Re-balancing soil-plant-animal interactions: towards reduction of nitrogen losses

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Abstract

The practice of farming implies a continuous process of re-moulding and re-balancing of resources. Normally, this process is slow and hardly noticeable, but in times of transition towards sustainability it is accelerated and becomes more visible. Re-moulding and re-balancing require a careful and multi-faceted monitoring as well as a high degree of involvement of the farmers concerned. This article is an overview that documents several aspects of the changes realized by two farmer co-operatives in the northern Netherlands: Vereniging Eastermar's Lânsdouwe (VEL) and Vereniging Agrarisch Natuur en Landschapsonderhoud Achtkarspelen (VANLA). It is shown that farmers process and manage manure, silages and diets. Emphasis is given to indications that the newly emerging balances are characterized by high levels of N efficiency. In a final combination of beta and gamma approaches it is shown that the goal-oriented practices of the VEL and VANLA farmers clearly indicate new trajectories towards and prospects for sustainability. Furthermore it is shown that recognition of relevant heterogeneity is crucial and that inter-farm comparisons, careful integration of beta and gamma approaches and multivariate modes of analysis are needed.

Additional keywords: dairy farming, monitoring, farming systems

Introduction

Farming is the art of fine-tuning, requiring the highest possible level of coherence through an active, reiterative and expert process of co-ordination and re-adjustments. Through fine-tuning a process of re-balancing is realized: resources are re-combined into new balances. Re-balancing is not a finite process as presumed for instance by Schultz (1964). Since fine-tuning considers resources and growth factors, re-balancing is a continuous process entailing time and again new possibilities.

Resources such as fields, cattle, crops, manure and water-management systems are to be unraveled and re-moulded in order to create combinations that are as productive and sustainable as possible. Evidently, this unraveling and re-moulding require fine-tuning (Bouma, 1997; Groen *et al.*, 1993; Portela, 1994; Van Der Ploeg, 2003). Because of mutual improvement of resources as well as mutual adjustment of relevant growth factors, specific, endogenous development trajectories and potentials are emerging and sustained.

With increasing insights – i.e., with developing local and/or scientific knowledge – and with adjusted singular growth factors (of whatever type) the relevant whole is to be re-balanced time and again. So, step-by-step improvements are created – a process that sometimes should be accelerated considerably.

Mostly, the process of re-balancing is slow, highly routinized and therefore more or less unnoticeable, although careful empirical analysis can bring out its presence and potential (Swagemakers, 2002). In periods of transition, however, re-balancing of farming systems as a whole comes to the fore.

The need for and prospects of re-balancing

In the early 1990s, a clear and new possibility to reshape farming arose at two farmer co-operatives in the northern Netherlands – Vereniging Eastermar's Lânsdouwe (VEL) and Vereniging Agrarisch Natuur en Landschapsonderhoud Achtkarspelen (VANLA) – to meet new environmental goals (Koeleman, 2003; Van Der Ploeg, 2002). Decisive for this was an agreement between the two co-operatives and the Minister of Agriculture that facilitated the creation of region-specific solutions to the many environmental problems (Renting, 2001). Environmental problems in this specific region are conceptualized broadly, i.e., they not only include nutrient losses but also landscape, nature, biodiversity, support by the surrounding community, product quality and water management.

So, an active search for a new balance in dairy farming, the dominant farming system in the region, was triggered. The search started in 1997 with a registration of the nitrogen (N) flows on the farms involved (n = 93), 3 years before the Dutch government obliged it. For this registration the 'MINAS' nutrient bookkeeping system is used, which is derived from the EU Nitrate Directive. Farmers have to monitor all incoming (mainly feed and fertilizer) and outgoing (mainly milk and meat) N at farm level on an annual basis. The difference between input and output is the N surplus, which is set to a maximum, and levies have to be paid if this maximum is exceeded (Henkens & Van Keulen, 2001). For sandy grassland soils the 'MINAS' maximum for 2003 has been set at a 180 kg N ha^{-1} $year^{-1}$.

To estimate the amount of N (kg ha^{-1}) in the fodder produced on the farm, the amounts of NEL (net energy lactation, MJ ha^{-1}) in feed were computed according to Van Bruchem *et al.* (1999). The amount of NEL in purchased feed was subtracted from the NEL requirements of the herd, including dry cattle and young stock. Following the observations of experimental farm A.P. Minderhoudhoeve and several commercial farms in the Netherlands the NEL requirements are corrected with a factor 1.1 (J. Van Bruchem, personal communication). From each farm the NEL/N ratio in grass silage and fresh grass was determined and the amount of N in feed produced on the farm was calculated. The amount of N in manure was calculated as N in imported feed and feed produced on the farm minus the N in milk and meat.

