Managing dairy farming systems for groundwater conservation in the sandy regions of the Netherlands

H.F.M. Aarts, C. Grashoff & H. van Keulen

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Address : Bornsesteeg 65, Wageningen, The Netherlands
: P.O. Box 14, 6700 AA Wageningen, The Netherlands
Tel. : + 31-317-475700
Fax : + 31-317-423110
E-mail : postkamer@ab.dlo.nl
Internet: : http://www.ab.dlo.nl

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Summary

In The Netherlands, the demand for clean groundwater for industrial en domestic purposes is still increasing. Moreover, groundwater level has to increase to preserve natural habitats. Possibilities to increase 'production' of extractable groundwater of high quality, by growing crops with lower water requirements, reducing irrigation, fertilization, grazing and drainage are examined. This report focuses on the benefits of these measures for water conservation and on the possibilities of their incorporation in dairy farming systems. On an experimental farm, 'De Marke', annual groundwater production could be increased by 550 m^3 per ha, while nitrate concentration decreased considerably to 50 mg/l. Annual milk production of 12,000 kg per ha was comparable with that of commercial farms. Additional costs appeared lower than the costs for purification of surface water. Therefore, it is concluded that integrating groundwater management in dairy farming is technically and economically feasible and therefore attractive to farmers, water companies and nature organizations. It may be feasible to estimate water production of individual farms on the basis of crop areas, use of fertilizer and irrigation water. Temporary storage of precipitation surplus, through reduced drainage, requires collaboration of farmers, regional authorities and water companies.

1. Introduction

Sandy soils in the East and South of the Netherlands are mainly used for forage production for dairy cattle, with 520,000 ha perennial ryegrass (*Lolium perenne* L.) and 180,000 ha silage maize (*Zea mays* L.) as main crops, representing 61% and 21% of the cultivated area, respectively. Besides, most of Dutch drinking water is processed from groundwater from these areas and drought-sensitive nature reserves are located there. The intensive farming systems in these regions require high and stable feed supplies, hence they are aiming at maximizing crop yields by high fertilization levels and ample water supply. Over the last decades, natural water supplying capacity of the cultivated sandy soils has strongly declined. The traditional arable fields, with a high water holding capacity in the humic upper layer, created by generations of farmers, were partly acquired for urban development and in the rather recently cultivated areas, groundwater table depths increased considerably, mainly due to improved drainage and extraction of groundwater, to levels in general between 1 and 3 m below the surface (Van der Molen et al., 1998). Consequently, capillary transport of groundwater to the rooted profile is negligible on most fields.

Farmers on these drought-sensitive soils now use sprinkler irrigation in periods of rainfall deficiency. However, irrigation possibilities will shortly be restricted to save groundwater for human consumption and to reduce water table depths for nature conservation and restoration. Moreover, groundwater quality has to be improved. Nitrate content has to be reduced to values not exceeding 50 mg/l, the standard of the 1980 EC Directive on Quality of Water for human consumption, a reduction of about 75% (Fraters et al., 1998; Oenema et al., 1998).

As the quantity of extractable groundwater is limited, additional water from the rivers Rhine and Meuse is purified for industrial and domestic purposes, at high costs. However, there is a consumer preference for drinking groundwater instead of water from rivers. As a consequence, a discussion has started about possibilities to increase 'production' of extractable groundwater of high quality, by growing crops with lower water requirements, reducing irrigation, fertilization and grazing, and reducing drainage in winter and early spring, causing also higher groundwater tables in summer.

This paper focuses on the benefits of these measures for water conservation and on the possibilities for their incorporation in dairy farming systems on sandy soils. First, water and nitrogen relationships of the soil/crop component of the dairy farm are quantified, using data from three experiments:

a) experiment 'Klein Gastel' provides information on water use efficiency and recovery after drought stress of different forage crops;
b) 'Heino' on the effects of sprinkler irrigation and fertilization on dry matter production and N uptake of grass; and
c) 'Steenbergen' on the influence of groundwater table depths on grass growth and efficiency of uptake of applied fertilizers.

Subsequently, flows of water on prototype dairy farming system 'De Marke' - focusing on long-term 'green' objectives of Dutch society and related possibilities and constraints for commercial dairy farming on sandy soil (Aarts et al., 1999a; b) - are quantified. Flows are compared to those at current commercial farms, allowing analysis of potential benefits and practical feasibility of integrating water management in dairy farming.

2. Water and nitrogen relationships in forage production

2.1. Effects of water availability on forage crops: experiment 'Klein Gastel'

2.1.1. Method and materials

Crops vary in water consumption and drought sensitivity. Experimental results with individual crop species are abundant, but comparisons of behavior of different species under equal, temperate conditions are scarce (Ehlers, 1997). Therefore, between 1994 and 1996, water use, growth and recovery after periods of drought stress of a number of forage crops were studied under Dutch climatic conditions (Aarts et al., 1996; Smid et al., 1998).

