Effects of cattle slurry manure management on grass yield

R.L.M. Schils* and I. Kok

Research Institute for Animal Husbandry, P.O. Box 2176, NL-8203 AD Lelystad, The Netherlands
* Corresponding author (fax: +31-320-241584; e-mail: rene.schils@wur.nl)

Received 25 April 2003; accepted 30 June 2003

Abstract

The effects of application method, cattle slurry manure type and use of additives on grassland performance were studied in a 3-year field experiment on two farms on sandy soils in the northern part of the Netherlands. The objectives were to determine the effects on (1) nitrogen (N) utilization, (2) soil organic matter and soil N content, and (3) botanical composition of the sward. Cattle slurry manure from the two dairy farms was compared. Farm Harkema represented conventional management, while farm Drogeham used the additive Euromestmix® and reduced the N content of the dairy cow rations. In additional treatments, the slurry manure types were combined with the additives Effective Microbes® (EM) or FIR-naturel®. In all slurry manure type – additive combinations the slurry manure was either surface-applied or slit-injected. The resulting 12 treatments were applied without or with additional inorganic fertilizer N (165 kg ha^{-1}). The annual apparent N recovery (ANR) of N fertilizer was 0.79 kg kg^{-1}. The ANR of surface-applied slurry manure (0.30 kg kg^{-1}) was consistently lower than that of slit-injected manure (0.44 kg kg^{-1}), a difference that could be fully attributed to the manure applications during the growing season. No effect of application method was observed at the first application in March. Slurry manure type and additive use had no consistent effects on grass yield or N utilization. Statistically significant effects were only observed occasionally, mostly in interaction with other experimental factors. During the three experimental years, the changes in soil organic matter and soil N content were small. Application method had no effect on the measured soil characteristics. Slurry manure type and additive use had a small statistically significant effect at one site only. However, longer-term monitoring is necessary to draw firm conclusions. Application method, slurry manure type or additive use did not affect the botanical composition of the sward.

Additional keywords: slurry manure additive, application method, N efficiency, grassland, N recovery.

Introduction

From the 1950s onwards, dairy farms in the Netherlands have been highly intensified and as a result became increasingly dependent on imports of inorganic fertilizers and concentrates (e.g. Aarts *et al.*, 1992; Van Der Meer, 1994). The amount of inorganic fertilizer nitrogen (N) applied to grassland increased from around 75 kg ha^{-1} $year^{-1}$ in 1950 to approximately 300 kg ha^{-1} $year^{-1}$ in the mid-1980s (Bussink & Oenema, 1998). Since then, developments such as the introduction of milk quotas, a growing interest in organic farming and concern about N emissions have caused a gradual decrease in the use of inorganic fertilizer N. At present, inorganic fertilizer N application levels are about 220 kg ha^{-1} $year^{-1}$ (Anon., 2002).

Apart from inorganic fertilizer, grassland receives N from animal excreta, either directly during grazing or through application of cattle slurry manure. For a typical dairy farm on sandy soils in the early 1980s, Aarts *et al.* (1992) estimated an additional N input of 164 kg ha^{-1} $year^{-1}$ through animal excreta during grazing and 120 kg ha^{-1} $year^{-1}$ through slurry manure application. Generally, slurry manure was surface-applied to grassland, leading to environmentally unacceptable N emissions through ammonia volatilization (Thompson *et al.*, 1987; Bussink *et al.*, 1994; Huijsmans *et al.*, 2001). To reduce ammonia emissions, alternative slurry manure application methods were developed (Van Der Meer *et al.*, 1987; Wouters, 1995), which led to a range of so-called low-emission techniques, from injection at a depth of 15 cm to band spreading. The most commonly used technique on sandy soils is slit injection at a depth of 5 to 10 cm and a distance between slits of 20 cm. In the Netherlands, the use of low-emission techniques on grassland is obligatory since 1990.

At present, slit injection is widely used on sandy and clay soils in the Netherlands and is mostly carried out by contractors. However, some farmers are reluctant to have contractors apply the manure. A number of farmers consider slit injection by contractors as inflexible. With a self-owned, relatively cheap unit for surface application farmers can apply slurry manure immediately after a pasture is grazed or cut without losing valuable regrowth time. Furthermore, being independent from a contractor means farmers can apply manure under suitable weather conditions and, consequently, can reduce the risk of ammonia emissions (Huijsmans *et al.*, 2001). Other farmers argue that slit injection has negative effects on the physical and biological properties of the soil. Generally, injection techniques involve relatively heavy machinery with a high risk of soil compaction. Due to the smaller effective working width of injection equipment, the tyres affect a large proportion of the area. The negative effect of injected manure on biological soil quality is based on visual observations of dead earthworms after manure injection and on the assumption that slurry manure may have toxic effects on soil organisms. Another argument against the use of slit injection is that feeding dairy cows with a lower N content in the diet leads to a lower concentration of inorganic N in slurry manure, and thus to a lower risk of ammonia volatilization following surface application. Finally, various kinds of chemical, biological and physical additives have been developed with the objective to reduce ammonia volatilization, and this might justify surface application. Until now, only the use of acids (Bussink *et al.*, 1994; Schils *et al.*, 1999) has a proven record in reducing ammonia losses from slurry manure. There is no literature on the effects of other additives on slurry manure utilization following application to grassland.

Within the Nutrient Management Project of 'Vereniging Eastermar's Lânsdouwe' (VEL) and 'Vereniging Agrarisch Natuur en Landschapsbeheer Achtkarspelen' (VANLA)

60 farms have formulated goals regarding the reduction of N emissions (Roep *et al.*, 2003). To achieve the target, both the use of inorganic fertilizer N and the N content in dairy cow rations are reduced. Beside these general practices, some farmers use the additive Euromestmix® or Effective Microbes®. Euromestmix® contains clay minerals and micro-organisms, and is added to the slurry manure. The absorbing capacity of the additive is claimed to immobilize toxic products in the manure. The farmers who use Euromestmix® have been granted a temporary permit for surface application of slurry manure. Effective Microbes® (Higa, 1994) is a mixture of bacteria, actinomycetes, yeasts and other micro-organisms, and is sprayed over the grass sward. The claimed effects are, amongst other, improvement of the physical, chemical and biological status of the soil, a better rooting system and an improved organic matter utilization.

Next to the general farm-monitoring programme, a field experiment was set up to study in detail the effects of some of the slurry manure management practices of the VEL & VANLA project. The objectives of this experiment were to determine the effect of slurry manure type, application method and additive use on (1) nitrogen utilization, (2) soil organic matter and soil N contents, and (3) botanical composition of the sward.

Materials and methods

Sites

The experiment was laid out on grassland paddocks of two commercial dairy farms – Harkema and Drogeham – that participated in the VEL & VANLA project. Both locations were on sandy soils rich in organic matter from anthropogenic origin (Table 1). The average groundwater table varied from –25 to –80 cm in winter to lower than

Table 1. Soil characteristics at the start of the experiments.

Location	Sampling depth	Organic matter	Total N	P_2O_5	K_2O
	(cm)	(%)	(g kg^{-1})	(mg per 100 g)	
Drogeham	0–5	11.2	4.77	40	39
	5–10	6.7	3.78	29	11
	10–20	5.4	2.36	20	7
	20–30	4.6	1.75	14	5
Harkema	0–5	9.2	3.80	46	32
	5–10	5.7	2.65	41	11
	10–20	4.7	2.04	36	5
	20–30	3.7	1.42	28	3

Table 2. Botanical composition (%) of the swards at Drogeham and Harkema at the start of the experiments (15 April 1999).

