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Report 709

On farm development of bedded pack dairy barns in The Netherlands

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Abstract
Nitrogen balances, total gaseous nitrogen emissions from barn and farmland, and manure quality of bedded-pack barns are compared with the free-stall barn

Keywords
Bedded-pack barn, free-stall barn, compost, nitrogen balance, nitrogen emissions, manure quality

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Nutrient balances and manure quality of bedding material

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Samenvatting

Omschakeling van de huisvesting van koeien in een ligboxenstal met productie van drijfmest naar een vrijloopstal met organische bodem en productie van gecomposteerde mest heeft gevolgen voor 1) de gasvormige emissies van stikstof uit de stal en na uitrijden van mest/compost op het het land, 2) de kwaliteit van de geproduceerde mest/compost, en 3) de bruikbaarheid van deze mest/compost voor de bemesting van gewassen en het onderhoud van bodemvruchtbaarheid. In dit rapport wordt verslag gedaan van de resultaten van onderzoek naar deze gevolgen.

Indicatieve gasvormige verliezen van stikstof vanuit de stal
Ter indicatie van het totale gasvormige stikstofverlies uit de vrijloopstal is bij twee verschillende vrijloopstallen (met jaarrond opstallen van de koeien) een stikstofbalans opgesteld over een periode van negen tot tien maanden. Tevens werd ook een fosfaat- en kalibalans opgesteld. Gasvormige stikstofverliezen bestaan vooral uit ammoniak (NH_3), lachgas (N_2O) en stikstofgas (N_2). Bij de onderzochte vrijloopstallen bestond de vloer deels uit een organische bedding en deels uit een betonnen roostervloer (met daaronder mestopslag). Uit de balansen kan afgeleid worden dat bij de vrijloopstal met houtsnippers als bedding naar schatting 19% van de stikstofexcretie door de koeien op de vloer in gasvorm verdween (zie tabel hieronder). Dit verlies is opgebouwd uit een verlies van 30% van de stikstofexcretie op de bedding en 10% van de excretie op de roostervloer. Geschat werd dat 45% van de excretie terechtkwam op de bedding en 55% op de roostervloer. Bij de vrijloopstal met GFT-compost als bedding verdween naar schatting in totaal 44% van de stikstofexcretie in de stal in gasvorm. Dit verlies is opgebouwd uit een verlies van 72% van de stikstofexcretie op de bedding en 9% van de excretie op de roostervloer. Het indicatieve gasvormige stikstofverlies uit de onderzochte vrijloopstallen is daarmee aanzienlijk hoger dan het berekende verlies uit de gemiddelde ligboxenstal met jaarrond opstallen (9% van stikstofexcretie).

Indicatieve gasvormige verliezen van stikstof na uitrijden op het het land
Op een melkveebedrijf met een ligboxenstal wordt grofweg de helft van het gasvormige stikstofverlies uit de stikstofexcretie in de stal gerealiseerd en de andere helft na uitrijden van de drijfmest op grasland. Voor een goede beoordeling van verschillen in gasvormige stikstofverliezen tussen huisvestingssystemen dienen daarom de verliezen in de stal én na uitrijden op het land bij elkaar opgeteld te worden. Als vrijloopstalcompost tijdelijk opgeslagen wordt op het erf, kan deze opslag een bijdrage leveren aan het totale gasvormige stikstofverlies. Deze bijdrage is in deze studie buiten beschouwing gelaten. Bij het zodebemesten van runderdrijfmest op grasland kan, op basis van bestaande gegevens, gerekend worden met een ammoniakemissie van 9,3% van de totaal uitgereden stikstof en een lachgasemissie van 0,3% van de totaal uitgereden stikstof. Voor vrijloopstalcompost zijn de emissies van deze gassen afgeleid van de gemiddelde emissies na bovengrondse toediening van GFT-compost. De afleiding is gebaseerd op het feit dat de samenstelling en het gedrag in de bodem van de onderzochte vrijloopstalcomposten grote overeenkomsten vertoont met GFT-compost. De emissie na het uitrijden van GFT-compost is gebaseerd op een internationale literatuurstudie. Op basis daarvan wordt de gemiddelde ammoniakemissie na het bovengronds uitrijden van vrijloopstalcompost geschat op 0,3% van de totaal uitgereden stikstof en de gemiddelde lachgasemissie op -0,3%. De verwachte gasvormige stikstofemissie na het uitrijden van vrijloopstalcompost is daarmee netto afwezig.

Systeembenadering gasvormige stikstofverliezen uit de stal en na uitrijden op het land
Op basis van de emissies uit de stal en na uitrijden op het land kan berekend worden dat bij de gemiddelde ligboxenstal (met jaarrond opstallen) in totaal 18% van de stikstofexcretie in gasvorm verloren gaat. Bij de onderzochte vrijloopstallen was dit respectievelijk 24% (houtsnippers) en 48% (GFT-compost). Daarmee is bij de systeembenadering het totale gasvormige stikstofverlies van de onderzochte twee vrijloopstallen hoger dan van de gangbare ligboxenstal. Een overzicht van het totale gasvormige stikstofverlies per stal is gegeven in de onderstaande tabel. Bij de vrijloopstal met houtsnippers is uit de lage C/N-verhouding (10,5) van de vrijloopstalcompost af te leiden dat de bedding te lang in de stal is blijven liggen, waardoor het stikstofverlies relatief hoog was. Aanpassingen in het bodemmanagement, zoals een kortere verblijfsduur van het beddingmateriaal of minder actieve ventilatie, kunnen de stikstofemissie verlagen.

Totale gasvormige stikstofverliezen in de stal en na toediening van de geproduceerde mest/compost aan grasland, berekend voor een ligboxenstal en twee verschillende vrijloopstallen, uitgedrukt als percentage van de stikstofexcretie in de stal

		Vrijloopstal		Ligboxenstal
	Vloerdeel	Houtsnippers	GFT-compost	
		Verdeling van de stikstofexcretie (%)		
Stal	*Bedding*	*45*	*55*	*0*
	Roostervloer	*55*	*45*	*100*
	Hele vloer	100	100	100
		Gasvormig stikstofverlies (als % van stikstofexcretie)		
Stal	*Bedding*	*13,5*	*39,9*	*0*
	Roostervloer	*5,4*	*4,0*	*8,9*
	Hele vloer	19,0	43,9	8,9
Land	*Bedding*	*0*	*0*	*0*
	Roostervloer	*4,8*	*3,9*	*8,7*
	Hele vloer	4,8	3,9	8,7
Stal+land	Hele vloer	23,8	47,8	17,6

Kwaliteit van de geproduceerde vrijloopstalcompost

Door de aanvoer van extra organisch materiaal en mineralen met beddingmateriaal kan in de vrijloopstal de mestproductie toenemen. Bij de vrijloopstal met GFT-compost werd met de compost over de balansperiode 5543 kg extra stikstof en 1000 kg extra fosfaat aangevoerd. Vergeleken met de stikstof- en fosfaataanvoer met ruwvoer en krachtvoer was dit 30% extra stikstof en 44% extra fosfaat. Door de aanvoer van extra fosfaat met beddingmateriaal, en het optreden van relatief hoge gasvormige stikstofverliezen, daalt de stikstof/fosfaatverhouding van de vrijloopstalcompost vergeleken met drijfmest. De hoeveelheid fosfaat in mest bepaald meestal hoeveel er op het land toegediend mag worden. Bij een lagere stikstof/fosfaatverhouding betekent dit dat er met vrijloopstalcompost bij eenzelfde fosfaatgift minder stikstof toegediend kan worden dan met runderdrijfmest. Uit mineralisatieonderzoek onder optimale condities blijkt dat de stikstof in de onderzochte vrijloopstalcomposten iets beter beschikbaar is voor opname door het gewas vergeleken met een GFT-compost, maar veel minder vergeleken met een runderdrijfmest. Twee maanden na het mengen met zandgrond was 48% van de stikstof in de runderdrijfmest beschikbaar voor opname door het gewas, vergeleken met gemiddeld 9% (7 tot 10%) voor drie vrijloopstalcomposten. Vergeleken met runderdrijfmest blijkt vrijloopstalcompost nauwelijks geschikt als stikstofmeststof voor de korte termijn, maar wel voor de lange termijn. Dit betekent dat bij een omschakeling van een ligboxenstal naar een vrijloopstal met productie van compost een boer ook moet omschakelen wat betreft zijn visie op bemesting en bemestingsstrategie. De onderzochte vrijloopstalcomposten braken na het mengen met zandgrond veel langzamer af dan een runderdrijfmest en iets sneller dan een GFT-compost. Bij bemesting met eenzelfde hoeveelheid organische stof dragen de onderzochte vrijloopstalcomposten daardoor veel meer bij aan de opbouw van bodemorganische stof en bodemvruchtbaarheid dan runderdrijfmest. Door het gebruik van GFT-compost of houtsnippers als beddingmateriaal wordt, vergeleken met de geproduceerde runderdrijfmest, extra organische stof toegevoegd aan de mest en aan de bodem. Bij de vrijloopstal met houtsnippers werd geschat dat er na tien jaar ongeveer zes keer zoveel bodemorganische stof overblijft van de geproduceerde compost vergeleken met de bijbehorende drijfmestproductie. Hierdoor is vrijloopstalcompost erg geschikt om het organische stofgehalte en de bodemvruchtbaarheid van percelen te verhogen.

Summary

A transition in cow housing concept from a free-stall barn with slatted floor and the production of liquid manure (slurry) to a bedded-pack barn with an organic bedding and the production of compost has consequences for 1) the gaseous nitrogen loss from the barn and farmland, 2) the quality of the produced compost, and 3) the usefulness of this compost for fertilisation of crops and the maintenance of soil productivity. In this publication, the results of research on these consequences are reported.

Indicative gaseous nitrogen losses from the barn
To indicate total gaseous nitrogen losses from the bedded-pack barn, nitrogen balances were calculated for two different bedded-pack barns (with year-round housing) for a period of nine to ten months. In addition, also phosphorus and potassium balances were calculated. Gaseous nitrogen losses mainly consist of ammonia (NH_3), nitrous oxide (N_2O) and nitrogen gas (N_2). The floor of the investigated bedded-pack barns consisted of both an organic bedding as well as a concrete slatted floor (with storage of liquid manure below). From the nitrogen balances, it can be derived that from the bedded-pack barn with woodchips as bedding material, about 19% of nitrogen excreted by the cows was lost in gaseous form (see table below). This total loss consisted of an estimated loss of 30% of nitrogen excreted on the bedding and 10% of nitrogen excreted on the slatted floor. Of the total amount of nitrogen excreted on the floor, an estimated 45% was excreted on the bedding and 55% on the slatted floor. From the bedded-pack barn with green waste compost as bedding material, about 44% of excreted nitrogen was lost in gaseous form. This total loss consisted of an estimated loss of 72% of nitrogen excreted on the bedding and 9% of nitrogen excreted on the slatted floor. Of the total amount of nitrogen excreted on the floor, an estimated 55% was excreted on the bedding and 45% on the slatted floor. The gaseous nitrogen loss from the studied bedded-pack barns is considerably higher when compared to a calculated nitrogen loss of 9% of excreted nitrogen for the average free-stall barn with slatted floor and year-round housing.

Indicative gaseous nitrogen losses from farmland
On a dairy farm with housing in a free-stall barn, roughly half of the total gaseous nitrogen losses are emitted from the barn; the other half is emitted after manure application to farmland. For a proper assessment of differences in gaseous nitrogen losses between housing systems, both nitrogen losses from the barn as well as from farmland have to be considered. When bedded-pack compost is temporarily stored in the farm yard, continuation of the composting process can contribute to gaseous nitrogen losses from the system. This potential contribution is not considered here. When liquid manure is applied by shallow injection on permanent grassland, ammonia emission from applied manure is calculated at 9.3% of applied total nitrogen and nitrous oxide emission at 0.3%. For bedded-pack compost, emission percentages are derived from the average emissions after surface spreading of green waste compost, as reported in international literature. This derivation seems justified, because the composition of the investigated bedded-pack composts, and their behaviour in soil, was largely similar to that of green waste compost. Based on international literature, the average ammonia emission after surface spreading of bedded-pack compost is estimated at 0.3% of total nitrogen applied, and average nitrous oxide emission at -0.3%. The expected nitrogen loss after surface spreading of bedded-pack compost is therefore negligible.

Indicative gaseous nitrogen losses from the housing system (barn and farmland)
Based on the gaseous nitrogen emissions from the barn and farmland, it can be estimated that about 18% of nitrogen excreted by dairy cattle is lost in gaseous form from the average free-stall barn with slatted floor and year-round housing. For the bedded-pack barns under investigation, this was 24% (woodchips) and 48% (green waste compost), respectively. As a result, gaseous nitrogen losses for the housing system are higher for the investigated bedded-pack barns compared to the average free-stall barn with slatted floor. The low C/N-ratio (10.5) of the compost from the bedded-pack barn with woodchips indicates that the residence time of the bedding was too long, resulting in relatively high nitrogen losses. Adaptations in bedding management, such as a shorter residence time of bedding material or less active ventilation, can decrease gaseous nitrogen loss.

