FAO European Cooperative
Research Network

RAMIRAN

Recycling of Agricultural, Municipal and Industrial Residues in Agriculture

Network Coordinator: José Martinez, Cemagref, Rennes (France)

RAMIRAN 2002

Proceedings of the 10th International Conference of the RAMIRAN Network

General Theme: Hygiene Safety

Štrbské Pleso, High Tatras, Slovak Republic
May 14 - 18, 2002

Edited by Ján Venglovský and Gertruda Gréserová

ISBN 80-88985-68-4

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RESTORING FARMER'S CONFIDENCE IN MANURE BENEFITS THE ENVIRONMENT

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ABSTRACT

The ongoing disintegration of agriculture into specialized farms, specialized regions and even specialized countries, has disrupted local nutrient cycles. This process is promoted and sustained by the use of mineral fertilizers. Ample availability of mineral fertilizers has changed farmers' perception and appreciation of manure. By now, manure is looked upon as 'waste' in some regions. It is a contradiction in terms, however, to regard biological by-products as 'waste'. Apart from this cultural aspect, economical and environmental considerations per se, justify a rehabilitation of manure. Undeniably, it is much easier to manage mineral fertilizers than manure. However, when proper attention is given to the composition of manure and decisions on rates, timing and placement are made correspondingly, the nitrogen fertilizer value of manure can be enhanced. This should lead to a drastic reduction of mineral fertilizer use, mineral surpluses and environmental pollution. Under such conditions, 'manure', 'precision farming' and 'environment' can become reconciled again.

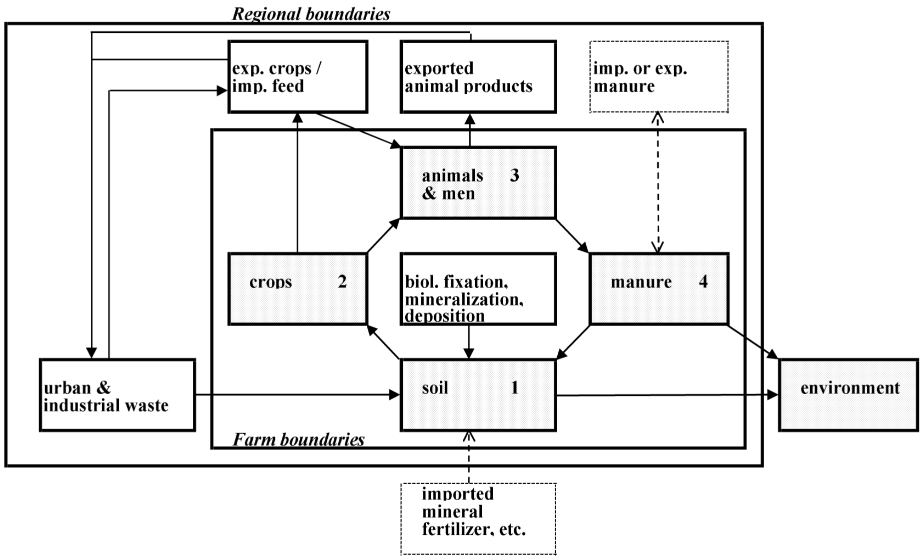
Keywords: environment, fertilizer value, integrity, manure, nitrogen, nutrient cycling, phosphorus, placement, timing

INTRODUCTION

Basically, agriculture can be seen as a chain of activities transferring nutrients in a cyclic way from 1) the soil, 2) via the crop, 3) via animals and men, 4) via manure to the soil again (Figure 1). In a mixed farm these four compartments are all present. In the course of history the integrity of mixed farming has gradually diminished, at least at a local and regional scale. Integrity should not be mistaken for sustainability, however, as losses to the environment are inevitable in any system, in particular losses of nitrogen (N) and potassium (K). History shows that the compensation of these losses by biological N-fixation, deposition, flooding, weathering and the exploitation of waste land through grazing animals, was not always sufficient. In Europe, too, the unbalance of outputs and inputs has resulted in local over-exploitation and even dessertification. Anyhow, in 'primitive' societies the awareness of the value of manure was probably much greater. Common sense prevented to think of manure as 'waste', although some of it may have ended as building material or fuel, as it still does in parts of the world today.

