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CONCERTED ACTION

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COST PROJECT 681

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Ammonia losses after animal slurry application

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Introduction

Discussion about an environmentally safe management of animal slurry so far has been mainly concerned with leaching of nitrate. In contrast, there is only few detailed information on the quantity of volatile ammonia losses. More recently, the question of ammonia emission is receiving increased attention. Atmospheric pollution by NH_3 is supposed to be partly responsible for soil acidification and for forest decline because after a short retention time in the atmosphere ammoniacal nitrogen is returned to the soil by wet and dry deposition (as NH_4 or NH_3).

In Europe, an estimate of 6.4 mio tons of NH_3 are emitted per year. About 80 % are supposed to be due to animal husbandry. Ammonia is emitted from stable air; it also evaporates during storage of animal excrements. Considerable amounts of NH_3 are released during and especially after application of slurry. Volatilization of NH_3 after slurry application can be in the range of 5 to 95 % of applied ammonium N. This variation in reported loss rates is mainly due to the great number of factors which determine the process of NH_3 release.

Our investigations were designed to measure NH_3 losses after slurry application under field conditions, and to determine the effects of meteorological parameters, type of slurry, as well as form and time of slurry application.

Material and methods

A wind tunnel technique was used to determine NH_3 losses.
The experimental area (1 m^2) is covered with a tunnel made from transparent polycarbonate. One end is tightly connected to a radial fan to form a partially closed system. Air is drawn into the tunnel by suction and passes over the experimental area. NH_3 released from slurry is transported in the tunnel by the air stream. An aliquot part of the exhaust air is introduced to an acid trap by means of a diaphragm air pump. NH_3 collected by the sulfuric acid is finally determined by distillation.
The system of small wind tunnels was suitable for comparative studies; we conducted single-factor experiments with 2 treatments and 2 replicates. NH_3 concentration in the air over an unmanured area was determined as control.
Slurries were applied on the basis of equal amounts of ammonium N: 100 kg NH_4-N/ha on arable land, 60 kg NH_4-N/ha on grassland.
Dry matter (DM) content of slurry ranged between 1.5 % (pig slurry) and 10 % (highly viscous cattle slurry), pH values between 7.0 and 7.7.
All experiments were conducted on a silty loam of pH 6.5 with a CEC of 14.1 meq/100g soil.
Air flow rate in the tunnel was equivalent to a 35- fold air exchange/ min.

Results and discussion

Pattern of NH_3 release with time

There is an approximately logarithmic relationship between time and cumulative values of NH_3 losses (expressed as % of applied NH_4-N) in all experiments (Fig. 1).
NH_3 release starts immediately after slurry application and reaches its greatest intensity (that means released NH_3/time

unit) already on the first day. Lateron the rates decrease. The total amount of loss therefore is mainly determined by the initial loss rates.

Loss of ammonia after surface application of various slurries - effect of dry matter content

Highly viscous cattle slurry with 10 % dry matter, applied in August on soil covered with stubbles and straw resulted in significantly higher NH_3 losses than cattle slurry with only 5 % DM, within 10 days about 70 % as compared to 40 % of applied NH_4 -N were released as NH_3 (Fig. 1).
After slurry application on compacted soil in November, NH_3 release also increased with dry matter contents. While thinly liquid pig slurry (1.5 % DM) gave only low losses of about 10 %, the rates for the viscous cattle slurry (7.8 % DM) were about 40 %.
This effect is due to the differing infiltration of the slurries. Slurries with low viscosity infiltrate the soil more rapidly and thus enable a stronger sorption of NH_4-N. Highly viscous slurries, however, with inhibited infiltration remain on the soil surface for a longer period where the direct contact to the atmosphere enhances NH_3 volatilization. The infiltration of slurry is additionally impaired by a layer of straw.

Slurry application to growing crops

One of the possibilities to use slurry in spring is the application to growing crops. Therefore it was to be tested how a crop canopy at growth stage EC 29-32 (end of tillering/beginning of shooting) effected ammonia volatilization (Fig. 2).
Winter wheat and winter barley had almost identical volatilization rates of about 25 %. Compared to soil application

without incorporation, losses were reduced by 40 or 50 %. The main reason for this decrease in NH_3 loss is probably the fact that the plant canopy lowers the wind velocity close to the soil surface, with slurry N thus being better protected against volatilization. It is also possible that part of the released NH_3 is taken up by the plants.

Slurry on grassland

The effects of varied time of application of slurry on grassland is given in Fig.3. With low temperatures in winter (minimum temperature -2° C, maximum temperature 15° C), slurry application to grassland resulted in losses of about 22 %. The same amounts of ammonium applied to the surface of tilled soil gave somewhat lower losses (about 16 %). Obviously the sod impaired the infiltration of slurry so that less NH_4 could be sorbed by the soil.
Extremely high losses of nearly 80 % were observed after slurry application in late summer with dry and warm weather conditions. In this case, NH_3 volatilization was enhanced by high temperatures (maximum 28° C) as well as by the high dry matter content (9.5 % DM) of the slurry.

Effect of mode of application

The mode of slurry application is an important factor determining ammonia volatilization. While losses were increased by surface application, incorporation with a cultivator reduced losses to about one third (Fig. 4). Due to mixing of slurry and soil, more slurry ammonium is getting in contact with sorptive sites of the soil and thus escapes potential evaporation. As can be seen from the diagram incorporation is only efficient if performed immediately after slurry application.

Conclusions

The remarkable differences in total amounts of ammonia volatilization are mainly due to differences in the composition of slurry, crop and weather conditions as well as method of application.
Losses can rise up to about 80 % of the NH_4-N applied with a great proportion of the total loss occurring within the first day after application.

Slurry dry matter content is an essential factor: high losses can be expected after surface application of highly viscous slurry on stubbles and straw, compacted soil and grassland.

The hazard of ammonia losses is lower after slurry application at low temperatures. The influence of temperature decreases, however, if infiltration of the slurry is impeded.

An immediate incorporation is a very efficient way to keep losses as low as possible. If incorporation into the soil is not feasible for instance after application on grassland or into growing crop, viscous slurry should be diluted with water.

By reducing ammonia losses, not only mineral fertilizer can be saved but also the contribution of agriculture to air pollution can be diminished.

