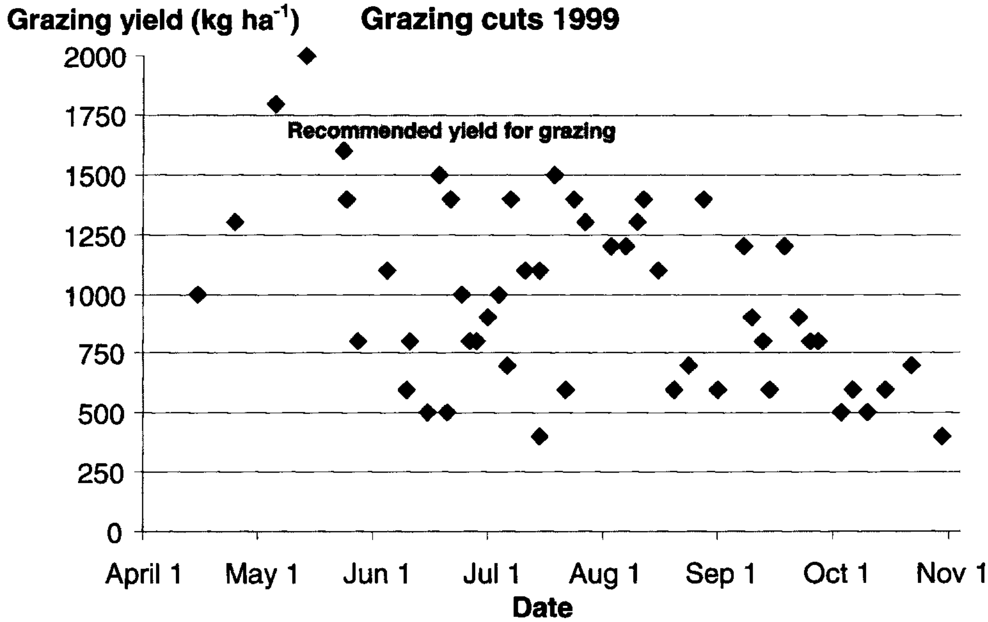

Figure 4. DM yields at grazing of dairy cows, heifers and calves in 1999 at 'De Marke'.

Herbage N content

The average N content of grass for grazing is 33 g per kg DM (Table 4). Variation among years is small, but is substantial within years (Figure 5). The variations in N rate per grazing cut, in DM yield and probably also in weather conditions, are responsible for the large variation. The standard value for N content is about 31–32 g per kg DM (Anon., 1998b), so herbage N content of 'De Marke' is only slightly higher. However, since 1998, fertilizer recommendations have been changed and the standard value for herbage N content is now about 29–30 g per kg DM (Vellinga, 1998).

N content of silage grass was 29–30 g per kg DM, which is in good agreement with the standard values (Anon., 1998b).

Growing days for grazing and cutting

The average number of growing days for grazing was 19–23 (Table 4). In the first half of the growing season the number of growing days was about 20. This later increased to 25–30 (Figure 6), although DM yield for grazing remained fairly constant over the season (Figure 4). Combining Figures 4 and 6 shows that the target yield for grazing is met, and that the number of growing days is the resultant.

The Handbook for Dairy Farming (Anon., 1997) suggests an average of 23–33 growing days for grazing cuts of 1700 kg DM ha^{-1} (Table 2), and 20–28 days for 'light' grazing cuts (1300 kg DM ha^{-1}). The average number of growing days (19–23) at 'De Marke' in the period 1997–2000, is in the lower range of average values for light grazing cuts in situations with a relatively high risk of drought stress.