Perennial ryegrass, maize, lucerne (*Medicago sativa* L.), triticale (*Triticosecale* Wittm.) and fodder beet (*Beta vulgaris* L.) were grown in containers with a surface area of 0.63 m^2. The containers were filled with 10 cm gravel at the bottom, covered by 30 cm sandy soil, with an organic matter content of 3.5%. Hence, the profile resembled a drought-sensitive sandy soil with a water supplying capacity of about 50 mm. Crops were fertilized according to 'good farming practice'. The containers were protected from rainfall by a transparent shelter. Crops were grown:

a) at optimal supply of water ('no drought', continuously 20 volume % water in soil, pF 2.0),
b) with a period of mild drought stress in early July - generally the driest period in the Netherlands – imposed by withholding water until the plants wilted at daytime but still recovered at night, keeping that water content of the soil constant for 10 days ('mild drought', 8 volume % water, pF 3.0), and
c) with a period of severe drought: no watering for 8 days after the moment plants started wilting ('severe drought', finally 4 volume % water, pF 4.2). After the drought periods, water content of the soils was restored to that of the treatment 'no drought'. Water consumption was monitored by weighing the containers twice weekly. Simultaneously, the same crop species and varieties were grown at different N fertilization levels on sandy soil, near the village of Gastel, to monitor crop performance under field conditions (Van der Schans & Stienezen, 1998).

2.1.2. Results and discussion

Crops re-watered after a period of mild drought stress showed annual yield reductions of less than 10% (Table 1). Grass yields were even increased (+5%) by a short period of drought. Maize yields, however, were reduced on average by 17%. After prolonged drought periods, crop performance strongly varied. Following re-watering, crops capable of forming new leaves (grass, lucerne and beets), rapidly replaced their lost leaves and continued to grow. None of these crops appeared permanently damaged by the drought period, lasting 3 or 4 weeks at most. The magnitude of yield depression is then correlated to the length of the dry period, in which photosynthesis was restricted, and to the dry matter lost during that period (mainly leaves). In the field experiments, drought sometimes lasted for more than 6 weeks, leading to death of the grass sward and, hence, the need for reseeding. Sward deterioration was clearly more severe at higher N fertilization levels.

Table 1. Average yield depression due to drought (% difference with dry matter yield 'no drought', 1994-1996).

	Mild drought	Severe drought
Perennial ryegrass	+5	-10
Lucerne	-9	-24
Triticale	-3	-7
Fodder beets	-9	-19
Maize	-17	-37

The relatively strong yield reduction in maize, after a period of severe drought, can be explained by sink limitation. Due to unfavorable conditions during seed set, seed number is very low and formation of new seeds or leaves is impossible (NeSmith & Ritchie, 1992; Artlip et al., 1995; Ray & Sinclair, 1998). If dry matter accumulation capacity of the grains is completely used, photosynthesis is reduced due to substrate inhibition (Van Keulen & Seligman, 1987). Moreover, feed quality at harvest is low, because of the low proportion of grains in total dry matter. For maize, therefore, formation of a sufficient sink capacity is critical, which can be realized, for instance, by a single irrigation during or just after flowering.

Total dry matter production of triticale and the proportion of grains in total yield were only slightly affected by drought, as flowering is rather early in summer, so that the main drought periods are avoided.

Nitrogen yields of all crop species were less affected by drought than dry matter yields. In general, nitrogen is taken up preferentially early in the crop's life cycle, and is subsequently 'diluted' by accumulation of carbohydrates and other nitrogen-free material (Van Keulen, 1977). However, in lucerne, nitrogen yield is reduced stronger than that of dry matter. Nitrogen acquisition of lucerne largely depends on fixation by symbiotic bacteria, which, apparently, is affected more strongly than photosynthesis.

Stubble and root dry matter was determined occasionally at the end of the growing season. Dry matter in roots and stubble of first-year perennial ryegrass was 39 (no drought) to 45% (severe drought) of total dry matter (1995), of first-year lucerne 53 and 69% (1996) and of maize 5 and 10% (1995), indicating that drought more strongly affected harvestable dry matter yield than formation of roots and stubble (Brouwer, 1963).

Water use per unit harvestable dry matter produced (transpiration coefficient; De Wit, 1958) strongly varied among species (Table 2). Lucerne has by far the highest requirement, with, on average, 516 kg water per kg dry matter. Values were higher in the first year than in the second year (data not presented), probably due to the formation of an extensive root system in the first year, which is only partially replaced and extended in the second year (Versteeg, 1985). Perennial ryegrass also has a high transpiration coefficient, i.e. 350 on average. The arable crops triticale, fodder beet and maize have much lower transpiration coefficients, 239, 219 and 166, respectively. Comparable results have been reported from Germany by Roth et al. (1988), but results obtained under different climatic conditions may differ considerably and are strongly correlated with average vapor pressure deficit of the air during the growing period (Tanner & Sinclair, 1983; Ehlers, 1997). The low values for the arable crops, compared to lucerne and perennial ryegrass, can be explained by the smaller proportion of dry matter invested in non-harvestable stubble and roots. The low transpiration coefficient of maize is, moreover, due to a more water-efficient photosynthetic mechanism (C_4), typical for crops originating from tropical and sub-tropical regions (Van Keulen & Van Laar, 1986). Evaporation from bare soil, kept at field capacity, was only 10–15 % of the evapotranspiration of optimally watered crops.

Table 2. Average seasonal transpiration coefficients (1994 –1996, kg water/kg harvestable dry matter).