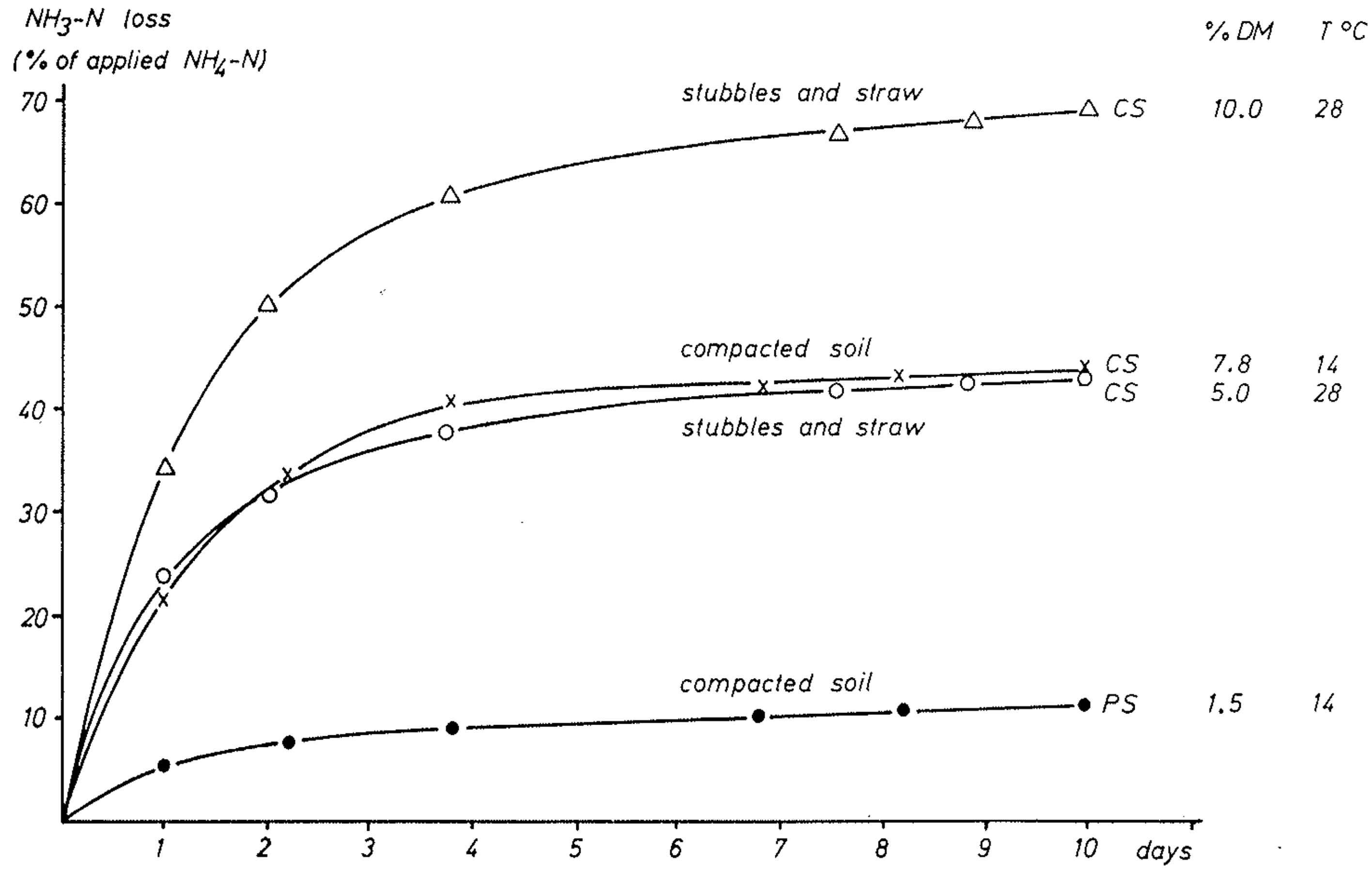

Fig. 1: NH_3 losses after surface application of cattle (CS) and pig slurry (PS) on stubbels and straw (August) or compacted soil (November)