Total gaseous nitrogen loss in the barn and after application of the produced manure/compost to grassland, calculated for an average free-stall barn with slatted floor, and two different bedded-pack barns, expressed as a percentage of nitrogen excretion in the barn

		Bedded-pack barn		Free-stall barn
	Floor type	Barn A (woodchips)	Barn B (green waste compost)	
		Distribution of N excretion (%)		
Barn	*Bedding*	*45*	*55*	*0*
	Slatted floor	*55*	*45*	*100*
	Whole floor	100	100	100
		Gaseous N loss (% of all excreted N)		
Barn	*Bedding*	*13.5*	*39.9*	*0*
	Slatted floor	*5.4*	*4.0*	*8.9*
	Whole floor	19.0	43.9	8.9
Land	*Bedding*	*0*	*0*	*0*
	Slatted floor	*4.8*	*3.9*	*8.7*
	Whole floor	4.8	3.9	8.7
System	Whole floor	23.8	47.8	17.6

Quality of produced bedded-pack compost

The amount of manure/compost produced by the bedded-pack barn can increase relative to the free-stall barn as a result of the extra input of bedding material and minerals therein contained. For the bedded-pack barn with green waste compost as bedding material, an extra 5543 kg of nitrogen and 1000 kg of phosphorus was supplied by the bedding material. Expressed as a percentage of the nitrogen and phosphorus input with roughage and concentrates, this was an increase of 30% in nitrogen input and 44% in phosphorus input. The extra phosphorus input, in combination with relatively high gaseous nitrogen loss, results in a decrease of the nitrogen/phosphorus ratio in bedded-pack compost compared to liquid cattle manure. In the Netherlands, the phosphorus level of manure usually limits the application rate on farmland. A lower nitrogen/phosporus ratio then means that less nitrogen can be applied with bedded-pack compost compared to liquid cattle manure. Mineralisation experiments, carried out under optimal conditions, show that nitrogen in the investigated bedded-pack composts was somewhat better available for crop uptake than nitrogen from a reference green waste compost, but considerably less compared to a liquid cattle manure. Two months after mixing with a sandy soil, 48% of the nitrogen in liquid cattle manure was available for crop uptake, compared to on average 9% (7 to 10%) for three different bedded-pack composts. Compared to liquid cattle manure, bedded-pack compost is hardly suitable as a nitrogen fertiliser in the short term, but is suitable as a fertiliser in the long term. This means that a transition from a free-stall barn to a bedded-pack barn with production of compost also requires a transition in a farmers' view on fertilisation and fertilisation strategy. The investigated bedded-pack composts decomposed considerably slower than the liquid cattle manure, and somewhat faster than the reference green waste compost, when mixed with sandy soil. When the same amount of organic matter is applied, bedded-pack compost contributes considerably more to the build-up of soil organic matter and soil fertility than liquid cattle manure. Through the use of green waste compost or woodchips as bedding material, extra organic material is added to the manure and the soil, compared with liquid cattle manure alone. For the bedded-pack barn with woodchips composting, it was estimated that about six times more organic matter remained in soil after a period of ten years, when compared to the original liquid manure produced. This makes bedded-pack compost very suitable to increase soil organic matter content and soil fertility of farmland.

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1 Nutrient balances of bedded-pack dairy barns

1.1 Introduction

To assess the environmental performance of a bedded-pack dairy barn, nutrient balances have to be calculated, especially for N. The nutrient input with feed is by far the largest input item on the balance sheet. Most of the nutrients taken up by the cow leave the cow again in the form of urine, feces and milk. A small portion is incorporated in body tissue (e.g. growing heifers) or in calves (pregnant cows). Nutrients in urine and feces are excreted and deposited on the floor. When deposited on a composting organic bedding, these nutrients can be incorporated in bacterial biomass and thus be fixed. N not incorporated will eventually volatilise in the form of NH_3, N_2O, NO_x and N_2. P and K not incorporated will remain in the bedding, because P and K do not volatilise. P and K also do not leach from a properly managed bedding.

Calculation of an N balance is important to estimate how much N is lost from N excreted with urine and feces. With this information, bedded-pack barns can be compared with the commonly used free-stall barn with slatted floor. P and K balances seem less important, because P and K are not lost from the bedding or barn. However, results from the P and K balance are useful to verify the accuracy of the calculated N balance. Bedded-pack barns usually have two floor types, a bedding and a slatted floor (feeding and walking area). The presence of two floor types makes the calculation of an N balance more complicated, because the distribution of excreted N over the floor types is not necessarily relative to floor area. It is also possible that the ratio in excreted urine to feces is different for the two floor types (e.g. if cows tend to defecate more on the bedding). Calculation of P and K balances can provide insight in the distribution of N over both floor types. A carbon (C) balance provides insight in how much C is lost from the bedding. C from bedding material and feces is mainly lost as CO_2 and to a lesser extent as CH_4. In this chapter, nutrient balances are calculated for two different bedded-pack barns: a barn with composting of woodchips (barn A) and a barn with the use of green waste compost, mainly for moisture absorption (barn B).

1.2 Indicative NPKC balances of a bedded-pack barn with composting of woodchips (barn A)

1.2.1 Introduction

The floor of barn A consists partly of a bedding (1138 m^2) and partly of a slatted concrete floor with manure storage below (557 m^2). This means that balances have to be calculated for both floor types. The balances of barn A are calculated for the period between January 15 and November 17 of 2011 (306 days). The bedding in barn A consists of woodchips that are intensively composted with cattle urine and feces during a relatively long period (up to 10 months). The heat generated by composting vaporizes the excreted moisture and keeps the bedding dry. During the composting process, excreted N is partly incorporated in bacterial biomass, which reduces volatile N losses.

During the balance period, on average 53.5 cows and 3.5 pregnant heifers were year-round housed in the barn (no grazing outside). The dry period of the cows was 15% of the total period. Dry cows were separated from the lactating cows by a fence. Heifers joined the lactating cows four months before giving birth, joined the dry cows one month before giving birth and joined the lactating cows again after giving birth. During the balance period, 43 calves were born. Milk production was on average 31.1 kg day^{-1} en 11369 kg $year^{-1}$ (including the dry period). Milk protein content was on average 3.38%.

During the balance period, in total 950 m^3 (253 Mg) of woodchips was brought into the barn and 407 m^3 (225 Mg) of composted material was removed at the end. The bedding, with a thickness of 35 to 40 cm at the end of the balance period, was cultivated with a rotary tiller once a day, and also actively ventilated (forced ventilation by blowing, 4 x 15 minutes per day). The composting procedure in a bedded-pack barn is different from traditional composting. One difference is that with traditional composting, all materials are usually mixed at the start of the process. The composting in barn A started with an energy-rich, N-poor bedding (initial C/N ratio of 80). Every day, relatively small amounts of N from urine and feces were deposited on the bedding and mixed with the bedding material. Another difference is that the bedding material is cultivated much more intensively (namely every day) than during traditional composting. During the balance period, the temperature in the bedding varied between 40 and 50°C at 20 cm depth.

1.2.2 Calculation of the NPKC balances

An overview of the calculated NPK balances for the whole barn is given in Table 1.

Table 1 NPK balances for the bedded-pack barn with composting of woodchips (barn A), between January 15 and November 17 of 2011

Item	**N (kg)**	**P (kg)**	**K (kg)**
Input with woodchips	889	94	385
Input with roughage	6739	915	7747
Lactating cows	*5806*	*761*	*6657*
Dry cows	*708*	*116*	*827*
Pregnant heifers	*225*	*37*	*263*
Input with concentrates	4315	746	1966
Output(1) with compost	3461	638	4271
Output with milk	2703	510	816
Output with liquid manure	4146	589	5002
Output with growing heifers	6	2	1
Output with born calves	55	15	9
Total input	11943	1755	10098
Total output	10371	1755	10098
Loss	1571	0(2)	0
Loss (%)	0.13	0.00	0.00

1) Amount of nutrients accounted for

2) Is exactly 0 because of the calculation method used

The input with woodchips (Table 1) was calculated by multiplication of the amount of woodchips, brought into the barn during the balance period, by its NPK contents. The used contents were from a sample of woodchips taken from a batch in November of 2011. These woodchips were brought into the barn for a new round of composting. The sample contained 3.51 g N, 0.37 g P and 1.52 g K per kg of fresh product. Dry matter content was 59% and bulk density was estimated at 0.27 kg l^{-1}, based on results of Smits et al. (2012).

The input with roughage (Table 1) was calculated from the amounts of NPK fed with the daily rations to lactating cows (Table 2), dry cows (Table 3) and pregnant heifers (Table 4), their respective numbers and the length of the balance period. The input with feed for the dry cows and pregnant heifers was calculated using their feed intake capacity, the ration composition (50% of grass silage, 50% of grass hay) and saturation levels from CVB (2007). For the mineral composition of ration components, either analysis results provided by the farmer or results provided by CVB (2007) were used.

Table 2 Daily NPK input with roughage for lactating cows.

Type of product	**Amount (kg DM)**	**Mineral contents (g kg^{-1} DM)**			**Amounts (g)**		
		N	*P*	*K*	*N*	*P*	*K*
Grass silage, 1st cut	4	32.0	4.2	33.3	128	17	133
Grass silage, July 2010	6	32.3	4.2	39.0	194	25	234
Silage maize, 2010	8	12.0	1.6	14.0	96	13	112
Total	18				418	55	479

Table 3 Daily NPK input with roughage for dry cows.

Type of product	**Amount (kg DM)**	**Mineral contents (g kg^{-1} DM)**			**Amounts (g)**		
		N	*P*	*K*	*N*	*P*	*K*
Grass silage, year av.	5.7	27.7	4.2	34.1	158	24	195
Grass hay, year av.	5.7	22.2	4.0	24.2	127	23	138
Total	11.4				286	47	333

Table 4 Daily NPK input with roughage for pregnant heifers

Type of product	**Amount (kg DM)**	**Mineral contents (g kg^{-1} DM)**			**Amounts (g)**		
		N	*P*	*K*	*N*	*P*	*K*
Grass silage, year av.	4.2	27.7	4.2	34.1	117	18	144
Grass hay, year av.	4.2	22.2	4.0	24.2	94	17	102
Total	8.4				210	35	245

The NPK input with concentrates for lactating cows (Table 1) was calculated using the amount of concentrates delivered on the farm between January 6 and November 24 of 2011. The calculated average daily use of concentrates per lactating cow amounted to 10.9 kg of product, 311 g of N, 54 g of P and 142 g of K, respectively.

The NPK output with compost (Table 1) was calculated using the amount of compost present in the barn at the end of the balance period and its measured NPK contents (Table 17). The amount of compost was calculated using the average thickness of the bedding layer (36 cm), the bedding area (1138 m^2) and an estimated bulk density of 0.55 kg l^{-1} (Smits et al., 2012). Measurement of the thickness of the bedding layer and sampling of the bedding layer were carried out immediately after cultivation of the whole layer, to represent the bulk density as reported in Smits et al. (2012).

The NPK output with milk (Table 1) was calculated using the total amount of milk delivered at the milk factory during the balance period, multiplied by its N, P and K contents. The N content was calculated from the protein content (3.38%) and amounted to 5.30 g kg^{-1}; for the P and K contents standard values of 1.0 and 1.6 g kg^{-1} milk were used (CBS, 2011).

The NPK output with born calves and pregnant heifers (Table 1, Table 6) was calculated using liveweights and contents in liveweight per life phase (Table 5). Pregnant heifers spent on average four months in the barn. Assuming an increase in liveweight of on average 70 kg during that period (excl. calve weight), and using the NPK-contents in Table 5, total N, P and K fixation in body tissue was calculated at 6 kg N, 2 kg P and 1 kg K, respectively. NPK fixation in lactating cows was assumed to be 0.

Table 5 Amounts of N, P and K present in newly born calves and growing young stock, depending on life phase.

Life phase	Liveweight (kg)	Mineral contents (g kg^{-1})			Mineral amounts (kg)		
		N	*P*	*K*	*N*	*P*	*K*
At birth	44	29.4	8.0	2.1	1.29	0.35	0.09
1 year old	320	24.1	7.4	2.0	7.71	2.37	0.64
2 years old	525	23.1	7.4	2.0	12.1	3.89	1.05
Adulthood	600	22.5	7.4	2.0	13.5	4.44	1.20

Source: CBS, 2011

The N output with liquid manure, produced on the slatted floor, could, for various reasons, not be measured and had therefore to be estimated from the N excretion on the slatted floor. This excretion can be estimated by subtraction of N excretion on the bedding from N excretion on the whole floor. First, N excretion on the whole floor was calculated by subtraction of the N output with milk, born calves and growing heifers, from the N input with feed (roughage and concentrates). N excretion on the whole floor was calculated at 8289 kg. Likewise, P and K excretion on the whole floor were calculated at 1134 and 8887 kg, respectively.

N excretion on the bedding was then calculated using the expected N/P ratio of urine and feces immediately after excretion, and the amount of P excreted on the bedding. The expected N/P ratio was calculated at 7.31 (8289/1134). P excretion on the bedding was calculated by subtraction of the P input with woodchips (94 kg) from the P output with bedded-pack compost (638 kg). Because P is not lost from the bedding, this amount (544 kg) should be the same as initially excreted. Likewise, K excretion on the bedding was calculated at 3886 kg. The N excretion on the bedding was then calculated at 3980 (7.31 x 544), or 48% of N excreted on the whole floor.

However, it has to be checked whether urine and feces are excreted in the same ratio on the bedding as on the slatted floor. This was realised by comparison of the expected P/K ratio of excreted urine and feces on the whole floor with the realised P/K ratio on the bedding. Similar to P, K does not disappear from the bedding. The expected P/K ratio was calculated using the same methodology as for the expected N/P ratio and amounts to 0.128 for the whole floor. The realised P/K ratio on the bedding was calculated at 0.140. The realised P/K ratio is therefore higher for the bedding than for the whole floor. A higher P/K ratio can be caused by a relatively higher deposition of feces on the bedding and/or a relatively lower deposition of urine. It is assumed that half of the increase in P/K ratio is caused by a lower deposition of urine on the bedding and the other half by a higher deposition of feces. Because feces and urine differ in N content, this difference in ratio has also consequences for the N/P ratio of excreted urine and feces on the bedding, and for the calculated N excretion on the bedding. The N/P ratio therefore has to be corrected.