	No drought	Mild drought	Severe drought
Perennial ryegrass	362	357	330
Lucerne	502	483	564
Triticale	251	238	228
Fodder beets	216	224	216
Maize	162	167	170

Average seasonal transpiration coefficients of the objects 'no drought', 'mild drought' and 'severe drought' were almost identical (Table 2), i.e. they were not affected by water availability to the crops. Hence, crops do not use water more efficiently under dry conditions (De Wit, 1958). On sandy soils, transpiration is hardly reduced until almost all available water has been transpired and the crop starts to wilt. Reductions in dry matter production, due to water shortage, are therefore associated with proportional reductions in water consumption, an observation in line with a long research tradition (Briggs & Shantz, 1914; De Wit, 1958; Hanks, 1974; Tanner & Sinclair, 1983; Ray & Sinclair, 1998).

Transpiration coefficients of grass (Table 3) and lucerne strongly increased during periods with high daily maximum temperatures (under Dutch conditions strongly correlated with high vapor pressure deficits). In the other crops this increase was less prominent, possibly because of partial stomatal closure in response to high vapor pressure deficits (Rawson et al., 1977; El-Sharkawy et al., 1984), resulting in lower water losses during such periods. Water use efficiency of grass and lucerne, therefore, is especially low in hot periods in summer, exactly when supplemental (irrigation) water is needed.

Table 3. Average maximum daily temperatures (°C) and transpiration coefficients of perennial ryegrass, for different periods in 1994.

	Period						
	1/5-20/5	20/5-6/6	6/6-21/6	21/6-6/7	6/7-28/7	28/7-23/8	23/8-21/9
No drought	297	203	244	392	754	412	231
Mild drought	306	207	238	407	741	400	227
Severe drought	293	208	239	378	650	407	241
Average	299	206	240	392	715	406	233
Average daily maximum temp.	18	17	18	25	27	24	18

Drought increased the relative amount of dry matter invested in stubble and roots (see also Hamblin et al., 1990; Schapendonk et al., 1997). As a consequence, measured transpiration coefficients could be expected to be higher, because they are based on harvestable dry matter. On the other hand, crop growth and associated water consumption cease during drought periods, generally characterized by high vapor pressure deficits and consequently high transpiration coefficients, so the average seasonal transpiration coefficient should decrease. In reality, the transpiration coefficient is hardly affected by drought (Table 2). Therefore, the drought-induced reduction in proportion harvestable dry matter on the transpiration coefficient seems to be compensated by reduced transpiration in periods with high vapor pressure deficits, coinciding with drought.

2.2. Effects of irrigation on grassland: experiment 'Heino'

2.2.1. Method and materials

The influence of irrigation frequency - without, moderate, intensive - on dry matter production and N uptake by cut perennial ryegrass was studied in the years 1982, 1983 and 1984, at four N-fertilization levels at Experimental Station Heino, situated on sandy soil in the East (Wouters et al., 1992). Groundwater level was between 2.0 and 2.5 m below surface, hence capillary transport did not reach into the rooted zone. The water supplying capacity of the soil was estimated at 125 mm, rather high compared to an average Dutch sandy soil, because of a rather thick upper humic layer (ancient arable field). At the 'moderately irrigated' fields, irrigation started when the soil at a depth of 25 cm reached a moisture content equivalent to pF 2.7 on the fields fertilized with 440 kg N per ha, annually. In the 'intensively irrigated' treatment, irrigation started at pF 2.3. Irrigation rates were adjusted to bring soil water content in the 0-25 cm soil layer to field capacity (pF 2.0). Water was applied very accurately in low doses. In all years a period of serious drought occurred in July and August. Total amounts of applied irrigation water for the object 'moderate irrigation' were 196, 169 and 84 mm for the years 1982, 1983 and 1984, respectively, and 246, 196 and 213 mm for the object 'intensive irrigation'.

2.2.2. Results and discussion

Dry matter yields were clearly raised by irrigation (Table 4), but differences between 'moderate' and 'intensive' were only small. Efficiency of irrigation - additional harvested dry matter per mm irrigation water – increased with fertilization level (Table 5), as at higher fertilization levels less of the additionally produced dry matter is invested in roots and stubble (Ennik et al., 1980). At a fertilization level of 440 kg N/ha, 492 and 682 kg water was needed to produce 1 kg additional harvestable dry matter ('moderate' and 'intensive', respectively), at 220 kg N/ha 26-30% more. These values are in agreement with those obtained in other experiments (Van Boheemen, 1984). In all years, irrigation allowed one additional cut in dry periods, and therefore not only resulted in higher annual yields, but also in a more regular grass production. Irrigation did not always lead to higher yields. When irrigation was followed by heavy rainfall, as happened in 1982 after the second cut, anaerobic conditions reduced grass growth and even sward quality. In general, the mild drought stress on non-irrigated fields improved sod quality, especially in the following spring. In some other irrigation trials, cuts following an irrigated cut yielded less than non-irrigated plots (Schothorst & Hettinga, 1983). Irrigation may have resulted in lower levels of reserves in roots and stubble, that sometimes are needed to compensate for unfavorable climatic or management conditions (Hamblin et al., 1990).

Table 4. Yields of dry matter and N in experiment 'Heino' (kg/ha).