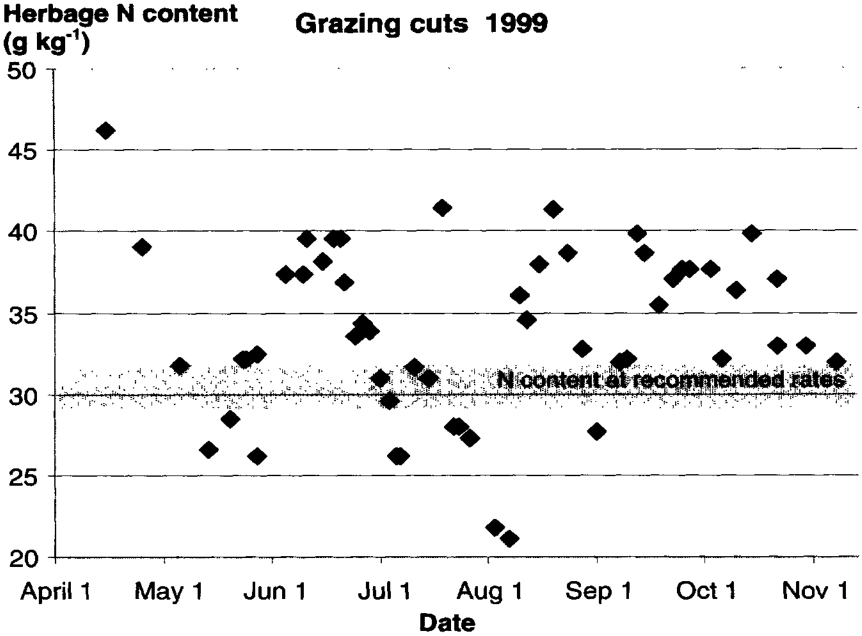

Figure 5. Herbage N content of grazing cuts in 1999 at 'De Marke'.

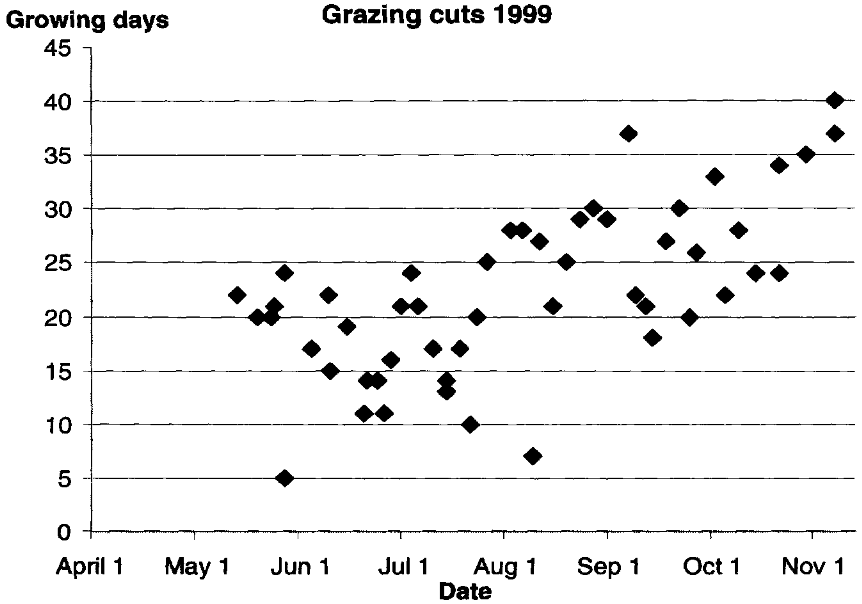

Figure 6. Number of growing days for a grazing cut (dairy cows, heifers and calves) in 1999 at 'De Marke'.

At 'De Marke' a number of 15 growing days or even less also occurs. This occasionally happened with dairy cows, but mostly with grazing calves.

The average number of growing days for silage varied from 29 to 36. The increase from almost 30 to slightly over 30 in the course of the growing season was smaller than for grazing cuts. So a growing period of 4.5–5 weeks was the target for cutting. DM yields were the resultant of this. For silage cuts of 3000 kg DM ha^{-1} (Table 2) on soils with a relatively high moisture holding capacity and fertilizer applications per cut amounting to an annual total of 250 kg N ha^{-1}, the Handbook for Dairy Farming (Anon., 1997) gives values of 30–40 growing days. The number of growing days for silage cuts on 'De Marke' in the period 1997–2000 is in good agreement with these values.

Grazing time and wilting period per paddock

The grazing system at 'De Marke combines dairy cows and heifers. Paddocks are grazed for 1–4 days by dairy cows, which are then followed by heifers. Average grazing time per paddock increased from more than 4 days in 1997 to almost 7 in 2000 (Table 4). This is the result of the reduction in number of grazing hours per day of the dairy cows, in combination with increased roughage supply during the indoor periods. So the grazing periods per paddock in every year of the study period lasted longer than the target value and the general recommendations.