Differences in amounts of N, P and K deposited with urine and feces can be calculated when it is known how excreted N, P and K are distributed over urine and feces. For N, it was assumed that 66% is excreted with urine and 34% with feces (Velthof et al., 2009). For P, it was assumed that 0% is excreted with urine and 100% with feces (fixed physiological ratio). For K, it was assumed that 81% is excreted with urine and 19% with feces (Gustafson, 2000). Based on these distributions, and using the expected P/K ratio, the relative amounts of P and K that are excreted with urine and feces were calculated. By varying the ratio of urine and feces, the calculated P/K ratio changes. As a result, it showed that with a 6% lower deposition of P and K with urine, and a 6% higher deposition with feces, the calculated P/K ratio is the same as the realised P/K ratio (0.140). Based on this adapted ratio, the N/P ratio could also be adjusted, from 7.31 to 6.79. Using the amount of P excreted on the bedding (544 kg), the amount of excreted N on the bedding was then calculated at 3694 kg, or 45% of the N excretion on the whole floor. This percentage was used to calculate the N balance sheet items for both the bedding and slatted floor.

Total N input directly on the bedding (woodchips and excretion) was then calculated at 4583 kg. With compost, 3461 kg N was removed from the barn, 1122 kg or 24% less than the N input with woodchips and excretion. When woodchips are composted alone, N from the ambient air can be immobilized in the chips, due to their high C/N-ratio (Beck et al., 1995; Csehi, 1997). As a result, it is unlikely that N in woodchips contributed to volatile N loss from the bedding. Therefore, all the N loss from the bedding should be assigned to N excretion. N loss from excreted N was then 1122 kg, or 30%. In order to calculate the N loss for the whole floor, the N loss for the slatted concrete floor (+ storage underneath) has to be calculated. A percentage of N excretion on the bedding of 45% gives a percentage of N excretion on the slatted floor of 55%. Almost all balance sheet items can then be calculated for the slatted floor, except the amount of N volatilised, because the N output with liquid manure could not be determined. This volatile loss is estimated using the N volatilization factor for this type of floor, given by Velthof et al. (2009). For dairy cattle, housed year-round in a free-stall barn with slatted floor in the Netherlands, total volatile N loss is on average 8.9% of excreted N (of which 86% in the form of NH_3). Because on the slatted floor 6% more N from urine was deposited than on the bedding, and because NH_4-N in urine is mainly responsible for NH_3-emission from liquid manure, the emission factor was corrected for the higher NH_4-N deposition on the slatted floor. This was pragmatically realised by increasing the emission factor with a relative 9% (6 / 66; 6% more urine deposition / 66% of total N excreted with urine). The emission factor for the slatted floor was then 9.8% and the N loss from N excreted on the slatted floor was calculated at 449 kg. Consequently, it was calculated that with liquid manure, 4146 kg N was removed from the barn. Combining the N losses for the bedding and slatted floor resulted in a combined N loss from excreted N of 1571 kg N or 19% of excretion on the whole floor. Expressed as percentage of total N input in the barn, N loss was 13% (Table 1).

In addition to the N, P and K balance, also an indicative C balance was calculated. This balance is indicative because the excretion of feces and urine was not measured and had to be estimated. The excretion was estimated at 35.3 Mg liquid manure cow^{-1} year^{-1}, based on KWIN data (KWIN, 2011; summer feeding, roughage ration of 50% grass silage and 50% silage maize; milk production of 11369 kg cow^{-1} year^{-1}). For 53.5 cows and a balance period of 306 days, the amount of excreted liquid manure was calculated at 1583 Mg. Manure production of the pregnant heifers was not known and was estimated based on their dry matter intake, using the ratio between dry matter intake and manure production for lactating cows. Multiplication of this ratio with the dry matter intake of heifers gave an estimation of their manure production of 10.3 Mg heifer^{-1} year^{-1} and 30 Mg during the period. The total production of fresh manure then amounts to 1613 Mg. Using the average C content in liquid dairy cattle manure of 38 g kg^{-1} fresh material (FM) (SD = 8.7) from De Boer & Bloem (2010), C excretion on the whole floor was calculated at 61 Mg.

The percentage of C that was deposited on the bedding was derived from the percentage of N that was deposited on the bedding (45%). With this percentage, C input on the bedding was calculated at 27 Mg. Based on the amount of supplied woodchips and their C content, C input with woodchips was calculated at 71 Mg. Using the same method, the C output with bedded-pack compost was calculated at 36 Mg. As a result, it was calculated that 62 Mg of C disappeared during the balance period, or 63% of the C input with woodchips and excreted feces. It is likely that most of this C emitted as CO_2 and a relatively small part as CH_4.

1.2.3 Discussion

The information used to calculate the NPK balances was partially measured and partially estimated. Potential weaknesses regarding the N balance are the variation in the composition of the fresh woodchips and the N, P and K input with roughage for the lactating cows. The used woodchip analysis results were not from the actual batch used during the balance period, but from a batch used for the following run (November 2011). Although the material came from the same type of source, it is possible that the composition of this batch differed from the batch actually used during the balance period. A 20% higher or lower N content in the woodchips would have resulted in an N loss from excreted N on the bedding of 35% or 26% instead of the calculated 30%.

The dry matter (DM) intake of the cows with roughage was based on a general ration composition provided by the farmer. When the DM intake is 10% lower or higher, the N loss from the bedding is 31 or 30%. This potential deviation is therefore small. Another relatively small weakness is the calculated N, P and K input with roughage for the dry cows and heifers. This input is calculated using the feed intake capacity etc. from CVB (2007) and using the general ration composition (50% grass silage and 50% grass hay). Because the residual daily roughage from lactating cows was fed to the dry cows and heifers, the intake of grass silage and grass hay may have been lower than calculated, and the same applies to the N, P and K input. This may have resulted in a small overestimation of the N loss from the bedding.

For assignment of the percentages of N excreted with urine and feces to the bedding and slatted floor, the difference between the realised P/K ratio on the bedding compared to the expected P/K ratio on the whole floor was used. Without this adjustment, the percentage N loss from the bedding had been 35% instead of 30%. This difference makes it clear that the measured P/K ratio of the bedding has a relatively large influence on the calculated N loss.

The farmer indicated that the bedding had been longer in the barn than usual and was about six weeks ‘overdue’. This is reflected in the C/N ratio of the composted bedding material, which was unusually low (Table 17). It is likely that the extended residence time resulted in a higher N loss compared to a more common, shorter residence time.

1.2.4 Conclusions

- The estimation of N losses using P/K-ratio's and N/P-ratio's is rather sensitive; the measured P/K ratio of the bedding has a relatively large influence on the calculated N loss. Because of several uncertainties, the calculated N loss should be regarded as indicative only

- Total volatile N loss (NH_3, N_2O, N_2, NO_x) from the bedding is estimated at 30% of N excreted with urine and feces on the bedding

- Assuming a total volatile N loss of 9.8% of N excreted on the slatted floor, total volatile N loss for the whole floor/barn is calculated at 19% of excreted N

- Of the total N excretion, an estimated 45% was excreted on the bedding and 55% on the slatted floor. These percentages are 48% and 52% for P excretion and 44% and 56% for K excretion

- During the balance period, an estimated 63% of C input with woodchips and feces excreted on the bedding was lost to the atmosphere in the form of CO_2 and CH_4

1.3 Indicative NP balances of a bedded-pack barn with green waste compost as bedding material (barn B)

1.3.1 Introduction

The floor of barn B consists partly of a bedding (982 m^2) and partly of a slatted concrete floor with liquid manure storage below (809 m^2). This means that balances have to be calculated for both floor types. The balances of barn B are calculated for the period between March 15 and December 11, 2012 (271 days).

During the balance period, on average 97 cows and 32 young stock (≤ 2 years) were year-round housed in the barn (no grazing outside). Cows were dry for 11% of the time. Lactating cows, dry cows, pregnant heifers and other young stock were all housed on both floor types. During the balance period, 66 calves were born. Milk production during the balance period was on average 19.3 kg cow^{-1} day^{-1} en 7045 kg $year^{-1}$ (including the dry period). Milk protein content was on average 3.48%.

During the balance period, 580 Mg of green waste compost was brought into the barn and 1191 Mg of bedded-pack compost was produced. Thickness of the bedding varied roughly between 15 and 45 cm. The bedding was cultivated every day with a rotary tiller. The main purpose of the green waste compost was moisture absorption. Temperature in the bedding varied roughly between 15 and 25°C at 20 cm depth.

1.3.2 Calculation of the NP balances

An overview of the initial NP balances for the whole barn is given in Table 6. A complete K balance could not be calculated because of missing data. A C balance was also not calculated because of missing data. .

Table 6 Initial NP balances for the bedded-pack barn with the use of green waste compost as bedding material (barn B), between March 15 and December 11 of 2012.

Item	**N (kg)**	**P (kg)**	**K (kg)**[1]
Input with green waste compost	5543	1000	
Input with roughage	13111	1733	11781
Lactating cows	*10355*	*1372*	*9628*
Dry cows	*1582*	*206*	*1670*
Young stock (≤ 2 years)	*1174*	*156*	*484*
Input with concentrates	5076	549	1229
Output[2] with compost	8744	2076	
Output with milk	2763	507	811
Output with liquid manure	7256	1098	9466
Output with growing young stock	139	45	12
Output with born calves	85	23	6
Total input	23730	3282	
Total output	18988	3748	
Loss	4743	-467	
Loss (%)	20	-14	

[1] A complete K balance was not calculated because of missing data

[2] Amount of nutrients accounted for

The NP input with green waste compost was calculated by multiplication of the amounts brought into the barn by their NP contents, as provided by the compost supplier. The NP contents were based on a moving average of the DM content of delivered batches, and a monthly analysis of composition. More information on the composition of the input green waste compost was collected by the sampling and analysis of five out of fifteen delivered batches. The results are presented in Table 7.

Table 7 Composition of five batches of input green waste compost, brought into the barn during the balance period (in g/kg of product).

Sampling date	Dm	Ash	Total N	Total P	Total K	NH_4-N	NO_3-N
16-02-2012	729	453	9.87	1.96	6.12	0.42	< 0.01
15-03-2012	621	369	9.02	2.74	6.04	0.45	< 0.01
25-04-2012	725	328	13.36	2.26	7.87	0.84	< 0.01
22-06-2012	773	480	10.45	1.88	6.07	0.75	< 0.01
06-08-2012	727	470	11.42	2.59	10.2	0.10	0.10
Average	715	420	10.82	2.28	7.26	0.52	0.02

The NPK input with roughage was calculated from the amounts of NPK fed with the daily rations to lactating cows (Table 8), dry cows (Table 9) and young stock. The general compositions of these rations were provided by the farmer; NPK contents in roughage components were provided by CVB (2007).

Table 8 Daily NPK input with roughage for lactating cows.

Type of product	**Amount (kg DM)**	**Mineral contents (g kg^{-1} DM)**			**Amounts (g)**		
		N	*P*	*K*	*N*	*P*	*K*
Silage maize	3.2	12.8	2.0	12.0	41	6	38
Chicory roots	1.6	9.30	2.0	22.2	15	3	36
Beet pulp	2.2	15.7	0.9	4.80	34	2	10
Brewers' grains	1.1	39.5	6.3	0.60	43	7	1
Grass silage, May	6.0	30.8	4.2	34.1	185	25	205
Grass silage, July/August	1.8	31.5	4.2	34.1	57	8	61
Grass silage, Sept./Oct.	1.8	38.2	4.2	34.1	69	8	61
Total	17.7				444	59	412

Table 9 Daily NPK input with roughage for dry cows.

Type of product	**Amount (kg DM)**	**Mineral contents (g kg^{-1} DM)**			**Amounts (g)**		
		N	*P*	*K*	*N*	*P*	*K*
Grass silage, May	10.6	30.8	4.2	34.1	325	44	360
Grass silage, July/August	3.1	31.5	4.2	34.1	98	13	106
Grass silage, Sept./Oct.	3.1	38.2	4.2	34.1	119	13	106
Total	16.8				543	71	573

Composition of the ration fed to young stock was the same as fed to lactating cows. The NPK input with roughage for young stock was calculated using the average energy requirement of young stock relative to lactating cows, using data from CVB (2007). The average DM intake of young stock, and also the derived NPK input was calculated at 30% of the intake by lactating cows. Average daily N, P and K intake by young stock was calculated at 135 g N, 18 g P, and 56 g K.

The NPK input with concentrates for lactating cows (Table 6) was calculated using the amount of concentrates delivered on the farm between September 5 of 2012 and January 4 of 2013. The average daily use of concentrates per lactating cow was calculated at 4.5 kg of product, 217 g of N, 23 g of P and 53 g of K.

The NPK output with compost (Table 6) consisted of NPK present in the amount of compost removed from the barn during the balance period and in the amount of compost present in the barn at the end of the balance period. Removed compost was weighed and analysed for N, P and K content. In total, 828 Mg of compost was removed, containing 6056 kg of N, 1488 kg of P, and 6230 kg of K. The amount of compost present in the barn at the end of the compost period was estimated, using the thickness of the compost layer (37 cm), the bedding surface area (982 m^2) and the bulk density. Bulk density and NPK contents were analysed after sampling of the compost layer. At the end of the balance period, an estimated 363 Mg of compost was present in the barn, containing 2689 kg of N, 589 kg of P and 2749 kg of K.