Component	Scientific name	Drogeham	Harkema
Total plant cover		91	86
Perennial ryegrass	*Lolium perenne* L.	44	56
Rough stalked meadowgrass	*Poa trivialis* L.	33	25
Annual meadowgrass	*Poa annua* L.	3	5
Creeping bentgrass	*Agrostis stolonifera* L.	9	0
Couch grass	*Elytrigia repens* L.	0	4
Other grasses		3	3
White clover	*Trifolium repens* L.	1	3
Dandelion	*Taraxacum officinale* Web s.l.	3	1
Other herbs		2	2

–120 cm in summer. The site at Harkema was slightly drier than the site at Drogeham. Both experimental sites were under grass for more than 50 years, and were used for grazing and silage cutting. Before the start of the experiment the approximate N application levels, through inorganic fertilizer and slurry manure, were about 400 kg N ha^{-1} $year^{-1}$ at Harkema and about 300 kg N ha^{-1} $year^{-1}$ at Drogeham. Drogeham started to use Euromestmix® in 1982. At the start of the experiment, in March 1990, the phosphorus status and the potassium status of the topsoil (0–5 cm) were agronomically amply sufficient (Anon., 1998). Soil nitrogen supply (SNS), estimated from soil N content of the 0–20 cm soil layer (Hassink, 1995; 1996), was 185 kg ha^{-1} $year^{-1}$ at Harkema and 200 kg ha^{-1} $year^{-1}$ at Drogeham, the latter being the maximum SNS for sandy soils. Organic matter and soil nutrient contents decreased with depth. However, at Harkema the phosphorus status in the 5–30 cm soil layer was relatively high.

At both sites the dominant sward components were perennial ryegrass and rough stalked meadowgrass (Table 2). Together they made up approximately 80% of the sward. The contribution of white clover to the sward production was minimal.

Weather data (Figure 1) were collected from the nearest weather station (Anon., 1999–2002). Additionally, precipitation was measured at the experimental sites, daily at Drogeham and weekly at Harkema. The three growing seasons were warmer than the 20-year average, *viz*. +1.4, +0.9 and + 0.6 °C in 1999, 2000 and 2001, respectively. Precipitation during the growing season (April–September) was normal in 1999, but higher than average in 2000 and 2001. The total precipitation surpluses, i.e., precipitation minus reference evaporation according to Makkink (Hooghart & Lablans, 1988), during the growing season amounted to –31, +187 and +167 mm, for the successive years. The experimental fields were not irrigated.

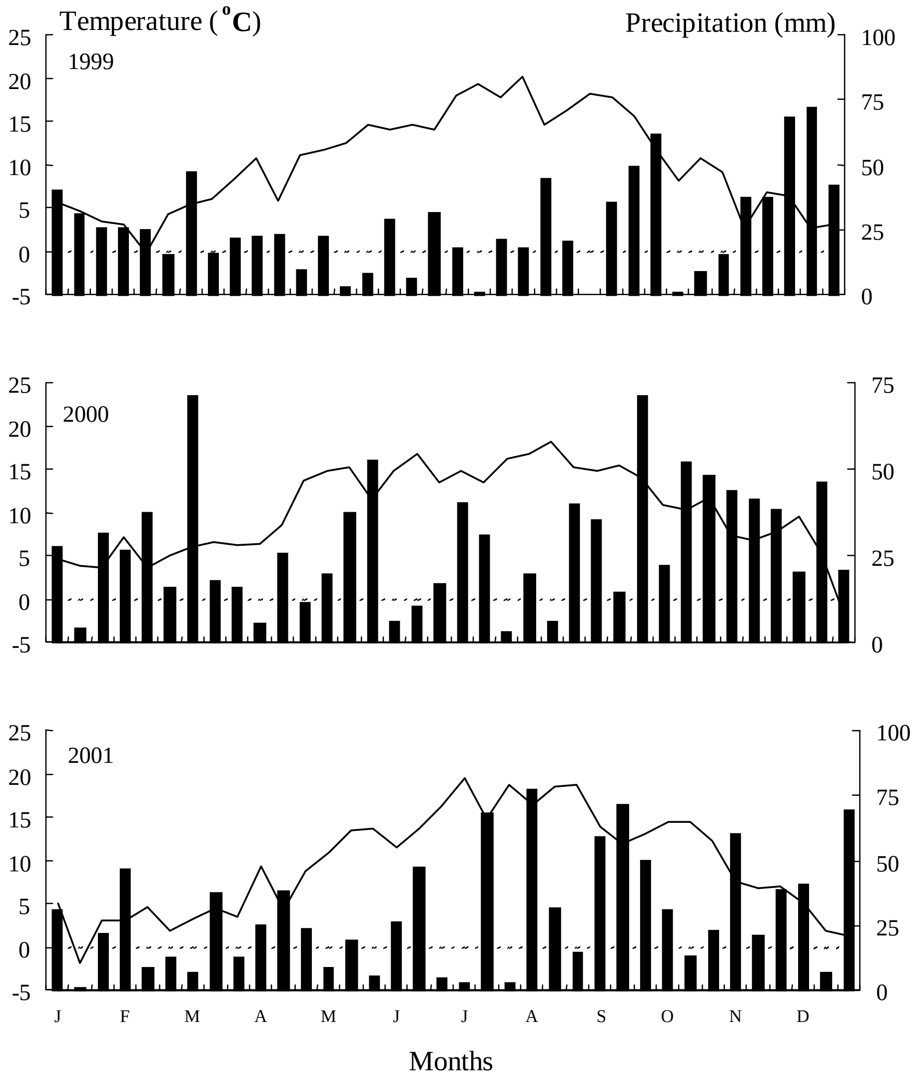

Figure 1. Mean temperature at 1.5 m (—) and total precipitation (bars) per 10-day periods during the growing seasons of 1999–2001.

Experimental treatments

The core of the experiment, designed as a split-plot, consisted of specific combinations of slurry manure type (Drogeham and Harkema), manure application method (slit injection and surface application) and additives (no additive, Effective Microbes® and FIR-naturel®). As the use of FIR-naturel® is not part of the VEL & VANLA project, it was only combined with Harkema slurry manure. (FIR-naturel® contains carbon and clay minerals, and is supposed to reduce the phosphate-fixing capacity of the soil

Table 3. Annual N application rate (kg ha^{-1}) through inorganic fertilizer (CAN) and cattle slurry manure.

N level	N source		Slurry N		Total N	
	CAN[1]	Slurry	Inorganic	Total	Inorganic	Total
Low	75				75	75
		Drogeham	71	155	71	155
		Harkema	70	151	70	151
High	243				243	243
	165	Drogeham	71	155	236	321
	165	Harkema	70	151	235	316

[1] CAN = calcium ammonium nitrate (27% N).

through the fixation of iron.) In addition to these treatment combinations the experiment included the treatments *inorganic fertilizer* (calcium ammonium nitrate – CAN) and *no inorganic fertilizer* (control). There were 2 replicates per farm, each consisting of 2 complete main plots, one with a low the other with a high N level.

The high and low N levels for the main plots were defined as the total amount of N applied through inorganic fertilizer and slurry manure. The high N level was set at 250 kg ha^{-1} year^{-1}, which is approximately equivalent to the application rate used by the farmers participating in the VEL & VANLA project. Approximately 170 kg ha^{-1} year^{-1} was applied as inorganic fertilizer, and 80 kg ha^{-1} year^{-1} in the form of slurry manure (Table 3). The partitioning of the annual application rate of inorganic N over the 5 successive cuts was 35, 15, 25, 15 and 10%, respectively. The low N level was set at 80 kg ha^{-1} year^{-1}, and involved either inorganic fertilizer or slurry manure, but not a combination.

Slurry manure was applied at a rate of 40 m^3 ha^{-1} year^{-1}, split into two or three applications. In 1999, 20 m^3 ha^{-1} was applied before the first and third cuts (Table 4).

Table 4. Fertilizer or cattle slurry manure application (A) and harvesting (H) dates[1] for the five cuts in the 3 years of the experiment.

Year	Cut									
	1		2		3		4		5	
	A	H	A	H	A	H	A	H	A	H
1999	18 III	6 V		4 VI	9 VI	15 VII		24 VIII		18 X
2000	29 III	11 V		20 VI	23 VI	25 VII	27 VII	29 VIII		16 X
2001		25 V	6 VI	27 VI	28 VI	3 VIII	8 VIII	5 IX		26 X

[1] For example: 18 III = 18 March; 6 V = 6 May.

Table 5. Chemical composition (g kg^{-1}) of the applied cattle slurry manures from the Drogeham and Harkema farms.