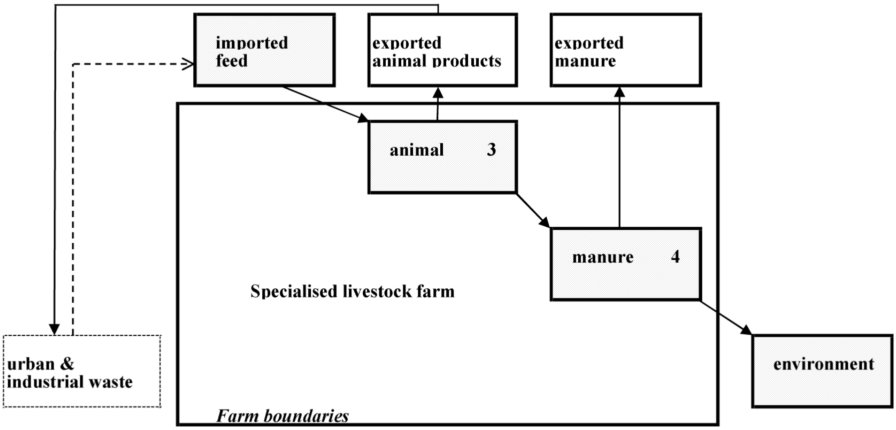
The introduction of mineral fertilizers undoubtedly contributed to the disruption of the integrity and the balance of crop production and animal production. Many farms disintegrated into specialized arable farms and specialized livestock farms (Figure 2). Disintegration may lead to an apparent improvement of the nutrient use efficiency (i.e. output/input) at the farm level, but this improvement disappears completely when evaluated at higher levels of integration (Schröder et al., 2002). Concomitantly, self-relying communities developed into either agricultural rural areas or industrialized urban areas. Globalization even resulted in trans-continental flows of nutrients, often with a preponderant one-way traffic character. Obviously, this spatial up scaling complicates a proper re-cycling of by-products, including manures. Hence, nutrients and thus soil fertility may become depleted in some regions, whereas nutrients have become 'wastes' in others.

Figure 1. Nutrient fluxes in a mixed farming system.



Surely, over-application of manure resulting from a too high regional animal density is unacceptable from many points of view including nitrate leaching (Table 1) and so is the injudicious handling of even moderate application rates. However, the partial political focus on manure rather than on all inputs and outputs together, is questionable and not at all a guarantee for a sufficient reduction of N emissions (Schröder et al., 2002). Apparently, in the eyes of decision-makers manure has become the root of all evil. Manure is metaphorical for the loss of environmental quality, the degradation of soil quality, and intensive production methods that are unfriendly to animal welfare.
Unfortunately, nowadays many farmers tend to think of manure as an unreliable source of nutrients, in particular of N. Effects of manure on crop production may indeed vary. This uncertainty is often incorrectly referred to as 'the inherent variability of any N source requiring mineralization'. However, variable effects may just as well originate from the variable composition of manures, from their irregular spreading pattern, or from volatilization losses when insufficient attention has been given to their incorporation. The experienced uncertainty makes farmers reluctant to fully credit the nutritional value of manure. Moreover, lack of incentives to prevent N losses, makes farmers indifferent. Consequently, the supplementation with mineral fertilizers is often unnecessarily high (e.g. Aarts et al., 2000; Schröder et al., 2000; Reijneveld & Le Gallic, 2001). This attitude does not do justice to manure and is extremely detrimental to the environment. The remainder of this paper therefore focuses on 1) methods to correctly assess the N fertilizer value of manures, and 2) methods to maximize the N fertilizer value of manures.

Figure 2. Nutrient fluxes in a specialized livestock farm (top) and a specialized arable farm (bottom)