The results showed a considerable variation among the VEL and VANLA farms (Table 1). Output ranged from 31 to 93 kg N ha^{-1} $year^{-1}$, with an average of 63 kg N ha^{-1} $year^{-1}$ (approximately 11,500 kg milk ha^{-1}). Some farms already used a relatively low inorganic fertilizer rate (154 kg N ha^{-1} $year^{-1}$) while other ones exceeded 400 kg N ha^{-1} $year^{-1}$. The average dose was 292 kg N ha^{-1} $year^{-1}$. The amount of N imported with concentrates ranged from 31 to 197 kg N ha^{-1} $year^{-1}$ per farm, with an average of 97 kg N ha^{-1} $year^{-1}$. The calculated N surpluses ranged from 162 to 560 kg N ha^{-1} $year^{-1}$. This means that already in 1996 there were farms that met the 2003 norm, while other farms still had to reduce their surplus considerably. The average N surplus of the farms involved was 326 kg N ha^{-1} $year^{-1}$, while the average surplus for the northern provinces at that time was about 350 kg N ha^{-1} $year^{-1}$. The apparent animal-N efficiency ranged from 8 to 24%, with an average of 17%. Apparent soil-N efficiency ranged from 33 to 78% with an average of 46%. At farm level apparent N efficiencies ranged from 10 to 28% with an average of 16%.

The variation in apparent N efficiency and N flows among the farms raised considerable debate within the two co-operatives about the relationships between productivity and the use of inputs. Some relationships are shown in Table 2. The average dry matter yield per ha per farm was not related to the use of inorganic N fertilizer and the

Table 1. N flows and efficiencies for the VEL and VANLA farms (n = 93) from 1 May 1995 to 30 April 1996.

	Minimum	Mean	Maximum
N flow (kg ha^{-1})			
Product	31	63	93
Concentrates	31	97	197
Inorganic fertilizer	154	292	478
Feed produced on farm	182	280	434
Slurry manure	195	314	533
Surplus	162	326	560
N efficiency (%)			
Animal level[1]	8	17	24
Soil level[2]	33	46	78
Farm level[3]	10	16	28

[1] Calculated as product over (concentrates + on-farm produced feed).
[2] Calculated as homegrown feed over (inorganic fertilizer + slurry manure).
[3] Calculated as product over (inorganic fertilizer + concentrates).

Table 2. Generic relationships[1] derived from first regional appraisal.

Equation[2]
Dry matter yield = 7618 + 4.15 (1.91*)[3] × N fertilizer [R^2 = 0.049]
N surplus = 165 + 24.1 (7.87**) × milk yield [R^2 = 0.094]
N product = 28.3 + 0.281(0.026***) × N concentrates + 0.024 (0.012*) × N fertilizer [R^2 = 0.632]

[1] The generic relationships were derived from (multiple) regression analyses.

[2] All quantities are in kg ha^{-1} except milk yield (t $year^{-1}$).

[3] Standard error of the mean in parentheses. * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

N surplus was not related to the amount of milk produced per cow. The amount of N produced per ha was strongly related to the amount of concentrates imported: the more intensive the farm, the more N was imported.

Figure 1 (based on 37 farms and on the agricultural year 1998/99) presents the outcome of a 'soil-plant-animal-manure' analysis. It compares the 1995/96 data with the ones of 1998/99. All farms with available and reliable data were included in this

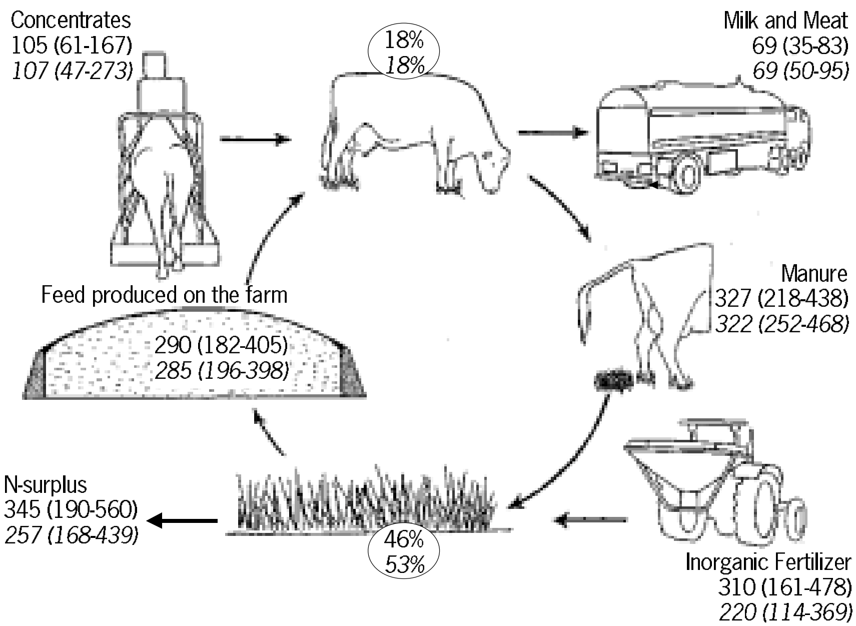

Figure 1. Average, minimum and maximum N flows (kg ha^{-1} $year^{-1}$) in the soil-plant-animal-manure system of 37 VEL and VANLA farms before the start of the project (1995/1996: upper data) and during its second year (1998/1999: lower data), and average animal- and soil-N efficiencies (%).

comparison. Figure 1 shows that a drastic reduction in N surplus had been realized within a few years. Inorganic N fertilizer use had been sharply reduced, whilst the apparent soil-N efficiency had slightly improved. Figure 1 also shows that the decrease in N fertilizer use (from 310 kg N ha^{-1} in 1995/96 to 220 kg N ha^{-1} in 1998/99) had not caused a reduction in production or an increase of the amount of concentrates imported. The average farm-N efficiency increased from 17 to 21%, a relative increase of 24%. The N surplus decreased from 345 kg ha^{-1} to 257 kg ha^{-1}, a relative decrease of 34%. An important additional effect in these first years, in which attention was focused on decreasing inorganic fertilizer use, was that farmers also became familiar with on-farm experimentation. This turned out to be highly useful when more difficult steps in the construction of a more sustainable way of farming were to be taken.