Component	Drogeham			Harkema		
	Mean	Min.	Max.	Mean	Min.	Max.
Dry matter	86	83	91	69	23	120
Organic matter	62	55	67	50	15	87
Total N	4.0	3.6	4.6	3.9	1.7	5.8
Inorganic N	1.8	0.6	2.2	1.8	0.9	2.4
Organic N	2.2	1.6	3.7	2.1	0.8	3.9
P_2O_5	1.4	1.2	1.7	1.4	0.3	2.7
K_2O	6.1	5.8	6.5	5.6	3.6	7.0

As the farmers in the project considered a surface application of 20 m^3 ha^{-1} during the growing season as impractical, the second application was split into two applications of 10 m^3 ha^{-1} each. In 2001, the experiment was hampered by the outbreak of Foot and Mouth disease, and spring application of slurry manure was not possible. Therefore the slurry manure was applied before the second, third and fourth cuts.

The slurry manures from Drogeham and Harkema contained 4.0 and 3.9 kg N m^{-3}, respectively (Table 5). Taking into account the lower DM content, on a DM basis the manure from Harkema contained 20% more N, which might be a reflection of the different feeding strategies. The average crude protein content in the winter ration was 163 g kg^{-1} DM at Drogeham and 177 g kg^{-1} DM at Harkema. The ratio between inorganic and organic N hardly differed. The composition of the slurry manure from Harkema showed much variation due to the addition of cleaning water from the milking parlour. Especially during the grazing season, with relatively low amounts of manure in storage, this dilution effect can be considerable. Furthermore, 2 kg Euromestmix® per m^3 slurry was added to the manure at Drogeham.

The additive Effective Microbes® was sprayed onto the plots before the first, third and fourth cuts. At the first application, one litre of Effective Microbes® was mixed with 1 litre of molasses and diluted with 100 litres of water. The second and third application rate was 0.5 l ha^{-1}. The additive FIR-naturel® was applied in spring before the first cut, at a rate of 7500 kg ha^{-1}.

The slurry manure was applied with a Vredo®, slit injection unit. For surface application, the unit was equipped with four splash plates. The application rate was calculated from the difference in weight before and after application, as calibrated on a test field for each date of application and manure type. Inorganic fertilizer N was given as CAN and applied manually. All treatments received ample additional phosphate and potassium through inorganic fertilizers.

Measurements and data analysis

Harvests were planned to take place when the fastest growing plots yielded approximately 3.5 to 4.0 t DM ha^{-1} at the first cut, and approximately 2.5 t DM ha^{-1} at later cuts. All treatments were harvested on the same day (Table 4) using a Haldrup® forage harvester. The area cut was 10 m × 1.5 m and a stubble was left of 5–6 cm. Yields were recorded and a sample was taken for analysis of DM and total N. The botanical composition of each plot was assessed visually during the growth of the first cut. Before the start of the experiment, soil samples consisting of 40 cores per bulked sample were taken on both sites at depths of 0–5, 5–10, 10–20 and 20–30 cm and analysed for organic matter, total N, phosphorus (P-AL) and potassium (K-HCl). This was repeated per plot (20 cores bulked per sample) each year after the last cut.

Apparent N recoveries (ANR) at the low N level were calculated as (N yield of fertilized plot – N yield of unfertilized plot) / total N applied. Apparent N efficiencies (ANE) were calculated as (DM yield of fertilized plot – DM yield of unfertilized plot) / total N applied. Efficiency index for the effect on N yield (EI-N) was calculated as (ANR of slurry manure) × 100 / (ANR of CAN). Efficiency index for the effect on DM yield (EI-DM) was calculated as (ANE of slurry manure) × 100 / (ANE of CAN).

Data were analysed by means of standard programmes for analysis of variance and multiple regression analysis, using GENSTAT 5 (Anon., 2001).

Results

Sward characteristics

The most dominant grass species differed among treatments and mainly depended on N level (data not shown). During the experiment total plant cover increased on all plots, and was higher on the low-N plots. On the unfertilized control plots the proportion of perennial ryegrass decreased with 7%. This was compensated at Drogeham by an increased proportion of creeping bentgrass and at Harkema by rough stalked meadowgrass. At Drogeham the proportion of perennial ryegrass only increased on the high-N plots, at the expense of rough stalked meadowgrass. The proportion of couch grass slightly decreased at the low N level at Harkema, but increased at the high N level. Slurry manure type, additives and application method had no effect on botanical composition.

Annual dry matter yield

At Drogeham the overall mean annual DM yield was 10.1, 11.4 and 9.1 t ha^{-1}, in the three successive years. The DM yield at Harkema showed a similar pattern over the three years: 9.9, 10.9 and 8.3 t ha^{-1}, respectively. The DM yield at Harkema was consistently lower than at Drogeham, on average 0.5 t ha^{-1}.

In 1999 and 2000, the DM yield of the unfertilized treatments (Table 6) was slightly higher at Harkema than at Drogeham. In 2001, however, the DM yield of the unfertilized treatment at Drogeham was higher than at Harkema. There was a clear

Table 6a. Annual grass dry matter yields (t ha^{-1}) in 1999 at Drogeham and Harkema in relation to nitrogen level, nitrogen source, cattle slurry manure application method, slurry manure type and additive use.

N level/ N source	Slurry type	Additive[1]	Drogeham				Harkema			
				Surface applied	Injected	Mean		Surface applied	Injected	Mean
Nil			6.37				6.61			
Low										
CAN[2]			9.21				9.85			
Slurry	Harkema	None		7.33	7.96	7.65		8.57	9.01	8.79
		EM		7.51	7.71	7.61		9.13	9.45	9.29
		FIR		7.44	7.92	7.68		8.50	9.13	8.82
	Drogeham	None		6.87	7.70	7.29		8.35	9.11	8.73
		EM		6.72	7.93	7.32		8.35	8.91	8.63
	Mean			7.17	7.84	7.51		8.58	9.12	8.85
High										
CAN			14.43				11.80			
Slurry	Harkema	None		12.94	13.08	13.01		11.54	11.63	11.59
		EM		12.48	13.25	12.86		11.26	12.13	11.70
		FIR		13.01	13.69	13.35		11.21	11.89	11.58
	Drogeham	None		13.29	12.99	13.14		11.05	11.61	11.33
		EM		12.26	13.04	12.65		11.22	11.46	11.34
	Mean			12.80	13.21	13.00		11.26	11.74	11.50
	Statistical significance[3]									
	Application method				**				**	
	Slurry type				n.s.				*	
	Additive				n.s.				n.s.	

[1] EM = Effective Microbes®; FIR = FIR-naturel®.

[2] CAN = calcium ammonium nitrate (27% N).

[3] * = $P < 0.05$; ** = $P < 0.01$; n.s. = not statistically different.

contrast in the response to fertilizer N at both sites. At Drogeham the response was positive and linear up to 250 kg N ha^{-1}, while at Harkema the response to N decreased with an increasing application rate (Figure 2, quadrant II).

Each year, and on both sites, the DM yield was significantly higher on the plots with injected slurry manure than on the plots with surface-applied manure. At the low N level, the average yield difference was 0.69 t ha^{-1} $year^{-1}$, with a range of 0.54 to 0.76 t ha^{-1} $year^{-1}$. In the second and third year, there was a significant interaction between N level and application method. The positive effect of slit injection on the DM yield was less apparent at the high N level than at the low N level.

Table 6b. Annual grass dry matter yields (t ha^{-1}) in 2000 at Drogeham and Harkema in relation to nitrogen level, nitrogen source, cattle slurry manure application method, slurry manure type and additive use.