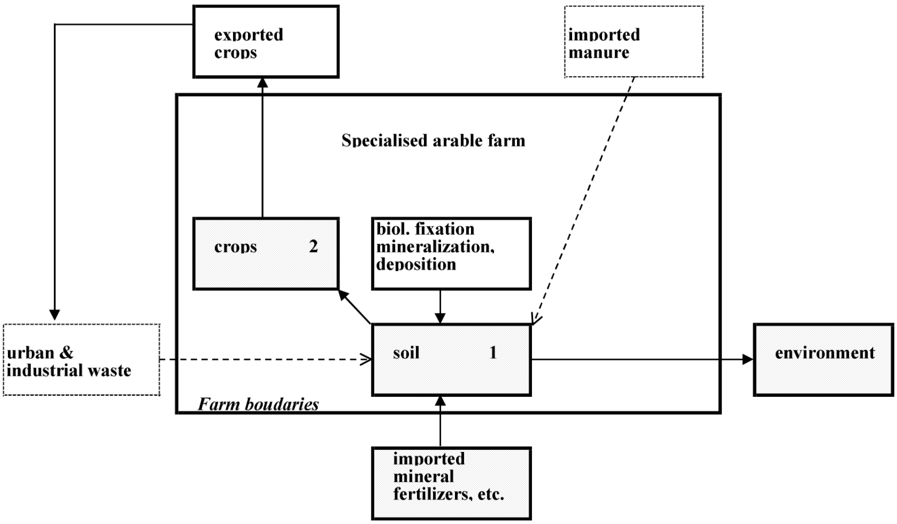


Table 1. Balance sheet of yearly N inputs and outputs (kg N ha^{-1} yr^{-1}) derived from a continuous maize trial on sandy soil (1976-1982), the effect of the inbalance on the accumulation of soil organic N after seven years (kg N ha^{-1}), and the N yield (kg N ha^{-1}) of a following unfertilized grass ley in 1983 (Schröder & Van Keulen, 1997)

		Treatment:					
		I	II	III	IV	V	VI
Inputs	Manure-N	258	519	781	1036	1292	1548
	Mineral fertilizer-N	51	0	0	0	0	0
	Deposition	62	62	62	62	62	62
Outputs	Harvest	137	159	177	199	195	198
	Soil organic N*	89	118	147	175	203	231
	Leaching	145	150	230	316	406	430
	Not accounted for	0	154	289	408	550	751
Accumulated soil organic N from Year 1-7*		623	826	1029	1225	1421	1617
N yield of unfertilized grass in Year 8		78	85	110	136	151	146

* estimated by linear regression

HOW TO ASSESS THE N FERTILIZER VALUE OF MANURES?

Response curves

Different methods are used to assess the N fertilizer value (NFV, kg ha^{-1}) of manures. Not all of them lead to unbiased conclusions. A common and valid method consists of a comparison of the N yield of a test crop having received a specified amount of manure-N, with the N yields from a response curve of a crop having received increasing rates of mineral N. In other words: the NFV is determined by solving the N yield response function of crop fertilized with mineral N, for the N yield of a manured crop (e.g. Schröder et al., 1997a). Subsequently, the relative NFV (RNFV, kg kg^{-1}) can be calculated as the ratio of the NFV and amount of manure-N applied. Others refer to RNFV as 'fertilizer N equivalence'. Simple algebra shows that the RNFV is the ratio of the apparent N recovery (Van Keulen & Stol, 1990) of manure (ANR_{man}) and that of mineral fertilizer (ANR_{fer}). The described procedure only yields reliable results if the initial response to N can be accurately determined. Sufficient mineral N rates, including low ones, and moderate manure rates are needed for this.

As the effect on the N yield is not necessarily equivalent to the effect on the marketable yield, one may argue that it is relevant to deduce the NFV from the response function of the marketable yield rather than the N yield. RNFV than equals the ratio of the apparent nitrogen efficiency (ANE; Van der Meer et al., 1987) of manure (ANE_{man}) and mineral fertilizer (ANE_{fer}).

Overestimation

According to Lorry et al. (1995) both previous methods may ignore the non-N effects of manures. They advocated to construct mineral N response curves for manured and non-manured plots and use the differences in the economic optimum rates as a measure of the fertilizer value. Manure can indeed have a so-called positive specific effect on yields. This effect cannot be brought about with additional mineral N. Such effects are often attributed to the 'improved physical soil fertility' (e.g. Wadman et al., 1987). Specific effects may, however, also originate from chemical deficiencies in the non-manured control plots. In some instances specific effects have been unmasked as ordinary K effects, for example (Schröder & Dilz, 1987). Negligence of these aspects may easily lead to overestimation of the NFV of manure.

Underestimation

An incorrect experimental set-up may also lead to underestimation of the NFV. Assessment of the NFV through a simple experiment in which the N yield of a manured crop is compared with the N yield of an unfertilized control is often doomed to underestimate the NFV, as it ignores the inability of most annual crops to recover mineral N (either present due to mineralization prior to the growing season or mineralized during the season) for the full hundred percent. Chances for such an incomplete recovery are large when the manure rate exceeds the crop requirements or when a test crop with an inherent low recovery is chosen. Assessing the NFV in this way can be improved slightly when the dynamics of soil mineral N (SMN) from spring to autumn are included in the calculated difference between manured and unfertilized treatments (Schröder et al., 1996; Schröder, 1999).