The wilting period for silage cuts was always very short. Data have not been explicitly recorded, but the standard is 2 days, with cutting and tedding on the first day, and windrowing and ensilage on the second.

Nitrate leaching

Tactical and operational management on 'De Marke' was set up to reduce the nitrate concentration in the upper groundwater to less than 50 mg l^{-1}, at the same ensuring the production of enough roughage. During the last years, measurements of the nitrate concentration showed average values of 65 mg l^{-1} (Boumans *et al.*, 2001). Calculations with the model NURP ('1999 high' in Figure 7) show nitrate concentrations of 65 mg l^{-1} under grassland, which is in good agreement with the measurements. The '1999 high' situation refers to the grazing system and to the N rate of 1999 and the years before, i.e. 8 hours grazing per day for dairy cows, a long grazing period for heifers and an annual N rate of 250 kg ha^{-1}.

A reduction in N rate to 190 kg ha^{-1}, i.e., the average of irrigated and non-irrigated farming systems (Table 3), without changing the grazing system ('1999 low' in Figure 7), reduces the nitrate concentration, but not sufficiently.

The planned reduction in grazing duration at 'De Marke' [6 hours per day, heifers graze till 1 November ('2000 high' in Figure 7)] does not lead to a satisfactory reduction in nitrate concentration.

Restricting grazing duration in combination with a lower N application level of 190 kg ha^{-1} ('2000-low' in Figure 7) reduces the nitrate concentration in the upper groundwater to 51 mg l^{-1}.

A more severe restriction of grazing duration, as proposed for 'De Marke' in 2001 (dairy cows grazing 4 hours per day, heifers and calves permanently housed),

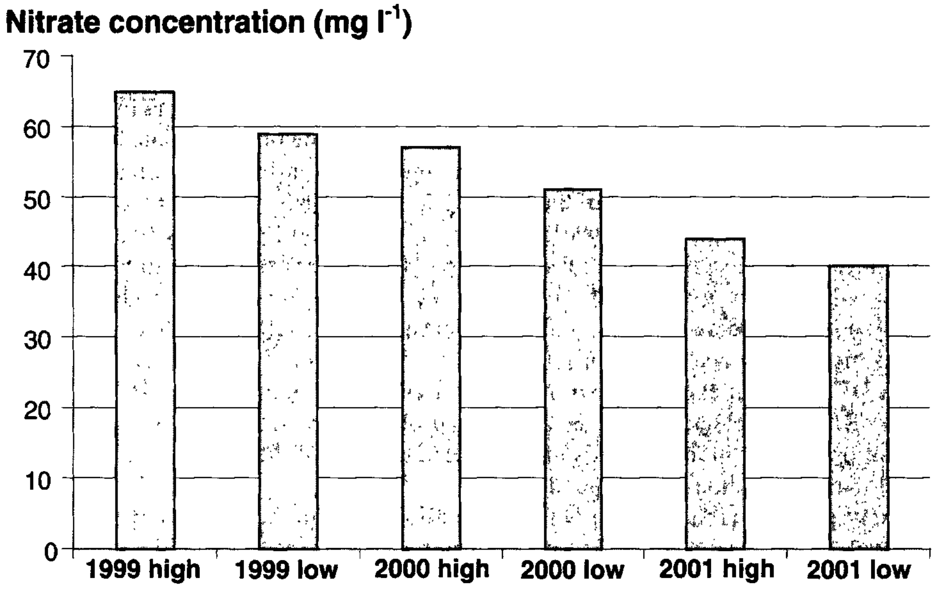

Figure 7. Nitrate concentration in the upper groundwater at 'De Marke', calculated with the model NURP (Vellinga *et al.*, 2001), for dairy cows grazing 8 hours per day and heifers until 1 December, at 250 and 190 kg N ha^{-1} (1999 high and 1999 low, respectively); for dairy cows grazing 6 hours per day and heifers until 1 November, at 250 and 190 kg N ha^{-1} (2000 high and 2000 low, respectively) and for dairy cows grazing 4 hours per day without heifers, at 250 and 190 kg N ha^{-1} (2001 high and 2001 low, respectively).

reduces the nitrate concentration to values well below 50 mg l^{-1}. This is the case in situations with 250 kg N ha^{-1} ('2001-high' in Figure 7) and with 190 kg N ha^{-1} ('2001-low' in Figure 7). In the '2001-low' situation there is enough room for grazing calves and heifers, which is attractive from the point of view of animal welfare, animal health and a positive image to society. In general, reductions in nitrate leaching are attainable through a combination of restricting grazing and N application levels.