N level/ N source	Slurry type	Additive[1]	Drogeham				Harkema			
				Surface applied	Injected	Mean		Surface applied	Injected	Mean
Nil			7.96				8.04			
Low										
CAN[2]			9.41				10.25			
Slurry	Harkema	None		9.79	10.07	9.93		9.48	10.86	10.17
		EM		9.64	9.85	9.74		10.05	10.33	10.19
		FIR		9.37	10.13	9.75		9.48	10.74	10.11
	Drogeham	None		9.43	10.00	9.71		9.78	10.34	10.06
		EM		8.81	10.23	9.52		10.24	10.26	10.25
	Mean			9.41	10.06	9.73		9.80	10.50	10.15
High										
CAN			14.28				12.11			
Slurry	Harkema	None		13.92	13.69	13.80		12.14	12.58	12.36
		EM		13.62	13.62	13.62		12.69	11.73	12.21
		FIR		13.83	13.79	13.81		12.03	12.73	12.20
	Drogeham	None		13.91	13.81	13.86		12.15	11.86	12.01
		EM		13.39	14.16	13.77		12.53	12.84	12.69
	Mean			13.73	13.81	13.77		12.31	12.28	12.29
	Statistical significance[3]									
	Application method				**				*	
	Slurry type				n.s.				n.s.	
	Additive				n.s.				n.s.	
	N level × Application method				*				*	
	Slurry type × Application method				*				n.s.	

[1] EM = Effective Microbes®; FIR = FIR-naturel®.

[2] CAN = calcium ammonium nitrate (27% N).

[3] * = $P < 0.05$; ** = $P < 0.01$; n.s. = not statistically different.

At Harkema in the first year, slurry manure from Harkema resulted in a significantly higher DM yield than manure from Drogeham. This can be explained by the higher rate of N application in that year. Other statistically significant main effects of slurry manure type or additive were not observed. Only incidentally statistically significant interactions involving slurry manure type or additive use were found. At Drogeham in the second year, the effect of application method was less apparent with slurry

Table 6c. Annual grass dry matter yields (t ha⁻¹) in 2001 at Drogeham and Harkema in relation to nitrogen level, nitrogen source, cattle slurry manure application method, slurry manure type and additive use.

N level/ N source	Slurry type	Additive[1]	Drogeham				Harkema			
				Surface applied	Injected	Mean		Surface applied	Injected	Mean
Nil			5.61				4.93			
Low										
CAN[2]			6.92				7.36			
Slurry	Harkema	None		7.12	7.89	7.51		6.76	8.32	7.54
		EM		7.23	7.86	7.54		7.20	8.43	7.82
		FIR		7.74	8.22	7.98		7.64	7.93	7.79
	Drogeham	None		7.66	7.84	7.75		7.70	8.63	7.98
		EM		6.94	8.27	7.60		8.01	8.14	8.08
	Mean			7.34	8.02	7.68		7.46	8.26	7.84
High										
CAN			11.30				9.79			
Slurry	Harkema	None		11.48	10.84	11.16		9.70	9.31	9.51
		EM		11.06	11.54	11.30		9.17	10.11	9.64
		FIR		10.77	11.12	10.94		9.53	9.56	9.54
	Drogeham	None		11.40	11.43	11.42		9.65	9.15	9.40
		EM		11.34	11.83	11.59		9.51	10.11	9.81
	Mean			11.21	11.35	11.28		9.51	9.65	9.58
	Statistical significance[3]									
	Application method				**				**	
	Slurry type				n.s.				n.s.	
	Additive				n.s.				n.s.	
	N level × Application method				n.s.				*	
	Application method × Additive				*				n.s.	
	N level × FIR				*				n.s.	
	N level × Applic. method × Additive				n.s.				*	

[1] EM = Effective Microbes®; FIR = FIR-naturel®.

[2] CAN = calcium ammonium nitrate (27% N).

[3] * = $P < 0.05$; ** = $P < 0.01$; n.s. = not statistically different.

manure from Harkema than with slurry manure from Drogeham. In the third year, the use of Effective Microbes® had a positive effect on DM yield, but only with slit injection. Finally, at Drogeham in the third year, FIR-naturel® had a positive effect on DM yield at the low N level, but a negative effect on DM yield at the high N level.

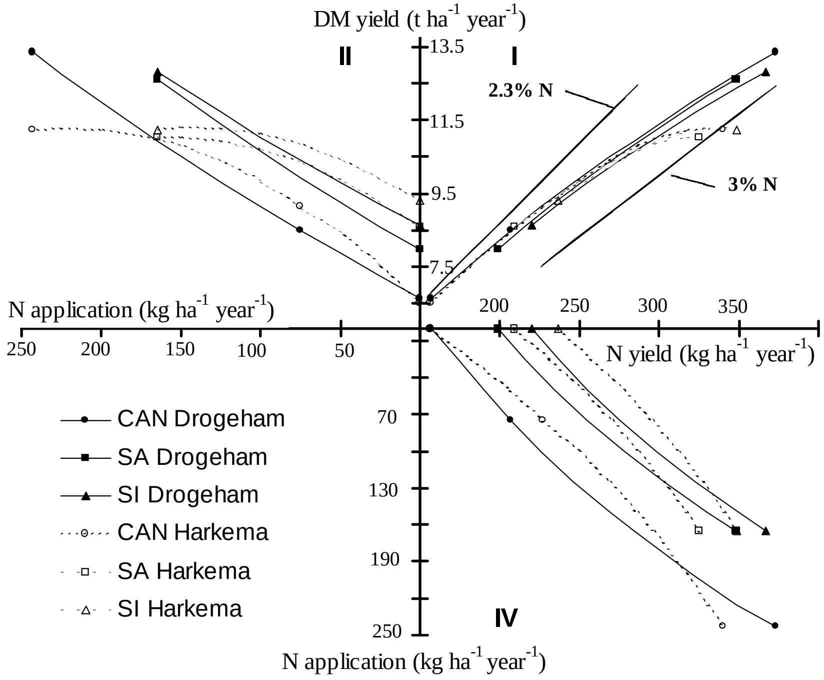

Figure 2. Relationship between annual fertilizer-N application, N yield and DM yield for inorganic N (CAN), surface-applied (SA) and slit-injected (SI) cattle slurry manure at Harkema and Drogeham. Data are averages over the period 1999–2001.

Annual nitrogen yield

In the three successive years the overall mean annual N yields were 250, 333 and 233 kg ha^{-1}. The average annual N yield was almost similar at the two sites (Table 7). The N yields on the unfertilized plots followed a similar pattern over the three years but the differences between the two sites were larger. In the first year, the N yield on the unfertilized plots was higher at Harkema than at Drogeham, but in the third year the opposite was found. Only in the second year, the annual N yields of the unfertilized plots were close to the calculated SNS of 185 kg ha^{-1} $year^{-1}$ at Harkema and 200 kg ha^{-1} $year^{-1}$ at Drogeham. In the first and third year, the N yields of the unfertilized plots were clearly lower than the calculated SNS. The average response of the N yield to inorganic fertilizer N was almost similar, but the shape of the response curve was not identical (Figure 2, quadrant IV).

The effect of application method as observed for the DM yield was also established for the N yield. At both N levels, N yield was significantly higher with slit injection than with surface application. The average yield difference was 23 kg N ha^{-1} $year^{-1}$, with a range of 18 to 30 kg N ha^{-1} $year^{-1}$.

Table 7a. Annual N yields (kg ha⁻¹) in 1999 at Drogeham and Harkema in relation to nitrogen level, nitrogen source, cattle slurry manure application method, slurry manure type and additive use.

N level/ N source	Slurry type	Additive[1]	Drogeham				Harkema			
				Surface applied	Injected	Mean		Surface applied	Injected	Mean
Nil			138				155			
Low										
CAN[2]			211				232			
Slurry	Harkema	None		173	178	175		198	209	204
		EM		164	172	168		229	229	229
		FIR		169	181	175		199	233	216
	Drogeham	None		148	174	161		200	228	214
		EM		146	183	165		195	222	209
	Mean			160	178	169		204	224	214
High										
CAN			380				315			
Slurry	Harkema	None		325	360	342		308	316	312
		EM		319	332	326		307	345	326
		FIR		336	352	344		300	336	318
	Drogeham	None		320	329	324		293	319	306
		EM		306	326	316		307	312	309
	Mean			321	340	331		303	326	314
	Statistical significance[3]									
	Application method				***				**	
	Slurry type				*				n.s.	
	Additive				n.s.				n.s.	
	FIR				*				n.s.	

[1] EM = Effective Microbes®; FIR = FIR-naturel®.

[2] CAN = calcium ammonium nitrate (27% N).