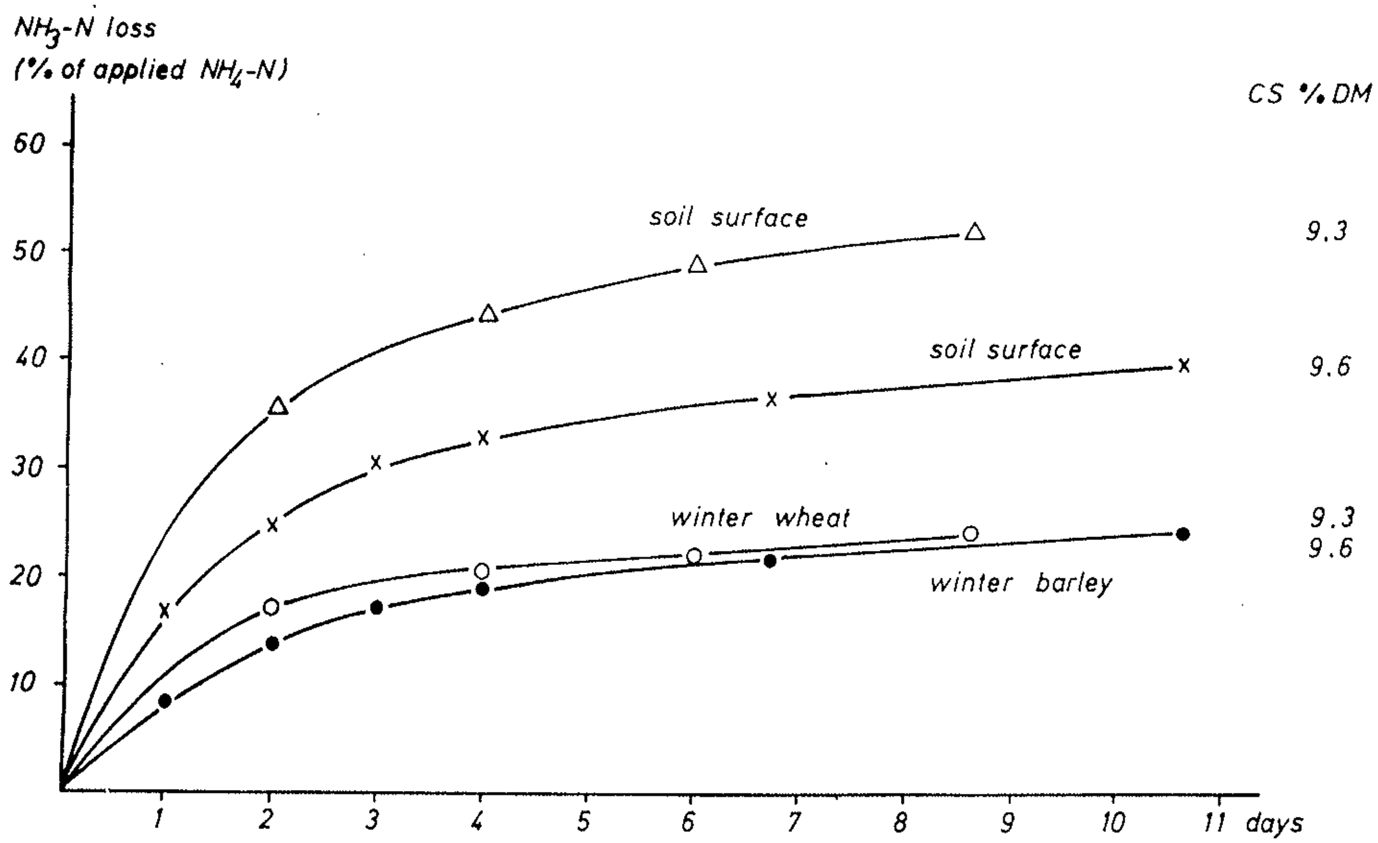

Fig. 2: NH_3 losses after spring application of cattle slurry (CS) into growing crops (winter wheat, winter barley : EC 29-32) or on soil surface resp.

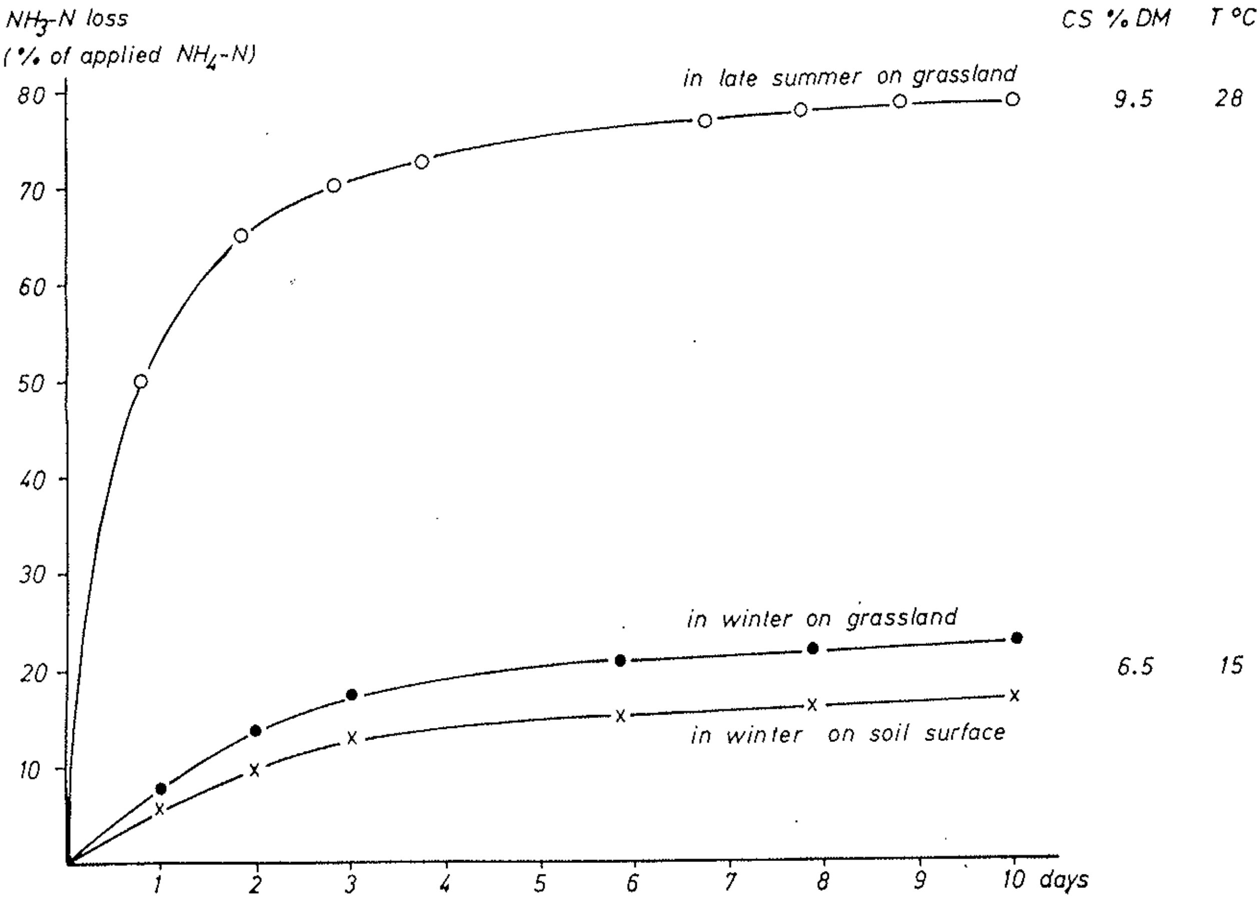

Fig. 3: NH_3 losses from cattle slurry (CS) on grassland

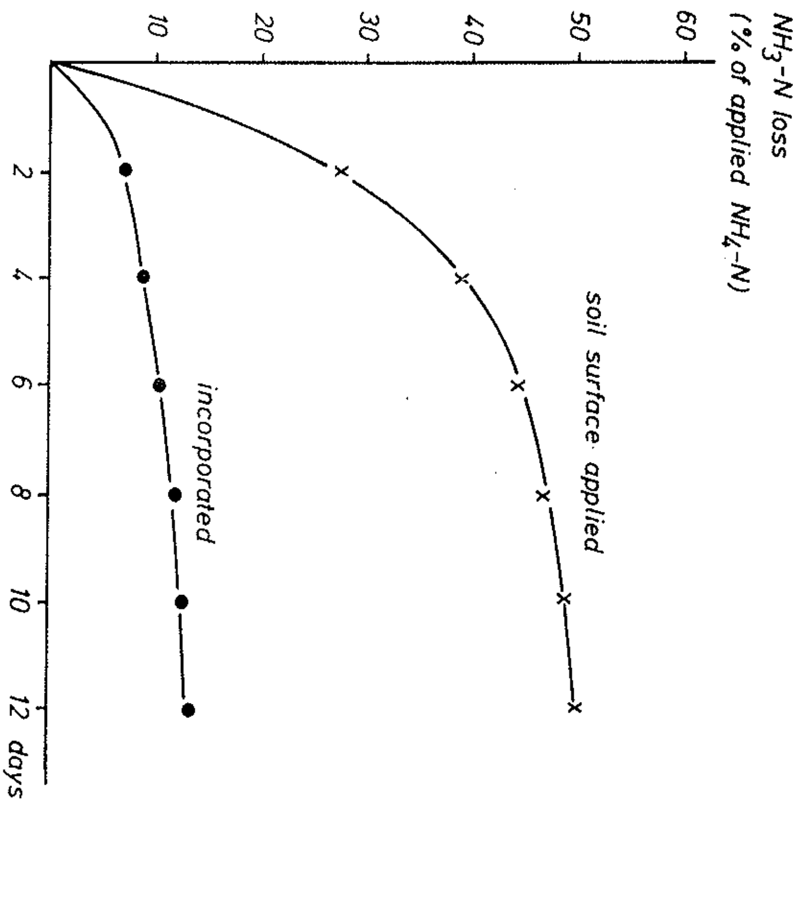

Fig. 4: NH_3 losses from cattle slurry dependent on mode of application to the soil