NURP provides no information on the effect of the deviations in operational management. But it can be expected that light grazing cuts and late slurry applications will contribute to nitrate leaching. Long grazing periods per paddock are not expected to have any effect on nitrate leaching.

Discussion

Improved management is an important issue in the reduction of N losses on dairy farms. It is tried out in experimental farming systems like 'De Marke', but also in monitoring projects (Beldman, 1997a; Rougoor *et al.*, 1999; Koskamp *et al.*, 2001). Comparison of 'De Marke' with monitoring projects will provide information about the 'state of art' in operational and tactical grassland management in the Netherlands.

Transfer of N surpluses

The average MINAS-N surplus on 'De Marke' was 80 kg ha^{-1} (Aarts *et al.*, 1999), which is below the planned levels (Van Den Brandt & Smit, 1998). The low average surplus for the farm as a whole is the result of a low N rate on maize land and a relatively high annual N rate on grassland. The low N rate on maize land leads to surpluses that are much lower than the MINAS levels and will reduce nitrate leaching under maize to acceptable levels (Aarts *et al.*, 1999). The difference between the MINAS level and the actual level on maize land is partly transferred to grassland, because N uptake by grass can be high. We therefore expect nitrate leaching under grassland to fall below 50 mg l^{-1}. The transfer leads to an annual N rate on grassland that is higher than calculated for pure grassland farms with a MINAS surplus of 140 kg ha^{-1} (Table 3). It can be shown from measurements (Boumans *et al.*, 2001) and by the NURP model calculations that a high N surplus on grassland leads to nitrate concentrations above 50 mg l^{-1}. This indicates that transfer of the N surplus from maize land to grassland should be avoided.

A consequence is that annual N rates on grassland could be reduced by 60 kg ha^{-1} to about 190 kg ha^{-1}, which in turn will lead to a decreased DM yield. Assuming a DM response to N of 10–15 kg per kg N, DM yield decreases with 600 to 900 kg ha^{-1} per annum. Many dairy farms in the Netherlands have to reduce N rates on grassland (Van Den Brandt & Smit, 1998) and will also be facing reduced DM yields.

The importance of good operational management

Reduction of fertilizer inputs should be combined with optimizing the N utilization on the farm as a whole (Aarts *et al.*, 1992; Beldman, 1997a; Burns, 1997; Laws *et al.*, 2000; Koskamp *et al.*, 2001). This will serve two goals. In addition to reduced inputs, optimizing N cycling will reduce N losses even more and can partly compensate the decrease in DM production. The main road to N surplus reduction and improved N utilization on dairy farms runs on the strategic and tactical level. Measures advised are: (i) increasing milk production per cow, (ii) reducing the number of young stock, (iii) increasing slurry storage, (iv) technically improving slurry application, (v) reducing inputs of fertilizers and concentrates, (vi) replacement of fertilizers by white clover, and (vii) reducing grazing losses by changing the grazing system. In operational management a better timing of slurry application and use of recommendation programmes for fertilizer application are the most used ways to maintain DM production as high as possible. Realizing target yields for grazing and grazing periods per paddock are not explicitly mentioned, except for 'De Marke'. As much attention has already been paid to improvement of strategic and tactical choices on dairy farms, it is important to know whether the operational grassland management on 'De Marke' is general practice or not.