[3] * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$; n.s. = not statistically different.

As observed with DM yield, there were no consistent main effects of slurry manure type or additive use on N yield. At Drogeham in the first year, N yield was significantly higher on plots receiving manure from Harkema than on plots receiving manure from Drogeham. As stated earlier, this can be explained by the higher N application rate. At Drogeham in the third year, a positive effect of Effective Microbes® was also observed for N yield, but only in combination with slit injection. In two out of the six cases, the use of FIR-naturel® had a statistically significant positive effect on N yield. At Droge-

Table 7b. Annual N yields (kg ha⁻¹) in 2000 at Drogeham and Harkema in relation to nitrogen level, nitrogen source, cattle slurry manure application method, slurry manure type and additive use.

N level/ N source	Slurry type	Additive[1]	Drogeham				Harkema			
				Surface applied	Injected	Mean		Surface applied	Injected	Mean
Nil			204				197			
Low										
CAN[2]			246				268			
Slurry	Harkema	None		264	284	274		242	292	267
		EM		254	265	260		248	276	262
		FIR		254	284	269		243	287	265
	Drogeham	None		250	282	266		247	282	265
		EM		245	281	263		268	265	267
	Mean			253	279	266		250	280	265
High										
CAN			441				406			
Slurry	Harkema	None		438	439	439		371	428	400
		EM		416	443	430		439	418	428
		FIR		421	455	438		396	444	420
	Drogeham	None		423	436	429		386	407	397
		EM		437	458	448		409	444	427
	Mean			427	446	437		400	428	414
	Statistical significance[3]									
	Application method				**				**	
	Slurry type				n.s.				n.s.	
	Additive				n.s.				n.s.	

[1] EM = Effective Microbes®; FIR = FIR-naturel®.
[2] CAN = calcium ammonium nitrate (27% N).
[3] ** = $P < 0.01$; n.s. = not statistically different.

ham in the first year, N yield was higher on the FIR-naturel® plots than on the other slurry manure plots. At Drogeham in the third year, a similar effect was observed, but only at the low N level.

Annual nitrogen content

The overall mean annual N content in the harvested herbage was 25, 30 and 27 g N per kg DM, in the three successive years (data not shown). At Drogeham, herbage N

Table 7c. Annual N yields (kg ha^{-1}) in 2001 at Drogeham and Harkema in relation to nitrogen level, nitrogen source, cattle slurry manure application method, slurry manure type and additive use.

N level/ N source	Slurry type	Additive[1]	Drogeham				Harkema			
				Surface applied	Injected	Mean		Surface applied	Injected	Mean
Nil			144				116			
Low										
CAN[2]			173				182			
Slurry	Harkema	None		176	197	186		163	206	185
		EM		180	205	192		173	204	189
		FIR		193	209	201		186	193	190
	Drogeham	None		189	201	195		181	205	193
		EM		175	208	192		186	200	193
	Mean			183	204	193		178	202	190
High										
CAN			298				299			
Slurry	Harkema	None		311	301	306		276	276	276
		EM		282	333	308		267	308	287
		FIR		278	304	291		272	293	283
	Drogeham	None		302	319	311		276	283	279
		EM		305	320	312		274	307	291
	Mean			296	315	306		273	293	283
	Statistical significance[3]									
	Application method				***				***	
	Slurry type				n.s.				n.s.	
	Additive				n.s.				n.s.	
	Application method × Additive				*				n.s.	
	N level × FIR				*				n.s.	

1 EM = Effective Microbes®; FIR = FIR-naturel®.

2 CAN = calcium ammonium nitrate (27% N).

3 * = $P < 0.05$; ***= $P < 0.001$; n.s. = not statistically different.

content increased from 24 g N per kg DM without inorganic fertilizer to 28 g N per kg DM, with inorganic fertilizer N. At Harkema the response to the same range of inorganic fertilizer N was from 24 to 30 g N per kg DM.

Slit injection resulted in significantly higher N contents than surface application, on average 1.0 g N per kg DM. DM yield production per unit N yield (Figure 2, quadrant I) was lower with slit injection than with surface application, especially at Drogeham.

At Drogeham there was a consistent statistically significant interaction between slurry manure type and additive. On plots receiving manure from Drogeham, the use of Effective Microbes® increased the annual N content of the herbage from 26.1 to 26.8 g N per kg DM. On plots receiving manure from Harkema, the use of Effective Microbes® decreased the annual N content from 27.1 to 26.4 g N per kg DM. Furthermore, in two out of the six cases the use of Effective Microbes® increased the N content after surface application.

Apparent nitrogen efficiency and recovery

The mean ANE of CAN was 27.8 kg DM per kg N, while the mean ANR of CAN was 0.79 kg kg^{-1} (Tables 8 and 9). Although the mean ANE and ANR were nearly similar at both sites, the ANE and ANR showed more variation at Drogeham than at Harkema. It has to be taken into account that for the year 2001 the calculation of the ANE and ANR was based on the annual yield, excluding the first unfertilized cut.

Table 8. Annual apparent nitrogen efficiency (kg DM per kg N) at Drogeham and Harkema in the years 1999 to 2001 in relation to cattle slurry application method, inorganic fertilizer (CAN), type of slurry manure, and additive use, at the low N level.

N source	Additive[1]	Drogeham				Harkema			
		1999	2000	2001[2]	mean	1999	2000	2001[2]	mean
CAN[3]		37.6	28.8	18.8	28.4	32.0	24.1	25.5	27.2
Surface application									
Harkema slurry	None	7.1	21.5	7.5	12.0	7.5	8.9	7.6	8.0
	EM	7.9	20.2	5.8	11.3	9.2	13.7	11.0	11.3
	FIR	7.6	18.0	8.8	11.5	7.2	8.9	11.1	9.1
Drogeham slurry	None	6.2	15.2	5.5	9.0	8.2	9.3	8.7	8.7
	EM	5.3	10.9	4.6	6.9	8.2	12.5	8.4	9.7
Mean		6.8	17.2	6.4	10.1	8.1	10.7	9.4	9.4
Slit injection									
Harkema slurry	None	10.1	20.3	12.5	14.3	10.6	17.4	16.3	14.8
	EM	8.9	18.8	10.6	12.8	12.7	13.6	17.6	14.6
	FIR	9.9	20.8	13.4	14.7	10.2	16.5	14.1	13.6
Drogeham slurry	None	11.1	17.3	11.0	13.1	12.7	11.9	14.1	12.9
	EM	12.5	18.8	11.3	14.2	11.6	11.5	13.2	12.1
Mean		10.5	19.2	11.8	13.8	11.6	14.2	15.1	13.6

[1] EM = Effective Microbes®; FIR = FIR-naturel®.
[2] Not including the unfertilized 1st cut.
[3] CAN = calcium ammonium nitrate (27% N).

Table 9. Annual apparent nitrogen recovery (kg N per kg N) at Drogeham and Harkema in the years 1999 to 2001 in relation to cattle slurry manure application method, inorganic fertilizer (CAN), type of slurry manure and additive use, at the low N level.

N source	Additive[1]	Drogeham				Harkema			
		1999	2000	2001[2]	mean	1999	2000	2001[2]	mean
CAN[3]		0.96	0.84	0.54	0.78	0.75	0.86	0.78	0.80
Surface application									
Harkema slurry	None	0.23	0.69	0.21	0.38	0.16	0.33	0.23	0.24
	EM	0.19	0.60	0.20	0.33	0.29	0.38	0.32	0.33
	FIR	0.21	0.60	0.26	0.36	0.16	0.34	0.36	0.29
Drogeham slurry	None	0.14	0.47	0.18	0.26	0.21	0.30	0.25	0.25
	EM	0.13	0.43	0.14	0.23	0.18	0.45	0.25	0.29
Mean		0.18	0.56	0.20	0.31	0.20	0.36	0.28	0.28
Slit injection									
Harkema slurry	None	0.25	0.73	0.37	0.45	0.22	0.64	0.51	0.46
	EM	0.22	0.60	0.37	0.40	0.31	0.52	0.52	0.45
	FIR	0.27	0.73	0.42	0.47	0,32	0.60	0.43	0.45
Drogeham slurry	None	0.29	0.62	0.34	0.42	0.38	0.50	0.42	0.43
	EM	0.35	0.62	0.35	0.44	0.34	0.39	0.40	0.38
Mean		0.28	0.66	0.37	0.44	0.32	0.53	0.46	0.44

[1] EM = Effective Microbes®; FIR = FIR-naturel®.