Re-moulding resources

Using the results of the first analyses together with the successful strategies developed by local innovators, the co-operatives and the researchers supporting the co-operatives

Table 3. Progress by the VEL and VANLA farms over the period 1997/1998 – 2001/2002 (n = 55)[1].

	1997/1998	1998/1999	1999/2000	2000/2001	2001/2002
N input (kg N ha^{-1})					
Feed	95	98	105	91	101
Inorganic fertilizer	266	232	183	152	136
Slurry manure	3	2	10	6	4
Other	1	2	2	1	1
N output (kg N ha^{-1})					
Milk	59	60	59	59	60
Meat	10	11	17	10	11
Roughage	1	1	1	0	0
Slurry manure	1	1	5	0	0
Other	0	2	0	0	0
Surplus (kg N ha^{-1})	270	255	204	184	172
N efficiency at farm level (%)	21	27	29	32	33
Farms that meet legislation (%)	11	18	33	49	67

[1] Average annual milk production per farm: 539,700 kg (156,398–1,368,483 kg).
Farm acreage: 49 ha (12–101 ha).

Table 4. Composition[1] of diets, grass silage and cattle slurry manure, and animal performance for the VEL and VANLA farms in the seasons 1998/1999 and 1999/2000, in comparison with experimental farm 'A.P. Minderhoudhoeve' (APM) for 1999/2000. Standard error of the mean in parentheses.

	1998/1999	1999/2000	Statistical significance[2]	APM 1999/2000
Diet[3]				
NEL[4] (MJ kg^{-1})	6.51 (0.034)	6.48 (0.039)		5.95
DVE[5] (g kg^{-1})	86 (1.21)	86 (0.9)		77
CP[6] (g kg^{-1})	170 (2.4)	159	$P < 0.001$	131
OEB[7] (g day^{-1})	625 (38.6)	355 (41.9)	$P < 0.001$	–18
Concentrates (kg per kg milk)	0.30 (0.015)	0.27 (0.009		0.19
Feed produced on farm (%)	59.7 (1.26)	63.7 (1.15)	$P < 0.01$	73.0
Grass silage				
NEL (MJ kg^{-1})	5.99 (0.052)	6.03 (0.048)		5.97
CP (g kg^{-1})	176 (3.1)	158 (2.7)	$P < 0.001$	131
Slurry manure				
N total (g kg^{-1})	4.7	4.8		2.8
N mineral (g kg^{-1})	2.6	2.2	$P < 0.01$	1.4
Production				
Milk (kg day^{-1})	24.5 (0.57)	24.2 (0.43)		27.5
Milk fat (%)	4.50 (0.037)	4.55 (0.030)		4.52
Milk protein (%)	3.48 (0.018)	3.49 (0.017)		3.33
Milk urea (mg l^{-1})	27.7	21.5	$P < 0.001$	18.7

[1] On a dry matter basis.
[2] Paired Student T test.
[3] November–February.
[4] NEL = net energy lactation.
[5] DVE = digestible protein in the intestine.
[6] OEB = undegradable protein balance in the rumen.
[7] CP = crude protein.

developed a strategy for further reducing N surpluses. The strategy included elements like (1) revitalization of soil life, by (2) a further decrease in the amount of inorganic N fertilizer, (3) improving slurry manure quality, (4) changing the slurry-manure and inorganic-fertilizer application strategies, (5) cutting the grass at a more mature stage, and (6) feeding the cows lower-protein and higher-fibre diets. In other words, the strategy basically aimed at making better manure, better feed and fodder as well as improving the soil. Thus resources were to be re-moulded, whilst the relevant whole (the soil-plant-animal system) was re-balanced.

Sixty farmers agreed to work according to this strategy. Strategy and first results were thoroughly discussed in small groups of farmers. The N surplus was reduced through re-moulding and re-balancing (Table 3). The table shows the changes in N surplus. In 1997, a small percentage of the farms (11%) met the norm set by legislation for 2003, whereas in 2001 the norm was met by already 67%.

Re-moulding feed and fodder as part of re-balancing

Based on the first findings at the experimental farm A.P. Minderhoudhoeve (Koeleman, 2003), more specific guidelines were formulated for diet composition at the VEL and VANLA farms. These guidelines can be summarized as follows:

- Limit crude protein (CP) to about 150 g kg^{-1} dry matter (DM) or less.
- Limit net energy lactation (NEL) to about 6.2 MJ kg^{-1} DM or less.
- DVE-values must fulfil requirements [DVE is the Dutch standard for the sum of the digestible feed and microbial true protein available in the small intestine of the cow (Tamminga *et al.*, 1994)].
- Limit OEB to 0 g day^{-1} [OEB is the Dutch standard for the difference between potential microbial synthesis based on degraded feed protein and synthesis based on energy available for microbial fermentation in the rumen (Tamminga *et al.*, 1994)].