In grassland experiment the NFV may also be underestimated when the clover content of the sward in the manured treatment and the unfertilized control diverge in the course of time (Van der Meer & Van Uum-Loohuyzen, 1986). The relative N deficiency in the control may promote clover production, which in turn increases the total yield of the control. Consequently, ANR_{man} and ANE_{man} (based on the calculated difference in yield of manured and unfertilized crops) will decrease, whereas this has nothing to do with a reduced ability of the manure to provide N to the crop.

Residual effects

One of the major pitfalls encountered while assessing the NFV of manure originates from its organic nature. Consequently, mineralization generally extends over a much longer period than just one year. Manures therefore have a residual effect (Lund & Doss, 1980; Görlitz et al., 1985; Magdoff & Amadon, 1988; Sommerfeldt et al., 1988; Werner et al., 1985; Dilz et al., 1990; Whitmore & Schröder, 1996; Schröder & Van Keulen, 1997). An example of it is given in Table 1. Hence, when NFV is determined on a formerly unmanured field, the NFV is underestimated in the first (few) year(s) of the experiment. This phenomenon is mimicked in Figure 3. In the first year after its application (year 1), only a fraction of the organic input mineralizes. When a similar amount of organic material is applied in the subsequent year (year 2), the total mineralization equals the sum of a fraction of the total organic input in year 2 (similar to that in year 1) and a fraction of the organic pool left over from year 1. When manure applications are continued in year 3, the total mineralization equals the sum of mineralizations from meanwhile three batches, and so on. Eventually, an equilibrium will be established between the yearly organic inputs and the yearly mineralization. It may take decades before such an equilibrium is attained, depending on the energy-N ratio in the manure (Sims, 1995). This implies that the long-term effects of reduced inputs, too, become fully visible after many years (Motavalli et al., 1992). Hence, long lasting experiments are needed to approximate the true NFV of manure and to construct and verify appropriate models (e.g. Wolf et al., 1989; Wolf & Van Keulen, 1989).

Figure 3. Simulation of cumulative mineralization due to yearly repeated manure applications.

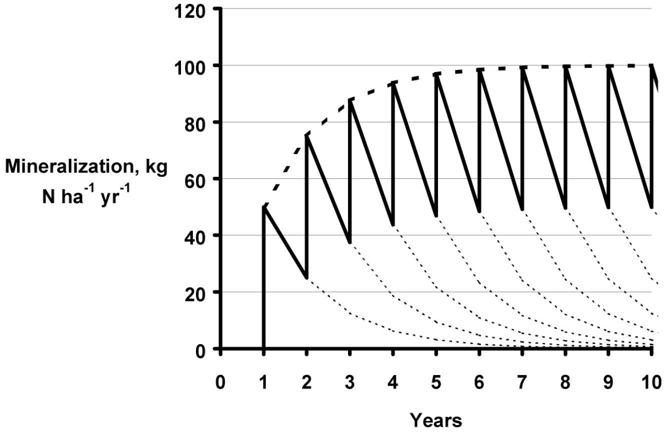
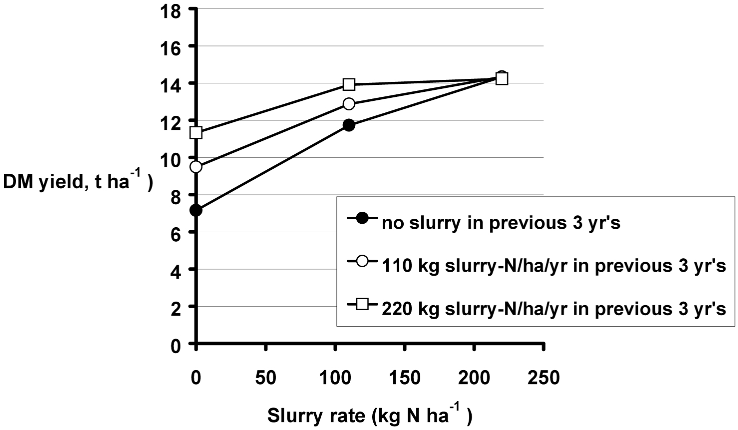


Figure 4. Dry matter yield of silage maize as affected by manure rates and manuring history