Irrigated	N-fert. (kg N/ha)	Dry matter			N		
		1982	1983	1984	1982	1983	1984
Not	0	4500	5700	5300	122	133	111
	220	9700	10100	10000	306	305	258
	440	12300	12500	11800	436	437	407
	660	12300	12700	10800	514	528	479
Moderately	0	6100	7700	6300	153	212	146
1982 = 196 mm	220	11800	13100	12300	354	367	314
1983 = 169 mm	440	14900	16400	14700	512	513	440
1984 = 84 mm	660	15500	17400	13700	626	649	525
Intensively	0	7000	7400	5800	169	197	153
1982 = 246 mm	220	12600	13300	11800	376	358	335
1983 = 196 mm	440	15700	16400	14400	535	504	469
1984 = 213 mm	660	16300	16900	13500	645	636	554

Irrigation resulted in higher uptake of nitrogen, also in non-fertilized fields (43 kg/ha, on average), originating from increased mineralization of organic N. Recovery of N from fertilizers - calculated as: (Nyield fertilized plot – Nyield unfertilized plot)/fertilizer dose) - was improved by irrigation, but decreased at higher fertilization levels. Hence, irrigation in combination with higher fertilization levels – needed to express the higher growth potential - can result in larger amounts of residual mineral N. At the end of the growing season, residual mineral N in irrigated plots was located deeper in the profile than in non-irrigated plots. On plots with a thin humic upper layer, typical for drought-sensitive soils, inaccurate irrigation can easily lead to leaching of nitrate below the rooting depth during the growing season.

Table 5. Efficiency of irrigation (kg additional dry matter and N per mm irrigation water) in experiment 'Heino'.

Irrigated	N-fert. (kg N/ha)	Dry matter 1982	Dry matter 1983	Dry matter 1984	N 1982	N 1983	N 1984
Moderately	0	8	12	12	0.2	0.5	0.4
	220	11	18	27	0.2	0.4	0.7
	440	13	23	35	0.4	0.4	0.4
	660	16	28	35	0.6	0.7	0.5
	Average	12	20	27	0.3	0.5	0.5
Intensively	0	10	9	2	0.2	0.3	0.2
	220	12	16	8	0.3	0.3	0.4
	440	14	20	12	0.4	0.3	0.3
	660	16	21	13	0.5	0.6	0.4
	Average	13	17	9	0.4	0.4	0.3

2.3. Effects of groundwater level on grassland: experiment 'Steenbergen'

2.3.1. Method and materials

Between 1964 and 1974, the influence of groundwater level on dry matter production and N uptake of permanent grassland on sandy soils was studied in the Central and Eastern parts of the Netherlands (Van Steenbergen, 1977; Noij et al., 1997). Fields were classified (Table 6) as 'rather dry' (groundwater level 85–131 cm below surface), 'humid' (51–99 cm) or 'wet' (30–66 cm). Fertilization levels varied between 0 and 500 kg N/ha, annually. To maintain a sward quality comparable to that on commercial farms, cutting-only treatments were applied once in three years. In the two other years, plots were fertilized according to treatment, but used alternately for cutting and grazing, making it impossible to measure yields accurately. Each field comprised three replicates, and each year one replicate was used for estimating crop yields by cutting. Harvestable dry matter and N yields are presented as averages of all growing seasons, of the wet growing seasons 1965 and 1966 only, and of the dry seasons 1964, 1967, 1970 and 1971 (Table 7).

Table 6. Average groundwater level (1964–1974; cm below surface) in experiment 'Steenbergen'.

Field classification	Winter 1/11-28/2	Spring 1/3-30/4	Early summer 1/5-30/6	Late summer 1/7-31/8	Autumn 1/9-31/10
Rather dry	93	85	120	126	131
Humid	55	51	85	99	99
Wet	30	38	59	66	62

2.3.2. Results and discussion

Dry matter and N yields of the unfertilized plots are fairly high compared to values currently obtained in field trials. This is mainly due to the fertilizing effects of excreta of grazing cattle. In the year yields were measured by cutting, residual effects of excreta, voided in the preceding two years during grazing, can have resulted in higher yields, especially of the 'unfertilized' plots. Due to the high N yields in the non-fertilized plots, recovery of fertilizers is rather low. For our purpose – analyzing effects of water and nitrogen supply on yields - that effect is not serious.

Humid plots have the highest average dry matter yields. Moreover, yield is most stable, convenient for a farmer, because relatively wet or dry years do no affect fodder production to such an extent that the diet of cattle has to be changed. On rather dry plots, dry matter yield is strongly determined by rainfall during the growing season. Crop production in dry years may be too low to cover the grazing requirements. Severe damage to the sward, caused by drought, was not reported and is not plausible, because very drought-sensitive soils and extremely dry years were not included. On wet soils in wet years, crop production is negatively affected as a result of poor functioning of the roots, leading to a low uptake of fertilizers. Moreover, in that situation grazing is risky, because the sward can easily be damaged by trampling.

N yields of unfertilized plots are lowest on rather dry fields, especially in relatively dry years, as mineralization of organic nitrogen is most strongly reduced in dry soils. In wet years, however, mineralization on dry soils is stimulated and on humid and wet soils obstructed, resulting in the highest N yields on dry soils. Dry matter yields of non-fertilized plots are strongly related to the amount of N originating from mineralization. The recovery of applied fertilizers is negatively correlated to seasonal rainfall, and is lowest on wet soils.