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Use of Organic Wastes as Fertilizers and its Environmental Implications

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INTRODUCTION

Each type of land use ultimately leads to a more or less severe impact on natural ecosystems. The return of organic wastes from agriculture to the natural cycle (recycling) is a necessity in terms of farm management and political economics. When applied in normal amounts, they contribute essentially to an enhanced plant growth and to a sustained and increased soil fertility; however, when applied in excess or at the wrong time, they may result in pollution of soil, water, or air. Consequently, the question arises of the limitations of an economical and ecologically justifiable use of residues from plant and animal production.

Soil fertility is a parameter determined by site and management conditions; it is an index for the soil's productivity and security of yield. The dynamics of the organic matter and of nitrogen (of which 95 % is bound in organic matter) is especially important.

Mineralization, nitrification and denitrification alternate with biological or chemical N immobilization, these processes being dependent on site and management as well as on the composition and C/N ratio of the applied organic material. The goal of an orderly land use, therefore, must be to optimize the growth of crop plants while keeping environmental pollution, in its broadest sense, as low as possible.

The environmental implications of organic waste application can be as follows :

a) An excess supply of organic matter may result in a temporary strong immobilization of soil nitrogen (causing N deficiency in crops) ; the turnover capacity of the soil can be exceeded and soil structure can be impaired.

b) By a high rate of mineralization and nitrification especially in the fall large amounts of nitrate can be released and leached into the groundwater in the subsequent fallow season.

c) By surface runoff (erosion) of animal wastes, particularly of slurry, surface waters can get heavily polluted.

d) Gaseous emissions of nitrogen in form of NH_3, to a lesser extent also of NO_x, are the cause of acid depositions with all their familiar consequences like forest damages and soil acidification.

RESIDUES OF PLANT PRODUCTION

The most important residues from plant production are straw and green material.

Straw material

Straw normally remaining on the fields after harvest is incorporated into the soil and submitted to decomposition. Cereal straw (Table 1) with a dry matter content of about 75 to 80 % is rich in cellulose, pentosanes and lignin the latter being very resistant to microbial attack, but important for the formation of 'stable humus'. The C/N ratio is wide. Maize straw (Table 1) has a higher N content and a lower C/N ratio; the cores contain higher amounts of sugars. Therefore maize straw will be degraded faster.

Table 1. Components of cereal straw (average % in dry matter).

	small grains	grain maize		small grains	grain maize
cellulose	44	35	N	0.5	1.0
pentosanes	28	28	P	0.1	0.2
easily hydrol. carbohydrates	5	12	K	1.1	1.8
lignin	18	18	Mg	0.1	0.2
C/N ratio	100	60	ash	4.7	7

The same holds true for field bean and rape straw or for potato foliage with a C/N ratio between 60 and 70 (Amberger, 1987). Generally speaking, a wide C/N ratio results in immobilization of soil nitrogen for at least several months. During this time, N is 'biologically blocked', but also prevented from being leached (Table 2; Amberger, 1987). Part of the remineralized N is again available to the plants but not before the middle of the following cropping season; complete decomposition takes 1 to 2 years. In fertile soils, the native nitrogen available in autumn can be 'conserved' in this way and is protected from leaching. Long-term experiments with fertilizer application reveal that straw manuring undoubtedly enhances biological activity, whereas the increase in stable humus is only minor. The 'biologically blocked' nitrogen is directly utilized by plants with an effiency of only 8 %. The remainder enters into the basic turnover of the soil.

The main positive effect of straw manuring is based on its high C supply which serves as food for microorganisms, resulting in an increased biological activity, a biological N conservation and a decrease of nitrate leaching. However, negative effects on soil fertility can occur when excessive amounts of straw (in close successions of cereal crops) are applied particularly to heavy soils where oxygen diffusion is temporarily depressed. Under these conditions, anaerobic fermentation takes place, detrimental degradation products accumulate, and N_2 escapes into the atmosphere. In case of low soil moisture, a 'puffy' structure can be the result of many years of intensive straw manuring, resulting in an increased risk of erosion.

Green material

In farms without livestock, sugar beet leaves and catch crops remain on the field and are incorporated into the soil as green manure. Their dry matter content is relatively low (between 15 and 30 %) and easily decomposable; their nitrogen content varies

Table 2. N leaching and N uptake after wheat straw manuring in pot trials (silty loam, pH 6.5, N appl.: 690 mg pot^{-1}).

Time of straw and N application	N leaching mg pot^{-1}		N uptake by ryegrass mg pot^{-1}	
	without straw	with straw		
control (N_0)	160	6	49	36
August	564	164	68	67
September	434	280	64	58
October	264	109	82	74
LSD%	25			

between 1 and 4 % mainly depending on fertilization. The C/N ratio ranges between 12 and 30 (Vilsmeier and Gutser, 1988 a, b).

Since the 'critical limit' lies between 25 and 30, green material undergoes a faster mineralization compared to straw, which may increase leaching of nitrate.

In model experiments with soil temperatures simulating field conditions during autumn, and spring (on the basis of long-term mean values), it could be demonstrated (Fig. 1) that with a C/N ratio of 24 the N mineralization of sugar beet leaves incorporated in October was low; with a C/N ratio of 13 and 17, however, release of nitrate started already during the autumn/winter period, and reached a maximum in May. N mineralization of catch crops gives a similar picture (Fig. 2).

