C. Rodriguez-Barrueco (ed.), Fertilizers and Environment, 345–350.

403

Cattle-slurry – ^{15}N turnover in a long-term lysimeter trial*

R. Gutser & P. Dosch
Institute of Plant Nutrition, Technical University Munich, D-85350 Freising-Weihenstephan, Germany

Key words: Slurry, lysimeter, N utilization, N leaching, N immobilization, N accumulation

Abstract

The usual application systems for slurry leads to unsatisfying N utilization by plants. Causes are not only the low availability of the organic N and losses of NH_3, but also the low efficiency of potentially plant available NH_4-N of slurry due to immobilization. In an 11 year lysimeter trial (^{15}N) the utilization of the NH_4-N of optimally applied slurry by plants in the first year was only 32% as compared to 59% from mineral fertilizers (CAN). In the next years the rates of remobilization of immobilized fertilizer N of both treatments were nearly the same with 9 to 11% in the 2nd year and 4 to 10% thereafter, depending on the crop. The soil analysis confirmed the strong accumulation of nitrogen in soil by slurry (N_t = 0.165%; CAN 0.130%). According to a simplified calculation the fertilizer specific N accumulation in soil would approach its equilibrium after a continuous manuring for 40 to 60 years. The N accumulation in soil not only increases its fertility, but also the danger of uncontrolled N losses; long-term application of slurry (on average 120 kg N ha^{-1}, slurry only NH_4-N) enhanced the N leaching by on average 10 kg N ha^{-1} yr^{-1} compared to mineral fertilization. Modifying the composition of the slurry by reducing its carbon content decreased the immobilization of NH_4-N in soil with consequence of a reduced N accumulation in soil by long-term supply.

Introduction

The actual cultivation methods of conventional agriculture lead to an increasing load of our environment; negative effects on hydrosphere, atmosphere, pedosphere and biosphere are known (Isermann, 1993). Farms with high density of livestock contribute to a N eutrophication of environment. The N surplus between fertilizer input and removal by harvest products frequently exceeds 100 kg N ha^{-1}. The calculation of the effect of organic and inorganic nitrogen in organic manure is very difficult (Gutser and Dosch, 1992). The knowledge of the N availability of organic and inorganic fertilizer in the year of application and later is necessary, not only for regulating the specific N nutrition of plants but also for a coarse regulating of the fertilizer management for several years; thus the decrease of N surplus is possible without considerably yield losses. Reduced N losses during storage and in the field directly after application are suppositions for an optimized N effect of organic manures.

In this paper we studied the short- and long-term turnover of slurry N in lysimeter and field trials as well as in model trials and deduced recognitions for optimized strategies of slurry with special regard to agricultural – environmental relationships. Additional results are found in Dosch and Gutser (1995) in the same proceedings.

Methods

Lysimeter trial: In a lysimeter trial (1980–1993) in Weihenstephan (794 mm mean precipitation, 7.4 °C air temperature) 40 km northern to Munich, the N turnover of mineral fertilizer (CAN = calcium ammonium nitrate) and cattle slurry were tested (Gutser *et al.*, 1988; Vilsmeier and Gutser, 1989; Gutser and Claassen, 1993).

Soil: silty loam (20% clay, 70% silt), pH($CaCl_2$) = 6.5, 1978 filled in lysimeter plots conform to the natural stratification (horizons of 20 cm) of a brown earth.

* Dedicated to Prof. Dr. A. Amberger on his 75th birthday.

Crop rotation: sugar beet – winter wheat – (winter barley); leaves and straw remained on plots. Catch crops were only cultivated in the treatment "slurry to catch crop".

Fertilizing: CAN: on average 120 resp. 165 kg N ha^{-1} yr^{-1}; slurry: on average 70 (NH_4) = 134 (total) kg N ha^{-1} yr^{-1}, adequate to a density of livestock of 1.8 livestock units (LU) ha^{-1}; the slurry treatments were supplied with on average 50 kg N as CAN ha^{-1} yr^{-1}.

Application time of slurry: (i) to main crop in early spring or (ii) to cash crop in autumn in combination with straw manuring – immediate incorporation or surface band application in growing cereals reduced NH_3 losses.

Since 1988 the utilization of NH_4-N of slurry in comparison with CAN by use of ^{15}N labelled fertilizers (for slurry an addition of $(NH_4)_2SO_4$) was tested – labelling: 12–15 atom% ^{15}N. The effect in the first year and later (5 years = 1989–1993) were studied and the yearly available N (= sum of N uptake by plants + N leaching) were determined and converted in % of fertilizer residue in soil at harvest time of the last crop (including N in leaves or straw).