[2] Not including the unfertilized 1st cut.

[3] CAN = calcium ammonium nitrate (27% N).

The statistically significant effect of application method on the DM and N yields is clearly reflected in the ANE and ANR. The mean ANE of slurry manure was 9.8 kg DM per kg N following surface application, and 13.7 kg DM per kg N following slit injection. Compared with the ANE of CAN this results in an efficiency index for the effect of slurry-manure N on DM yield (EI-DM) of 36% for surface application and 50% for slit injection. The mean ANR of surface-applied slurry manure was 0.30 kg kg^{-1}, while the mean ANR of slit-injected manure was 0.44 kg kg^{-1}. This leads to an efficiency index for the effect of slurry manure N on N yield (EI-N) of 38% for surface application and 56% for slit injection. Similar to the observation for CAN, it was found that the variation in ANE and ANR of slurry manure was higher at Drogeham than at Harkema. The annual variation for the two application methods was not different.

Slurry manure type and additive use had no consistent main effect on ANE or ANR. Considering the stated effects of slurry manure type and additive on DM and N yields, there are two relevant observations. At Drogeham in each year, slurry manure from Harkema had a higher ANE and ANR than slurry manure from Drogeham, but only if surface-applied. Averaged over three years (Drogeham), EI-N for surface-applied slurry manure from Harkema and Drogeham was 46 and 32%, respectively, whereas for injected manure these figures were 56 and 55%, respectively. The second observation is that at Drogeham in the third year, treatments with FIR-naturel® had a higher ANE and ANR than the other slurry manure treatments.

Seasonal apparent nitrogen recovery

The ANR per individual application was calculated from the accumulated N yield of the harvests between two applications (Table 10). For instance in 2000, the ANR of the first application was based on the first and second cuts, while the ANR of the second application was only based on the third cut. This method was chosen because it allowed the best possible comparison between the two application methods.

ANR of CAN and slurry manure showed a considerable variation between application times. In 1999 and 2000, ANR of CAN tended to increase with application time, but ANR of the later cuts was possibly affected by a residual effect of earlier applications. ANR of the first application in 2001 was remarkably low, especially considering that the first cut was not fertilized.

For the first application in 1999 and 2000 there was no difference in ANR between surface-applied and injected slurry manure. The beneficial effect of slit injection was restricted to the later application times.

Regression analysis was used to determine relationships between the ANR of slur-

Table 10. Effect of inorganic fertilizer (CAN[1]) and cattle slurry manure application method[2] on apparent nitrogen recovery (kg N per kg N) of the 1st through 4th cut at Drogeham and Harkema in the years 1999 to 2001.

Location	Year	1st Cut			2nd Cut			3rd Cut			4th Cut		
		CAN[1]	SAS[2]	SIS[2]	CAN	SAS	SIS	CAN	SAS	SIS	CAN	SAS	SIS
Drogeham	1999	0.91	0.28	0.28				1.01	0.08	0.27			
	2000	0.89	0.59	0.59				0.67	0,14	0.34	0.89	0.86	1.08
	2001				–0.14	–0.05	0.04	0.46	0.05	0.29	0.97	0.74	0.94
Harkema	1999	0.60	0.22	0.25				0.90	0.16	0.40			
	2000	0.67	0.29	0.40				0.88	0.16	0.41	1.14	0.67	0.86
	2001				0.34	0.06	0.17	0.67	0.14	0.42	1.18	0.89	1.02
Mean		0.77	0.35	0.38	–0.10	–0.01	0.11	0.77	0.12	0.36	1.05	0.79	0.98

[1] CAN = calcium ammonium nitrate (27% N).

[2] SAS = surface-applied slurry manure; SIS = slit-injected slurry manure.

Table 11. Changes in soil organic matter (% units; 0–10 cm) at Drogeham and Harkema over the 3-year experimental period (1999–2001) in relation to nitrogen level, nitrogen source, cattle slurry manure application method, slurry manure type and additive use.

N level/ N source	Slurry type	Additive[1]	Drogeham				Harkema			
				Surface applied	Injected	Mean		Surface applied	Injected	Mean
Nil			1.5				0.2			
Low										
CAN[2]			0.8				0.2			
Slurry	Harkema	None		0.7	1.4	1.0		−0.3	0.2	−0.1
		EM		1.0	0.5	0.7		0.1	0.2	0.1
		FIR		1.6	1.1	1.3		0.4	0.2	0.3
	Drogeham	None		0.9	1.2	1.0		0.0	0.4	0.2
		EM		0.7	0.2	0.5		0.0	0.4	0.2
	Mean			1.0	0.9	0.9		0.0	0.3	0.1
High										
CAN			1.0				−0.5			
Slurry	Harkema	None		0.0	0.8	0.4		−0.4	−0.8	−0.6
		EM		0.8	0.3	0.5		0.0	−0.9	−0.4
		FIR		1.4	0.5	0.9		0.1	−0.1	0.0
	Drogeham	None		1.1	1.2	1.1		−0.6	−0.5	−0.6
		EM		0.7	0.7	0.7		−0.5	0.3	−0.1
	Mean			0.8	0.7	0.7		−0.3	−0.4	−0.3
	Statistical significance[3]									
	Application method				n.s.				n.s.	
	Slurry type				n.s.				n.s.	
	Additive				n.s.				n.s.	
	FIR				*				n.s	
	Application method × Additive				*				n.s.	

[1] EM = Effective Microbes®; FIR = FIR-naturel®.
[2] CAN = calcium ammonium nitrate (27% N).
[3] * = $P < 0.05$; n.s. = not statistically different.

ry manure and weather parameters (like temperature, precipitation, evaporation and precipitation surplus) and manure characteristics (like dry matter content and inorganic N content). Irrespective of application method, the precipitation surplus at the day of application had a significant positive effect on ANR. Furthermore, DM content of slurry manure had a statistically significant negative effect on ANR. Together, the factors application method, precipitation surplus and DM content accounted for 63% of the variation in ANR.

Soil organic matter and nitrogen

At the end of the third year, mean soil organic matter content measured at a depth of 10 cm had increased by 0.9% at Drogeham but had stabilized at Harkema (Table 11). The changes in N content were even smaller (data not shown). At Drogeham, average soil N content decreased with 0.13 g kg^{-1}, which is only 3% of the initial value. At Harkema no change in average soil N content was observed.

At both sites, application method had no effect on the changes in soil organic matter or soil N content. At Drogeham, the use of FIR-naturel® had a positive statistically significant effect on organic matter content, especially with surface application. Furthermore, at Drogeham the use of Effective Microbes® had a statistically significant negative effect on soil organic matter content only in combination with slit injection.

Also at Drogeham there was a significant interaction between slurry manure type and N level in their effect on soil N content. At the low N level, soil N content was higher with manure from Harkema, while at the high N level soil N content was higher with manure from Drogeham.

Discussion

General

This paper presents the results of the first three years of an experiment of which the third year was hampered by an outbreak of Foot and Mouth disease. The main findings concern the direct relationship, within one year, between N input through various sources and N uptake and DM yield of grass. These results allow us to meet the first objective, i.e., to establish the effect of slurry manure management on N utilization. As to the longer-term objectives, i.e., the effects on soil and sward characteristics, only preliminary conclusions can be drawn. As the experiment will be continued, more conclusive results are to be expected in the future.