The NPK output with milk (Table 6) was calculated using the amount of milk delivered at the milk factory during the balance period, and its N, P and K contents. The N content was calculated from the protein content (3.48%) and amounted to 5.45 g kg^{-1}; for the P and K contents standard values of 1.0 and 1.6 g kg^{-1} milk were used (CBS, 2011).

The NPK output with liquid manure (Table 6) consisted of NPK in manure removed from the barn during the balance period and manure present below the slatted floor at the end of the balance period. The average daily manure production during the balance period was calculated at 7.0 Mg fresh manure, totalling 1894 Mg over the period. The manure in storage was sampled on August 1 and December 11 of 2012 and analysed for bulk density and NPK contents (Table 10). The average results were used to calculate the NPK in manure produced during the period.

Table 10 Composition of liquid manure, sampled during the balance period (in g kg^{-1} product; density in kg l^{-1})

Sampling date	Density	Dm	Ash	Total N	Total P	Total K	NH_4-N
01-08-2012	1.07	191	98	5.52	1.08	6.31	1.67
11-12-2012	1.04	98	31	4.48	0.73	5.27	2.25
Average	1.05	145	65	5.00	0.91	5.79	1.96

The fixation of NPK in born calves (Table 6) was calculated using liveweights and contents in liveweight at birth (Table 5). The NPK fixation in growing young stock (Table 6) was calculated using average liveweights and contents in liveweight (Table 5) of 22.0 stock younger than one year and 10.4 stock younger than two years. Further NPK fixation in heifers and adult cows was set at 0; the contribution to the NPK output is relatively small (see Table 1) and difficult to determine.

1.3.3 Discussion

Based on the total N input and output, N loss during the balance period was 4743 kg N (Table 6). The P balance indicates that P output was overestimated by 14%, because the P balance should be 0. When the P output is overestimated, it is likely that the N output is overestimated as well, and that the N loss is underestimated. The overestimation of the P output was used to correct the N and P output items, under the assumption that the overestimation was the same for all output items. Output items were corrected by dividing them by factor 1.14. The correction results in an adjusted balance, as given in Table 11.

Table 11 Corrected N and P balances for barn B, with correction of the N and P output items for an observed overestimation of total P output of 14% (Table 6)

Item	**N (kg)**	**P (kg)**	**K (kg)**[1)]
Input with green waste compost	5543	1000	
Input with roughage	13111	1733	11781
Lactating cows	*10355*	*1372*	*9628*
Dry cows	*1582*	*206*	*1670*
Young stock (≤ 2 years)	*1174*	*156*	*484*
Input with concentrates	5076	549	1229
Output[2)] with compost	7657	1818	
Output with milk	2419	444	
Output with liquid manure	6354	961	
Output with growing young stock	122	39	
Output with born calves	75	20	
Total input	23730	3282	

Total output	16626	3282
Loss	7104	0
Loss (%)	30	0

[1] A complete K balance was not calculated because of missing data
[2] Amount of nutrients accounted for

After correction for overestimation, N output was calculated at 16626 kg, N loss at 7104 kg and N loss as percentage of total N input at 30%. The following calculations are all based on the corrected N and P balance and the corrected N loss. The total N excretion with urine and feces was calculated with the same methodology as used for barn A and amounted to 15572 kg N. Including the N input with green waste compost, net N supply on the whole floor was 21115 kg. Expressed as a percentage of this net N input, N loss was 34%. Part of the N loss consists of volatilization of mineral N present in the input green waste compost. This N can also volatilize during alternative use, during storage or after application to farmland. It can therefore be argued that N loss from the bedding should be corrected for this loss. From the analysis of five batches of input green waste compost, it can be concluded that 4.8% of total N was in mineral form. This indicates that 266 kg N can easily volatilize from green waste compost during alternative use. Corrected for this amount, N loss was not 7104 but 6838 kg.

With the collected data, it is not possible to make a distinction between other N that is lost from input green waste compost and N lost from excreted N. Because the remaining N loss from input green waste compost is entirely the result of the housing concept applied, the choice was made to assign all remaining N loss to N excretion. Expressed as a percentage of excreted N, N loss was 44%. In the reference free-stall barn with slatted floor and year-round housing, the (calculated) N loss is 8.9% of excreted N (Velthof et al., 2009).

With an N output with liquid manure of 6354 kg and an assumed N loss from the slatted floor of 8.9% of N excreted on that floor, N excretion on the slatted floor can be calculated at 6975 kg and N excretion on the bedding at 8597 kg. This indicates that about 45% of total N excretion is excreted on the slatted floor and 55% on the bedding. N loss from the slatted floor can be calculated at 621 kg and N loss from the bedding at 6483 kg (7104 – 621 kg). After correction for the 266 kg N potentially lost during alternative use of input green waste compost, N loss from the bedding is calculated at 6217 kg N or 72% of N excreted on the bedding.

1.3.4 Conclusions

- Total volatile N loss (NH_3, N_2O, N_2, NO_x) from the barn was calculated at 30% of total N input and at 44% of N excreted with urine and feces
- Assuming a total volatile N loss of 8.9% of N excreted on the slatted floor, it was estimated that 45% of total N excretion was on the slatted floor and 55% on the bedding
- N loss on the bedding was estimated at 46% of N input on the bedding and at 72% of N excretion on the bedding (when completely assigned to excretion)

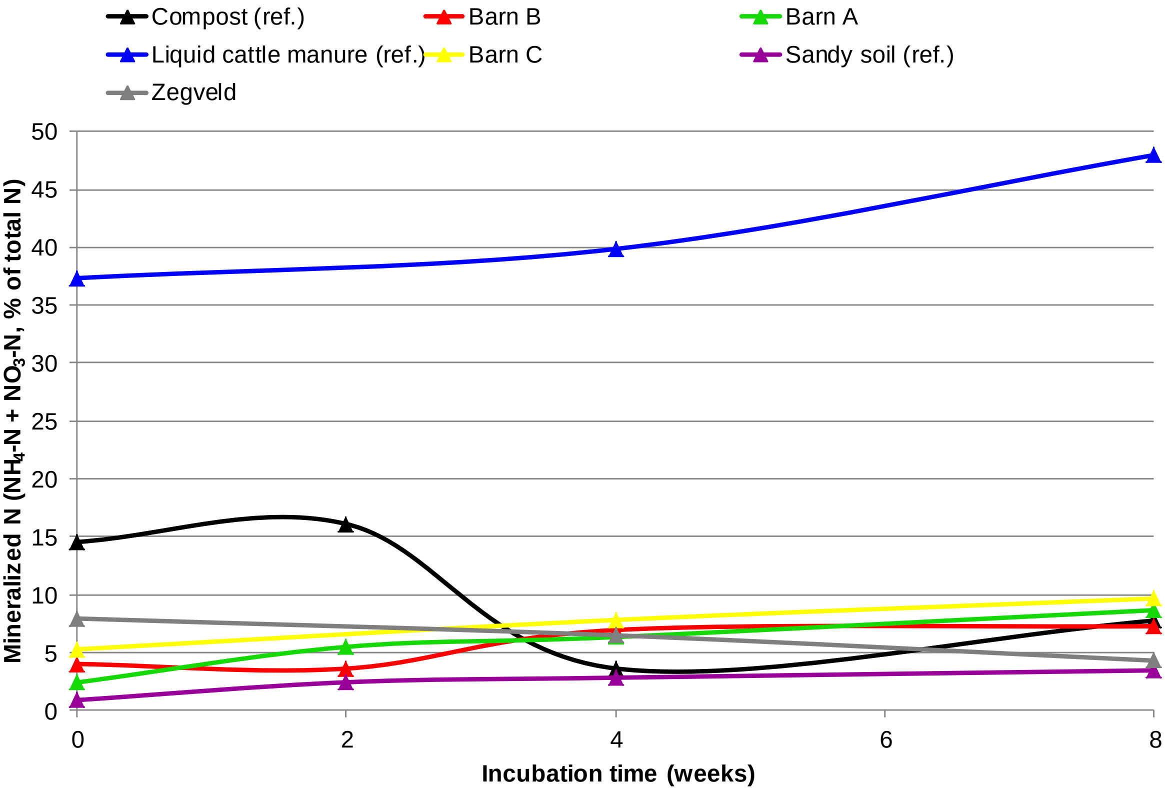
2 Emissions of NH_3, N_2O and CH_4 during storage and application of bedded-pack compost

2.1 Introduction

Just like the conventional free-stall barn with slatted floor, the bedded-pack barn emits several gases to the environment. These gases emit from the barn itself (barn period), during (optional) storage of the liquid manure or the bedded-pack compost (storage period) and after application of liquid manure or bedded-pack compost to farmland (land period). For a good comparison of the total emission potential of different housing systems, it is necessary that emissions during the different periods are taken into consideration, and not only emissions during one period. For example, high emissions during the barn period can be compensated by low emissions during a storage period or after application of organic material to farmland.

From a free-stall barn with slatted floor, gases emit from liquid manure on the floor and stored below. In a bedded-pack barn, gases emit from bedded-pack (urine and feces mixed with bedding material). After removal of liquid manure or bedded-pack compost from the barn, this material can either be directly applied to farmland or stored intermediately. During the storage period, additional emissions can occur. In practice, such a storage period is relatively short (up to a few weeks) and most farmers apply liquid manure or bedded-pack compost almost immediately after removal from the barn. Additional emissions also occur after application of liquid manure or bedded-pack compost on farmland. Liquid manure is usually shallowly injected into grassland or arable land, or harrowed into arable land. Bedding material is either surface-applied on grassland or also harrowed into arable land.

Emissions of NH_3, N_2O and CH_4 during the barn period were measured (Van Dooren et al., 2013). Emissions during storage and after application to farmland were not measured but derived from emission factors found in literature for green waste compost or municipal compost. This derivation seems justified because the chemical composition (Table 17) and behaviour of the studied bedded-pack composts (Figure 4-1, Figure 4-4) in soil were very similar to those of regular green waste compost. The bedding material from the Zegveld barn had a different chemical composition and behaviour compared to the other



barns, but this housing system was also quite different, and resembled rather anaerobical stacking of bedding material than aerobic composting.

2.2 Literature results & discussion

2.2.1 NH_3, N_2O and CH_4 emissions during compost storage

In a conventional free-stall barn with slatted floor, the emissions from liquid manure in the storage below the floor are combined with the emissions from the floor itself. After removal from the storage, liquid manure can be stored separately. On dairy farms, however, most of the liquid manure is directly applied to farmland after removal from storage. Therefore, separate storage emissions are not reported for liquid manure. Bedded-pack composts can also be stored in the farmyard, which can result in additional emissions to the atmosphere. Very little information on emissions from stored compost was found in literature; the only useful information found was from Hao (2007).

Hao (2007) composted cattle feedlot manure for 133 days and stored this compost afterwards for 233 days in the open air (November to July, in Canada). The manure was composted without additions or mixed with increasing contents of sand or phosphogypsum. At the end of the composting period, the compost without additions had a C/N ratio of 11.3, a total N content of 13.7 kg Mg^{-1} DM, an NH_4-N content of 0.35 kg Mg^{-1} DM, and a pH of 7.8.

Over the 233 days storage period, total CH_4 emission from the untreated compost was 0.002% of the C initially present. This emission was much smaller that the emission during the previous active composting period (0.2% to 6.1%; Hao et al. (2005). CH_4 emission during active composting mainly occurs in the first weeks (Chang et al., 2009). The N_2O emission from the untreated control was 0.003% of the total N initially present, roughly 1000 times lower than during active composting. The NH_3 emission during the storage period was not measured. Differences in total N content at the beginning and end of the composting period (13.7 and 12.4 kg N Mg^{-1} DM, respectively) suggest a total N loss (due to NH_3, N_2O, N_2 emission; possibly also N leaching) of about 9%, but this decrease was not significant. In addition, differences between treatments with increasing contents of phosphogypsum or sand were not consistent. Therefore, it cannot be concluded that there was meaningful NH_3 emission during the storage period.

It can be concluded that little information is available on the potential for emission of NH_3, N_2O and CH_4 during compost storage. From the available data, it can be concluded that this potential is very small for N_2O and CH_4, especially when the storage period is relatively short. It is advisable to collect additional information on this emission potential, preferably by emission measurements.

2.2.2 N_2O emission after compost application

Little information could be found on N_2O emission after compost application. Most data found were on the emission after harrowing of compost into arable land; no information was found for surface application to grassland. Also, no information was found on compost application in the Netherlands.

Alluvione et al. (2010) reported an N_2O emission factor of 0.11% (% N of applied total N emitted as N_2O) for compost (mixture of park, garden and municipal waste), compared to 1.34% for a green manure crop and 3.42% for synthetic fertiliser urea. These fertilisers were harrowed into the soil in spring, at a rate of 130 kg N ha^{-1}, during maize cultivation in Italy. The used compost had an average total N content (12.8 to 14.2 kg N Mg^{-1} FM) and a relatively low C/N ratio (9.8 to 12.2).