Comparison with the project 'Management on Sustainable Dairy Farms'

Although no explicit operational goals have been set in the monitoring project 'Management on Sustainable Dairy Farms'– except for using a fertilizer-recommendation computer programme – grassland management has been registered very well (Beldman, 1977a). Comparing the results of this project with the model in Figure 1 and the recommendations in Table 1, the following data can be obtained:

1. Actual N rates for grazing and cutting were 5–10 kg ha^{-1} higher than recommended (Beldman, 1997c). The main reason was that effective N from slurry was underestimated. Slurry applications after 1 August were about 10 to 15 % of the total amount of slurry applied (Beldman, 1997b).
2. The realized yield for grazing was not measured, but the average growing period for a grazing cut was 15 days (Holshof, 1997a). So the grazing yield on the monitoring farms will probably have been lower than at 'De Marke', although drought incidence generally is lower. The average number of growing days for cutting was 28. For grazing and cutting this is 5 days less than at 'De Marke'. Rougoor *et al.* (1999) found that there is a clear relationship between farmers' behaviour in grazing and in cutting management, which also suggests that low yields for grazing are often 'accompanied' by low yields for cutting.
3. The low DM yields for grazing have been supported by the rather high herbage N contents of 41 g per kg DM (Holshof, 1997b).
4. Average growing time for grazing and silage cuts was 15 and 28 days, respectively, with very little difference between the first and the second half of the growing season.
5. The average grazing time per paddock on the monitoring farms was 3.7 days, which is closer to the recommendations than the results of 'De Marke', although large variations are seen among farms and among paddocks per farm (Holshof, 1997a). Also Rougoor *et al.* (1999) found that on many farms the average grazing period per paddock lasted more than 4 days.

Although the annual N rate is mentioned as an aspect of tactical management, it is a result of N rates per cut and thus is strongly related to operational management. N fertilizer recommendations based on the same target rate per annum can lead to different results in different years, caused by different weather conditions (Beldman, 1997c). Farmers in the monitoring project 'Management on Sustainable Dairy Farms' responded to these differences to a limited extent. The N rate on grassland of 'De Marke' during the last 4 years showed some variation, giving the impression that different weather conditions did affect grassland management.

We therefore can conclude that operational grassland management of 'De Marke' is a good example of a group of farms that work intensively with nutrient management. This means that conclusions based on data of 'De Marke' can be useful in general. The central items where operational grassland management can be improved are: (i) low DM yield for grazing, especially in relation to the N rate per cut, (ii) long grazing periods per paddock, and (iii) slurry applications after 1 August.

Combining increased grazing yield and reduced grazing time per paddock

As mentioned before, a DM yield for grazing of 1700 kg ha^{-1} is based more on practical than on scientific evidence. Grass should not have too many stems, and growing periods for grazing cuts should not last longer than 4 weeks to prevent the presence of dead leaves in the herbage allowance (Lemaire, 1988). The data show that in most cases a yield of 1700 kg ha^{-1} is not realized. Low DM yields lead to low N responses and relatively high herbage N contents (Vellinga *et al.*, 1993). So a high utilization frequency leads to lower annual DM yields (Vellinga & André, 1999).

The popularity of low DM yields for grazing is related to the emphasis on milk production, the avoidance of risks and visual advantages. Young grass has a high-energy content, is supposed to be very tasty and should guarantee a high herbage intake, and thus is important for high-yielding dairy cows. It is assumed that grazing efficiency is higher and paddocks are left 'clearer'.

However, Meijs (1980) found that grazing efficiency depends on the herbage allowance per cow per day and not on the DM yield per hectare. Long grazing periods per paddock start with very high herbage allowances, which will lead to higher grazing losses. This in turn will result in lower silage yields, because more grassland is needed for grazing (Boxem, 1982). If it is assumed that paddock size will not change, grazing at low DM yields per hectare will lead to shorter grazing periods and thus to lower grazing losses. On many farms the number of dairy cows decreased as a result of a combination of increased milk production and the system of fixed milk-quota. So the only way to reduce grazing losses without reducing paddock size was to graze at low DM yields, with a relatively low annual DM production as a side effect. If paddock size does not change, grazing at higher DM yields will lead to longer grazing periods per paddock and to higher grazing losses. In other words, in the case of grazing, the combination of increased DM yields and reduced paddock size is essential for optimizing grass production and grass utilization on dairy farms. This is confirmed by Rougoor *et al.* (1999). The relationship between DM yield for grazing and paddock size can be described by the formula:

$$\text{Paddock size (ha)} = \frac{\text{(gross) daily herbage intake (kg day}^{-1}\text{) x target grazing days per paddock (days)}}{\text{DM yield (kg ha}^{-1}\text{)}}$$

To avoid problems with very small paddocks, flexible fences can be used if silage cuts are made. Such fences can be removed easily and provide the possibility of changing paddock size when grazing systems change, as is the planning on 'De Marke'.