The strategy of the VEL and VANLA farmers to attain their objectives comprises a combination of management measures. Slurry manure management is only one of them, but is recognized to play a key role in the total N cycle of a dairy farm. So a field experiment that studies a single aspect in detail, which would not be possible in a whole-farm experiment, is justified. However, a field experiment brings about certain implications that have to be accounted for when translating its results to the farm situation. The experiment was carried out as a cutting trial, which excludes extra variation through grazing and thus is not representative for the grassland management in the region. Grazing involves an additional but very heterogeneous input of N and organic matter. It furthermore may affect sward composition, which can mask the effects of the experimental factors studied. The measured grass yields in a cutting experiment are gross yields and do not necessarily represent the net intake by the grazing dairy cows. Slurry manure type or application method may affect grazing behaviour and thus net production of grassland (Laws & Pain, 2002). All plots were cut on the same day, which means that the slower growing treatments were harvested at a lower DM yield than the faster growing ones. In practice, a slow-growing pasture is grazed or harvested at a later date, but at the same yield as a fast-growing pasture. So in this experiment the lower yielding plots had a higher cutting frequency than they would have had in practice, which resulted in an under-estimation of annual DM yield and in an over-estimation of crude protein content (Vellinga & André, 1999). On the other hand, the regrowth is faster for a lower yielding plot than for a higher yielding plot (De Wit, 1987).

Application method

The annual N utilization of surface-applied slurry manure was consistently lower than that of slurry manure applied by slit injection, which is in line with earlier findings in the Netherlands (Van Der Meer *et al.*, 1987; Schils, 1992a; Schreuder *et al.*, 1995). Although ammonia volatilization was not measured in this experiment, it is most likely that the lower N utilization is caused by higher ammonia losses (Huijsmans *et al.*, 2001).

In this experiment the average N efficiency index (EI-N) for surface application and slit injection was 38 and 56%, respectively. Although consistent and statistically significant, this difference between application methods is smaller than the difference found in earlier experiments. Integration of earlier experiments by Noij *et al.* (1992), in which EI-N for surface application and slit injection was 26 and 50%, respectively, has led to the present recommendations (Anon., 1994; 1998). In our experiment the relatively high annual EI-N for surface application was caused entirely by the relatively high N utilization following the first slurry manure application in March. However, this experiment was not suitable to determine effects of application time. The two or three applications were given to the same plot. Consequently, the observed effect after the second application was a combination of the direct effect of the second and the residual effects of the first application. In earlier experiments with surface application and slit injection approximately 50 to 60% of the annual yield effect was found in the first cut following slurry manure application. The remaining 40 to 50% was obtained in later cuts. This probably contributes to the high ANR values found at later application times. Nevertheless, the present results clearly show that the difference between surface application and slit injection only occurred at later application times. Until now an effect of application time on N utilization has only been observed for injection (Schils, 1992a, b; Schreuder *et al.*, 1995). As to our experiment it is unclear what caused the higher N utilization with spring application. Based on ammonia volatilization measurements (Bussink *et al.*, 1994; Huijsmans *et al.*, 2001) it can be argued that the generally prevailing lower temperature and lower radiation in spring justify the expectation of a higher N utilization in that season. The positive effect of precipitation surplus on N utilization found in this experiment could not be specifically related to spring application. Furthermore, the observed effect of precipitation surplus was irrespective of the application method, and thus does not explain the relative differences between application methods.

The higher EI-N for surface application in comparison with earlier experiments can be split into two effects. First, the ANR of surface-applied slurry manure (0.30 kg kg^{-1}) was indeed higher than in earlier experiments, e.g. 0.23 kg kg^{-1} by Van Der Meer *et al.* (1987), 0.21 kg kg^{-1} by Schils (1992a) and 0.15 kg kg^{-1} by Schreuder *et al.* (1995). In addition, the ANR of CAN in the present experiment (0.79 kg kg^{-1}) was lower than in earlier experiments by Van Der Meer *et al.* (1987), Schils (1992a) and Schreuder *et al.* (1985), who found ANR values of 0.91, 0.87 and 0.87 kg kg^{-1}, respectively.

The overall results of the present experiment substantiate the claim that slit injection has a positive effect on N utilization of grassland. However, it can be argued that within the Mineral Accounting System (MINAS) (Henkens & Van Keulen, 2001) farmers have their own responsibility in attaining the objectives. If they choose to use surface application, the N losses increase by approximately 30 kg ha^{-1} $year^{-1}$. Consequently they will have to take other measures to compensate these losses. Such a system would encourage farmers to maximize N utilization from surface-applied slurry manure, and thus carefully choose the appropriate time of application.

Beside N utilization, the choice of the application method should be judged against other criteria, such as costs, flexibility, precision of application, energy use, denitrification losses (Thompson *et al.*, 1987) and impact on soil quality. De Goede *et al.* (2003) studied the latter within the same field experiment. They found for instance that in the summer of 2000 slit injection at Drogeham had a negative effect on the earthworm population. A reduced earthworm population signifies a potentially lower N mineralization. During the course of the first three years of this experiment, soil data have not shown any effect of application method on soil organic matter or soil N content.

Slurry manure type and additive use

The characteristics of the two slurry manure types used are brought about by a combination of management measures. The slurry manure from Harkema could be considered as manure from conventional management. Compared with the average composition of slurry manure in the Netherlands in 1998, it contained a similar amount of N (Anon., 1998). The slurry manure from Harkema had a lower DM content than the manure from Drogeham, especially in the second and third year. Harkema manure had a positive effect on grass DM yield at Drogeham in the second year. As many experiments have shown beneficial effects of slurry manure dilution on ammonia volatilization (Bussink & Bruins, 1992; Sommer & Oleson, 1999) and N utilization (Stevens *et al.*, 1992; Van Der Meer, 1994) this positive response may have been caused by the lower DM content. The farm at Drogeham combined two management measures, i.e., the use of Euromestmix® and a reduction in protein supply of the dairy herd. The manure from Drogeham contained a similar amount of N as the manure from farms participating in the 'Cows & Opportunities' project (Oenema *et al.*, 2001). These farms also aim to reduce the N losses through a range of measures.

Slurry manure type and additive had no consistent effect on manure-N utilization. However, occasionally a statistically significant effect was observed, but mostly in interaction with other factors. If we consider that the experiment consisted of 24 comparisons (2 locations, 3 years, 2 N levels and 2 application methods), the effects of slurry manure type and additive can be summarized as follows. The annual DM yield was positively affected by the use of Harkema slurry manure (2×), Effective Microbes® (2×) and FIR-naturel® (2×), and negatively affected by FIR-naturel® (2×). The annual N yield was positively affected by Harkema slurry manure (4×), Effective Microbes® (2×), and FIR-naturel® (6×). Further research is necessary to study whether a longer-term consistent effect can be found, and moreover, what factors affect the large variation in the observations. In this respect it is remarkable that nearly all statistically significant effects of slurry manure type and additive use were found at Drogeham and none at Harkema.

At Drogeham the observed higher N yield with the use of FIR-naturel® might be associated with the higher organic matter content of the FIR-naturel® plots. It has to be realized that the organic matter was determined with the 'loss on ignition' method at 550 °C. Although the carbon in FIR-naturel® is inert, the added clay minerals lead to an overestimation of the organic matter content.

Apart from the statistical significance of the effects of slurry manure type and additive, it is important to consider the relevance of the observed effects, especially in relation to the costs. The annual costs of the additives, in accordance with the way they were used in this experiment, are € 52, € 29 and € 852 ha^{-1} $year^{-1}$, for Euromestmix®, Effective Microbes® and FIR-naturel®, respectively. In practice, FIR-naturel® is usually not applied each year like in this experiment, but once every 10 or 20 years. When using Euromestmix®, for instance, a fodder price of € 0.10 per kg DM requires an annual DM yield increase of 520 kg ha^{-1} to break even.

Conclusions

– The annual N utilization of slurry manure was 18% higher with slit injection than with surface application. The positive effect of slit injection was obtained with applications from June onwards. Slurry manure application in March resulted in a similar N utilization for both application techniques.
– Slurry manure type and additive use had no consistent effect on the manure-N utilization, but statistically significant effects – always in interaction with another experimental factor – were occasionally observed for both factors,
– Application method, slurry manure type or additive use had no effect on changes in soil organic matter or soil N content. Longer-term monitoring is necessary to draw firm conclusions.
– Application method, slurry manure type or additive use did not affect the botanical composition of the sward.