Consequently, green material should be incorporated into the soils as late in fall as possible, or even better, if soil properties are favourable, not before spring. Nitrate leaching and pollution of ground water can be actually reduced this way, as was demonstrated by the results of our 6-years lysimeter trials in Weihenstephan (Gutser and Vilsmeier, 1989). In a crop rotation of wheat and sugar beets (Table 3), the combination of slurry application with inorganic fertilizers and catch cropping gave the lowest rate of N leaching (less than in the control!) with the annual N uptake by

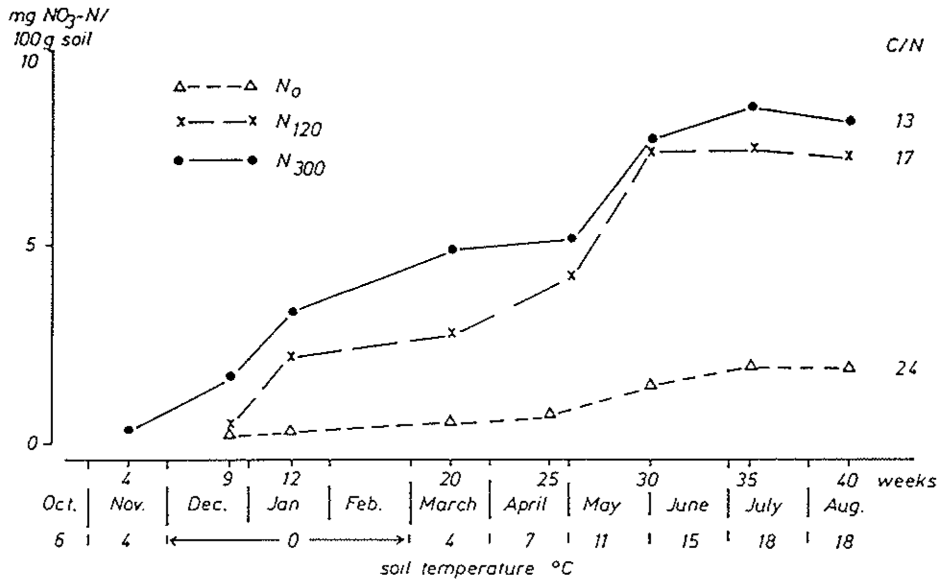

Fig. 1. Release of nitrate from sugar beet leaves after incorporation in October (Vilsmeier and Gutser, 1988a).

the crops being nearly on the same level. According to these observations, the great advantage of easily decomposable green material for soil fertility does not necessarily result in an increased pollution of ground water with nitrate.

WASTES FROM THE PROCESSING OF PLANT PRODUCTS

Potato starch waste water

In processing potatoes for starch production, waste water is produced in the season between end of August and December and is irrigated on agricultural land (Amberger and Gutser, 1984, Bayer *et al.*, 1987, Amberger and Tucher, 1989).

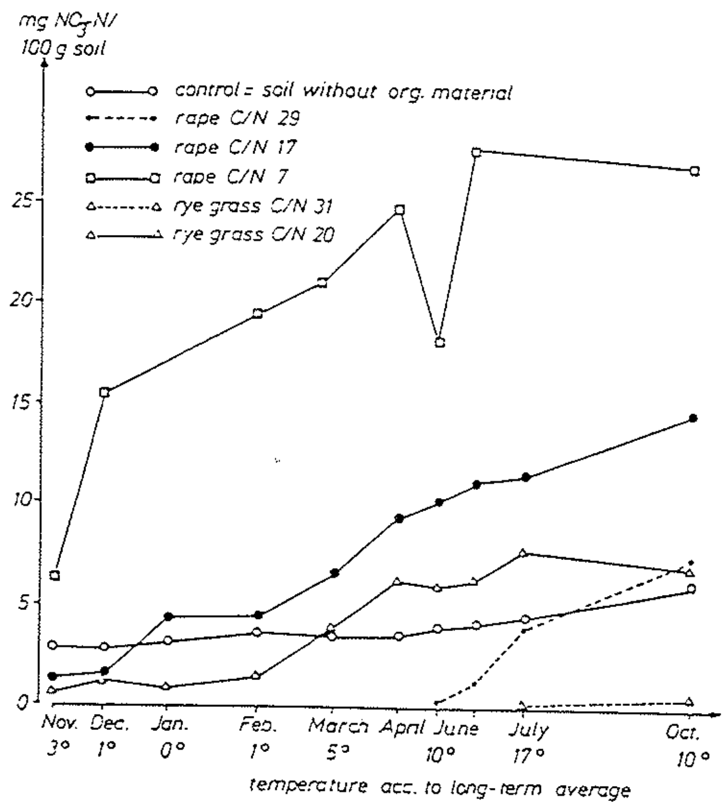

Fig. 2. N mineralization from catch crops (incl. roots), incorporated in November (Vilsmeier and Gutser, 1988b).

Table 3. N-leaching and N-uptake in lysimeter trials "Weihenstephan" (Gutser and Vilsmeier, 1989). Crop sequence: wheat, sugar beets, Ø from 1983-1988.

N application	leaching kg N ha^{-1}	uptake kg N ha^{-1}
control	37	46
inorganic fert. (opt.)	37	92
slurry / inorg. fert.	43	89
slurry / inorg. fert. + catch crops	29	88

Table 4. Composition of potato starch water (after protein precipitation) (Amberger and v. Tucher, 1989).

			mg l^{-1}	
dry matter	1%	N	700	0.7
C/N ratio	4.2	P	110	0.1
pH	6.6	K	1550	1.6
		Mg	115	0.1

Potato starch waste water processed according to current techniques which include protein precipitation, contains (Table 4) little dry matter, high amounts of nutrients, and has a narrow C/N ratio. N compounds (amino acids and amides) are mineralized and nitrified relatively fast, thus being subject to leaching. By adding straw, green manure, or a nitrification inhibitor (dicyandiamide, DCD) this nitrogen can be conserved and thereby protected from leaching (Bayer, 1988).

With overall straw application, the nitrate concentration in the soil profile is low and does not change much during the winter (Fig. 3). After potato starch water application together with green manuring in September, nitrification starts at a slow rate in April. When potato starch water was applied in November, very high amounts of nitrate occurred already in February and could be leached; the addition of DCD, however, could postpone nitrification until April, the beginning of growth of the following crop.

With respect to its high nutrient content, potato starch water application should be limited to a total supply equivalent to 200 kg N ha^{-1}. This amount can be utilized by the subsequent crop if its application is combined with the described agro-technical methods.

Potato residues from distilleries

Distiller's wash produced in the alcohol fabrication from potatoes so far has been used as animal feed on an obligatory basis. At present, its direct employment as an organic fertilizer with high nutrient for agricultural purposes is being considered.

In incubation trials at 8°C over a period of 70 days we could observe no release of nitrate, but rather a biological immobilization of N. In field trials with oats (Table 5), however, an application of 40 m^3 distiller's residues (ca. 128 kg N ha^{-1}) was nearly as effective as a mineral fertilizer dressing of 30 kg N as calcium ammonium nitrate. Consequently, fertilization with these residues in late fall/spring does not result in ground water pollution (Gutser and Amberger, 1989).