DVE and OEB have been developed for a more N efficient feeding. A surplus of OEB will result in a higher urea secretion in the urine. This can lead to an increase of ammonia volatilization (Erisman, 2002; Smits *et al.*, 1995).

Using the guidelines, from 1999/2000 onwards the participating farmers started to adapt several management practices. Initial results are shown in Table 4. Farmers succeeded in lowering dietary protein content by 11 g per kg DM, which was mainly due to a decreased protein content in grass silage. The lower OEB can be attributed to a reduction in CP surplus, but the variation among farms was still large (Figure 2). About 10% of the farmers succeeded in decreasing dietary protein content by 30 to 40 g kg^{-1}, 10% by 20 to 30 g kg^{-1}, 25% by 10 to 20 g kg^{-1} and 55% by less than 10 g kg^{-1}.

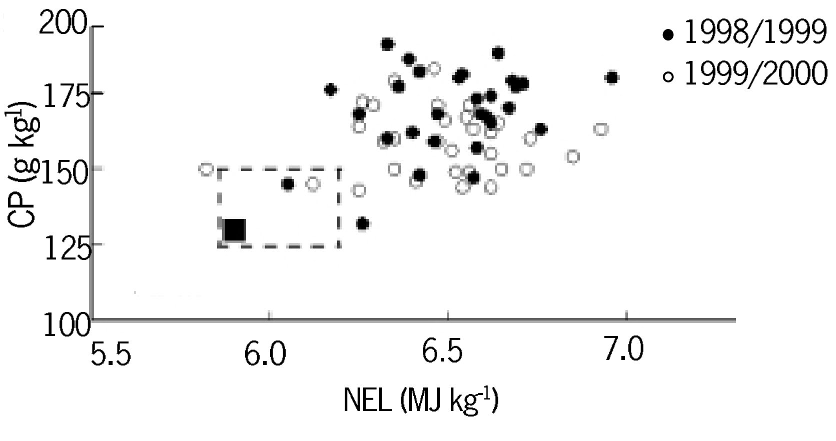

Figure 2. Crude protein (CP) versus Net energy lactation (NEL) for the diets of 33 VEL and VANLA farms in the years 1998/1999 and 1999/2000 and for the A.P. Minderhoudhoeve (APM) diets (■). The broken-line box indicates the values aimed at in the VEL & VANLA project.

In the first year there was not yet a reduction in energy content of the diets.

Farmers reduced the amount of concentrates they purchased by 10%, while milk production and composition did not change. The urea content of the milk decreased considerably (from 27.7 to 21.5 mg per liter milk on average). There were also statistically significant changes in the composition of the slurry manure. Dry matter content and organic matter content increased, the amount of N in the manure remained at the same level while the ratio inorganic N / organic N decreased. The percentage of N available in organic form increased from 45% in 1999 to 54% in 2000. Comparison with the results of the experimental farm A.P. Minderhoudhoeve shows that there are still large possibilities to further decrease the CP and energy content of the diet.

Grass silage as part of the re-balancing strategy

Grass silage is playing an important role in the soil-plant-animal-manure-system of dairy farms. On most farms a major part of the diet consists of grass or grass silage. It is therefore the (most important) link between the subsystems soil and animal. One of the formulated measures of the VEL & VANLA project was to produce silage lower in CP content by reducing the amount of inorganic fertilizer, and higher in crude fibre (CF) content by cutting at a more mature stage. In this way the silage can serve as basis for the low protein/high fibre diets.

Apart from fertilization level and stage of maturity at cutting, the chemical composition of grass silages depends on several other factors. Especially weather conditions

Table 5. Grass silage characteristics of the VEL and VANLA (V&V) farms in the period 1997–2001, in comparison with the national roughage (BLGG) characteristics (Anon., 2002). Standard error of the mean in parentheses.

Year	Source	n	Component[1]					
			DM (g kg^{-1})	CP	CF - - - - - (g per kg DM)	Sugar	DVE	OEB - - - - -
1997	V&V	111	453 (8.0)	179 (2.0)	248 (1.2)	64 (3.2)	65 (0.8)	66 (2.6)
	BLGG		436	182	253	64	66	68
1998	V&V	146	432 (9.0)	166 (2.1)	250 (2.0)	72 (3.3)	68 (1.1)	48 (2.1)
	BLGG		415	174	252	60	70	58
1999	V&V	144	503 (7.2)	158 (1.8)	243 (1.4)	123 (3.6)	74 (0.7)	28 (1.8)
	BLGG		494	180	242	102	78	50
2000	V&V	112	460 (7.8)	167 (1.8)	258 (1.4)	75 (3.7)	72 (0.7)	44 (2.3)
	BLGG		480	176	256	74	76	51
2001	V&V	97	489 (6.0)	155 (1.5)	248 (2.8)	106 (3.2)	74 (0.6)	24 (1.5)
	BLGG		516	173	251	113	81	37

[1] DM = dry matter; CF = crude fibre. For other abbreviations see Table 4.

play an important role. To obtain some idea about their influence, the average composition of all silages produced by the VEL and VANLA farms during the period 1997–2001 was compared with the national average (Anon., 2002). The results show that the national average varies much among years (Table 5). We assume that large part of this variation is due to annual differences in weather and that the differences in weather conditions between the VEL & VANLA location and the country as a whole are comparable for all years.