Grazing at higher DM yields carries the risk that in periods with favourable growing conditions grass could be too long for grazing. It thus requires careful planning and higher management qualities, but also another attitude towards risks and visual effects.

More careful planning and another attitude towards risks could also prevent the use of planned silage cuts for grazing (Figure 3).

Earlier slurry application

A limited slurry storage capacity is an important reason for applying slurry in late summer (D.Z. Van Der Vegte, pers. comm.; Beldman, 1997b). At the same time, slurry application in spring will be delayed till after 15 March, to reduce the risk of leaching (Aarts *et al.*, 2001). To prevent late applications, the slurry storage capacity should be increased and slurry should be applied as early as possible. Recent experiments on sandy soils have shown limited leaching risks and high N utilization of early slurry application after 1 February (Den Boer, 1999; Bussink, 1999). Also the amount of slurry applied could be increased from 20 m^3 ha^{-1} to, for instance, 30 and 25 m^3 ha^{-1} for the first and second cut, respectively. Slurry application should be discontinued after 1 July to prevent effective N from being available in November.

The gain of good grassland management

It is difficult to provide exact figures on the advantage of increased grazing yields, reduced grazing periods per paddock, and earlier slurry applications, but impression can be given using estimates.

1. Reducing the grazing periods from 6 to 4 days is expected to reduce grazing losses from more than 25 to less than 20%. In case of 8000 kg DM ha^{-1} and 50% grazing, this means 200 kg DM ha^{-1}.
2. Increased growing periods per cut are expected to lead to increased DM yields of about 200 kg DM ha^{-1}.
3. About 200 to 400 m^3 slurry has been applied after 1 August, which on average is about 10 m^3 per hectare of grassland. About 5–10 kg N ha^{-1} is lost. Assuming a DM response of 10 kg per kg N, this loss is comparable with about 50–100 kg DM ha^{-1}, especially if this N is applied earlier in the growing season.

In all an amount of about 450–500 kg DM ha^{-1} can be gained. This figure of course depends on the farm situation and on the farmers' actual grassland management. Although good operational grassland management cannot fully compensate the decrease in DM production, it can contribute to good grassland production.

The reduction in nitrate leaching is difficult to quantify. On the one hand, improved operational management gives room to reduced N inputs, on the other, increased grazing yields will lead to lower herbage N contents and lower N intake by cattle. Earlier slurry applications will reduce the potentially leachable N at the end of the growing season. So although quantification is difficult, the effects on nitrate leaching are positive.

Conclusions and recommendations

Analysis of grassland fertilization and utilization parameters according to the grassland utilization scheme as shown in Figure 1 shows opportunities for improving operational grassland management by the following measures.

1. Target yields of 1700 and 3000 kg DM ha^{-1} for grazing and cutting, respectively, should be aimed at to increase annual grass production and improve N utilization efficiency.
2. To increase grazing efficiency, the grazing period per paddock should be reduced

to a maximum of 4 days. This can be achieved by adjusting paddock size. There is a strict relationship between daily herbage intake, grazing DM yield, grazing period per paddock and paddock size.
3. Slurry should be applied as early as possible to improve N utilization efficiency and to reduce grass production in late autumn.
4. The decrease in grass production by reduced rates of N fertilizer can be partly compensated by a combination of grazing and cutting at higher DM yields per cut, shorter grazing periods per paddock and earlier slurry application.
5. Improved operational grassland management can help to reduce nitrate leaching.
6. The grassland utilization scheme proved to be a useful tool in analysing and improving grassland management
7. At 'De Marke' a combination of restricted grazing and reduced rates of N fertilizer, higher grazing yields, shorter grazing time per paddock, and earlier slurry application provides ample scope for reduced nitrate leaching on dry sandy soils.

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