WASTES OF ANIMAL PRODUCTION

Stable manure and liquid manure

Stable and liquid manure have for a long time been the only wastes of animal production. Stable manure, a mixture of straw, dung and urine, left to decompose for several months, finally reaches a C/N ratio of 20 to 30 and is normally applied to the field in autumn. Per livestock unit (LU) and year on the average 10 ton of solid manure are produced which equals a total of 25 dt dry matter and as little as ca. 5 kg of immediately available (ammonium) nitrogen (Table 6; Amberger, 1987). During the following crop, however, 30 to 40 % of the total N become plant available. The limiting factor for stable manure production on a farm is the supply of straw which depends on the proportion of small grains in a crop rotation. In stable manure farms, livestock intensity normally does not exceed 1 LU ha^{-1}, and therefore scarcely any environmental problems arise concerning groundwater pollution with leached nitrate, with the exception of a certain extent of NH_3 volatilization at the manure yard. The nutrients of stable manure are not sufficient for the following crop and have to be supplemented by adequate mineral fertilizer applications. Liquid manure, which is urine of livestock mixed with water is applied directly to the main and catch crops.

Semi-liquid manure slurry

Manure slurry is a mixture of dung and urine, usually without straw, which undergoes anaerobic fermentation. Dung, especially of ruminants, contains only minor amounts of degradable carbon compounds (Table 7) and therefore has a low C/N ratio of 7 to 10; 50 to 60 % of the total N is in the form of ammonium which can be nitrified

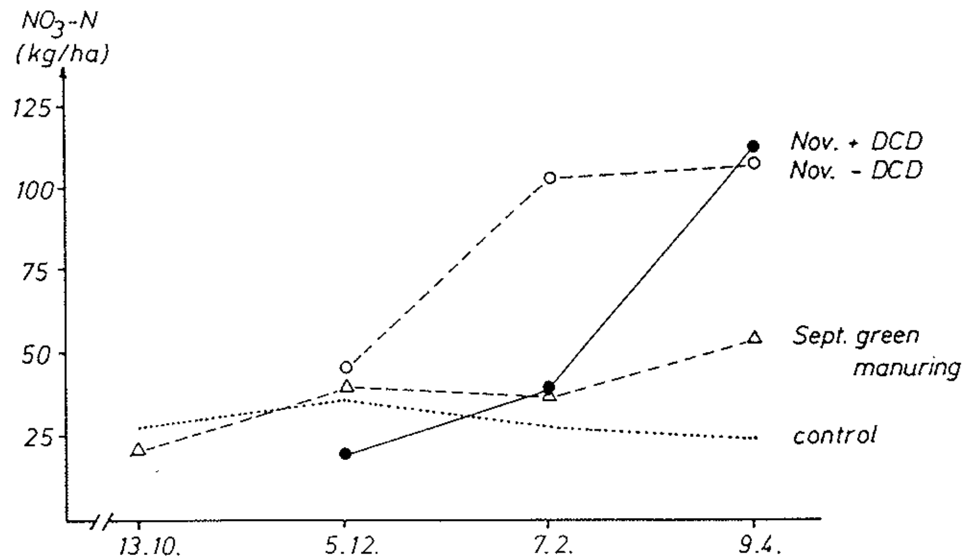

Fig. 3. Effect of spray irrigation of potato starch waste water (30 mm ha^{-1}) and straw manuring in all plots on the nitrate concentration in the profile (0-90 cm) of loamy sand (Bayer,1988).

Table 5. Effectiveness and uptake of N from potato distillation residues in field trials with oats. Nutrient contents (% of fresh weight): 0.27 N, 0.11 P_2O_5, 0.42 K_2O, 2.7 C, C/N = 10.

calcium ammonium nitrate kg N ha^{-1}	potato residues kg N ha^{-1} (m^3)	grains yield dt ha^{-1} (86% dry m.)	grains N uptake kg ha^{-1}
50	-	42	63
50	128 (40) Nov.	48	72
50	128 (40) March	49	75
80	-	48	72
$LSD_{5\%}$		6	8

Table 6. Nutrient content of solid and liquid manure.

manure	dry m. %	N(NH_4^+-N) kg t^{-1} or kg m^{-3}	P_2O_5	K_2O
solid manure [1]				
cattle	25	5 (0.5)	2.5	6.5
pigs	23	6 (0.5)	4	5
poultry	70	35 (15)	35	25
liquid manure [2]				
cattle	2	2 (2)	-	8
pigs	2	4 (4)	1	3

[1] 10 t LU^{-1}
[2] 4m^3 LU^{-1}

Table 7. Nutrient content of semi-liquid manure ("slurry").

slurry	production m^3 LU^{-1}	dry m. %	N(NH_4^+-N)	P_2O_5 kg m^{-3}	K_2O
dairy cows	20	7.5	4 (2)	2	6
feeder cattle	20	7.5	4 (2)	2	3
pigs	15	7.5	6 (4)	5	3
poultry	6	15	10 (7)	9	5

in the soil within a short time (Amberger, 1984a, 1986a); even in September/October the temperatures are high enough to increase environmental hazards. The remaining amount of organic N enters into the nitrogen pool of the soil. Its initial availability averages between 5 and 10 % (Amberger *et al.*, 1982). 1 LU (cattle or pigs) supplies as much as 15 to 20 m^3 slurry equivalent to 40 to 60 kg ammonium N (Amberger, 1984a, 1986 a). In contrast to stable manure farms, slurry farms are independent of straw supply and acreage, and therefore animal intensity can be drastically increased. Livestock intensities of more than 2.5 or 3 LU ha^{-1}, however, may give rise to severe environmental hazards.

Which are these problems connected with slurry manuring ?

a) A great difficulty in slurry farming is not only the excess of nutrients but also the limited time for a proper application.