In 1997, the project had not started yet, so 1997 can be seen as a reference year. In that year CP and CF content of the VEL and VANLA farms hardly differed from the national average. In the course of the project (1998–2001), however, the VEL and VANLA farmers succeeded in reducing CP content. Striking is that the lower CP content did not result in a loss of DVE-value of the silage, but only in a reduction in OEB. This indicates that the protein-nutritional value of the silage remained at the same level while OEB, which is an important indicator of N losses, was reduced. Although the opposite was expected, CF content did not increase over the last 4 years, but the standard error of the mean increased markedly. Indeed, it is known that CF reaches a maximum (Terry & Tilley, 1964), but not all farmers postponed their cutting date to the same extent.

Improving the quality of slurry manure as part of the re-balancing strategy

An important goal of the VEL & VANLA project is to improve the quality of the cattle slurry manure. The most important characteristic farmers aim for is an increase in C/N ratio while at the same time increasing organic-N content and reducing mineral-N content. In this way a reduction of gaseous emissions might be attained. Table 6 shows to what extent the farmers succeeded.

The winter of 1999/2000 was the first period that the project was focusing on the feeding of low-energy/low-protein diets. Average mineral-N content of the slurry manure decreased while the percentage of N in organic form and the C/N ratio increased. Striking is the change in mineral N, the amount decreased with 28.6%. According to Erisman (2000) this would imply a considerable reduction of ammonia volatilization.

A good impression of the underlying changes can be obtained from the percentage farms that produced slurry manure containing less than 50% mineral N (Table 6, last column). Whilst slurry manure in the Netherlands in 1996 contained 54% mineral N on average (Mooij, 1996), 93% of the VEL and VANLA farms involved attained a level below 50%, with a lowest value of 17%.

Experimental plots: checking the effects of re-balancing

Where re-balancing leads to is in a way uncertain. On some farms newly constructed balances may function fairly well, although it remains uncertain for how long this will

Table 6. Cattle slurry manure characteristics for the VEL and VANLA farms in the period 1998–2002 (one sample per farm per winter), in comparison with standard values (Mooij, 1996). Standard error of the mean in parentheses.

Year	n	Component						% farms < 50% N-mineral
		DM (g kg^{-1})	OM	N-total	N-mineral	N-mineral (%)	C/N[1]	
			------- (g per kg DM) -------					
1989	54	90 (2.6)	718 (5.4)	52 (1.0)	28 (1.1)	53 (1.4)	7.0 (0.14)	29
1999	54	93 (3.3)	705 (7.1)	54 (1.5)	30 (1.4)	56 (1.4)	6.8 (0.19)	18
2000	54	96 (1.9)	737 (4.8)	51 (1.0)	24 (1.0)	46 (1.1)	7.3 (0.15)	69
2001	47	99 (2.7)	718 (8.4)	50 (1.0)	20 (0.8)	40 (1.5)	7.3 (0.15)	86
2002	45	92 (2.0)	752 (4.4)	47 (0.8)	20 (0.7)	42 (1.1)	8.1 (0.16)	93
Mooij (1996)		90	733	54	29	54	6.8	

[1] C/N is calculated as 0.5 * OM/2, assuming a 50% C content of the organic matter.

be the case. On other farms the effects may be less prominent or lacking from the beginning if not negative. And even on the relatively successful farms the explanation of their 'relative success' may still be incomplete. The question arises whether this is because of realized interventions and implied growth factors, or do other not yet fully understood and/or explored factors decisive for a proper understanding of what is actually occurring play a role. The answer to this question is important. Only if the real dynamics are understood, a further optimization of the strategies concerned is possible. Therefore, it is precisely within the context of action research (characterized by an on-farm re-balancing) that careful monitoring and control emerge as a strategic need.

Within the VEL and VANLA co-operatives several systematic experiments have been laid out to control the (possibly interrelated) effects of the created changes. These effects concern both the short term and the long term. Many of these experiments reflect the insights and experiences obtained by farmers.

One of these experiments is on grassland production in relation to different slurry-manure application techniques, slurry-manure qualities and soils. The experiment was located on two different farms: Hoeksema's farm in Drogeham and Sikkema's farm in Harkema, hereafter referred to as Drogeham and Harkema, respectively. The two specific locations had been recommended by the VEL and VANLA co-operatives. Drogeham represented – in their view – an exemplary application of the new VEL and VANLA approach, whereas Harkema represented conventional management practices. Drogeham included a combination of improved soils (Bouma, 1997; Sonneveld & Bouma, 2003; De Goede *et al.*, 2003), improved slurry manure [high C/N ratio and the use of additive Euromestmix® (MX)], surface application of slurry manure and low fertilizer rates. Harkema, on the other hand, combined normal slurry manure (without

MX), slit injection, and a different phenoform (Sonneveld & Bouma, 2003) as far as the soil is concerned. Beside this there was also an interest in testing other additives, like Effective Microbes® (EM).