Field trial: similar treatments as in lysimeter trial; begin: 1979; soil: brown earth (silty loam, pH ($CaCl_2$) = 6.2); crop rotation: silage maize-cereals (1–2 ×). In the first period (1979–1987) slurry was given exclusively to maize, later to each main crop by special application techniques to reduce NH_3 losses.

Slurry dose: on average 83 NH_4 = 148 (total) kg N ha^{-1} yr^{-1}, adequate to a density of livestock of 2 LU ha^{-1}. Till 1988 cereals (winter wheat) received an unit supply of on average 90 kg N as CAN ha^{-1}. Straw remained on field.

Model trial: incubation trial to study the immobilization of ^{15}N labelled slurries (NH_4-N) and CAN; 3 soils differing in clay contents (20, 9 and 6%) – soil moisture 60% of maximum water capacity; fertilizing: 0.2 mg NH_4-N g^{-1} soil – incubation period: 4, 11, 21 weeks.

N immobilization = ^{15}N fertilization minus $^{15}N_{min}$(2 M KCl extractable NO_3- and NH_4-N) or ^{15}N residue in soil (see Vilsmeier and Gutser, 1989).

Methods for ^{15}N in plants, soils, drainage water: $^{15}N/^{14}N$ ratios were determined with ^{15}N analysator NO1 Fa. Jasco, Japan resp. mass spectrometer Europa Scientific.

Special methods for soil analysis: microbial biomass (Anderson and Domsch, 1978)

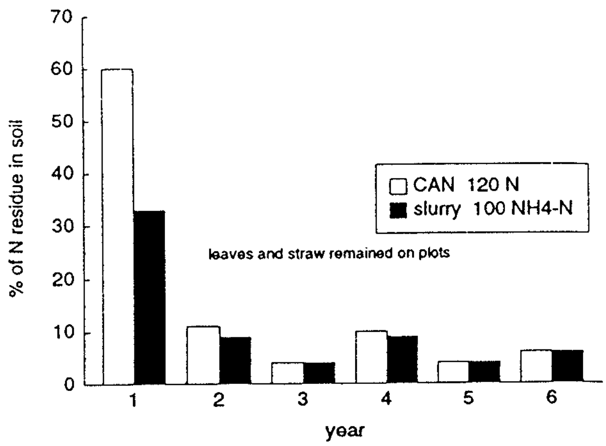

Fig. 1. Available fertilizer N (^{15}N) in the first year (1988) and later (1989–1993)
available N = N uptake (beets, leaves, grain) + N leaching.

N_{org} = soluble organic N, extractable by 0.01 M $CaCl_2$ (Gutser *et al.* 1990) or EUF (electro-ultrafiltration, Nemeth, 1982).

Results

In a 15 years old field trial the known unsatisfying N utilization of slurry by plants was confirmed (Table 1). The average N utilization of slurry by a crop rotation maize/wheat was 16% in the beginning (1979–1987) due to high N losses after broadcast application without incorporation and predominant supply to maize. Afterwards, a slightly but not sufficient increase of N utilization (1987–1993: 20%) was reached by the improvement of application techniques and supply to both crops (equivalence of slurry-N to mineral fertilizer N was near to 50%).

Slurry attained a better result in an 11 years old lysimeter trial with an equivalence to mineral fertilizer of 72% (base: NH_4-N) – (Table 2). This increased utilization should be contributed to minimized NH_3 losses due to better application techniques (immediate incorporation and surface band application).

On base of NH_4-N of slurry the two variants slurry/CAN and CAN alone reached similar yields and N removals; however, N leaching and nitrate content of drainage water were increased by slurry and the increase will extent in time (Fig. 2). On base of total N slurry obtained a 8% lower yield as CAN; the differences in N leaching were unimportant. Corresponding to Fig. 2 the deficit in yields will decrease in time.

Table 1. Utilization of slurry N by a crop rotation maize-wheat (1979–1993)

average N-dose: 83 (NH_4) resp. 148 (total) kg N ha^{-1} yr^{-1}

calculation base	utilization %*		
	1979–1987	1979–1993	1989–1993
NH_4-N	28.9	32.7	35.9
total N	16.2	18.3	20.2
CAN		mean 50–60	

utilization = N uptake (maize shoots + grain) minus control in % of N input by slurry