Extension services supplying information on the NFV of manures to farmers, do generally take little account of the residual effects of manure. Too often, only the short term NFV's are given, indicating that the RNFV is at most 20-60 percent. The larger the ratio of mineral N (Nm) and organic N (Norg) in manure (e.g. as in farm yard manure), the greater the underestimation. These theoretical considerations were illustrated in an experiment in which we could calculate the ANR_{man} of cattle slurry in various ways. During three consecutive years we built up different manuring histories by applying 0, 110 or 220 kg cattle slurry-N ha^{-1} yr^{-1}. In the subsequent fourth year we assessed the ANR_{man} of rates of 110 and 220 kg cattle slurry-N ha^{-1}. These rates were either applied during four consecutive years or for the first time after three years without manuring (but with mineral P and K supplementation). Results confirmed that yields (Figure 4) as well as recovery values (Table 2) are strongly determined by the manuring history of the field.

Table 2. The apparent N recovery (ANR_{man}, %) of cattle slurry (110 and 220 kg N ha^{-1} yr^{-1}) determined according Van Keulen & Stol (1990), as affected by the preceding manuring history (Schröder et al., 2001)

Manuring history of controls (kg slurry N ha^{-1} yr^{-1})				ANR_{man} of slurry applied in Yr 4 at a rate of:			
				110 kg N ha^{-1}		220 kg N ha^{-1}	
Yr 1	Yr 2	Yr 3	Yr 4	Applied in all 4 years	Applied in Yr 4 only	Applied in all 4 years	Applied in Yr 4 only
0	0	0	0	60	46	45	39
110	110	110	0	43	-	-	-
220	220	220	0	-	-	24	-

HOW TO MAXIMIZE THE N FERTILIZER VALUE OF MANURE?

Rates

The utilization of manure is determined by the right time, the right place and last but not least the right amount. Prior knowledge of the composition of manure and an accurate estimate of crop requirements is instrumental to an accurate determination of site-specific application rates and the consequential utilization of manure. Estimates of crop requirements may be too high when N-recommendations are based on uncritically chosen regression models (Cerrato & Blackmer, 1990; Bullock & Bullock, 1994; Stecker et al., 1995; Schröder et al., 1998) or when inspired by expected yield levels only (Vanotti & Bundy, 1994a; -, 1994b; Sims et al., 1995; Schlegel et al., 1996; Schröder et al., 1998). Moreover, N can be saved by a realistic instead of a pessimistic estimate of the N that is to be released from former organic inputs.

It is generally impossible to meet the N requirements of the crop rotation as a whole with manure only, if excessive applications of phosphorus (P) are to be avoided. The reason for this is that the N/P_2O_5 ratio in most crops averages >2.5, whereas the ratio of effectively available N and P_2O_5 in manures is generally (much) lower than 2 (Table 3). Hence, sustainable production systems (i.e. in which P inputs do not exceed P outputs) are always short of N. In organic farming this relative N deficiency must be met by the presence of legumes in the rotation, whereas in conventional systems mineral fertilizer N must be

Table 3. The ratio of N and P_2O_5 in harvested crops and in various types of manures (based on Lammers (1983) and Beukeboom (1996) and Beijer & Westhoek (1996)).

Product	When based on:		
	Total N/ P_2O_5	Effectively available N / P_2O_5:	
		Short term	Long term
Crops	>2.5		
Slurry, cattle	2.7	0.9-1.8	1.2-2.3
Farm yard manure, cattle	1.8	0.6-0.9	1.0-1.5
Slurry, pigs	1.7	0.6-1.2	0.8-1.4
Farm yard manure, goats	1.6	0.6-0.9	0.9-1.5
Farm yard manure, pigs	0.8	0.3-0.5	0.5-0.7

supplemented. In order to adjust such mineral N supplements to the actual mineralization and crop requirements, indicator-based spoon-feeding strategies can be useful. The pro's and con's of such a site-specific strategy have recently been reviewed for maize production (Schröder et al., 2000).