Table 7. Yields (kg/ha) of harvestable dry matter (Dm) and nitrogen (N) as averages of the years 1964-1974, of the wet years 1965 and 1966, and of the dry years 1964, 1967, 1970 and 1971 in experiment 'Steenbergen'.

	N fertilization (kg/ha)					
	0	100	200	300	400	500
All years						
Rather dry fields						
N yield	161	208	266	331	375	424
Dm yield	7090	8890	10010	11280	11560	12030
Recovery fertilizer		0.47	0.51	0.54	0.53	0.52
Humid fields						
N yield	204	247	309	385	414	477
Dm yield	8330	10020	11280	12700	12630	13390
Recovery fertilizer		0.39	0.48	0.55	0.50	0.52
Wet fields						
N yield	199	239	288	348	374	414
Dm yield	8130	9630	10880	12290	12310	12660
Recovery fertilizer		0.36	0.41	0.46	0.43	0.42
Relatively wet years						
Rather dry fields						
N yield	197	238	296	347	383	431
Dm yield	8350	9820	11150	12180	12480	12730
Recovery fertilizer		0.40	0.46	0.47	0.45	0.45
Humid fields						
N yield	178	213	259	326	336	402
Dm yield	7750	9380	10590	12290	11890	13040
Recovery fertilizer		0.34	0.39	0.46	0.39	0.44
Wet fields						
N yield	166	188	237	269	286	312
Dm yield	6660	8350	10020	10780	10430	11010
Recovery fertilizer		0.21	0.34	0.33	0.31	0.30
Relatively dry years						
Rather dry fields						
N yield	144	190	246	311	358	408
Dm yield	6300	8210	9320	10630	11000	11520
Recovery fertilizer		0.46	0.49	0.54	0.54	0.52
Humid fields						
N yield	218	257	324	395	438	498
Dm yield	8470	9940	11460	12640	12790	13500
Recovery fertilizer		0.36	0.48	0.53	0.52	0.53
Wet fields						
N yield	205	242	290	358	395	443
Dm yield	8250	9620	10810	12550	12580	13060
Recovery fertilizer		0.34	0.39	0.47	0.46	0.46

3. Management options in dairy farming: experimental farm 'De Marke'

3.1. Method and materials

Current dairy farming systems have to be adapted in the near future, especially in sandy regions, to reduce negative impacts on the environment to levels acceptable by society. To identify options for commercial farms in the long term, research started in 1988, by designing farming systems that, theoretically, combine strict environmental goals with a milk production intensity similar to that on commercial farms (on average 12.000 kg/ha). The environmental goals include increased production of high-quality groundwater. One of these systems was selected for testing and improvement under practical conditions at farm scale. This prototype experimental farm, 'De Marke', is located in the East of the Netherlands on light sandy soil, and will continue at least until 2002 (Aarts et al., 1992; 1999a; b). The name of the farm has a symbolic meaning. A 'marke' is an old legal form to manage common land in that region. Now again there is a common interest: exploring the options and constraints for efficient dairy farming in a clean environment and attractive landscape. Prototyping is funded equally by the Ministries of Agriculture and the Environment and by the Farmers Union. Research is conducted jointly by the Research Institute for Cattle, Sheep and Horse Husbandry (PR), the Centre for Agriculture and Environment (CLM) and AB-DLO. In 1989, most of the land was acquired and used as intended; however, cattle were introduced in 1992.

The land comprising the farm was reclaimed from heather at the beginning of this century. An upper layer of 25 to 30 cm with an organic matter content of 4.9% overlies a layer of practically humusless sand. Groundwater level is at most places so deep that water cannot reach the root zone by capillary transport. The low groundwater level is partly (50 cm) due to groundwater extraction close to the farm of 5 million m^3 annually by a drinking water company. The water supplying capacity of the rooted zone is less than 50 mm on most of the fields.

The proportion of grassland in the total area of 'De Marke' is smaller than on most commercial farms, and the proportion of maize consequently larger (Table 8). The main reason is the demand for energy-rich feed with a low nitrogen content to compensate for the rather high nitrogen contents of the grass products in the ration to reduce N excretion by cattle. Moreover, the water and fertilizer requirements of grass per unit harvestable dry matter are much higher than for maize. Nevertheless, also at 'De Marke' the area of grassland still exceeds that of maize. Important reasons are the required N and P supply to cover the feed requirements of the cattle, the possibilities for grazing, and the fact that more animal manure can be applied per ha grassland. Grazing of lactating cows is restricted to 8 hours daily and cows are stabled in autumn one month earlier than on commercial farms to reduce the number of urine patches and the associated nitrate leaching (Deenen & Middelkoop, 1992).

Table 8. The water balance of 'De Marke' and of an 'average' commercial farm.