The field experiment was of a split-plot design with two replications per location. The main factor was N, at two levels. The treatments per main plot included 2 types of slurry manure, 2 slurry-manure application methods, 2 levels of additive use (none versus EM), plus 2 control plots, which resulted in 40 experimental units per farm. Physical soil characteristics are described by De Goede *et al.* (2003), and chemical soil characteristics and an outline of the field experiment are presented by Schils & Kok (2003).

Nitrogen levels were 'low' = 76 kg N ha^{-1} $year^{-1}$ (slurry manure, no inorganic fertilizer) and 'high' = 258 kg N ha^{-1} $year^{-1}$ (76 kg slurry-N ha^{-1} $year^{-1}$ + 182 kg inorganic fertilizer-N ha^{-1} $year^{-1}$). The experiment also included control plots, i.e., plots without organic manure. These plots were fertilized with calcium ammonium nitrate at rates of 0, 76 or 258 kg N ha^{-1} $year^{-1}$.

The two types of slurry manure that were used were slurry originating from Harkema (conventional diet composition) and slurry from Drogeham (diet according to the VEL and VANLA diet-composition guidelines). Moreover, Drogeham added MX to its slurry manure. MX is a clay-based mixture that has been added weekly at a rate of 2 kg m^{-3} since 1981. Since that year the soil organic matter content has steadily increased from about 8% to 12.5% 10 years later (Eshuis *et al.*, 2001). Before the experiment started MX had not been used at Harkema. EM was applied three times during the growing season at a total rate of 2 litres EM ha^{-1} $year^{-1}$.

Methods of slurry-manure application were slit injection (5 cm deep) and surface application.

This multifactorial field experiment took 5 factors into account: (1) phenoform of the soil, (2) type of manure ('normal slurry manure' versus 'improved slurry manure', (3) slurry manure application technique (slit injection versus surface application), (4) N-fertilization level ('high' versus 'low'), and (5) EM (added versus not added). The grass on the experimental plots was cut five times per year, when samples were taken for analysis. The data used in our analysis are from the first two years of the experiment: 1999 and 2000.

Within the 2 × 40 experimental units, two plots could be designated as characteristic for the specific balance as created at Drogeham (i.e., slurry manure from Drogeham, surface application, the use of inorganic fertilizer and no addition of EM). Two other plots were characteristic for the more conventional farm management at Harkema (i.e., slurry manure from Harkema, slit injection, the use of inorganic fertilizer and no addition of EM). Comparison of these 4 plots over two years shows that Harkema's type of farm management resulted in a dry matter production per hectare per year of 12,104 kg against 13,598 kg DM ha^{-1} $year^{-1}$ for Drogeham's farm management. This is a statistically significant difference ($P = 0.003$). As to N efficiency (= DM production per kg N) the contrast was even more remarkable. N-efficiency was 13.8 kg DM per kg N for Harkema's type of farm management against 19.6 kg DM per kg N for Drogeham's type of management. The latter included surface application, which is assumed to be less efficient (Anon., 1998).

Evidently, this straightforward comparison excludes any exploration of underlying mechanisms. To assess the effect of the different variables and their possible interaction, further analysis is needed.

The interesting point we want to bring to the fore here, is that the experimental layout allows for two types of analysis. The first type is essentially a monofactorial analysis whereas the second type is a multivariate analysis, both of the same multifactorial experiment.

The first type of interpretation (which goes from one isolated change to a specified effect, e.g. the effect of improved slurry manure on N efficiency) generally yields hardly any significant effects. As described by Kok *et al.* (2002) no effects were found of soil type, slurry manure type or additive use. However, if fine-tuning is taken into account (i.e., the *simultaneous* re-adjustment or re-balancing of a range of resources and growth factors), the overall picture changes considerably. This can be shown with different approaches.

To investigate effects of deviations from the farm-characteristic management, for each location and year a new predictor variable – CHANGE – was introduced based on the treatments (a) slurry-manure type, (b) slurry-manure application method, (c) the use of EM, and (d) inorganic fertilizer rate (De Goede *et al.*, 2003). CHANGE was 0 when the combination of treatments in the field experiment was identical to the farm-characteristic management at that specific location, and CHANGE was 1, 2, 3 or 4 when 1, 2, 3 or all 4 treatments differed from the farm-characteristic management. For example, if CHANGE = 2, all plots were involved where 2 variables (a and b, a and c, a and d, b and c, b and d or c and d) were not characteristic for the farm management. The predictor variable CHANGE was tested with a generalized regression model (GRM) using STATISTICA (data analysis software system, version 6, StatSoft, Inc.) including location and year as categorical predictors. Statistically significant (interactions between) predictors were selected using a forward stepwise model with a P value ≤ 0.10 to enter or remove predictors from the model.