Time

Nitrogen should be water-soluble (Nm) during the growing season to be available to plants, whereas it should be bound (Norg) from late summer to spring in order to avoid losses. Manures differ strongly in the ratio of Nm and Norg. Hence, manure ideotypes depend on the soil type-imposed time windows for spreading. Manures with a low Nm/Norg ratio (e.g. farmyard manures) are generally better suited for autumn applications than manures with a high Nm/Norg ratio (e.g. slurries) (Smith & Chambers, 1993). When applied in spring, farm yard manures may not be able to meet the crop requirements in time, especially not when the associated bedding material (e.g. cereal straw) is not yet fully decomposed and hence tends to immobilize SMN. From late summer-applied slurries, on the other hand, considerable amounts of mineral N can be lost, unless Nm is timely sequestered with cover crops and successfully transferred to the subsequent spring (Steffens & Vetter, 1984; Schröder et al., 1997a). When the soil type permits field traffic in early spring, the RNFV of slurry is maximized by postponement of applications until spring (Van Dijk, 1985; Unwin et al., 1986; Görlitz, 1989; Van der Meer & Van der Putten, 1995). A series of experiments carried out on sandy soils in The Netherlands confirmed that silage maize utilizes spring-applied slurry-N better than autumn-applied slurry-N. Addition of a nitrification inhibitor to autumn-applied slurry improves the performance but in The Netherlands this not considered a sufficiently adequate alternative to spring-application (Table 4). Table 4 shows that the utilization of spring-applied slurry, too, can be further improved by the addition of a nitrification inhibitor. Van der Meer & Van der Putten (1995) reported a similar finding for grassland. These observations indicate that even spring-applied manure can be exposed to N losses whenever crops take up little N until late spring. Synchronization may be improved when the application of manure is postponed until after crop emergence (Beauchamp, 1983), reminiscent of the common slurry splitting strategy in grassland. Such a deliberate postponement is not without risks in annual crops, however (Schröder et al., 2000). Especially when manure is the source of

Table 4. Dry matter yield (t DM ha^{-1}) of silage maize and the apparent N recovery (ANR_{man}, %) of cattle slurry, as affected by the application time and nitrification inhibitor addition (average 1984-1989; mix of continuous and one-year trials (Schröder et al., 1993))

Manure-N, kg ha^{-1}	Application time	Nitrification inhibitor	DM yield	ANR_{man}
0	-	No	10.8	-
250	Autumn	No	14.3	20
250	Autumn	Yes	15.1	27
250	Spring	No	15.4	29
250	Spring	Yes	15.7	33
LSD (P<0.05)			0.5	

N, the equipment involved may damage the soil structure and/or crop. Moreover, incorporation is needed to avoid ammonia volatilization. In a standing crop post-emergence application may damage the root system. Crop damage can be minimized, though, by sidedressing in between the plant rows. From a plant nutrition perspective, however, this position can be less effective as root length densities between the rows can remain low for a long time, in particular when row distances are wide (Schröder et al., 1997b). A series of experiments carried out in The Netherlands indicated that, on average, silage maize yield did not benefit significantly from slurry splitting (Table 5). Apparently, root damage (especially when injected) or ammonia volatilization (especially when surface-applied) counteracted potential benefits of post-emergence applications. The latter hypothesis was supported by the calculated difference between the balance sheets of N inputs and N outputs of injected and surface-applied treatments, indicating losses of 15-30 percent of the ammonium-N applied. Note, that the slurry application rates in the present experiments were high. Benefits of slurry splitting may be more evident at lower levels of N availability (Schröder, 1999; Schröder et al., 2000).
So far, this section addressed synchronization problems at the start of the growing season. Lack of synchronization between supply and demand can also occur at the end of the season, however. By nature, N mineralization from manure continues beyond the period in which arable crops take up N. That N is redundant and can be lost when the arable crop is followed by a long fallow period after its harvest. The establishment of a catch crop can thus help to save N and transfer it to the next growing season. (Martinez & Guiraud, 1990; McCracken et al., 1994). Unfortunately, crops leaving considerable SMN residues are often harvested relatively late in the season. This implies that the N sequestration potential of catch crops is strongly determined by weather conditions (Schröder et al., 1996). Despite this annotation, the utilization of manure-N can be enhanced slightly by catch cropping, as shown by the results presented in Table 6. In this experiment winter rye cover crops were able to recycle residual SMN left by maize which improved the apparent recovery of slurry-N in subsequent maize crops. Undersown Italian ryegrass was a less

Table 5. Dry matter yield (t DM ha^{-1}) of silage maize and the apparent N recovery (ANR_{man}, %) of spring-applied cattle slurry, as affected by splitting and application method (average 1983-1987; mainly one-year trials (Schröder, 1999))