In a study by Dalal et al. (2010), green waste compost (total N of 8.0 kg Mg^{-1} FM; C/N ratio of 19) harrowed into the soil just before sowing of sorghum in Australia, had a negative N_2O emission factor of -0.74% (less emission than the unfertilised control treatment), compared to 0.61% for farmyard manure (total N of 17.2 kg Mg^{-1} FM; C/N ratio of 11.6) and 0.71% for synthetic fertiliser urea. Amounts of total N applied were 80, 187 and 150 kg N ha^{-1} for green waste compost, farmyard manure and urea, respectively. A combination of green waste compost and farmyard manure (50/50 on a fresh weight basis) resulted in an emission factor of 0.22% for a total N application of 267 kg ha^{-1}. In a laboratory study by Dalal et al. (2009), the emission factor was also considerably lower for green waste compost compared to farmyard manure, but this study had some unusual characteristics (the green waste compost had a very low total N content (4.7 kg N Mg^{-1} FM) and a very high C/N ratio (38.3)). Given these characteristics, the results of Dalal et al. (2009) are not used in the assessment of emission potential. Results of both studies of Dalal et al. suggest that the N_2O emission factor decreases when the application rate of farmyard manure or green waste compost increases. In Dalal et al. (2009), the emission factor was 0.14 with application of 10 Mg ha^{-1} of green waste compost and 0.01% with application of 20 Mg ha^{-1}. In Dalal et al. (2010), the emission factor was 0.61% with application of 10 Mg ha^{-1} and 0.38% with application of 20 Mg ha^{-1}.

Meijide et al. (2007) measured an N_2O emission factor of -0.58% for composted municipal solid waste (total N of 8.9 kg Mg^{-1} FM, C/N ratio of 26.3) after harrowing 249 kg total N ha^{-1} with this material into the soil in the irrigated cultivation of silage maize in Spain. This emission factor is determined over the whole cultivation period and corrected for emission from added urea and the control treatment. Application of 250 kg total N ha^{-1} with the composted solid fraction of liquid pig manure (total N of 15.6 kg Mg^{-1} FM; C/N ratio of 12.8) resulted in an emission factor of 0.28% (after correction for the control). Application of 175 kg total N ha^{-1} with unprocessed liquid pig manure (total N of 4.4 kg Mg^{-1} FM; C/N ratio of 6.5) gave an emission factor of 1.31% (after correction for the control).

In the irrigated potato cultivation in Spain, Vallejo et al. (2006) measured an N_2O- emission factor of -0.007% after harrowing 250 kg total N ha^{-1} with composted municipal solid waste (total N of 9.6 kg Mg^{-1} FM; C/N ratio of 26.3) into the soil. This emission factor was determined over the whole cultivation period and was corrected for emission from added urea and the control treatment. Application of 300 kg total N ha^{-1} with the composted solid fraction of liquid pig manure (total N of 14.1; C/N ratio of 10.3) gave an emission factor of 0.009% (after correction for the control). Application of 175 kg total N ha^{-1} with liquid pig manure (total N of 4.7 kg Mg^{-1} FM; C/N ratio of 6.5) gave an emission factor of 0.01% (after correction for the control). It should be mentioned that the compost in this study had an unusually high mineral N content (2.9 kg Mg^{-1} FM, with a total N content of 9.6 kg Mg^{-1} FM).
Yang et al. (2002) measured an emission factor of 0.2% for garden compost (total N of 16.3 kg Mg^{-1} DM; NH_4-N of 0.87 kg Mg^{-1} DM; C/N ratio of 15.2) and an emission factor of 0.1% for liquid pig manure (total N of 2.3 kg Mg^{-1} FM; NH_4-N of 2.0 kg Mg^{-1} FM; C/N ratio of 4.1). In this laboratory study, emissions were measured for a period of 144 hours after mixing the organic fertilisers with soil. The composition of the liquid pig manure was unusual, with a low total N content, a high NH_4-N content relative to total N, and a low C/N ratio. Such a liquid manure composition is not common under practical conditions. Because of this lack of representativity, these data are not included in the emission factors inventory below.

In blueberry cultivation, the addition of composted sawdust (total N of 21 kg Mg^{-1} FM; NH_4-N of 0.09 kg Mg^{-1} FM; C/N ratio of 19.1) decreased the N_2O emission from applied $(NH_4)_2SO_3$ from 2.4% to 1.0% of applied mineral N (Vano et al., 2011).

From this inventory, it can be concluded that the N_2O emission factor from compost, harrowed into arable land, is on average very low to negative, with emission factors varying between 0.1 to -0.7% and an averaged emission of -0.30% (Table 12). The occurrence of negative emissions shows the potential of compost to decrease N_2O emission compared to an unfertilised control. This decrease is realised because mineral N in soil is converted to organic N and thus immobilised. Data on N_2O emission after surface application of composts on grassland were not found. It is expected, however, that this emission will rather be lower than higher if compared to application to arable land. N_2O emission is stimulated by oxygen shortage, and the risk of oxygen shortage is higher after harrowing compost into the soil than after surface application. It should be noted that the bedding materials from the bedded-pack barns (Table 17) may contain higher NO_3-contents than the green waste composts from the present desk study, which may result in higher N_2O emissions through the denitrification process. However, a higher NO_3-content does not necessarily translate into higher N_2O emission, particularly not when compost is applied to a growing, N absorbing crop. Besides, high NH_4-N contents in the compost from Meijide et al. (2007) and Vallejo et al. (2006) may also have been quickly converted into NO_3-N after application. Therefore, the averaged emission factor of -0.30% can be maintained.

Table 12 N_2O emission factors (% of total N applied) and chemical composition of composts, harrowed into the soil of arable land, cultivated with different crops; data from four different studies.

Total N[1)]	NH_4-N*	NO_3-N	C/N ratio	N_2O emission factor (%)	Source
12.8 - 14.2	-[2)]	-	9.8 - 12.2	0.11	Alluvione et al. (2010)
8.0	0.03	0.002	19	-0.74	Dalal et al. (2010)
8.9	2.6	-	26.3	-0.58	Meijide et al. (2007)
9.6	2.9	-	26.3	-0.01	Vallejo et al. (2006)

[1)] Kg Mg^{-1} FM
[2)] Not determined

In two studies in which emission factors were determined for both liquid manure and compost (Meijide et al., 2007; Vallejo et al., 2006), the average N_2O emission factor was 0.66% for liquid manure and -0.29% for compost. A recent update of the N_2O emission factors after application of liquid cattle manure in the Netherlands gives an emission factor of 1.3% for harrowing of liquid manure into the soil of arable land and 0.3% for shallow injection into grassland (Velthof and Mosquera, 2011).

2.2.3 NH_3 emission after compost application

In the desk study on NH_3 emissions after compost application to farmland a limited number of studies were found. In a study by Mulder (1992), composted cattle manure (total N of 6.09 kg Mg^{-1} FM; NH_4-N of 84 g Mg^{-1} FM) was surface-applied on arable land in the Netherlands, at a rate of 22.5 Mg ha^{-1}. Four days after application, on average 76% of NH_4-N was volatilised as NH_3 (1.0% of total N).

In a study by Amon et al. (2001), fresh cattle manure was stored, both in summer and winter, in two different ways (active composting or anaerobical stacking). After composting or stacking for 80 days, 20 Mg ha^{-1} of each product was surface-applied on grassland. Both in summer as well as in winter, NH_3 emission after application of the composted manure was negligible. In summer, no NH_4-N was present in the composted manure; data for the winter compost are not given. An interesting feature of the study of Amon et al. (2001) is that NH_3 emissions were measured both during the composting/stacking period as well as after application to grassland. Results show that NH_3 emission during composting was higher than during stacking, but that emission after application was lower for composted manure compared to stacked manure. Total NH_3 emission was higher for composting than for stacking, with most of the emission realised during the composting period. N_2O emission was lower for composting compared to stacking. N-leaching from the heap was lower for composting compared to stacking in summer and comparable for both treatments in winter. Eventually, more N was lost with composting than with anaerobical stacking. For both treatments, however, total N-losses were relatively low, with no more N lost than 11% of total N excreted by the cows. The total emission of greenhouse gasses was 25% lower for composting compared to stacking.

In a greenhouse experiment with Chinese cabbage, Matsushima et al. (2009) found virtually no NH_3 emission during ten days after harrowing of 15 Mg ha^{-1} of compost (C/N ratio of 11 to 12; total N of 21 to 23 kg Mg^{-1} FM; NH_4-N of 0.2 to 0.3 kg ton^{-1} FM) into the topsoil. This compost had an unusually high NO_3-N content of 2.5 to 3.5 kg Mg^{-1} FM.

Brinson et al. (1994) applied two different types of composted poultry manure to the surface of an uncultivated soil in a laboratory experiment: manure composted with paper (1307 kg N ha^{-1}) or with wood shavings (1465 kg N ha^{-1}). Of the total amount of N applied, no more than 0.03% (paper compost) to 0.24% (shavings compost) was lost as NH_3-N during the first 21 days after application. Expressed as percentage of applied NH_4-N, losses were not higher than 1 and 10%, respectively. Poultry manure composted with paper contained 0.3 NH_4-N Mg^{-1} (C/N ratio of 10; total N of 14.8 kg Mg^{-1} FM) and poultry manure composted with wood shavings contained also 0.3 kg NH_4-N Mg^{-1} (C/N ratio of 15; total N of 10.7 kg Mg^{-1} FM).

In a laboratory experiment by He et al. (2003) with application of compost (C/N ratio of 15; total N of 18.8 kg Mg^{-1}; NH_4-N of 0.05 kg Mg^{-1}) on a calcareous, uncovered soil, 18.3% of mineralised N was lost as NH_3-N after surface application and 0.12% after harrowing into the soil, during a period of 180 days. Net mineralization of totally applied N was 2.0% for the surface application and 17.4% for the harrowing application. In this experiment, there was no N uptake by a crop. If there had been N uptake by a crop, NH_3-N emission after application could have been lower.

The limited availability of studies focused on NH_3 emission after compost application to farmland has probably to do with the usually very low NH_4-N contents in these composts. Whereas in liquid dairy cattle manure roughly 50% of total N is present in the form of NH_4, this is typically 1.0-1.5% for compost (1.1 to 1.3% for the bedded-pack composts in paragraph 4.3.1). Consequently, NH_3 emission after application of bedded-back compost to farmland appears to be small. From this desk study, it appears that emission after harrowing into arable land will be negligible, provided the compost is covered with soil. After surface application to grassland, it appears that no more than 75% of NH_4-N will volatilise as NH_3. This will typically be no more than 1% of total N present in the compost. In several studies, NH_3-N emission after surface application was (much) lower than 1% of total N. Averaging the NH_3 emission factor over all results found (Table 13) gives an emission factor of 0.3% after surface application and ≈ 0 after harrowing into arable land. If the NH_4-N content in a particular bedded-pack compost is considerably higher than reported in the present study, NH_3-N emission after application will also be considerably higher, particularly after surface-application.

Table 13 NH_3 emission factors (% of total N applied) and chemical composition of composts, surface-applied or harrowed into the soil, data from six different studies.

Total N[1]	NH_4-N*	C/N ratio	Application method	NH_3 emission factor (%)	Source
6.09	0.084	-[2]	Surface	1.0	Mulder (1992)
-	-	-	Surface (summer)	≈ 0	Amon et al. (2001)
-	-		Surface (winter)	≈ 0	Amon et al. (2001)
21 - 23	0.2 – 0.3	11 - 12	Harrowing	≈ 0	Matsushima et al. (2009)
14.8	0.3	10	Surface (paper)	0.03	Brinson et al. (1994)
10.7	0.3	15	Surface (shavings)	0.24	Brinson et al. (1994)
18.8	0.05	15	Surface	0.37	He et al. (2003)
18.8	0.05	15	Harrowing	0.02	He et al. (2003)

[1] Kg Mg^{-1} FM

[2] Not determined

For liquid cattle manure, the standard NH_3 emission factor used in the Netherlands is 19% of applied NH_4-N after shallow into grassland and 22% of NH_4-N after immediate harrowing into arable land (Velthof et al., 2009). With an average total N content in liquid cattle manure of 4.1 kg Mg^{-1} FM, and an NH_4-N content of 2.0 kg Mg^{-1} FM (Adviesbasis bemesting, 2012), this means that 9.3% of total applied N volatilises after shallow injection of grassland and 10.7% after harrowing into arable land.

2.2.4 CH_4 emission after compost application

No data could be found regarding CH_4 emission after compost application. CH_4 emission after application of liquid cattle manure is usually low, and CH_4 emission of bedded-pack composts will likely be even lower, because the amount of readily decomposable organic matter in composts is usually much lower than in liquid cattle manure (Figure 4-1), and composts are applied under more aerobic conditions (especially with surface spreading).

2.3 Conclusions

- Based on (very little) available data, emissions of NH_3, N_2O and CH_4 during storage of mature bedded-pack composts can be regarded as small to negligible. More research is however necessary.

- N_2O emissions after harrowing of (bedded-pack) compost into arable land can be estimated at on average -0.30% of total N applied. N_2O emissions after application of liquid cattle manure on arable land (harrowing) or grassland (shallow injection) are 1.3% and 0.3% of total N applied, respectively.

- N_2O emission after surface application of (bedded-pack) compost on grassland is unknown, but unlikely to be higher than -0.30% due to the more aerobic conditions after surface application compared to harrowing into the soil.

- NH_3 emission after harrowing (bedded-pack) compost into arable land will be negligible, provided the compost is covered with soil. After surface application, NH_3 emission is estimated at on average 0.3%. This compares to a loss of 9.3 and 10.7% of total N in liquid cattle manure applied on grassland (sod-injection) or arable land (harrowing), respectively.

- If the NH_4-N content in a particular bedded-pack compost is considerably higher than usually found in composts, NH_3-N emission after application will also be higher, particularly after surface application.