Rates of more than 50 m^3 cattle, 35 m^3 pig, or 20 m^3 chicken slurry ha^{-1} on arable land in a single application enhance soil degradability and also endanger soil fertility. The amounts of manured slurry must be related to the nutrient demand of the following crop. Application should be performed at a time when the nutrients, particularly nitrogen, can be used immediately by a main, second or catch crop, that is at seeding or at the beginning of growth. Slurry manuring during the growing stage of a crop can also be recommended, even though a short, temporary depression of growth and some NH_3 emissions may occur.

b) Ammonia and odour emissions during and after spreading are a very large problem associated with slurry manuring. According to our present knowledge, about 90 % of ammonia emissions originate from livestock manuring on bare land (Fig. 4). Altogether, about 20 kg potentially harmful NH_3 per LU must be expected (Isermann, 1986). Volatilization of NH_3, if it is not immediately incorporated into

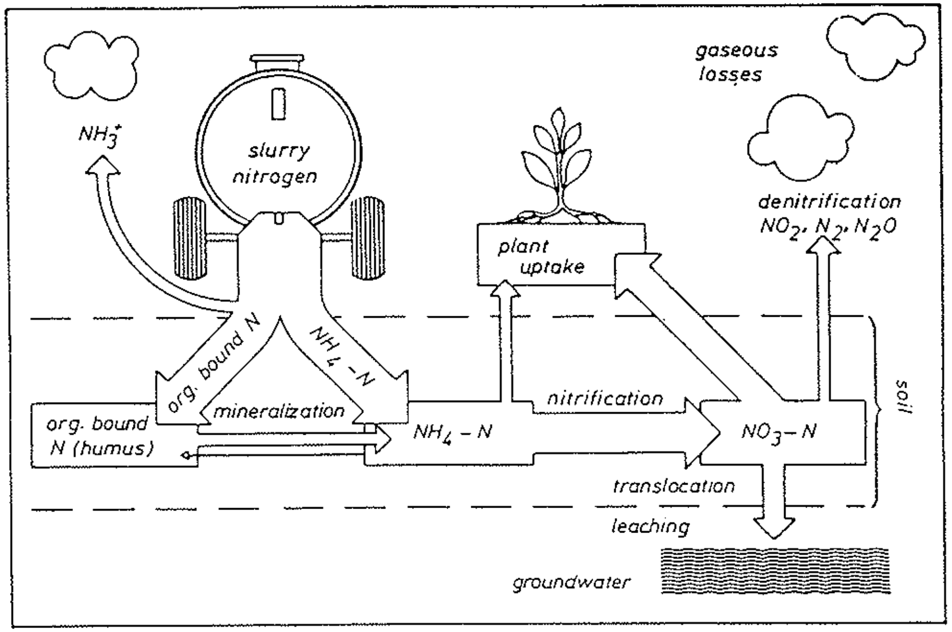

Fig. 4. Pathways of slurry nitrogen.

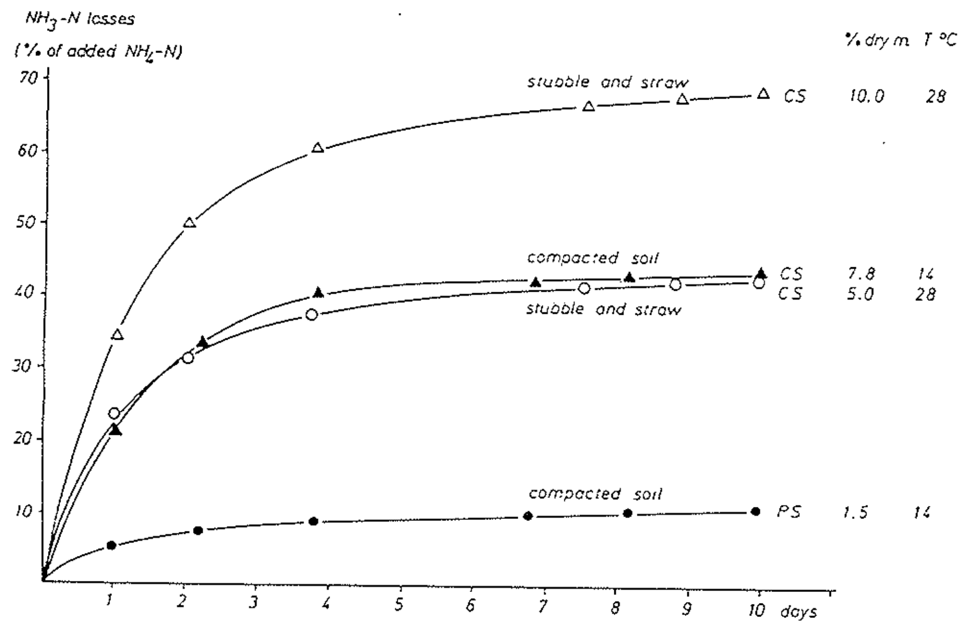

Fig. 5. NH_3 losses after surface application of cattle (CS) and pig (PS) slurry on stuble and straw (August) or compacted soil (November).

the soil, follows an approximately logarithmic curve with time and can reach values of up to 80 % of the applied ammonium-N (Rank and Amberger, 1987, Rank, 1988). The main factors increasing volatilization are (Fig. 5): high temperatures, compacted soil with stubble and straw or grassland, and a high dry matter content of slurry which impairs the penetration into the soil (Amberger and Huber, 1988, Huber, 1989). On the other hand, an immediate incorporation or injection into the soil, low temperatures, or rainy weather, can minimize both N losses and odour. The proper mode of application is therefore a very important factor, and immediate incorporation indispensable (Fig. 6).

c) A further hazard is the leaching of nitrate and the resulting groundwater pollution. Slurry manuring after cereal harvest is very common because the storage capacity of the tanks is often exhausted around this time, and application onto the stubble fields is easy. It has to be realized, however, that during September/October soil temperatures are still high enough to allow conversion of ammonia-N to nitrate

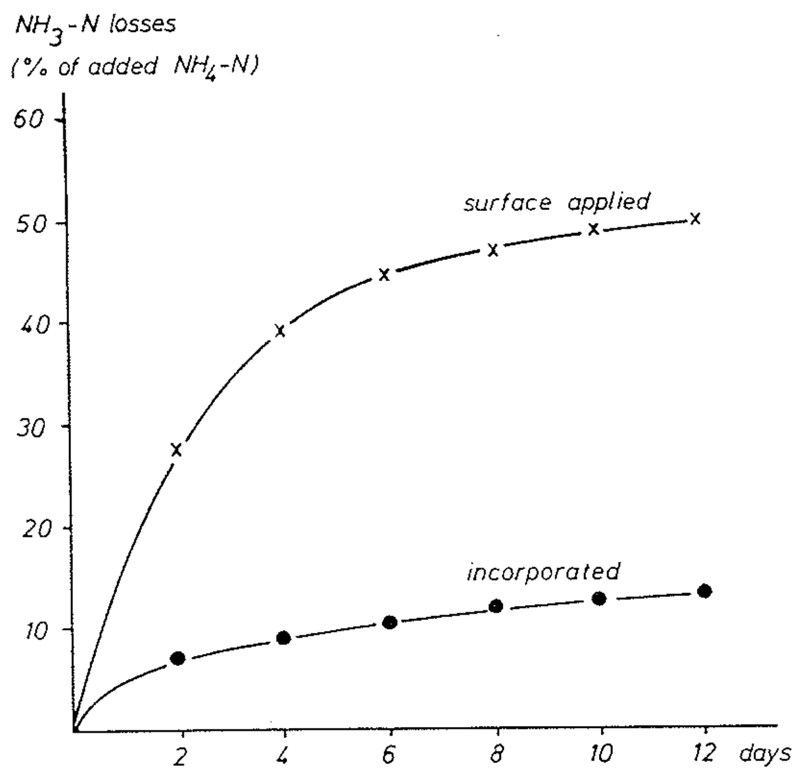

Fig. 6. NH_3 losses from slurry as dependent on mode of application.

within 2 or 3 weeks which consequently results in complete loss by leaching during winter (Fig. 7).