Figure 3 shows that at both Harkema and Drogeham any of the investigated deviations from the farm-characteristic management resulted in a statistically significant

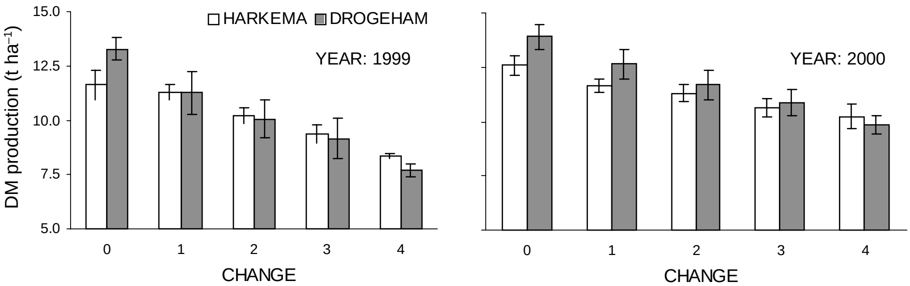

Figure 3. Generalized regression model (GRM) analysis of the grassland experiment. Dry matter production at Harkema and Drogeham in the years 1999 and 2000 as affected by CHANGE (see text for details). Error bars = Standard deviation/ n × 0.95.

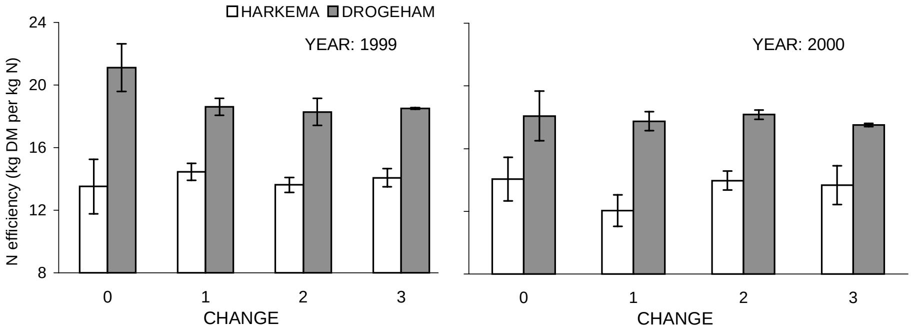

Figure 4. Generalized regression model (GRM) analysis of the grassland experiment. N efficiency at Harkema and Drogeham in the years 1999 and 2000 as affected by CHANGE (see text for details). Error bars = Standard deviation/ n × 0.95.

decrease in DM production per hectare per year. So, the interaction of different treatments, especially when combined with a specific soil phenoform, is essential in understanding the outcome of the re-balancing process. Figure 3 also shows that if there is no change in management (CHANGE = 0), the result at Drogeham is superior to the one at Harkema. In other words re-balancing results in significantly higher DM production than conventional farming. These outcomes underpin the 'promises' (Lente, 1993; Lente & Rip, 1998) of the VEL & VANLA approach.

Theoretically, the effect of the predictor variable CHANGE might be explained by an assumed dominant effect of inorganic fertilizer. Therefore, GRM analysis was repeated exclusively for plots receiving inorganic fertilizer. As to DM production per hectare, only location turned out to have a statistically significant effect. As regards N efficiency, however, CHANGE again turned out to have a statistically significant effect in the first year (Figure 4), whereas such an effect was not statistically significant in the second year (in Figure 4 the maximum value of CHANGE is 3, since fertilizer rate is fixed).

In conclusion, if all improved resources and practices (soil, slurry manure, surface application, etc.) are available and brought in balance, synergetic effects emerge that combine both production and environmental aspects of farming. It is shown that further development of multivariate analysis (and the subsequent re-design of experiments) might be a promising prospect.

Introducing sociological data: re-checking the effects of re-balancing

Using the farming-styles approach, Eshuis *et al.* (2001) distinguished three different attitudes amongst farmers when dealing with slurry manure. Firstly, for some farmers it applies that they simply 'dispose' of the manure as something they want to get rid of as quickly and as cheaply as possible. In short, they *dump* their manure. Secondly, there is a group of farmers that try to *use* the available manure as efficiently as possi-

Table 7. Factor analysis of VEL and VANLA farm characteristics; summary of results[1].

Variable[2]	Factor 1	Factor 2
N total in slurry manure (g per kg DM)	−0.74	
C/N slurry manure	+0.68	
OEB (g day^{-1})	−0.62	−0.38
Concentrates (kg day^{-1})	−0.61	
DM intake (kg day^{-1})	−0.57	+0.55
DVE (g per kg DM)	−0.56	−0.32
N efficiency (%)	+0.53	−0.60
Milk protein (%)	+0.42	
Milk urea (g l^{-1})	−0.36	
Fat and protein corrected milk production (kg day^{-1})	−0.36	−0.52
N organic in slurry manure (%)	+0.35	
VEM (g per kg DM)	−0.34	−0.51
CP silage (g per kg DM)	+0.31	−0.72
DM intake from roughage (kg day^{-1})		+0.69
CF silage (g per kg DM)		+0.31

[1] Both factors explain 42% of the variation in the data.