Rate:		Manure distribution:			DM yield	ANR_{man}	ANR_{man} /ANR_{fer}
Mineral fertilizer-N, kg ha^{-1}	Manure-N, kg ha^{-1}	Pre-planting	Post-emergence:**				
		Injected	Injected	Surface-applied			
0	0	-	-	-	10.1	-	-
100*	0	-	-		12.0	35	-
0	340	100%	0%	0%	11.8	14	38
0	340	50%	50%	0%	12.2	15	42
0	340	50%	0%	50%	11.8	12	30
LSD (P<0.05)					0.7		

* pre-emergence application
** 4-6 leaf stage

Table 6. Dry matter yield (t DM ha^{-1}) of silage maize, the apparent N recovery (ANR_{man}, %) of spring-applied cattle slurry and over-winter nitrate leaching (kg NO_3-N ha^{-1}), as affected by preceding winter cover crops (average 1989-1994; continuous trial (Schröder et al., 1996))

Winter cover	Manure-N, kg ha^{-1}	DM yield	ANR_{man}	N-leaching
None	0	10.8	-	40
None	175	14.9	45	73
Winter rye*	175	15.2	50	45
Italian ryegrass**	175	15.0	46	25
LSD (P<0.05)		0.6		45

* sown after harvest; average aboveground N yield in spring 38 kg ha^{-1}

** undersown; average aboveground N yield in spring 40 kg ha^{-1}

effective cover crop in this respect. However, grass was better able to reduce N leaching than rye, probably due to a more extensive sequestration of N in subterranean plant parts. Mind, that cover crops only improve the utilization of manure if the subsequent crop is in need of N. Hence, N mineralizing from catch crop residues must be correctly accounted for in the fertilizer management of subsequent crops. If not, catch cropping may eventually become a merely cosmetic measure.

Place

The NFV of manures is not only determined by the rate and timing of applications but also by the place of their application. Placement has both a vertical and a horizontal component. As to the vertical aspect, the reduction of ammonia losses is the major consideration. This is especially relevant for manures rich in Nm (slurries, urine). Ammonia losses are strongly determined by the application technique (Van der Meer & Van der Putten, 1995; Bussink & Oenema, 1998; Huijsmans & De Mol, 1999). Table 7 gives a summary of Dutch research on ammonia losses in relation to the application technique. These figures made Dutch authorities decide to make incorporation compulsory for all liquid manures. Too deep a placement, however, is not instrumental to the maximization of the NFV. The

Table 7. Ammonium volatilization losses (in % of the ammonium present in manure) from landspreading on arable land and grassland, as affected by the application technique (Steenvoorden et al., 1999)

Land use	Technique	Volatilization:	
		Observed range	Average
Arable	Surface application	20-100	68
	Surface application followed by incorporation	1-49	20
	Tine injection	0-40	9
Grassland	Surface application	27-98	68
	Trailing feet injection	9-50	24
	Sod injection	2-25	10
	Tine injection	0-3	1

initially developed injection techniques have therefore almost completely been replaced by shallow injection techniques, i.e. on grassland. There are trade-offs between what is best from a placement point of view and what is required from a point of view of soil conservation. The major reason for this is that low-emission techniques are normally left to contractors using relatively heavy equipment. If this equipment causes serious soil compaction, the intended improvement of the N utilization can be offset.

Too deep a placement should also be avoided on arable land. Application techniques and tillage methods should be tuned to each other, so that roots of young plants are in reach of the nutrients as quickly as possible. Schröder & Ehlert (1999) reviewed nine recent experiments evaluating the potential benefits of manure application after ploughing compared to the conventional pre-ploughing application. They concluded that silage maize yields did not benefit from a post-ploughing application unless the cumulative rainfall between the pre-ploughing application of manure and ploughing was high and the soil conditions after ploughing permitted field traffic without damage.

As to the horizontal aspect of placement, proper attention must be given to spreading techniques. Irregular, patchy spreading patterns increase the heterogeneity of the soil fertility. Consequently, some parts of the field become over-fertilized, whereas other parts may become deficient. Note that the grazing of animals may conflict with various recommendations presented in the previous sections: rates of urine and faeces that may be too high in places, exposure of these excretions to ammonia volatilization, and poor timing when grazing is extended into the end of the growing season.