- CH_4 emission after application of (bedded-pack) compost on grassland and arable land is unknown, but likely lower than after application of liquid cattle manure, due to a lower amount of readily decomposable organic matter in compost compared to liquid manure, and application under more aerobic conditions (especially with spreading)

3 Indicative total gaseous N losses from the housing systems

3.1 Synthesis

Because total gaseous N losses from the barn and after manure/compost application to farmland have been estimated, total gaseous N loss for the different housing systemes (bedded-pack barn, free-stall barn) can also be estimated. For barn A, total gaseous N loss from the bedding was estimated at 30% of excreted N and total gaseous N emission from the slatted floor at 9.8% of excreted N. The distribution of N excretion over the bedding and slatted floor was estimated at 45 and 55%, respectively. When the initial N excretion is set at 100% or 100 kg N, this means that (0.30 x 45 =) 13.5 kg was lost by gaseous N emission from the bedding and that 31.5 kg N in compost remains for application to grassland. From the slatted foor, (0.098 x 55 =) 5.4 kg N is lost by gaseous N emission and 50 kg N in liquid manure remains for application to grassland. Total N emission after application of the compost to farmland is 0% for compost (0.3% of total N is emitted as NH_3 and -0.3% as N_2O). Total N emission after application of liquid manure is 9.6% (9.3% of total N is emitted as NH_3, 0.3% as N_2O). With application of the compost, 0 kg N is lost by emission and 31.5 kg N remains. With application of liquid manure (0.096 x 50 =) 4.8 kg N is lost by emission and 45.2 kg N remains. In total, 76.2 kg N remains, and 23.8 kg or 23.8% of excreted N is lost by emission in the barn and after application to grassland. These calculations were also done for barn B. An overview of the distribution of N losses over the barn and land period for both bedded-pack barns and an average free-stall barn are given in Table 14.

Table 14 Total gaseous N emission in the barn and after manure/compost application to grassland, estimated for an average free-stall barn with slatted floor and two different bedded-pack barns, expressed in % of excreted N

		Bedded-pack barn		Free-stall barn
	Floor type	Barn A (woodchips)	Barn B (green waste compost)	
		Distribution of N excretion (%)		
Barn	*Bedding*	*45*	*55*	*0*
	Slatted floor	*55*	*45*	*100*
	Whole floor	100	100	100
		Gaseous N loss (% of all excreted N)		
Barn	*Bedding*	*13.5*	*39.9*	*0*
	Slatted floor	*5.4*	*4.0*	*8.9*
	Whole floor	19.0	43.9	8.9
Land	*Bedding*	*0*	*0*	*0*
	Slatted floor	*4.8*	*3.9*	*8.7*
	Whole floor	4.8	3.9	8.7
System	Whole floor	23.8	47.8	17.6

3.2 Conclusion

- Total gaseous N emission from the housing system (barn + land) is estimated at 18% for an average free-stall barn with slatted floor, 24% for a bedded-pack barn with woodchips as bedding material (Barn A) and 48% for a bedded-pack barn with green waste compost as bedding material (barn B)

4 Manure quality of bedded-pack composts

4.1 Introduction

In addition to the assessment of gaseous N losses from bedded-pack composts, it is also important to establish their quality and usefulness as a fertiliser for crops and the soil, relative to liquid manure. In this chapter, results are reported of experiments carried out to assess the value of the bedded-pack compost as N fertiliser for crops in the short term and an organic matter fertiliser for the soil in the long term.

4.2 Materials & methods

4.2.1 Introduction

To investigate several aspects of the fertiliser value, bedded-pack composts from several barns were sampled at the end of a ‘bedding run’, just before or just after the compost was removed from the barn. These samples were analysed for several characteristics and then used in two incubation experiments: an experiment to determine the decomposition rate of organic C (C decomposition experiment) and an experiment to determine the N mineralisation rate (N mineralisation experiment). The decomposition rate of an organic fertiliser shows how rapidly the organic matter in this fertiliser decomposes after addition to soil. A slower decomposition means that a larger amount of organic matter remains in the soil, resulting generally in higher soil fertility. The N mineralisation rate shows how rapidly the organic N from an organic material mineralises and becomes available for crop uptake; a high mineralisation rate increases the value of an organic material as a short-term N fertiliser for crops.

4.2.2 Sampling and analysis of bedded-pack composts

The sampling dates and a short description of the sampled materials are given in Table 15. For barn A, woodchips were used as input material; for barn B and C, green waste compost was used (composted waste from vegetables, fruits and garden materials). At the farm with barn B, also a sample of the input material (green waste compost) for the next bedding run was taken. This sample was used as a reference in both incubation experiments. A sample of liquid dairy cattle manure was also used as a reference. The sample is representative for liquid cattle manure from an ‘average’ Dutch dairy farm with a free-stall barn with slatted floor. This liquid manure was used in a study by De Boer & Bloem (2010) and had been stored since then at -18°C. The storage period was expected to have had little influence on decomposability of organic matter or nutrient composition of this sample, given the low storage temperature.

Table 15 Sampling dates and short description of the sampled bedded-pack composts and reference materials.

Description of sampled materials	Sampling date
Bedded-pack compost barn A (softwood chips as input)	17-11-2011
Bedded-pack compost barn B (green waste compost as input)	15-11-2011
Bedded-pack compost barn C (green waste compost as input)	16-11-2011
Finished bedding Zegveld (peat and common reed as input)	11-11-2011
Reference green waste compost	15-11-2011
Reference liquid dairy cattle manure	17-01-2008$^{1)}$

$^{1)}$ Stored at -18°C

The sample of bedding from barn A was taken while the bedding was still in the barn. Immediately after the daily cultivation with a rotary tiller, while the bedding was still loose, the bedding was sampled with a probe over the entire depth (35 to 40 cm). For barns B and C, the finished beddings had already been removed from the barn and were therefore sampled from the storage heap. The samples were mixed, divided in four subsamples and stored in labelled plastic bags. One subsample was sent to the laboratory for analyses of density, dry matter, ash, total N, total P, total K, total C, total S, NH_4-N, NO_2-

N, NO_3-N and pH (in liquid or in water). Samples were analysed by the Environmental Laboratory of the Agrotechnology & Food Sciences Group, Wageningen. The other subsamples were stored in the freezer at -18°C. After a few weeks of storage, a subsample of each material was taken from the freezer, thawed and used for the incubation experiments.

4.2.3 C decomposition experiment

The C decomposition rate of all materials was determined by repeated measurement of the CO_2 emission rate after mixing the materials with soil in an incubation experiment. The experiment was carried out by the Chemical and Biological Soil Laboratory in Wageningen. The experiment was carried out in glass bottles, at constant soil humidity and temperature (20°C), in the dark. The bottles (ø 6.9 cm; 575 ml) were filled with 10 cm of moist soil, to simulate topsoil (Photo 1). Air-dried sandy soil (Table 16) was brought to 60% of the water holding capacity by adding de-ionized water. The sandy soil came from the topsoil (0 to 30 cm) of a permanent grassland field located in Heino, the Netherlands; the soil was classified as a Plaggic Anthrosol.

Table 16 Characteristics of the sandy soil used in both incubation experiments.

Characteristic	**Unit**	**Value**
Organic matter	g/kg dry soil	52
Total N	g/kg dry soil	1.84
Total P	mg/kg dry soil	604
Total K	mg/kg dry soil	417
Total C	g/kg dry soil	31
C/N	-	16.8
DON	mg/kg dry soil	7
NH_4-N	mg/kg dry soil	5
NO_3-N+NO_2-N	mg/kg dry soil	3
pH in KCl	-	4.8
pH in water	-	5.9

Photo 1 Bottles filled with 10 cm moist soil

For all treatments with application of organic material, 15 g of FM was mixed with the 10 cm moist soil, after clipping the materials to a particle size of maximal 1 cm. Clipping was deemed necessary to produce a representative sample at these application rates. The application rate of 15 g corresponds with 40 Mg ha^{-1}, when related to surface area. However, when it is taken into account that these materials are in practice incorporated into the soil to a depth of 20 cm rather than 10 cm, this rate corresponds rather to 80 Mg ha^{-1}. The mixtures of soil and added materials were put into the bottles, total weight was written on each bottle, bottles were capped with cotton wool (to enable free gas exchange) and put in the dark at 20°C in an incubation chamber. CO_2 emissions in the bottles were measured after 1, 3, 7, 14, 28, 56, 112 and 168 days. Four to six hours before each measurement, the cotton wool caps were replaced by air-tight screw caps with a flexible rubber middle section. After four to six hours, the accumulated content of CO_2 in the bottle was measured with an Innova 1412 gas monitor. After measurement, de-ionized water was added to all bottles to maintain bottle weight and thus original soil moisture content. The typical moisture loss was no more than 1 mL per week. After water addition, the screw caps were replaced by the cotton wool caps and the bottles were placed back in the incubation chamber.

Net CO_2 and C emission rates were calculated for each treatment (see for an example Appendix 1). The C decomposition rate was calculated using linear integration over time. The decrease in C over time, expressed in percentages of the initially present C, was used to derive the parameters R and S for the C decomposition model described by Yang and Janssen (2000). To better represent practical conditions, data were adjusted from the incubation temperature (20°C) to the lower average annual soil temperature in the Netherlands (9°C). This adjustment was done using the methodology described by Janssen (2002) and resulted in multiplication of the time scale by factor 2.33. After derivation of R and S, remaining C was predicted for up to 100 years, using the same C mineralisation model.

4.2.4 N mineralisation experiment

N mineralisation rate was determined by repeated measurement of the amounts of NH_4-N, NO_3-N en Nts (total dissolved N) after mixing of the organic materials with sandy soil in an incubation experiment. The experiment was carried out by the Chemical and Biological Soil Laboratory in Wageningen. The experiment was performed with sealed (air-permeable) polyethylene bags (Photo 2) under the same environmental conditions as the C decomposition experiment. All organic materials were mixed and incubated with the previously described sandy soil (Table 16) at the same rates as in the C decomposition experiment. The amount of mineralised N was determined at start of the experiment (all treatments and reference sandy soil), after two weeks (treatments with compost from barn A & B, reference green waste compost and reference sandy soil), after four weeks (all treatments) and after eight weeks (all treatments). Each treatment was duplicated, resulting in 12+8+12+12 = 44 bags. A further description of this mineralisation method and the analysis method used for determination of mineral N (NH_4-N, NO_3-N and Nts) is given in Velthof and Oenema (2010). Comparison of the amounts of mineralised N (NH_4-N and NO_3-N) between the treatments enables to determine differences in usefulness of the materials as a short-term N fertiliser for crops. The amounts of mineralised N were for all treatments corrected for mineralisation of the sandy soil and expressed as a percentage of the total amount of N initially applied with the treatment. For the sandy soil, the percentage of mineralised N was expressed as percentage of the total amount of N present at start.

Photo 2 Polyethylene bag filled with moist soil to measure N mineralisation rate

4.3 Results & discussion

4.3.1 Composition of organic materials

The analysis results of all sampled organic materials are given in Table 17. Ash content was high in bedded-pack compost from barn B and C; this is mainly the result of sand already present in input green waste compost. Total N content in the compost from barn A was roughly double the content in the compost from barn B and C and the reference compost. This is the result of intensive composting, which leads to higher decomposition of organic material and higher content of nutrients. As a consequence, C/N-ratio of the compost from barn A was the lowest of all bedded-pack composts. An important characteristic of an organic fertiliser is its NH_4-N content. NH_4-N not only gives an indication of how much N can be taken up by crops after fertilisation, but also indicates the risk of NH_3 and N_2O emission after application to farmland. In the bedded-pack composts (barn A, B & C), the contents of NH_4-N and NO_3-N were very low, indicating that the risk of NH_3 or N_2O emission after application is almost negligible (see also paragraph 2.2.2, 2.2.3). The reference green waste compost contained a relatively high amount of NH_4-N; 1.23 kg Mg^{-1} FM represents 16% of total N. The percentage of NH_4-N in total N was about 1% for the bedded-pack composts, 15% for the largely undecomposed bedding material from Zegveld and 48% for the reference liquid cattle manure. The pH of the bedded-pack composts was relatively high. A high pH stimulates NH_3-emission, provided sufficient NH_4-N is present. N/P ratios were lower for bedded-pack composts compared to liquid manure. A decrease in N/P-ratio of manure reduces the amounts that can be applied on farmland, due to P application limits. N/P-ratios in the studied materials were 7.5 for liquid cattle manure, 5.4 for the compost from barn A, 4.3 for the compost from barn C, and 3.5 for the compost from barn B. This means that permissible manure/compost application rates also decrease in that order. The decrease in N/P ratio is caused by gaseous N losses in the barn and the addition of bedding materials with a relatively low N/P-ratio. The reference green waste compost had an N/P-ratio of 4.1.

Table 17 Analysis results of different bedded-pack materials and two organic reference materials (in kg Mg^{-1} FM, except density (kg m^{-3}), C/N and pH).