Table 2. N effect of mineral fertilizer (CAN) and slurry/mineral fertilizer in a lysimeter trial (1983–1993)

measured parameters	control	Base: NH_4-N of slurry		Base: total N of slurry	
	N_o	CAN	slurry	CAN	slurry
fertilizing (kg N ha^{-1} yr^{-1})	–	120	120 (70 + 50)	165	184 (134 + 50)
yield (relative)	54	= 100	102	111 = 100	102 92
removal (grain, beets) (kg N ha^{-1} yr^{-1})	42	94	91	119	91
utilization of fert. (%)		43	31	46	26
equivalence to min. fert. (%)	–	= 100	72	= 100	57
leaching (kg N ha^{-1} yr^{-1})	37	35	45	42	45
avg. mg NO_3 l^{-1} drain. water	46	58	75	72	75

Causes for the low utilization of slurry are not only the slow mineralization of organic N (Amberger *et al.*, 1982) or N losses (NH_3, NO_3), but also the low efficiency of NH_4-N in the first year.

In 7th year of trial slurry and CAN reached nearly the same N uptake in sugar beets (Table 3), because of the high N mineralization in soil long-term treated with slurry. The utilization of slurry N (only NH_4-N ^{15}N labelled) applied to beet was 32% compared to 59% of CAN; the slurry to catch crops attained only an efficiency of 18% in the first year. It is remarkable that the leached N always comes from the N pool of soil and only to an unimportant extent from the fertilizer, directly applied to the main crop.

The availability of the immobilized NH_4-N of slurry in following years was not different from that of immobilized mineral fertilizer (Fig. 1); depending on crop the mineralization rate reached 4 to 10% of the actual residue of fertilizer N in soil.

In 6 years (2 crop rotations) only 24 to 30% of 1988 applied NH_4-N of slurry were utilized in harvest products in relation to 51% in case of CAN (Table 4). Accordingly the N losses by leaching in slurry plots were higher than that of CAN plots. Without considering gaseous losses the calculated residues of slurry N in soil after 6 years came to 60 resp. 68% of applied NH_4-N (100 kg N ha^{-1}); the relative value for CAN was 42%.

The low utilization of NH_4-N and especially that of organic N (on average 50% of total N) led to an evident N accumulation in soil (Table 5); the required carbon was delivered by slurry in addition to roots and harvest residues (see control and CAN treatment) – the contents increased like N.

The differences in N contents of soil are well explained by calculated N balances; of course a correct calculation of N amount in soil is not possible in consequence of mistakes in soil analysis (sampling, plant

Table 3. Utilization of NH_4-N (^{15}N) of slurry by sugar beets in relation to mineral fertilizer (CAN) 7th year of lysimeter trial (1988) – kg N ha^{-1}

treatment	N-uptake (beets + leaves)			N leaching	
	fertilizer	soil	total	fertilizer	soil
slurry (march)*	32 = 32%	156	188	1	82
slurry (catch crop)*	18 = 18%	182	200	3	34
CAN	71 = 59%	111	182	1	61
control	–	97	97	–	57

* +40N as CAN.

Table 4. Utilization of ^{15}N-fertilizer in a lysimeter trial (1988–1993) fertilizing 1988 (kg N ha^{-1}): slurry: 100 NH_4-N, CAN 120 N

treatment	% of fertilized N		
	leaching	removal (beets, grain)	residue in soil calculated*
slurry march	10	30	60
slurry catch crop	8	24	68
CAN	7	51	42

* without considering gaseous N losses.

Table 5. N balance (1983–1993) resp. N and C contents of soil (1991) in a lysimeter trial
N balance = fertilizer input – removal (beets, grain) – leaching

treatment	balance kg N ha^{-1}	soil (0–25 cm)%	
		N_t	C_{org}
control	– 855	0.130	1.17
slurry spring	+ 459	0.165	1.60
slurry catch crop	+ 639	0.170	1.62
CAN	0	0.138	1.45
at begin (1982)	–	0.127	1.12

Table 6. N leaching after application of slurry in relation to mineral fertilizer – ^{15}N lysimeter trial 1988 (= 7^{th} year): sugar beets – (kg N ha^{-1})

treatment		N leaching		
		fertilizer	soil	total
control	N_0	–	57	57
slurry march	N_{100}	1	82	83
slurry catch crop	N_{100}	3	34	37
CAN	N_{120}	1	61	62

residues in soil) resp. the limitation only for surface soil.

The results from lysimeter trial with ^{15}N showed, that the yearly N leaching is less dependent from the fertilizer given to the growing crop than really more from the N pool of soil specific accumulated by long-term fertilizing management (Table 6). Supposition for this establishment is a correctly terminated application of fertilizers.

Therefore the reason of an increased N leaching in slurry plot (application in march) was not the direct effect of the last manuring, but the mobilization from N pool of soil enriched by a long-term application of slurry. The low N leaching on plots with "slurry to catch crop" emphasized the evident N conserving effect of catch crops (other treatments without catch crops).