[2] For abbreviations see Tables 4 & 5.

ble. As to the number of applications, the timing, the application techniques and the possible differentiation according to fields there was a considerable number of significant differences between these first two groups. In the third group these differences increased even further. Eshuis *et al.* (2001) characterized this third group as farmers who *make* good manure.

To be able to check the relevance of this distinction, and above all, to check whether there was a statistically significant degree of re-balancing especially in the third group, a range of variables was analysed regarding diets, milk production and slurry manure quality. The results of a principal component analysis (Table 7) show the presence of two patterns of coherence, aspects that are to be understood as the outcome of re-balancing. The first pattern describes, basically, the difference between 'good' and 'poor' slurry manure and the diets from which they result. Farms that score high on this pattern (factor 1) have slurry manure with a high C/N ratio and a low percentage N, and what is more, N that manifests itself in organic form. The diets are low in undegradable protein, which in turn is also reflected in the low urea concentration in the milk. All this will likely result in low emission levels of ammonia.

The second pattern of coherence (factor 2) is different and varies from a *low external input* to a *high external input* agriculture. Here, farms scoring high use diets with much on-farm produced roughage, which contains less energy. Grass silage will have a lower protein content and more fibre.

If the farms representing the three manure management groups are plotted in relation to the two patterns of coherence discussed (factors 1 and 2 in Table 7), it

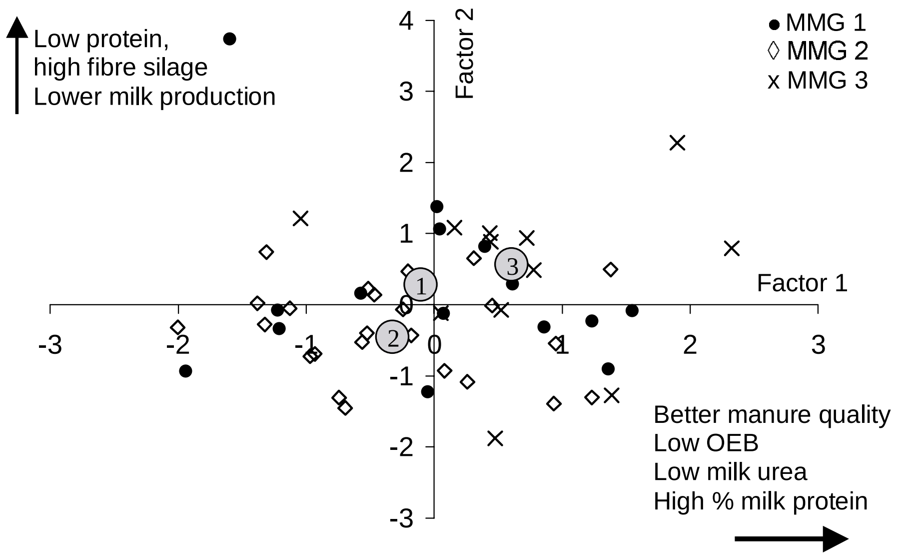

Figure 5. Position of the VEL and VANLA farms of the 3 manure management groups (MMG) in relation to the two patterns of coherence (Factor 1 and Factor 2). The numbers 1, 2 and 3 in the squares indicate the average position of each group (see text for explanation). For a more detailed description see Verhoeven & Van Der Ploeg (2001).

becomes evident that a more sustainable agriculture (the upper right quadrant of Figure 5) is actively explored (if not *created*) by farmers that are re-balancing their soil-plant-animal systems, a strategy that – in this case – very much focuses on making good manure. Table 8 presents some data reflecting the environmental 'scores' of the three groups.

Table 8. Farm parameters for the 3 manure management groups within the VEL and VANLA co-operatives.

Parameter[1]	Slurry manure management		
	1. Dumping	2. Using	3. Making
N surplus 1998 (kg ha^{-1})	298	266	205
OEB (g day^{-1})	359	397	142
Concentrates (kg per 100 kg milk)	25.6	27.3	24.6
Milk urea content (g mg^{-1})	20	22	19
N total in manure (g per kg DM)	51.2	51.2	45.9
C/N manure	7.4	7.3	8.0

[1] For abbreviations see Tables 4 & 5.

Concluding remarks

In this paper we have indicated how resources (like grass silage, concentrates, manure and soils) are re-moulded and recombined – through an ongoing process of re-balancing and fine-tuning – into more sustainable farming systems. This implies complex, multi-faceted and multi-level changes involving a social and material reconstruction of farming (Roep, 2000). To re-present, understand and strengthen such a process, multivariate analysis is needed, especially if the movements through time and the newly emerging patterns of diversity are to be understood. Since most (material) changes are goal-oriented and inspired by different sets of knowledge of the actors involved, it is important to link – within this analysis – the beta and gamma approaches. In that way different views on e.g. the relevance and use of slurry manure can be monitored through their effects, while the same monitoring might function as an important feedback mechanism that allows for further development of both local and scientific knowledge. 'Field laboratories' like VEL and VANLA (Stuiver *et al.,* 2003) provide optimal conditions for such combined processes of change and learning.

On the whole, in the region where VEL and VANLA farmers are located, learning and changing resulted in impressive reductions in N losses. As a consequence, new effective roads towards sustainability are emerging.

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