	De Marke 1993-1996	Commercial farm 1997
Crop proportion (%):		
- grass	55	80
- maize	36	20
- fodder beet	9	0
Harvestable yield (kg dm/ha):		
- grass	9800	10780
- maize	10800	11880
- fodder beet	14400	15840
Water consumption grassland (mm):		
- crop production	343	377
- outside growing season	75	75
- total	418	452
Water consumption maize land (mm):		
- crop production	178	196
- outside growing season	109	74
- total	287	270
Water consumption fodder beet land (mm):		
- crop production	320	
- outside growing season	50	
- total	370	
Average water consumption farm (mm)	367	416
Rainfall	844	844
Groundwater production (mm)	477	428

The farm area is divided into permanent grassland (near the stable, convenient because cows are milked indoors) and two crop rotations. In crop rotation I, located rather close to the stable ('house plot'), a three-year grassland period is followed by three years arable cropping, and in rotation II, located at a greater distance ('field plot'), by five years. Until 1995, fodder beet were grown the first year after a grass period, followed by maize. Since then, maize is the only arable crop, because it appeared more attractive in feeding while excess nitrate leaching, following breaking up the grass sward (Whitehead, 1990), could also be prevented by an adapted maize production system. This implies that in the first year maize is not fertilized and in all years Italian ryegrass is sown between the rows in June, taking up excess fertilizer and nitrogen mineralized from the end of summer onwards, and creating possibilities for grazing the maize stubble in autumn. At the end of February the Italian ryegrass sward is broken up mechanically to reduce evapotranspiration. On most commercial farms, fields are used continuously either for growing maize or grass, and growing a catch crop after maize harvest is not common. Nitrogen fertilization levels at 'De Marke' do not exceed 250 kg/ha for grassland and 100 kg for maize, including N from slurry, clover and green manure, about 40% below the levels on commercial farms. No fertilizers are applied between 15th August and 1st March to reduce the risk of nitrate leaching in the period with limited crop growth and precipitation surplus. Yields of arable crops are estimated per field; grass yields by estimating silage yields and fresh grass yields just before and after grazing. The National Institute of Public Health and the Environment (RIVM) assesses the quality of the upper groundwater annually, just after the growing season.

The permanent grassland and the grassland and arable crops of rotation I, combined about 70% of the total farm area, are irrigated by sprinkling if needed to prevent death of the crop, with the consequence of high costs for reseeding and increased risks of nitrate leaching by increased mineralization (Whitehead, 1990). Additionally, sprinkling is permitted to guarantee grass supply for restricted grazing. Crop rotation II is never irrigated.

3.2. Results and discussion

Irrigation water requirements vary substantially among crops and years (Table 9). Differences among years evidently are associated with differences in rainfall during the growing season. In all years, even in the wet year 1993, grass had to be irrigated, mostly four times a year, with on average 96 mm water (960 m^3/ha), maize with 20 mm and fodder beet with 12 mm only. On average, 70 mm irrigation was needed on the farm area that could be irrigated, equivalent to 50 mm when including the non-irrigated rotation II. On average, 91% of the irrigation water was used on grassland, 8% on maize and only 1% on fodder beet.

Table 9. Irrigation on permanent grassland and crop rotation I at 'De Marke' (m^3 per ha per year).

	1993	1994	1995	1996	Average
Grass	207	915	1238	1565	962
Maize	0	246	605	57	205
Fodder beets	0	0	419	–[1]	124
Average	133	708	1043	970	706

1) No fodder beet were grown in 1996.

Because crop yields at the farm were estimated, water consumption can be roughly estimated by multiplying these yields by the transpiration coefficients, derived from experiment 'Klein Gastel' and its related field trials. For maize, 175 kg water per kg harvestable dry matter is assumed, according to results of the field trials (Van der Schans & Stienezen, 1998), slightly higher than measured in 'Klein Gastel', because of the higher stubble in the field trials. The transpiration coefficient of grass is set to 350 and of beets to 220 (leaves included), values derived from the field trials and experiment 'Klein Gastel'.

Outside the growing season of the crop, water is also lost from soil surface and/or vegetation, the quantity depending on the length of that period. Fields covered with vegetation loose more water through evapotranspiration than bare soils. To calculate water loss outside the growing season, it is assumed that on fields covered by vegetation, evapotranspiration is equal to the Makkink reference evaporation (short well-watered grass crop), and on bare soils 50% (Van Kraalingen & Stol, 1997). From directly after the maize harvest in the beginning of October until

March, the soil is covered by Italian ryegrass. For grassland, the period outside the growing season is supposed tot last from November 1st till 1st of April. The fodder beet crop is supposed to be harvested at the end of November and the soil is bare until mid-April. The associated water loss from maize land, grassland and fodder beet land outside the growing season is 109, 75 and 50 mm of water, respectively. Experiments at 'De Marke' with different levels of fertilization suggest a 10% higher crop yield in commercial farming systems. In those systems no Italian ryegrass is grown, resulting in 35 mm lower evapotranspiration outside the growing season of maize land. Transpiration coefficients of crops at 'De Marke' and on commercial farms are supposedly equal, despite the lower fertilization level of 'De Marke', which might lead to a higher transpiration coefficient of grassland as a result of a higher investment of dry matter in not harvestable stubble and roots (Ennik et al., 1980). However, it is assumed that this is compensated by more irrigation in summer on commercial farms, increasing average transpiration coefficients. Effects of fertilization level on arable crops, like maize, are not to be expected, because the partitioning between harvestable and not harvestable parts is only slightly affected (De Wit, 1958; Tisdale et al., 1985; Walker & Richard, 1985; Bürckly, 1993).