Acknowledgements

We wish to thank Messrs S. Sikkema and T. Hoeksma for their kind permission to conduct the experiments on their farms. We also thank Jan Zonderland, Jan Boonstra, Klaas Sikkema, Henk Schilder and Tim Wiersma for their contribution to the fieldwork, and Johan Van Riel for the statistical analysis. This project was funded by the Ministry of Agriculture, Nature and Food Quality, through Research Programme PO-9.

References

Anonymous, 1994. Fertilizer Recommendations for Grassland and Fodder Crops. Publikatie No 44. Information and Knowledge Center (IKC), Lelystad, 82 pp. (In Dutch)

Anonymous, 1998. Fertilizer Recommendations for Grassland and Fodder Crops. Research Station for Cattle, Sheep and Horse Husbandry (PR), Lelystad, 53 pp. (In Dutch)

Anonymous, 1999–2001. Monthly Weather Surveys of the Netherlands. Koninklijk Nederlands Meteorologisch Instituut (KNMI), De Bilt. (In Dutch)

Anonymous, 2001. GENSTAT 5, Release 4.21. Lawes Agricultural Trust, Rothamsted Experimental Station, Harpenden 796 pp.

Anonymous, 2002. Farm Accountancy Data Network. Agricultural Economics Research Institute. (www.lei.wageningen-ur.nl).

Aarts, H.F.M., E.E. Biewinga & H. Van Keulen, 1992. Dairy farming systems based on efficient nutrient management. *Netherlands Journal of Agricultural Science* 40: 285–299.

Bussink, D.W. & M.A. Bruins, 1992. Reduction of Ammonia Volatilization using different Slurry Application Techniques on Grassland. *Meststoffen* 1992: 31–36. (In Dutch)

Bussink, D.W., J.F.M. Huijsmans & J.J.M.H. Ketelaars, 1994. Ammonia volatilization from nitric-acid-treated cattle slurry, surface applied to grassland. *Netherlands Journal of Agricultural Science* 42: 293–309.

Bussink, D.W. & O. Oenema, 1998. Ammonia volatilization from dairy farming systems in temperate areas: a review. *Nutrient Cycling in Agroecosystems* 51: 19–33.

De Goede, R.G.M., L. Brussaard & A.D.L. Akkermans, 2003. On-farm impact of cattle slurry manure management on biological soil quality. *NJAS – Wageningen Journal of Life Sciences* 51. (This issue)

De Wit, M.A.E., 1987. The Effect of the Yield of a Preceding Cut on the Regrowth of Grass. Rapport No 107, Research Station for Cattle, Sheep and Horse Husbandry (PR), Lelystad, 123 pp. (In Dutch)

Hassink, J., 1995. Organic matter dynamics and N mineralization in grassland soils. PhD thesis Wageningen Agricultural University, Wageningen, 250 pp.

Hassink, J., 1996. Prediction of the soil nitrogen supply of grassland soils. In: J.W.G.M. Loonen & W.E.M. Bach-De Wit. Stikstof in beeld. Onderzoek inzake de Mest- en Ammoniakproblematiek in de Veehouderij 20. DLO, Wageningen, pp. 15–35. (In Dutch)

Henkens, P.L.C.M. & H. Van Keulen, 2001. Mineral policy in the Netherlands and nitrate policy within the European Community. *Netherlands Journal of Agricultural Science* 49: 117–134.

Higa, T., 1994. Effective Micro-organisms for a Sustainale Agriculture and a Healthy Environment. Van Arkel, Utrecht, 191 pp. (In Dutch)

Hooghart, J.C. & W.N. Lablans, 1988. From Penman to Makkink: a new Calculation Method for Climatological Evaporation figures. Technische Rapporten No 11, Koninklijk Nederlands Meteorologisch Instituut (KNMI), De Bilt, 19 pp. (In Dutch)

Huijsmans, J.F.M., J.M.G. Hol & M.M.W.B. Hendriks, 2001. Effect of application technique, manure characteristics, weather and field conditions on ammonia volatilization from manure applied to grassland. *Netherlands Journal of Agricultural Science* 49: 323–342.

Laws, J.A. & B.F. Pain, 2002. Effect of method, rate and timing of slurry application to grassland on the preference by catlle for treated and untreated areas of pasture. *Grass and Forage Science* 57: 93–104.

Noij, I.G.A.M. & H.J. Westhoek, 1992. Utilization of Animal Manure on Grass and Maize following Low-emission Application. Intern Rapport No 8, Information and Knowledge Centre (IKC), Lelystad, 44 pp. (In Dutch)

Oenema, J., G.J. Koskamp & P.J. Galama, 2001. Guiding commercial pilot farms to bridge the gap between experimental and commercial dairy farms; the project 'cows & opportunities'. *Netherlands Journal of Agricultural Science* 49: 277–296.

Roep, D., J.D. Van Der Ploeg & J.C.S. Wiskerke, 2003. Managing technical-institutional design processes: some strategic lessons from environmental co-operatives in the Netherlands. *NJAS – Wageningen Journal of Life Sciences* 51. (This issue)

Schils, R.L.M., 1992a. Effect of Application Time on Nitrogen Utilization of Cattle Slurry Applied to Grassland. Rapport No 136, Research Station for Cattle, Sheep and Horse Husbandry (PR), Lelystad, 139 pp. (In Dutch)

Schils, R.L.M., 1992b. Injection of cattle slurry into grassland; effects of application time. In: Proceedings of the 14th General Meeting of the European Grassland Federation, 8–11 June 1992, Lahti, pp. 336–339.

Schils, R.L.M., H.G. Van Der Meer H.G., A.P. Wouters, J.H. Geurink & K. Sikkema, 1999. Nitrogen utilization from diluted and undiluted nitric acid treated cattle slurry following surface application to grassland. *Nutrient Cycling in Agroecosystems* 53: 269–280.

Schreuder, R., A.P. Wouters & P.J.M. Snijders, 1995. Development Slit Injector and N Utilization of Cattle Slurry. Rapport No 162, Research Station for Cattle, Sheep and Horse Husbandry (PR), Lelystad, 106 pp. (In Dutch)

Sommer, S.G. & J.E. Oleson, 1991. Effects of dry matter content and temperature on ammonia loss from surface applied cattle slurry. *Journal of Environmental Quality* 20: 679–683.

Stevens, R.J., R.J. Laughlin, J.P. Frost & R. Anderson, 1992. Evaluation of separation plus acidification with nitric acid and sepeartion plus dilution to make cattle slurry a balanced efficient fertilizer for grass and silage. *Journal of Agricultural Science, Cambridge* 119: 391–399.

Thompson, R.B., J.C. Ryden & D.R. Lockyer, 1987. Fate of nitrogen in cattle slurry following surface appliaction or injection to grassland. *Journal of Soil Science* 38: 689–700.

Van Der Meer, H.G., R.B. Thompson, P.J.M. Snijders & J.H. Geurink, 1987. Utilization of nitrogen from injected and surface-spread cattle slurry applied to grassland. In: H.G. Van Der Meer, R.J. Unwin, T.A. Van Dijk & G.C. Ennik (Eds), Animal Manure on Grassland and Fodder Crops. Fertilizer or Waste? Martinus Nijhoff, Dordrecht. pp. 47–72.

Van Der Meer, H.G., 1994. Grassland and society. In: L. 'T Mannetje & J. Frame (Eds), Grassland and Society. Proceedings of the 15th General Meeting of the European Grassland Federation, 6–9 June 1994, Wageningen. Wageningen Pers, Wageningen, pp. 19–32.

Vellinga, Th.V. & G. André, 1999. Sixty years of Dutch nitrogen fertiliser experiments, an overview of the effects of soil type, fertiliser input, management and developments in time. *Netherlands Journal of Agricultural Science* 47: 215–241.

Wouters, A.P., 1995. New application techniques make slurry again a valuable nutrient. In: W. Luten, H. Snoek, S. Schukking & M. Verboon (Eds), Proceedings of the Symposium Applied Research for Sustainable Dairy Farming, 31 May – 2 June 1995, Wageningen. Research Station for Cattle, Sheep and Horse Husbandry, Lelystad, pp. 13–18.