The N mobilization of N pool in soil, accumulated by manuring as a function of its time, is not only important for the N losses by leaching, but very substantial for the N nutrition of plants (see Table 3). To realize

Table 7. Suitability of microbiological and chemical methods to recognize the increased N potential of soils by long-term application of slurry 11^{th} year of field trials, surface soil (0–25 cm) – October 1988 – mg N resp. C kg^{-1} dry soil

treatment	N_t	aerobic incubation (12 weeks)	biomass-C	N_{org}	
				EUF	$CaCl_2$
Control	1180	33	370	13	6
slurry to catch crop	1300	48	480	16	6
slurry to main crop	1360	51	430	12	6

Table 8. Immobilization of slurry NH_4-N as a function of C content model trial (^{15}N) – avg. 4 to 12 weeks incubation time

treatment	C % fresh w.	N immobilization (% of fertil. dose)	
		sand	loess
slurry	4.4	24	44
slurry	2.0	16	34
slurry	0.6	13	30
CAN	–	7	13

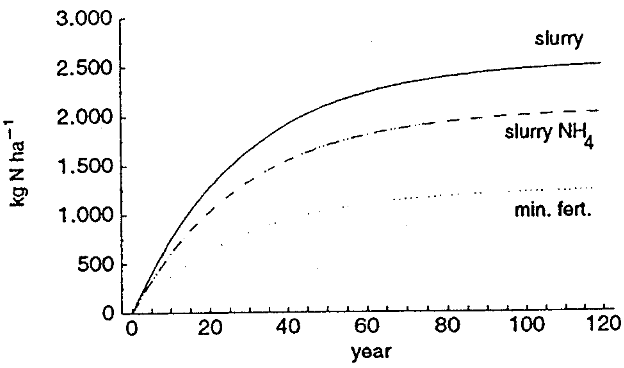

Fig. 2. N accumulation of soil by long-term application of slurry and mineral fertilizer (120 kg ha^{-1}) $N_{acc} = z \cdot r^{-1} \cdot (1 - e^{-r \cdot t})$ Z = input: fertilizer residue in soil after 2^{nd} year r = yearly rate of mineralization (constant 0.035) t = years mineralization rate ($1^{st}/2^{nd}$ yr): slurry 0.22 / 0.06 slurry NH_4: 0.35 / 0.08 min. fert.: 0.60 / 0.08.

a favorable fertilizing practice, that means to optimize the year – and plant-specific N fertilization, it would be helpful to know the N mineralization potential of soils. This N potential is hardly determinable with chemical methods, e.g.the determination of soluble organic N (N_{org}) after extraction with $CaCl_2$ or EUF. While microbiological methods should be more successful, their high analytical expense make them unsuitable for routine analysis (Table 7).

Table 3 shows the difference between the utilization of NH_4-N of slurry and mineral fertilizer. The most important cause for the low efficiency of the applied NH_4-N of slurry may be due to an immobilization in soil (Vilsmeier and Gutser, 1989).

In an incubation trial with cattle slurry (Table 8) of different carbon contents (0.6–4.4% in fresh weight) the positive correlation between C content of manure and extent of N immobilization could be demonstrated. These results point to a soil-specific immobilization potential.

Discussion

Due to the strong dependence from N losses (NH_3, NO_3, N_2, N_2O) and immobilization of the applied NH_4-N the N efficiency in the first year is hardly to calculate. Moreover the organic N of slurry shows a low availability. Therefore, slurry impedes an optimized N fertilization of agricultural crops. In long-term trials the utilization of mineral N of slurry reaches 18 to 26%, but mineral fertilizers attain 50% in average.

Therefore, fertilizer managements will produce on base of the same total N supply in case of slurry or slurry/mineral fertilizer combinations smaller yields than through mineral fertilizer alone. On base of NH_4-N of slurry the problems may be in higher N losses by leaching, increasing with long-term manuring.

Not only the level of fertilization but also the extent of immobilization of slurry N in the first year determine the intensity of N accumulation in soil. In a simplified calculation the different effects of slurry and mineral fertilizer on N accumulation of soil is clearly demonstrated (Fig. 2). Details of this calculation are found in Amberger *et al.* (1982) and particularly Gutser and Claassen (1994).