Water consumption of grassland is 34 mm lower on 'De Marke' than on an average commercial farm (Table 8), but of maize land 17 mm higher due to the presence of Italian ryegrass. However, water consumption of maize land is substantially below that of grassland. Mainly because of the smaller proportion of grassland at 'De Marke', compared to commercial farms, average water consumption per ha appears to be 49 mm lower in the situation that fodder beet were grown. In 1996, fodder beet were replaced by maize and, as a consequence, the difference between water consumption of an 'average' dairy farm and 'De Marke' increased to 57 mm. Moreover, the quality of the groundwater at 'De Marke' is acceptable, as shown in Table 10.

Table 10. Nitrate concentration in the upper groundwater of experimental farm 'De Marke' (mg/l).

	1990	1992	1993	1994	1995	1996	1997
Permanent grassland	159	80	50	43	60	52	96
Rotation I	220	117	43	46	54	36	49
Rotation II	181	104	53	35	35	20	47
Average of the farm	199	107	47	43	51	35	57

After establishment of 'De Marke', average nitrate concentrations in the upper groundwater rapidly decreased from 200 mg/l to the threshold level of 50 mg/l. Levels below permanent grassland are relatively high, probably due to their relatively intensive grazing regime because they are located close to the stable. Additional costs of the experimental system for increasing groundwater quantity and improving quality, compared to current commercial farming, are estimated at about 1.5 EURO/100 kg milk, 180 EURO/ha and 5,400 EURO for a farm of average size.

4. Discussion

4.1. Crop selection

The experiment 'Klein Gastel' has shown that forage crops under Dutch conditions differ considerably in water consumption per unit harvestable dry matter. These differences are to a large extent associated with differences in the fraction of total dry matter production invested in non-harvestable stubble and roots. Therefore, from the point of view of water economy, it seems attractive to replace (perennial) grass by (annual) forage crops like fodder beet, triticale or maize. However, other considerations set a limit to the degree of replacement, i.e. the N and P contents of forage crops are lower, which may interfere with the minimum requirements in feeding cattle. Moreover, more slurry can be applied to grassland, and grass can be harvested by grazing, supposedly beneficial to the health of cattle. Especially on light sandy soils, the larger proportion of non-harvestable parts of grass, compared to forage crops, can play an important role in providing the soil with organic matter, needed to maintain or improve soil fertility characteristics, such as water holding capacity.

Fodder beet have the disadvantage that cultivation, storage and feeding are rather laborious and expensive. Maize, with its high energy and low nitrogen content, is an excellent feed in combination with grass, allowing a high milk yield per cow and a low excretion of N, resulting in reduced ammonia volatilization and nitrate leaching from urine and dung patches. As farmers on sandy soils are familiar with maize cultivation, expanding its area requires no additional management skills or machinery, and involves low costs. On very drought-sensitive soils, however, availability of water during flowering of maize is critical for yield formation. Therefore, possibilities for some irrigation in dry summers may be essential to realize acceptable levels of yield and quality. If irrigation is completely banned, triticale seems more suitable because it yields more under those conditions. The experimental system 'De Marke' has shown that about 45% of the farm area can be grown with maize without creating problems in cattle feeding or soil fertility, far more than the 20% on the current 'average' commercial dairy farm.

To reduce leaching, a catch crop following maize, like Italian ryegrass, is necessary, unfortunately leading to increased evapotranspiration after maize harvest. However, at 'De Marke' Italian ryegrass appears valuable from a farm management point of view because it can be used for feeding young stock and provides additional soil organic matter, allowing replacement of grassland by maize, reducing evapotranspiration at farm scale.

4.2. Fertilization

To attain the desired quality of groundwater, fertilization of grass and maize has to be reduced by about 40%, compared to current levels on commercial farms, resulting in a reduction in harvestable yields of about 10%. This reduction in yield can be compensated, as shown at 'De Marke', by reducing the feed requirements by more judicious feeding and a higher milk production per cow, reducing the number of animals on the farm. As a result, purchased feed per 100 kg milk and per ha at 'De Marke' is even lower than on commercial farms.

In general, reduced fertilizer levels lead to lower growth rates and, hence, to slower water consumption. As a consequence, drought stress is less severe, because the moment of depletion of all available water is delayed, reducing the length of drought periods. High fertilization levels result in more harvestable dry matter of grassland, partly because of a more favorable partitioning of dry matter (less roots and stubble). As a result, irrigation is more efficient at high fertilization levels, in terms of additional harvestable dry matter per mm irrigation water. However, reduced investment in stubble and roots can unfavorably affect sward quality and thus require more frequent reseeding. Especially the combination of frequent irrigation and high fertilization levels is threatening sward quality. Moreover, even at high fertilization levels, efficiency of irrigation in dry (hot) periods in terms of additional dry matter per unit irrigation water is very low, with probably 2 kg harvestable dry matter per m^3 water at most, representing a value of about 0.25 EURO.