Parameter	Bedding materials				Reference materials	
	Barn A	Barn B	Barn C	Zegveld	Compost	Liquid manure
Density	1.09	1.31	1.34	-[1)]	1.37	1.03
Dry matter	431	525	554	308	629	84
Ash	106	355	352	97	449	20
Total N	15.4	7.15	9.01	7.26	7.52	3.92
Total P	2.84	2.06	2.09	0.51	1.83	0.52
Total K	19.0	6.79	13.1	3.67	4.53	5.30
Total C	161	119	136	114	101	33
C/N	10.5	16.6	15.1	15.7	13.4	8.4
Total S	2.72	1.53	2.15	-	1.36	-
NH_4-N	0.17	0.09	0.10	1.11	1.23	1.88
NO_2-N	0.02	<0.01	0.01	-	<0.01	<0.01
NO_3-N	0.18	0.03	0.07	0.01	<0.01	<0.01
pH	8.6	8.3	8.8	7.4	8.8	7.1

[1)] Not determined

4.3.2 C decomposition rate

Liquid cattle manure had the highest C decomposition rate, with only 34% of initial C remaining after 168 days of incubation (Figure 4-1). Decomposition of C in liquid cattle manure was about 26 times faster than decomposition of C in soil and three to four times faster than decomposition of C in composted bedding materials. Decomposition of C in composted beddings was on average 3.5 times faster than decomposition of C in soil and on average only a little higher (18%) than decomposition of C in the reference green waste compost. The higher decomposition rate relative to green waste compost can be explained by the addition of fresh manure during the bedding period, which reduces the average 'age' of the organic material. Within the group of composted beddings, barn A and barn C had the highest decomposition rate (90% of C remaining), followed by barn B (91% of C remaining). Bedding material from the Zegveld barn had the highest C decomposition rate of all bedding materials. This is explained by the fact that the Zegveld bedding material (mixture of common reed and peat soil) was rather anaerobically stacked than composted, and the organic material therefore had a relatively low age.

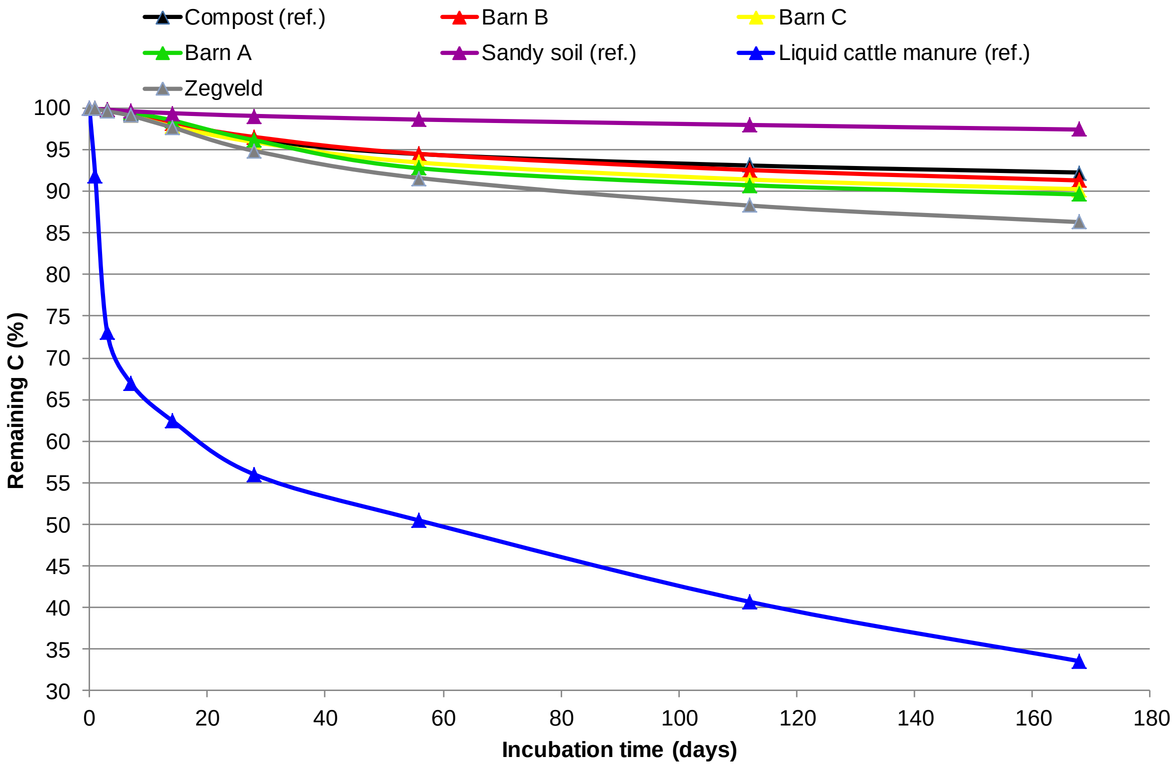


Figure 4-1 Decomposition of C in bedding materials and reference materials, after incubation with sandy soil at 20°C, calculated using repeated measurements of CO_2 emission

The measured data were used to derive the parameters R and S for the C mineralisation model described by Yang & Janssen (2000), after adjusting the data to the (lower) average annual field temperature (see paragraph 4.2.3). Derivation resulted in R and S values for all used organic materials (Table 18).

Table 18 R, S, and predicted remaining C (%) after 1, 5, 10, or 100 years of incubation of different organic materials with soil at 9°C, using the C mineralisation model of Yang and Janssen (2000) and the temperature adjustment methodology described by Yang and Janssen (2002).

Material	R	S	R^2_{adj} [1)]	Predicted remaining C (%) at:			
				t = 1 y	t = 5 y	t = 10 y	t = 100 y
Sandy soil (ref.)	0.0253	0.4103	99.8	98	94	91	68
Compost (ref.)	0.0839	0.4428	95.6	92	81	74	34
Barn A	0.1143	0.3473	95.4	89	72	60	10
Barn B	0.0922	0.3861	97.8	91	78	68	21
Barn C	0.1055	0.4027	97.0	90	76	66	19
Zegveld	0.1492	0.3379	97.8	86	65	50	4.3
Liquid cattle manure (ref.)	1.0466	0.6482	97.0	35	16	9.5	0.5

[1)] R^2_{adj} = percentage of variance accounted for by the C mineralisation model when fitted through the measured data

Whereas differences in (predicted) remaining C between several bedding materials are relatively small in the short term (up to one year), they are much larger in the longer term. C in the sandy soil had the lowest decomposition rate, with 98% of initial C still present after one year and 68% still present after 100 years (Figure 4-2). Liquid cattle manure had the highest decomposition rate, with 35% of initial C still present after one year and only 0.5% after 100 years. Most of the initial C was remaining after application of the reference green waste compost, followed by barn B, Havermans, barn A, Zegveld and reference liquid cattle manure.

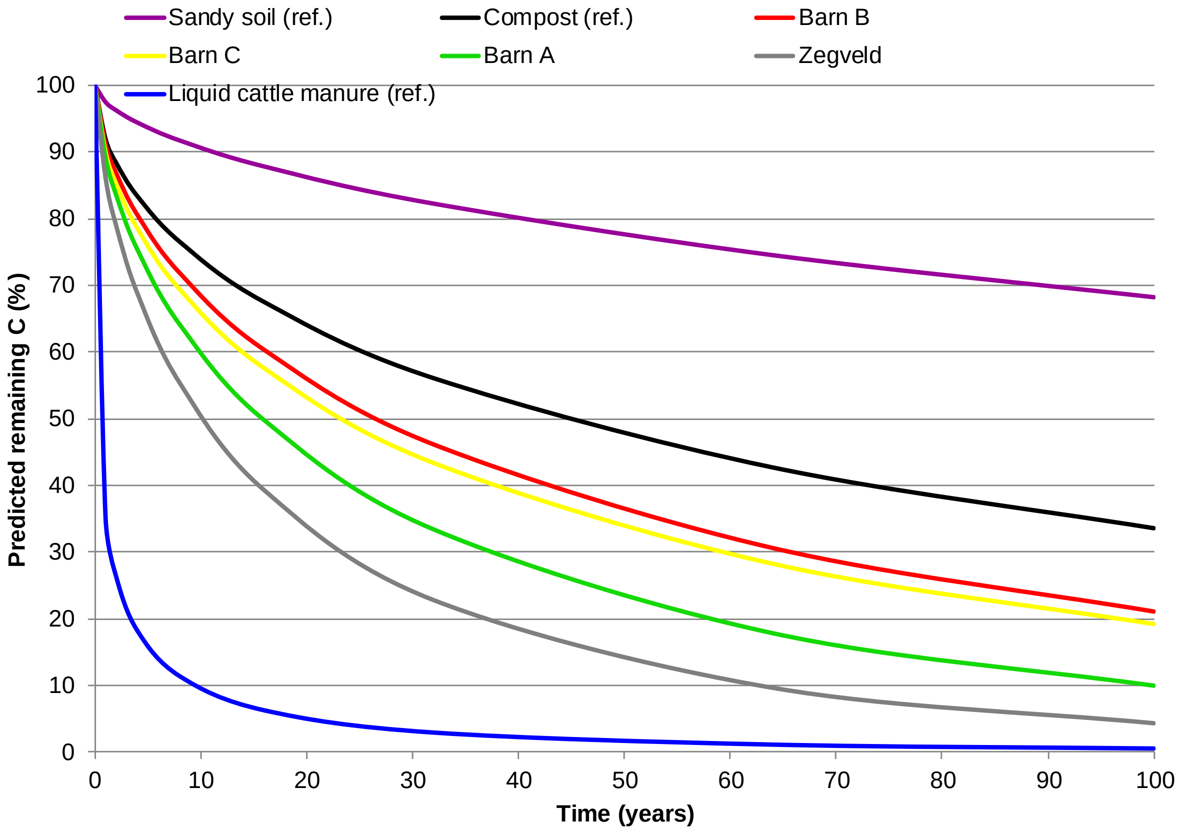


Figure 4-2 Predicted decomposition of C (% of initial C remaining) of several bedding materials and reference materials, over a time period of 100 years, after incubation with sandy soil at 9°C, using the C mineralisation model of Yang and Janssen (2000)

The differences in decomposition rates suggest that the choice for a particular housing system, and the associated organic fertiliser produced, can have considerable impact on soil fertility in the long run. However, it should be noted that not only the decomposability but also the amount of available material determines the impact on soil fertility. For the build-up of soil organic matter, it is likely not relevant whether 10% of 10 Mg applied C is remaining or 20% or 5 Mg applied C is remaining. In both cases, 1 Mg of C is remaining. The decomposability of the applied organic material can, however, have effects on composition of soil food webs and thus on soil quality. Though the composting of cow feces in bedding results in less feces-C applied to farmland (compared to feces stored as liquid manure), this C is more stable and decomposes slower. The addition of bedding material (such as woodchips or compost), however, will add extra C to soil, compared to a conventional housing system with liquid manure. In order to estimate the differences between the two systems in the amount of organic C found in soil after a period of time, it is necessary to estimate the amount of liquid manure that was excreted by the cows and would have been applied to the farmland if it had not been composted in the bedding.

This estimation can be done for the 2011 run of barn A, by using the ash content of the bedded-pack compost. With the finished bedding material, 23.8 Mg of ash was removed from the barn. With the fresh woodchips, about 3.6 Mg ash had been supplied. This means that about 20.2 Mg of ash was excreted by the cows. Using an average ash content of 22 g Mg^{-1} (SD = 4.7) in fresh liquid dairy cattle manure (De Boer & Bloem, 2010), the amount of corresponding liquid cattle manure is calculated at 920 Mg. Using an average C content in fresh liquid dairy cattle manure of 38 g Mg^{-1} (SD = 8.7) (De Boer & Bloem, 2010), the amount of excreted C can be estimated at 34.9 Mg. Of this amount, about 3.3 Mg (9.5%) is predicted to remain in soil, ten years after application (Table 18, Figure 4-3). With the finished bedding material, 36.2 Mg C was removed from the barn. Of this material, about 21.7 Mg (60%) is predicted to remain in soil after ten years, about 6.5 times the amount of C remaining from liquid manure. After 100 years, about 0.2 Mg C ha^{-1} of the applied C from liquid cattle manure is predicted to remain in soil, whereas 3.6 Mg C ha^{-1} is predicted to remain from the bedded-pack compost, about 20 times the remaining C from liquid cattle manure. These calculations show that composting of liquid cattle manure in a woodchip bedding, and application of the composted material to farmland, can have a large effect on the amount of soil organic matter remaining in the long term, and thus on soil quality and fertility. This effect is likely mainly caused by the addition of the woodchips. The much higher amount of C remaining in soil after application of the bedding material from barn A also means that the significance of farmland as a C sink (to mitigate CO_2 emissions) can increase dramatically.