A very appropriate measure to avoid this is to apply slurry to a following second crop or to combine it with straw and green manure. In both cases the slurry nitrogen will be biologically immobilized at least till the middle of the following year. If slurry however has to be spread on fallow land in late autumn or winter, then the only possiblity to avoid groundwater pollution is the addition of a nitrification inhibitor (Amberger, 1981, 1984 b, 1986 b, Gutser and Amberger, 1984). As the inhibiting effect strongly depends on the temperature and only lasts for 2 to 4 months, success is greater with later applications (Fig. 8; Vilsmeier and Amberger, 1987). Unlike 'biologically blocked' nitrogen after straw manuring, the slurry N 'conserved' by dicyandiamide is fully available to the subsequent crop. Even during winter the ap-

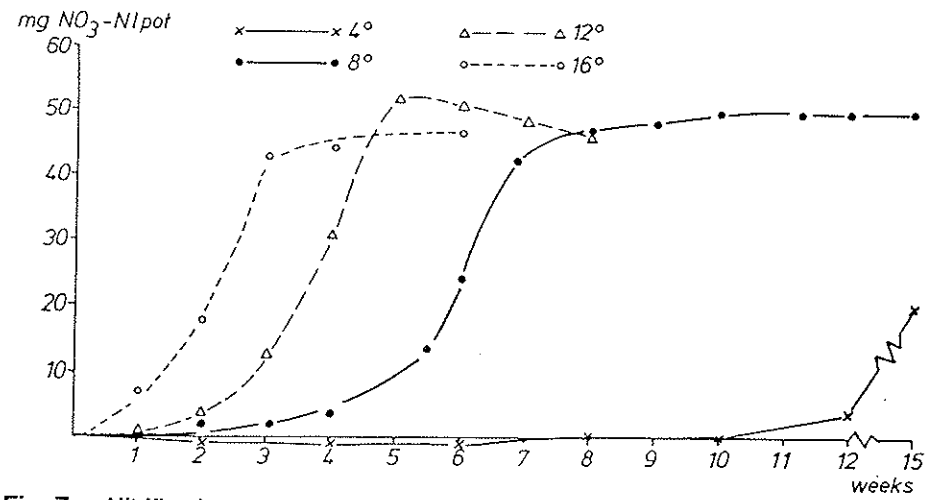

Fig. 7. Nitrification of cattle slurry as dependent on temperature.

plication of slurry is justifiable on level fields in areas with only minor frost.

d) On the other hand, slurry, even in small amounts, must never be applied to slopes or to frozen soils. Under those conditions, slurry cannot penetrate into the soils and the hazard of surface runoff and erosion and thereby pollution of surface waters with all its negative consequences for the aquatic life, is substantial.

CONCLUSIONS

The return of plant and animal wastes to the natural cycle by a proper agrotechnical management is a necessity with regard to farm management and political economics.

Plant residues applied in normal quantities create only minor problems and rarely (e.g. in monoculture systems or on heavy soils) affect soil fertility and soil structure. The same holds true for customary rates of animal wastes in form of stable and liquid manure if they are used properly (amount, date). With an highly intensive animal production independent of acreage and straw supply, large amounts of animal slurry

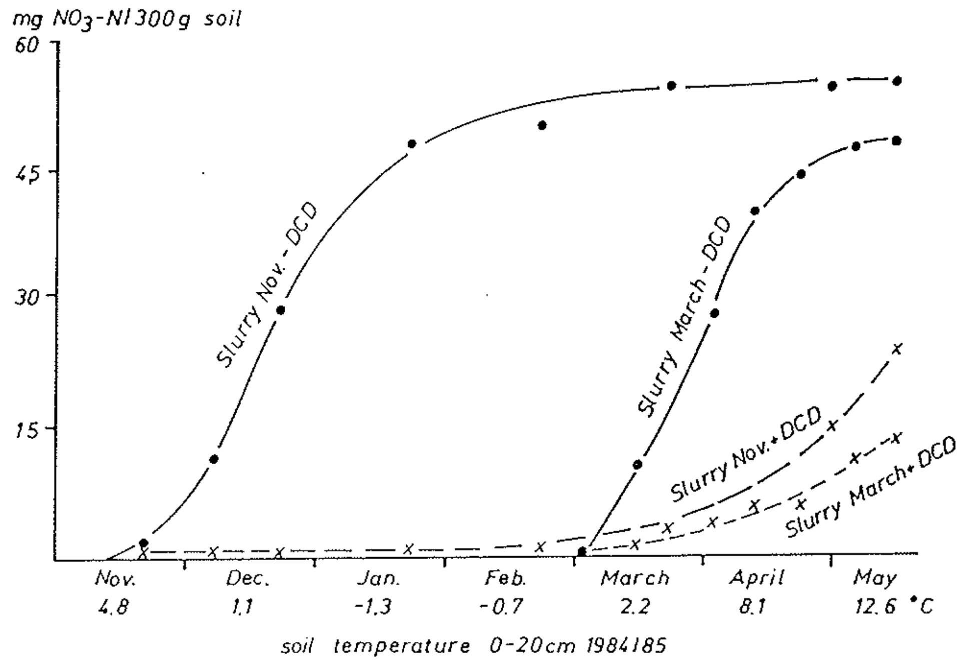

Fig. 8. Nitrification of cattle slurry (with simulated outdoor temperatures November-May) (Vilsmeier and Amberger, 1987).

rich in nutrients are produced which can neither be applied at an appropriate date nor be completely utilized by the following crop. Thus, major ammonia and odour emissions as well as pollution of ground water with nitrate may be the consequence.

Severe hazards always arise when the type of farm management is very intensive and one-sided, more so from exclusive livestock farming than from single crop systems with cereals. These problems can and must be solved by an orderly agricultural management with the goal to conserve or rather optimize soil fertility and to minize environmental pollution.

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