As shown in the lysimeter trial the mineralization rate of fertilizer residues in soil (immobilized N of slurry) after two years and later is nearly the same between slurry and CAN; in the calculation of Fig. 2 a constant rate of 0.035 was fixed (the problems for different conditions of soil, climate and cultivation systems are known). The main reason for the differences in specific accumulation curves are the extent of fertilizer residues in soil after the first year and partly second year; in case of fertilizer dose of 120 kg N ha^{-1} the residues after 2^{nd} year reach 44 (mineral fertilizer) or 89 (cattle slurry) kg N ha^{-1}. The fertilizer specific N accumulation in soil would approach its equilibrium after a continuous manuring for 40 to 60 years. Under practical conditions after about 40 years there should be nearly the same amounts of available N in soil (mineral fertilizer 109, slurry 98 kg N ha^{-1}). The predominant part of the available N comes in case of mineral fertilizer directly from fertilizer (66%), in case of slurry from N pool in soil (73%).

The N accumulation in soil not only improves its fertility, but also the dangers of uncontrolled N losses. The extent of N accumulation is limitable by a reduced N fertilization (densities of livestock should not exceed 1.5 LU ha^{-1}) (Enquete Kommission, 1994) as well as an increased utilization of slurry N in the first year. The reduction of C contents of slurry by separation techniques or anaerobic fermentation (Messner and Amberger, 1988) should be a possibility to decrease the immobilization in soil and increase N utilization by plants. For an optimized strategy of slurry with special regards to agricultural-environmental relationship a high efficiency of slurry N in the first year is necessary, which is attainable by reducing N losses, but also N immobilization (see Dosch and Gutser (1995) in the same proceedings).

References

Amberger A, Vilsmeier K and Gutser R (1982) Stickstofffraktionen verschiedener Güllen und deren Wirkung im Pflanzenversuch. Z Pflanzenern u Bodenkde 145: 325–336.

Anderson JPE and Domsch KH (1978) A physiological method of the quantitative measurement of microbial biomass. Soil Biol Biochem 10: 215–221.

Dosch P and Gutser R (1996) Reducing N losses (NH_3, N_2O, N_2) and immobilization from slurry through optimized application techniques. In: Rodriguez-Barrueco C. (ed) Fertilizers and Environment. pp 269–276. Kluwer Acad. Publ., Dordrecht.

Enquete Kommission des Deutschen Bundestages (1994) "Schutz der Erdatmosphäre". Agra-Europe, August 1994, 35.

Gutser R, Amberger A, Vilsmeier K (1989) N-Bilanzen nach Mineral- und Gülledüngung mit Dicyandiamid-Zusatz in langjährigen Lysimeter- und Feldversuchen. Landw Forsch, Kongreßband 1988, VDLUFA-Schriftenreihe 28: 503–516.

Gutser R, Teicher K and Maier S (1991) Gefäßversuche zur Aussagekraft des N_{org}-Stickstoffs für das N-Potential von Böden. Landw Forsch, Kongreßband 1990, VDLUFA-Schriftenreihe 32: 243–248.

Gutser R and Dosch P (1992) Strategien zur Optimierung der Stickstoffwirkung von Flüssigmist. Tagung "Neue Techniken zum umweltgerechten und wirtschaftlichen Einsatz von mineralischen und organischen Düngern", 11 Nov 1992, Neumarkt, Landtechnik Weihenstephan, Schrift 2, 38–48.

Gutser R and Claassen N (1994) Langzeitversuche zum N-Umsatz von Wirtschaftsdüngern und kommunalen Komposten. Mitt Dtsch Bodenkundl Gesellsch 73: 47–50.

Isermann K (1993) Territorial, continental and global aspects of C, N, P and S emissions from agricultural ecosystems. In: Wollast R, Mackenzie FT and Chou L (eds) Interactions of C, N, P and S biogeochemical cycles and global change. Springer-Verlag, Heidelberg: NATO AS, Series 14, 79–121.

Messner H and Amberger A (1988) Composition, nitrification and fertilizing effect of anaerobically fermented manure slurry. Proc IV CIEC Symp 1987, Braunschweig-Völkenrode 1: 125–130.

Nemeth K (1982) Electro-ultrafiltration of aqueous soil suspension with simultaneously varying temperature and voltage. Plant Soil 64: 7–23.

Vilsmeier K, Gutser R and Amberger A (1988) Zur Wirkung des NH_4-^{15}N aus Gülle und Ammoniumsulfat in Modell- und Gefäßversuchen. Landw Forsch, Kongreßband 1987, VDLUFA-Schriftenreihe 23: 297–312.

Vilsmeier K and Gutser R (1990) N-Ausnutzung nach Mineral- und Gülledüngung (^{15}N) im Weihenstephaner Lysimeter. Landw Forsch, Kongreßband 1989, VDLUFA – Schriftenreihe 30: 175–180.