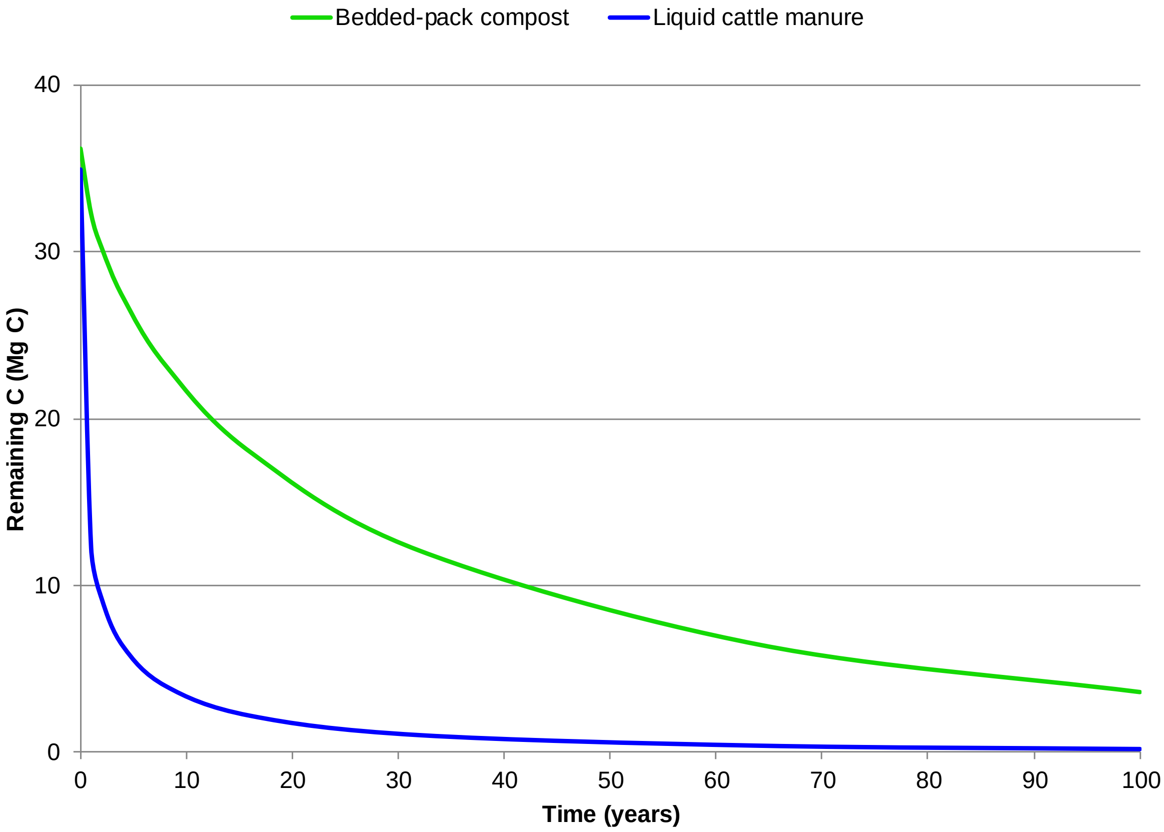


Figure 4-3 C predicted to remain in soil over time, after application of C with bedded-pack compost (excreted C composted with woodchips) or after application of the corresponding amount of excreted C in the form of liquid cattle manure; estimation for barn A (run 2011)

4.3.3 N mineralisation rate

Mineral N, present immediately after start of the mineralisation experiment, was highest for the reference liquid cattle manure (37% of total N), followed by reference green waste compost (15%), Zegveld (8%), barn C (5%), barn B (4%), barn A (2%) and the sandy soil (1%)
(

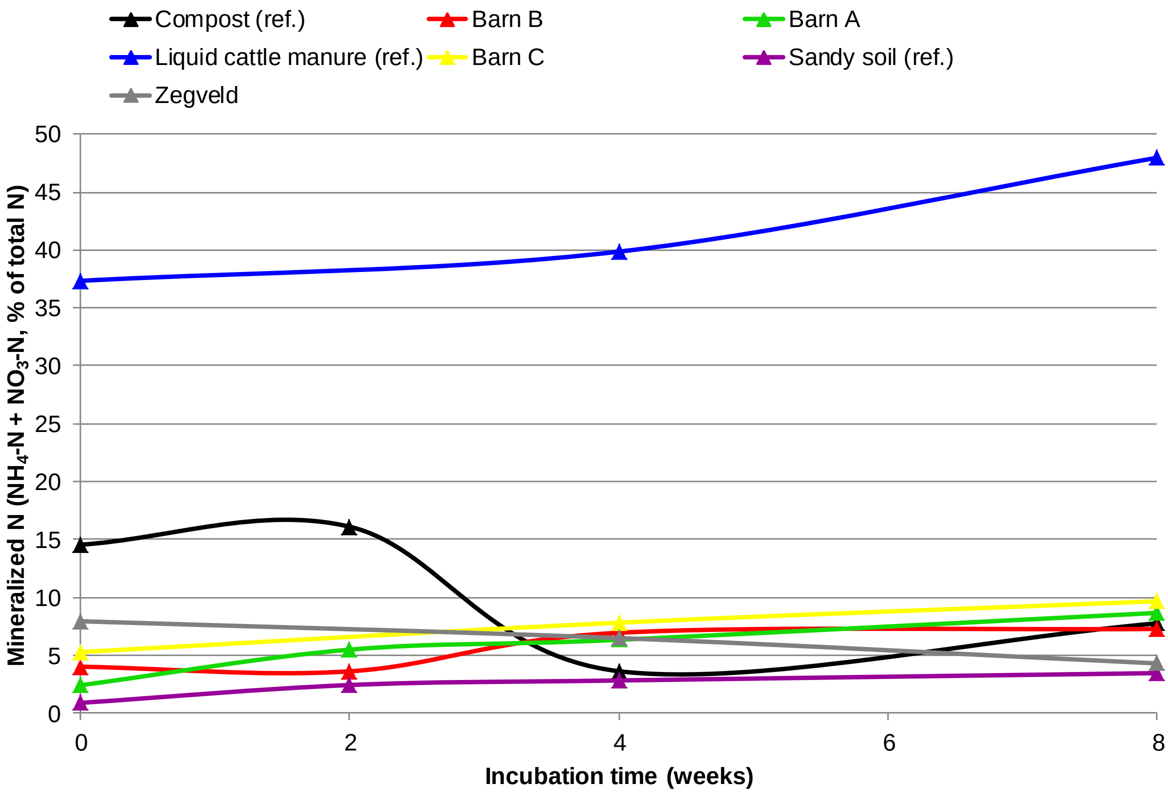


Figure 4-4). Mineralisation rate between t = 0 and t = 8 w was highest for the liquid cattle manure (+11 percentage points, pp.), followed by barn A (+6 pp.), barn C (+4 pp.), barn B (+3 pp.) and the sandy soil (+3 pp.). The reference compost (-7 pp.) and Zegveld bedding material (-4 pp.) experienced net N immobilisation.

Liquid cattle manure had the highest value as a short-term N fertiliser, not only because of the relatively high mineralisation rate, but mainly because, at start of the experiment, already 37% of total N was present in mineral form and therefore available for plant uptake. The short-term N fertiliser value of all bedded-pack composts was low, because of the very low presence of initial mineral N and the low mineralisation rate. As a result, a 1:1 replacement of N from liquid cattle manure N with N from bedded-pack compost will result in considerably lower crop N uptake and yield. In the long term, however, mineralisation of soil N can increase for farmland fertilised with bedding material compared to farmland fertilised with liquid cattle manure, due to larger accumulation of organic N in soil.

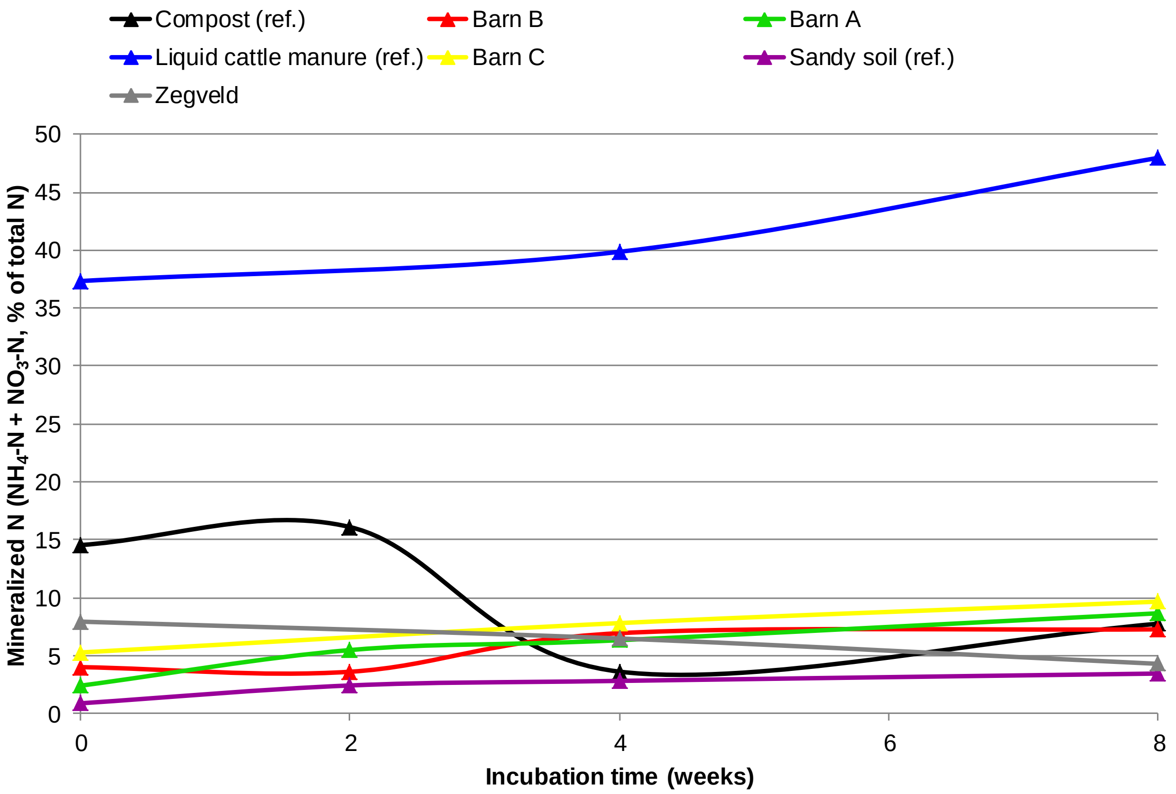


Figure 4-4 Changes in mineralised N (NH_4-N + NO_3-N, % of total N applied) for several bedded-pack composts and reference materials, over a time period of eight weeks, after incubation with sandy soil at 20°C

The net N immobilisation after application of reference green waste compost and bedding material from Zegveld suggests that application of these materials will, in the short term, rather deprive crops of available N than providing them with available N. In the longer term, initially immobilised N will eventually mineralise and become available for crop uptake.

It can be concluded that the composted bedding materials are less suitable as a short-term N fertiliser when compared to liquid cattle manure. In the long term, more N will mineralise from accumulating organic N in soil, but it can take years before the level of N available for crop uptake is the same for farmland fertilised with composted bedding material and farmland fertilised with liquid cattle manure. Meanwhile, yield levels and yield quality will be lower. To avoid these losses, dairy farmers could choose to use the available bedded-pack compost to increase soil organic matter levels on the poorer fields, and sell the rest to the market, for instance to arable farmers. The minerals taken off the farm can be replaced by minerals in cattle or pig slurry to be acquired in the market. Another option might be to continue the composting period in the farmyard. Extended composting can further reduce C/N ratio and increase the availability of mineral N, thus increasing the short-term N fertiliser value (Note that the N mineralisation rate of the compost from barn A (C/N = 10) is higher when compared to the compost from barn B and C (C/N = 15 -17). Important aspects to consider with extended composting are the necessary length of this period, the potential increase in mineralisation rate and the risk of additional mineral losses through emissions.

4.4 Conclusions

- Compost from bedded-pack barns can have lower N/P ratios than regular liquid cattle manure. Given the limits on P application to farmland, this means that the maximal allowed application of N with bedded-pack compost can be lower compared to regular liquid cattle manure

- The composition, C decomposability and N mineralisation rate of composted beddings are largely similar to regular green waste compost

- Application of C with bedded-pack compost (excreted C composted with e.g. woodchips) can result in considerable higher amounts of remaining soil organic matter than application of the excreted C in the form of liquid cattle manure

- An estimation for barn A (2011 run) shows that ten years after application, the amount of remaining C can be seven times higher and 100 years after application this amount can be 20 times higher

- A much larger amount of remaining C in soil means that application of bedded-pack compost can dramatically increase the storage of C in farmland and thus decrease CO_2 concentration in the atmosphere

- Compared to liquid cattle manure, composted bedding material is not suitable as a short-term N fertiliser for crops, due to a low initial amount of mineral N and a slow N mineralisation rate

- Possibly, the value of this material as a short-term N fertiliser can be increased by prolonged composting on the farm

- In the long run, N mineralisation of soil fertilised with composted bedding material will be considerably higher compared to soil fertilised with liquid cattle manure, because of larger accumulation of organic N

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Appendices

Appendix 1 Calculation example for C emissions in the decomposition experiment

Example using data of one of two replications of the treatment with addition of liquid cattle manure to soil; calculated is the decrease in C between t = 72h and t = 168h (C emissions in this example are not corrected for emission from the sandy soil itself).

C from liquid cattle manure present at t = 72h: 0.3410 g (= 70% of C at t = 0h)
Internal volume of gas monitor + tubes: 71 mL
Air volume in bottle: 385 mL
Headspace: 385 + 71 = 456 mL
Measured CO_2 concentration at t = 168h: 5070 ppm (= 5070 µL CO_2 L^{-1} air)
Measured CO_2 concentration in internal volume: 537 µL CO_2 L^{-1}
Time between the two measurements: 96 hours
Incubation time: 4h

CO_2 concentration in bottle corrected for 'pollution' with internal volume of gas monitor + tubes:
= ((5070 x 456) - (537 x 71)) / 385 = 5906 µL CO_2 L^{-1}

CO_2 concentration in bottle volume:
= (385 / 1000) x 5906 = 2274 µL CO_2

CO_2 concentration expressed in mole per bottle:
= 2274 / 24.04 (molar volume of an ideal gas at 20°C) = 94.6 µmol CO_2

94.6 µmol CO_2 contains 94.6 µmol C

C concentration expressed in g per bottle:
= 94.6 x 12.01 (molar mass of C) = 1136 µg C

C emission rate per bottle:
= 1136 / 4 = 284 µg C h^{-1}

Calculated C emission rate at t = 72h: 732 µg C $bottle^{-1}$ h^{-1}

Average C emission rate per bottle (between t = 72h en t = 168h):
= (732 + 284) / 2 = 508 µg C h^{-1}

Total amount of C emitted (between t = 72h and t = 168h):
= 96 x 508 = 48747 µg C

% C from liquid cattle manure remaining at t = 168h:
= (0.3410 – 0.04875) = 0.2923 g C (= 60% of C present at t = 0 h)



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