From the point of view of water management, nitrogen fertilization of grassland is most profitable in spring. Water is used most efficiently then, as water requirement per kg harvestable dry matter is related to temperature, as shown in experiment 'Klein Gastel'. Therefore, a larger part of the total annual fertilizer dose should be applied in spring and early summer than under current management on commercial farms, leading to relatively high grass yields in spring. Fortunately, grass silage harvested in that period is in general of higher quality than silage harvested later.

4.3. Grazing

Grazing has to be restricted, especially in late summer and autumn, to limit leaching from urine patches. Restricted grazing has the additional advantage that more of the excreta are collected in the stable and can be used as fertilizer, saving costs on mineral fertilizers. If cows are stabled relatively early in autumn, fertilization can be stopped earlier because no fresh grass is needed for grazing in autumn. In general, limiting fertilization in late summer and autumn will make the sward less susceptible to frost damage, reducing the need for reseeding and the related risk of nitrate leaching.

4.4. Irrigation

On dry sandy soils irrigation can be needed to prevent dying of crops, which would lead to high costs of reseeding and high risks of nitrate leaching (reduced uptake of nutrients and increased mineralization after reseeding). More research is needed to establish under what combinations of conditions, with respect to drought (intensity and length), fertilization (time and dose) and grassland utilization (grazing, cutting), grass swards will be permanently damaged if not irrigated timely. Field observations suggest that on sandy soil drought-susceptibility of the grass sward increases with age. If so, a rotation of grass and maize can be attractive to reduce irrigation needs of grassland. Moreover, frequent irrigation presumably increases drought-susceptibility. Both observations could be explained by a shallower rooting depth, induced by compression of the (sub) soil and availability of water and nutrients in upper layers only. However, no research results are available to support these hypotheses. Maize may need irrigation only during flowering, grass during a much longer period. Therefore, replacing grass by maize, in general, reduces the need for irrigation. The amount of irrigation water should not exceed the storage capacity of the rooted zone. Moreover, because of irregular distribution of irrigation water on commercial farms, high doses may locally cause leaching, and damage to the sward, as observed in experiment 'Heino'. Irrigation can start 'too early', because some drought stress may improve sward quality, resulting in higher production in the long term. However, irrigation may result in one additional cut and more evenly spread grass production in the course of the season, which is attractive from a grazing point of view.

Irrigation, or a relatively wet growing season, stimulates mineralization on light sandy soils. Moreover, the additional cut under irrigation requires additional fertilizer, with the associated risks of leaching of residual N. Production of grass for grazing during drought periods, based on irrigation, requires large amounts of water per kg dry matter and additional fertilizer. Restricted grazing during drought periods, therefore, will reduce irrigation and fertilization requirements.

4.5. Groundwater table

Results of 'De Marke' show that percolation, i.e. 'production' of groundwater, of a much better quality than on commercial farms, can be increased by about 55 mm or 550 m^3/ha. To allow 'harvest' of this additional surplus, water has to be stored temporarily in the soil, leading to higher water tables, especially in spring and early summer. The amount of 55 mm corresponds to about 18 cm difference in groundwater level. The higher groundwater level will affect crop yields only when it reaches the upper meter of the soil. Groundwater levels between 1 and 0.5 m result in higher crop yields, and the effects of saving on crop water use are then attractive from both an agricultural and environmental point of view, as shown in experiment 'Steenbergen'. Grass production is more stable and fertilizer utilization efficiency improves. In that situation, however, part of the stored water will be 'lost' by increased transpiration of the crops, associated with increased growth. However, shallower groundwater levels, reaching the rooted zone, result in lower recovery of fertilizers, as a substantial part of the mineral nitrogen may be lost by denitrification, not negatively affecting the quality of groundwater, but contributing to the greenhouse effect through the production of di-nitrogen oxides. Moreover, in that situation, groundwater quality may be negatively affected by increased concentrations of P (Aarts et al., 1999a), while lower parts of the farm may become so wet that problems occur for grazing or crop growth. Cultivation of maize may even become impossible.

4.6. Economics

In the Netherlands, average annual per capita water consumption is 50 m^3, i.e. the additional groundwater production of 550 m^3/ha, realized at 'De Marke', can replace surface water for 11 individuals. At an average farm size of 30 ha, about 330 persons could profit from improved water management.

Additional costs for purification of surface water, compared to groundwater, are about 0.50 EURO per m^3 (L. Joosten, pers. comm., Netherlands Drinking Water Association), so 8,250 EURO would be saved, not taking into account the higher quality of the groundwater, reducing costs of purification. When current agricultural practices continue, drinking water companies in sandy areas will have to invest in additional purification of groundwater, estimated at 100 million EURO annually (Joosten et al., 1998). The additional costs at dairy farming system 'De Marke', for production of a larger quantity groundwater of excellent quality, are estimated at about 5,400 EURO for a farm of average size.

5. Conclusion

In theory, integration of groundwater management in dairy farming on sandy soils seems to be feasible and attractive for farmers, drinking water companies and nature organizations and deserves support of Dutch society. It might be feasible to estimate groundwater production and quality of individual farms on the basis of farm data like crop areas, use of fertilizer and irrigation water, data monitored already or soon needed for other purposes (Van der Molen et al., 1998). Additional information may be needed on soil properties. Measures, such as temporary storage of precipitation surplus through reduced drainage, leading to shallower groundwater levels, require collaboration of farmers, regional authorities and water companies, but seem realistic.

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