The previous warning for a too patchy distribution of manure must not be seen as a general argument for a uniform distribution. In crops with a wide row distance, for instance, yields may benefit from techniques that apply manure close to the anticipated position of the crop roots (Sawyer et al., 1991). A series of experiments pointed out that a banded sub-surface application of manure promoted silage yields of maize (Table 8). Effects in this series were mainly attributable to a better availability of P (Schröder et al., 1997), but research indicates that the N availability can also be improved by sub-surface banding (Van Dijk & Brouwer, 1998).

Table 8. Dry matter yield (t DM ha^{-1}) of silage maize and the apparent N recovery (ANR_{man}, %) of spring-applied cattle slurry, as affected by sub-surface banding (average of five one-year trials;1993-1994 (Schröder et al., 1997b)

Rate: Mineral fertilizer-P_2O_5, kg ha^{-1}	Manure-N, kg ha^{-1}	Placement*	DM yield	ANR_{man}
0	0	-	10.1	-
0	120	Standard	11.9	15
0	120	Banded	12.7	22
50	0	-	10.7	-
50	120	Standard	13.0	24
50	120	Banded	13.0	24
LSD (P<0.05)			0.7	

* pre-planting injection in slots 25 cm ('standard') or 75 cm ('banded') apart, followed by maize planting at a row spacing of 75 cm parallel to injection slot, either at random positions ('standard') or 10 cm next to the slot ('banded')

Solid or liquid?
Debates on whether solid farm yard manures are better than liquid slurries (or vice versa) continue, not at least within the organic farming community. Unfortunately, statements often have a categorical character. In previous sections it has already been stated that farm yard manure can be a sensible choice when late summer or autumn provide the only time windows for application. Accurate placement, however, is better served with liquid manures than with solid manures.
There are other arguments in favour of liquid manures. By nature, the kg's organic matter per kg P_2O_5 are generally much larger in solid manures than in liquid manures. Solid manures may hence fit well in farming systems that are in need of additional organic matter. However, the kg's N per kg P_2O_5 are generally much lower in solid manures than in liquid manures (Table 3). This lower ratio of N and P_2O_5 results from losses associated with the production, storage and handling of solid manures. Bokhorst & Ter Berg (2001) reviewed the literature and concluded that on average 40 percent of the initial N content is lost before application. One may argue that Nm in slurries can be lost easily too, be it on the field instead of the yard. However, relatively simple measures can be taken against ammonia volatilization from land spreading, as indicated in the previous section.
On farms of similar intensity, the use of solid manures is associated with (much) smaller yearly applications of directly available Nm and larger applications Norg. A larger (equilibrium) supply of soil organic N and more abundant soil life result from this. Consequently, the yearly mineralization is also larger, in accordance with the increased soil organic N supply. These phenomena are sometimes twisted around as if the soil life abundance itself is the cause of the enhanced mineralization. Until now, there is no convincing evidence that the promotion of soil life through the use of farm yard manure contributes to a better recovery of N by crops (Langmeijer et al., 2001). Therefore, it seems fair to say that solid manures with their inherent lower N/P_2O_5 ratio, need larger N supplementations via either legumes or mineral N fertilizers. The only alternative for that would be to over-apply solid manure in terms of P, but that would not be sustainable.
In The Netherlands slurries are the most common form of manure, as in most European countries. However, solid manures are still preferred in intensive crop rotations that are unable to replenish organic matter pools via crop residues. These rotations can be found in both conventional farms (e.g. bulb growing) and vegetable-based organic farms. Those farms leave the (economically less attractive) production of legumes, grass leys and cereals, needed for the production of manure in general and that of farm yard manure in particular, to others in the region or even abroad.
Preferences for farm yard manure are also inspired by the desire to provide a proper bedding to farm animals. However, for the production of each 25 tons of farm yard manure, the straw of circa 1 ha of cereals is needed. The imperfect tuning of cereal production to animal numbers may thus constrain an unlimited preference for solid manures. Research directed at the reconciliation of efficient N use and animal welfare is therefore urgently needed.

CONCLUSIONS

When proper attention is given to the composition of manure and decisions on rates, timing and placement are made correspondingly, the nitrogen fertilizer value of manure can be enhanced. This should lead to a drastic reduction of mineral fertilizer use, mineral surpluses and environmental pollution. It could and should be our ambition to raise the current conservative estimates of the relative N fertilizer value of 20-60 percent, to values of 40-80 percent in the near future. Under such conditions, 'manure', 'precision farming' and 'environment' can become reconciled again.

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